Direct proton-decay properties of the isobaric analog and isovector monopole giant resonances

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A self-consistent shell-model continuum-random-phase approximation approach is developed to evaluate the partial proton widths of isobaric analog resonances in spherical nuclei from a wide mass interval. The results are found to be in reasonable agreement with the experimental data. An attempt to deduce the single-particle spectroscopic factors from the comparison of the experimental and calculated widths is undertaken. The direct proton-decay branching ratio for the isovector giant monopole resonance in ^{208}Bi is estimated in connection with recent experimental data.

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I. INTRODUCTION

For more than 30 years, many experimental data on partial proton-escape widths of the isobaric analog resonances (IAR) have been accumulated mainly from the cross sections of proton-induced resonance reactions. Considerable efforts have also been undertaken in the 1970s and 1980s to describe in a quantitative way the proton widths of IAR (see, e.g., Refs. [1,2] and references therein). These studies aspire to understand the decay mechanism directly connected with the isospin-symmetry violation in nuclei. Also, there is a hope to realize an alternative method for finding the single-particle (SP) spectroscopic factors of nuclear states by the comparison of the experimental and calculated SP proton-escape widths of IAR (the SP escape widths are the widths calculated assuming the pure single-particle nature of the states of parent or product nuclei). To achieve this objective, it is necessary, in particular, to develop a sufficiently exact method for calculating the SP proton widths of IAR. The calculated widths should be stable against reasonable variations of model parameters. Being related to the reduced SP escape widths (i.e., to the widths divided by the potential-barrier penetrability for protons), these requirements are fulfilled in self-consistent continuum-random-phase approximation (CRPA) or continuum Tamm-Dancoff approximation (CTDA) approaches developed only in the last decade. In Ref. [3] the CTDA approach based on the use of the Hartree-Fock (HF) mean field and the Skyrme interaction was applied for describing the relative intensities of direct proton decays from the analog of the ^{208}Pb ground state. The partial proton widths of this IAR were also described in Ref. [4] in the CTDA approach. In the CRPA approach of Ref. [5] the *S* matrix for nucleon-nucleus scattering was calculated [6] with the use of a phenomenological isoscalar part of the nuclear mean field and the Landau-Migdal particle-hole interaction. The isovector part of the nuclear mean field has been calculated in a self-consistent way to avoid the nonphysical violation of the isospin symmetry within a shell model. A number of experimental data on the partial proton widths of IAR in nuclei from a wide mass interval have been rather satisfactorily described in Ref. [5] with the use of the experimental spectroscopic factors for the corresponding states of odd-neutron nuclei. However, some shortcomings of the approach of Ref. [5] should be noted. The mean Coulomb field was calculated in a non-self-consistent way, and a variant of the perturbation theory was used in the formulation of the IAR theory in terms of the mean Coulomb field. Besides, the closed-(neutron)-shell and ''closed-(neutron)-shell +valence-neutron'' parent nuclei were only considered.

IAR properties are often associated with properties of the isovector giant monopole resonance (IVGMR) (see, e.g., Ref. [1]). Actually the resonance, having the ''normal'' isospin, is the overtone of IAR. Some attempts to find it experimentally by means of charge-exchange reactions were undertaken [7,8]. The proton-decay probability for the IVGMR is expected to be relatively large since this resonance is located at a rather high excitation energy.

As compared with Ref. [5], in the present work the approach to evaluation of partial proton escape widths of IAR is extended in the following ways.

(i) We use the CRPA approach based on calculating the reaction amplitudes [9,10]. The approach is equivalent to that of Ref. [6] and more simple in practical realization.

(ii) The mean Coulomb field is calculated in a self-consistent way.

(iii) The SP proton widths of IAR are exactly (in the CRPA) expressed in terms of the mean Coulomb field.

(iv) The approach is generalized to include the effect of neutron pairing correlations into consideration and, therefore, to extend the number of considered nuclei.

Another aim of this work is to estimate the branching ratio for the direct proton decay of the IVGMR in ^{208}Bi. This part of the work is stimulated by recent experimental data [8].

II. BASIC RELATIONSHIPS

In view of the approximate isospin conservation in nuclei the decay properties of IAR can be directly described in terms of the mean Coulomb field $U_C(r)$. To realize such a description in the shell-model CRPA approach, the isovector partial self-consistency condition should be satisfied. Following Refs. [5,9], we use the phenomenological isoscalar part of the nuclear mean field $U_0(x)$ (including the spin-orbit term) and the isovector part of the phenomenological

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Landau-Migdal particle-hole interaction $F'\vec{\tau}_1\vec{\tau}_2\delta(\vec{r}_1-\vec{r}_2)$ as input quantities for this approach. The isovector part of the nuclear mean field $U_1=(1/2)\tau^{(3)}v(r)$, where $v(r)$ is the symmetry potential, satisfies the self-consistency condition. This condition can be derived within the RPA from the equation [11]

$$[\hat{H},\hat{T}^{(-)}]=-\sum_a [v(r_a)-2F'n^{(-)}(r_a)]\tau_a^{(-)} + \sum_a U_C(r_a)\tau_a^{(-)} = \Delta_C\hat{T}^{(-)}+\hat{V}_C^{(-)}. \quad (1)$$

Here, $\hat{H}$ is the shell-model Hamiltonian, $\hat{T}^{(-)}=\Sigma_a\tau_a^{(-)}$, where $\tau_a^{(-)}$ is the one-body Fermi operator, $n^{(-)}=n^n-n^p$ is the neutron excess density, Δ_C is the so-called Coulomb displacement energy (defined below), and $\hat{V}_C^{(-)}=\Sigma_a[U_C(r_a)-\Delta_C]\tau_a^{(-)}$. From Eq. (1) one can see (i) the isovector partial self-consistency condition $v(r)=2F'n^{(-)}(r)$, which has been previously obtained in another way [12] and (ii) the representation of the ''charge-exchange'' Coulomb field in the form, which is convenient for describing decay properties of IAR and IVGMR. We calculate the Coulomb field $U_C(r)$ also self-consistently in the Hartree approximation via the proton density $n^p(r)$. Thus, as in Refs. [9,10], the mean field $U=U_0+U_1+U_C$, is used below for realization of the approach. The isovector self-consistency condition allows us to consider the IAR in the shell-model CRPA approach as an ordinary giant resonance and we start from this consideration.

To evaluate the IAR partial proton widths in the CRPA we calculate the Fermi strength function (''inclusive-reaction cross section'') and the ''(β^-,p)-reaction'' amplitudes. The Fermi strength function is generally defined as

$$S_F(\omega)=\sum_s |\langle s|\hat{T}^{(-)}|0\rangle|^2\delta(E_s-E_0-\omega). \quad (2)$$

Here, E_s and E_0 are, respectively, the energies of an excited state of the isobaric nucleus and the parent-nucleus ground state, and ω is the isobaric-nucleus excitation energy measured from E_0. In the CRPA, the strength function is determined by the free particle-hole propagator of the proton-neutron-hole type, calculated with taking the single-particle continuum exactly into account and by the effective Fermi operator. This operator is energy and radial dependent, and satisfies the well-known integral equation [13], which describes the polarization effect caused by the particle-hole interaction mentioned above. After separation of isospin and spin-angular variables the equations for the above quantities have the following form, which is valid for arbitrary monopole one-body probe operator $V(r)\tau^{(-)}$:

$$S_V(\omega)=-\frac{1}{\pi}\mathrm{Im}\int V^*(r)A(r,r',\omega)\tilde{V}(r',\omega)drdr', \quad (3)$$

$$\tilde{V}(r,\omega)=V(r)+\frac{2F'}{4\pi r^2}\int A(r,r',\omega)\tilde{V}(r',\omega)dr', \quad (4)$$

and

$$A(r,r',\omega)=\sum_\nu n_\nu(2j_\nu+1)\chi_\nu(r)\chi_\nu(r')g_{(\pi)}(r,r',\varepsilon_\nu+\omega) + \sum_\pi n_\pi(2j_\pi+1)\chi_\pi(r)\chi_\pi(r') \times g_{(\nu)}(r,r',\varepsilon_\pi-\omega). \quad (5)$$

In Eq. (5) $\lambda=\nu,\pi$ is the set of quantum numbers n_r,l,j [with $(\lambda)\equiv j,l$] for neutron $(\lambda=\nu)$ and proton $(\lambda=\pi)$ SP bound states; besides, $(\pi)=(\nu)$; $N_\lambda=n_\lambda(2j_\lambda+1)$ is the number of nucleons filling the SP level λ, n_λ is the occupation factor; $r^{-1}\chi_\lambda(r)$ and $(rr')^{-1}g_{(\lambda)}(r,r',\varepsilon)$ are, respectively, the radial bound-state wave function and the Green function of the radial Schrödinger equation. The neutron and proton densities used for realization of the above-mentioned self-consistency conditions are

$$n(r)=\frac{1}{4\pi r^2}\sum_\lambda n_\lambda(2j_\lambda+1)\chi_\lambda^2(r), \left[N=\sum_\lambda n_\lambda(2j_\lambda+1)\right]. \quad (6)$$

From Eqs. (3) and (4) follows the unitarity condition

$$S_V(\omega)=\sum_\nu |M_\nu^V(\omega)|^2. \quad (7)$$

Here, $M_\nu^V(\omega)$ is the ''(β^-,p) reaction'' amplitude determined by the matrix element of the effective one-body operator

$$M_\nu^V(\omega)=N_\nu^{1/2}\int \chi_{\varepsilon',(\pi)}(r)\tilde{V}(r,\omega)\chi_\nu(r)dr, \quad (8)$$

where $r^{-1}\chi_{\varepsilon,(\pi)}(r)$ is the radial continuum-state wave function (normalized to the δ function of energy) for protons with energy $\varepsilon'=\varepsilon_\nu+\omega$ and $(\pi)=(\nu)$. Equations (3)–(8), which are similar to those used in Ref. [9] for describing charge-exchange spin giant resonances, can be directly applied to the closed-shell nuclei. To describe excitations in the β^+ channel one has to substitute in the above equations $\pi\to\nu$, $\nu\to\pi$, and also to consider ω as the excitation energy of the respective isobaric nucleus. For description of Fermi excitations in the β^- channel one has to put $V(r)=V_F=1$ in Eqs. (3), (4), and (8).

In the vicinity of the IAR energy ω_A, the Fermi strength function $S_F(\omega)$ and the reaction amplitudes $M_\nu^F(\omega)$ exhibit the resonancelike behavior and can be parametrized in the Breit-Wigner form to deduce the IAR parameters,

$$S_F(\omega)=-\frac{1}{\pi}\mathrm{Im}\frac{S_A}{\omega-\omega_A+\frac{i}{2}\Gamma},$$

$$|M_\nu^F(\omega)| = \frac{1}{\sqrt{2\pi}} \left| \frac{S_A^{1/2}\Gamma_\nu^{1/2}}{\omega-\omega_A+\frac{i}{2}\Gamma} \right|. \tag{9}$$

Here, S_A is the IAR Fermi strength, and Γ_ν and $\Gamma=\Sigma_\nu\Gamma_\nu$ are, respectively, the IAR partial and total proton escape widths. Before comparing the calculation results with the corresponding experimental widths Γ_ν^{exp} we note that (i) the experimental escape-proton energy ε^{exp} is, as a rule, different from the energy $\varepsilon=\varepsilon_\nu+\omega_A$ calculated within a shell-model approach and (ii) the strength of the occupied one-neutron states is somewhat reduced mainly due to their coupling to low-lying collective states (phonons). Therefore, the experimental widths should be compared with the quantities

$$\Gamma_\nu^{calc}=s_\nu^{exp}\Gamma_\nu^{calc}(\mathrm{SP}), \quad \Gamma_\nu^{calc}(\mathrm{SP})=\Gamma_\nu(\varepsilon)\frac{1}{N_\nu}\frac{P_l(\varepsilon^{exp})}{P_l(\varepsilon)}. \tag{10}$$

Here, $s_\nu^{exp}=S_\nu^{exp}(2j_\nu+1)$ is the experimental spectroscopic factor (S_ν^{exp} is the reduced factor), $P_l(\varepsilon)$ is the proton potential-barrier penetrability (the penetration factor), and the ratio $\Gamma_\nu(\varepsilon)/N_\nu P_l(\varepsilon)$ is the reduced SP proton width of the IAR calculated in the CRPA.

The following comments on the above-given equations can be made.

(i) In distinction to Refs. [6,5] the present CRPA approach to evaluation of partial widths $\Gamma_\nu(\varepsilon)$ is more simple in practical realization because only one integral equation (4) should be solved. In the approach of Refs. [6,5] the second integral equation (with the same kernel) for the so-called effective ''capture field'' should be also solved to calculate the S matrix of nucleon-nucleus scattering.

(ii) Experimental and calculated partial proton widths of IAR can be used to deduce the respective spectroscopic factors according to the equation

$$s_\nu^{exp}(\mathrm{IAR})=\frac{\Gamma_\nu^{exp}}{\Gamma_\nu^{calc}(\mathrm{SP})}. \tag{11}$$

This equation implies a reasonable accuracy of finding both widths.

(iii) In fact, RPA approaches are designed to describe the reduced partial escape widths of giant resonances. Namely, these widths carry directly the information about particle-hole structure of giant resonances. The reduced widths are determined by the channel coupling, which takes place due to the particle-hole interaction. The absolute and reduced widths are connected by the penetration factor. Fortunately, in the case of CRPA calculations only the ratio of the penetration factors should be used to recalculate each width $\Gamma_\nu(\varepsilon)$ to the experimental decay-channel energy ε^{exp}. This fact allows us to use in Eq. (10), the simplified expression from Refs. [9,14] for the penetration factor.

Since an exact self-consistent version of the CRPA for open-shell nuclei is not formulated yet, we take pairing correlations approximately into account. Within the accuracy $(2\Delta/\omega_A)^2$, with the pairing gap Δ, the pairing effect can be neglected in the equation for the effective Fermi operator. Thus, proton pairing correlations can be neglected in the CRPA description of the partial proton widths of IAR as for the giant resonance of the proton-neutron-hole type. This approximation was actually used in Ref. [5]. In open-(neutron)-shell nuclei neutron pairing correlations lead to changing the neutron occupation factors and the escape-proton energies, and as a result, to changing the reaction amplitude. We take both effects phenomenologically into account by means of Eq. (10), using the experimental spectroscopic factors and the experimental escape-proton energies. However, to reproduce approximately in calculations, the low-energy part of the observable single-quasiparticle spectrum in odd-neutron parent nuclei, we describe neutron pairing correlations in these nuclei in the BCS model (see, e.g., Ref. [15]). The value of the neutron gap is estimated by reproducing the experimental neutron separation energy. To determine the neutron chemical potential we can solve only one BCS equation taking the blocking effect into account. As a result, we calculate the neutron occupation factors $v_{\nu'}^2$ and the single-(neutron)-quasiparticle spectrum. Then we modify the CRPA equations (3)–(5) using $v_{\nu'}^2$ as the occupation factor for all neutron levels except the level ν occupied by the quasiparticle. For this level one has to use $N_\nu=(2j_\nu-1)v_\nu^2+1$ because of the blocking effect [15]. These modifications are also used to calculate the neutron excess density of Eq. (6) in order to keep the self-consistency condition. In Eq. (8) for the amplitude $M_\nu^F(\omega)$, corresponding to population of the ground state of the (even-neutron) product-nucleus, one has to substitute $N_\nu^{1/2}$ by factor $u_\nu=(1-v_\nu^2)^{1/2}$. This is the same factor that appears in the amplitude of the respective β^- decay of odd-neutron parent nuclei [15]. The IAR proton widths Γ_ν are calculated using the modified CRPA equations and Eq. (9). These widths are recalculated in accordance with Eq. (10). A simplified version of the above-described method has been recently realized in applying to some tin and tellurium parent nuclei [16]. Note that the experimental spectroscopic factors s_ν^{exp} can be markedly different from u_ν^2. This fact was pointed out for the case of tin isotopes [17]. The difference apparently comes from the quasiparticle-phonon coupling, which is not taken into account in the CRPA.

III. CALCULATION RESULTS

In the calculation of the IAR proton-escape widths we use the isoscalar part of the nuclear mean field $U_0(x)$ and strength F' of the Landau-Migdal interaction from Ref. [10], where the nucleon separation energies for ''closed-shell +one-nucleon'' subsystems in nuclei from Zr to Pb have satisfactorily been described. The calculation results obtained for nuclei from a wide mass interval are shown in Tables I–IV together with the experimental data.

Table I shows the experimental and calculated partial widths for proton decay from the analog of the ^{208}Pb ground state into neutron-hole states in ^{207}Pb. In calculations by Eq. (10) we use the rather old data for S_ν^{exp} [18]. In this table we show the reduced spectroscopic factors S_ν^{exp}(IAR) obtained

TABLE I. Experimental and calculated partial widths for proton decay from the IAR(0^+) in ^{208}Bi into neutron-hole states in ^{207}Pb. Reduced spectroscopic factors S_ν^{exp}(IAR) and S_ν^{exp}, calculated and experimental escape-proton energies, the CRPA partial widths $\Gamma_\nu(\varepsilon)$ are also given.

ν	S_ν^{exp} [a]	ε (MeV)	ε^{exp} (MeV) [b]	$\Gamma_\nu(\varepsilon)$ (keV)	Γ_ν^{calc} (keV)	Γ_ν^{exp} (keV) [c]	S_ν^{exp}(IAR)
$3p_{1/2}$	1.0	11.11	11.46	59.1	72	51.9±1.6	0.72
$2f_{5/2}$	0.98	10.35	10.91	15.9	25	26.4±2.0	1.03
$3p_{3/2}$	1.0	9.89	10.59	51.5	88	64.7±3.4	0.73
$1i_{13/2}$	0.91	8.30	9.74	0.02	0.16		
$2f_{7/2}$	0.70	7.26	9.15	0.45	4.8	4.2±0.6	0.61

[a]Taken from Ref. [18].
[b]Taken from Ref. [2].
[c]Taken from Ref. [19].

according to Eq. (11). The calculated decay-channel energies are also shown in Table I together with the CRPA partial widths $\Gamma_\nu(\varepsilon)$. In accordance with Eq. (10) the ratio of this width to $\Gamma_\nu^{calc}/S_\nu^{exp}$ is the ratio of the corresponding penetration factors. The self-consistent treatment of the mean Coulomb field allows us to reduce the number of model parameters because the Coulomb radius of nuclei is excluded from the consideration. The non-self-consistent treatment with the use of the radius from Refs. [14,6] ($r_{0C}=1.24$ fm) leads to a relatively small decreasing (less than 3–4 %) of the calculated widths (not shown in Table I), provided that the isovector self-consistency is fulfilled.

The experimental and calculated partial widths for proton decay from the analog of the ground and some excited states of the ''closed-(neutron)-shell+valence-neutron'' parent nuclei into the ground state of the closed-(neutron)-shell product nuclei are listed in Table II. The experimental and calculated partial widths for proton decay from the IAR ($1/2^+$) in several Sb and I isotopes to the ground state of, respectively, the Sn and Te product nuclei are given in Table III. The spectroscopic factors for the $3/2^+$ states in several Sn and Te parent nuclei are obtained by the comparison of the experimental partial widths [20,21] with the calculated IAR SP widths according to Eq. (11) (Table IV).

One can see from the tables that (i) the partial proton widths of IAR calculated for many nuclei from a wide mass interval agree satisfactorily with the experimental widths and (ii) the attempt to deduce the SP spectroscopic factors from

TABLE II. Experimental and calculated partial widths for proton decay from the analog of the ground and excited states of the ''closed-(neutron)-shell+valence neutron'' parent nuclei into the ground state of the closed-(neutron)-shell nuclei. The experimental escape-proton energies and spectroscopic factors are also given.

Parent nucleus	ν	s_ν^{exp} [a,b]	ε^{exp} (MeV) [a]	Γ_ν^{exp} (keV) [a]	Γ_ν^{calc} (keV)
^{49}Ca	$p_{3/2}$	0.93	1.93	1.9±0.2	2.3
^{91}Zr	$d_{5/2}$	0.89	4.67	4.0±0.5	3.3
	$s_{1/2}$	0.72 [c]	5.88 [c]	38±6[c]	42
	$d_{3/2}$	0.45	6.78	15±3	18
^{139}Ba	$f_{7/2}$	0.7	9.93	16±2	24
	$p_{3/2}$	0.32	10.56	26±3	35
	$p_{1/2}$	0.27	11.01	22±2	28
^{141}Ce	$f_{7/2}$	0.8	9.68	11±1	20
	$p_{3/2}$	0.4	10.33	24±2	40
	$p_{1/2}$	0.4	10.81	19±2	40
	$h_{9/2}$	1.0	11.06	1.2	1.5
^{209}Pb	$g_{9/2}$	0.78	14.83	22.7±0.6	27
	$i_{11/2}$	0.96	15.58	1.6±0.4	1.3
	$j_{15/2}$	0.53	16.30	0.9±0.8	0.75
	$d_{5/2}$	0.88	16.39	50.2±1.0	89
	$s_{1/2}$	0.88	16.87	56.6±3.4	79
	$g_{7/2}$	0.78	17.32	42.9±3.6	42
	$d_{3/2}$	0.88	17.37	62.8±5.4	69

[a]Taken from Ref. [2].
[b]Taken from Ref. [25].
[c]Taken from Ref. [26].

TABLE III. Experimental and calculated partial widths for proton decay from the IAR($1/2^+$) in Sb and I isotopes to the ground state of, respectively, Sn and Te isotopes. The experimental escape-proton energies and spectroscopic factors are also given.

Parent nucleus	s_ν^{exp} [a]	ε^{exp} (MeV) [b]	Γ_ν^{exp} (keV) [c]	Γ_ν^{exp} (keV) [d]	Γ_ν^{calc} (keV)
^{113}Sn	0.491	6.20		10.3 ± 2.1	12.4
^{115}Sn	0.430	6.35		8.0 ± 1.6	11.8
^{117}Sn	0.375	6.87	17.0 ± 0.5	16.5 ± 3.3	15.5
^{119}Sn	0.327	7.26		17.0 ± 3.4	17.0
^{121}Sn	0.285	7.57	17.0 ± 0.6	24.0 ± 4.8	17.2
^{123}Sn	0.249	7.82	18.4 ± 0.7	17.0 ± 3.4	16.4
^{125}Sn	0.220	8.07	11.7 ± 0.4	14.0 ± 2.8	15.7
^{125}Te	0.249	7.49		12.2 ± 2.4	11.6
^{127}Te	0.220	7.80		13.7 ± 2.7	11.8
^{129}Te	0.197	8.06		9.9 ± 2.0	11.7
^{131}Te	0.181	8.38		10.2 ± 2.0	12.0

[a]Taken from Ref. [17].
[b]Calculated from Ref. [27].
[c]Taken from Ref. [20].
[d]Taken from Ref. [21].

the comparison of the experimental widths with the calculated SP proton widths of IAR seems to be rather reasonable. It is worth noting that the calculated SP proton escape widths of IAR in Sb and I isotopes are only slightly dependent on taking neutron pairing correlations into account. This conclusion, obtained with the use of both the isovector self-consistency condition and the experimental proton decay-channel energies, was checked by direct calculations.

IV. ''COULOMB'' DESCRIPTION OF IAR AND IVGMR

Equation (1) allows us to formulate the shell-model theory of IAR in terms of the mean Coulomb field. Using Eqs. (1) and (2), we get

$$S_F(\omega)=S_C(\omega)/|\omega-\Delta_C|^2,$$
$$S_C(\omega)=\sum_s |\langle s|\hat{V}_C^{(-)}|0\rangle|^2\delta(E_s-E_0-\omega). \qquad (12)$$

Here, $S_C(\omega)$ is the Coulomb strength function corresponding to the operator $\hat{V}_C^{(-)}$. The strength function $S_C(\omega)=\Sigma_\nu|M_\nu^C(\omega)|^2$ and reaction amplitudes $M_\nu^C(\omega)$ can be calculated in the partially self-consistent shell-model CRPA approach by Eqs. (3)–(5) and (8), respectively, with the use of $V(r)=V_C(r)=U_C(r)-\Delta_C$. Comparing Eqs. (9) and (12), we find,

$$\Delta_C=\omega_A-(i/2)\Gamma, \quad \Gamma_\nu=2\pi S_A^{-1}|M_\nu^C(\omega=\omega_A)|^2. \qquad (13)$$

One can see from this equation that the Coulomb displacement energy has an imaginary part, which is proportional to the IAR total (proton) width, $-2Im\Delta_C=\Gamma$. This point (i) is a result of the exact (in the CRPA) description of IAR properties in terms of the mean Coulomb field and (ii) is essential in solution of the integral equation (4) for the effective one-body Coulomb operator, because it does not exhibit a resonancelike behavior in the vicinity of the IAR energy ω_A, as

TABLE IV. Experimental and calculated SP partial widths for proton decay from the IAR($3/2^+$) in Sb and I isotopes to the ground state of, respectively, Sn and Te isotopes. Spectroscopic factors s_ν^{exp}(IAR) and the experimental escape-proton energies are also given.

Parent nucleus	ε^{exp} (MeV) [a]	Γ_ν^{exp} (keV) [b]	Γ_ν^{exp} (keV) [c]	Γ_ν^{calc}(SP) (keV)	s_ν^{exp}(IAR)
^{117}Sn	7.02	7.5 ± 0.3		12.0	0.63
^{121}Sn	7.50	10.5 ± 0.7	7.5 ± 1.5	15.9	0.66 / 0.47
^{123}Sn	7.69	8.0 ± 0.5	7.0 ± 1.4	17.5	0.46 / 0.40
^{125}Sn	7.87	7.6 ± 0.3	9.0 ± 1.8	18.9	0.40 / 0.48
^{125}Te	7.52		4.8 ± 1.0	12.7	0.38
^{127}Te	7.73		5.7 ± 1.1	14.2	0.40
^{129}Te	7.87		6.2 ± 1.2	15.0	0.41
^{131}Te	8.07		8.5 ± 1.7	16.6	0.51

[a]Calculated from Ref. [27].
[b]Taken from Ref. [20].
[c]Taken from Ref. [21].

follows from Eqs. (9), (12), and (13). In other words, the IAR has zero strength corresponding to the one-body operator $V_C(r)\tau^{(-)}$. Except for $\text{Im}\,\Delta_C$, Eq. (13) for the CRPA partial width of IAR has the same form, as that given in Ref. [5], because the calculated IAR Fermi strength S_A is close to $N-Z$. Note, that the widths calculated by Eqs. (9) and (13) are the same. However, the description of isospin-forbidden processes in terms of the mean Coulomb field seems preferable (see, e.g., Refs. [1,2]).

The Coulomb CRPA strength function $S_C(\omega)$, calculated according to Eqs. (3)–(5) for the ^{208}Pb parent nucleus with the use of the above-mentioned model parameters, exhibits a resonancelike behavior in the vicinity of the IVGMR. The resonance shape and the total width (about 11 MeV) are close to those of the monopole strength function calculated in Ref. [22] for one-body operator $r^2\tau^{(-)}$ in the HF+CRPA approach with the Skyrme forces. The differences of the strength functions are in the mean energies (40.3 and 43.5 MeV, respectively), and in exhausting the corresponding non-energy-weighted sum rule (121% and 18%). The relative Coulomb strength of the IVGMR is distinctly greater than its relative monopole strength because the IAR exhausts most of the monopole strength (92%). For the opposite (β^+) channel the mean excitations energies and the relative strengths calculated with the use of the Coulomb and monopole strength functions are 14.7 MeV and 20%, and 16.3 MeV and 9%, respectively.

Following Refs. [6,9], we take the coupling of the CRPA doorway states to many-quasiparticle configurations phenomenologically into account. To evaluate the energy-averaged strength function $\overline{S_C}(\omega)$ and reaction amplitudes $\overline{M}_\nu^C(\omega)$, we solve the CRPA Eqs. (3), (4), and (8) using the substitution $\omega\to\omega+(i/2)I$ in Eq. (5). The smearing parameter I has the meaning of the mean doorway-state spreading width. For the ^{208}Pb parent nucleus we take the value $I=4$ MeV, which is close to that used in Ref. [9] for describing the experimental total width of the spin-dipole giant resonance in ^{208}Bi. The total width of the IVGMR in the calculated strength function $\overline{S_C}(\omega)$ is about 15 MeV. This value is not in disagreement with the experimental data [7,8]. The partial and total direct proton-decay branching ratios for the IVGMR are evaluated by using the equations

$$b_\nu=\frac{\int|\overline{M}_\nu^C(\omega)|^2d\omega}{\int\overline{S_C}(\omega)d\omega},\quad b=\sum_\nu b_\nu. \tag{14}$$

Calculations performed with these equations give about 70% for the value of b. A similar result was also obtained for the isovector spin-monopole resonance (IVSMR) in ^{208}Bi [23].

V. SUMMARY

We develop the partially self-consistent shell-model CRPA approach for describing direct proton-decay properties of the isobaric analog and isovector giant monopole resonances in medium-heavy spherical nuclei. Using the developed approach, we evaluate the partial proton escape widths of IAR in spherical nuclei from a wide mass interval. In the calculations we use the experimental spectroscopic factors for one-neutron states and the experimental escape-proton energies. The results agree with the experimental partial widths reasonably. The attempt to deduce the SP spectroscopic factors from the comparison of the experimental and calculated SP widths of IAR is found to be also reasonable. However, it seems desirable to perform a detailed analysis of experimental data on the partial proton widths of IAR and on the spectroscopic factors deduced from one-nucleon transfer reactions, and also to develop a more refined method for calculating the penetration factor before drawing the conclusion about possibility to use the experimental and calculated widths for deducing the spectroscopic factors. Note that the above-outlined approach for calculating the IAR SP proton widths was rather successfully used to describe the experimental relative intensities of the proton decay from the IAR ($11/2^-$) in ^{91}Nb into the 0^+, 3^-, and 5^- states in ^{90}Zr [24].

We formulate also the shell-model CRPA approach to describe the IAR and IVGMR in terms of the mean Coulomb field. We found a rather high value of the total proton direct-decay branching ratio for the IVGMR in ^{208}Bi. Bearing in mind the similar result obtained for the IVSMR in the same nucleus [23], one can understand the reason why these monopole giant resonances are observed in the proton-decay channel [8].

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