EPJ Web of Conferences **38**, 17009 (2012)
DOI: 10.1051/epjconf/20123817009

On direct proton decay of the Gamow-Teller giant resonance

I.V. Safonov[a] and M.H. Urin

National Research Nuclear University "MEPhI", 115409 Moscow, Russia

Abstract. The semi-microscopic approach to the description of giant resonances in medium-heavy mass closed-shell nuclei is implemented to treat partial probabilities of direct-proton decay of the Gamow-Teller giant resonance (GTGR) in ^{208}Bi. The corresponding experimental data are reasonably explained.

1 Introduction

Partial probabilities of direct nucleon decay of giant resonances (GRs) carry information about the particle-hole (p-h) structure and damping mechanisms of GRs. Therefore, these probabilities should be related to the main properties of GRs and included in their full description. As applied to medium-heavy mass closed-shell nuclei, this aim can be achieved within the semi-microscopic approach to the description of giant resonances (SMAGR). The present formulation of this approach has been initially given in [1] and then extended to a number of implementations (see the reviews [2, 3]). The SMAGR is a generalization of the standard and non-standard versions of the continuum-Random-Phase-Approximation (cRPA) developed to take into account a spreading effect. The latter is described phenomenologically in terms of the energy-dependent imaginary part of an effective optical-model potential directly used in cRPA equations [2, 3].

Being the spin-flip partner of the isobaric analog resonance (IAR), the GTGR corresponds to the 1^+ collective proton-(neutron-hole)-type nuclear excitations. In spite of a lot of experimental studies of the GTGR (predominantly via the direct (p,n)- and (^{3}He,t)-reactions), the proton decay of the GTGR in ^{208}Bi has only been studied by the coincident ^{208}Pb(^{3}He,tp) experiments [4]. The same method has later been used for studying proton decay of the GTGR overtone, isovector giant spin-monopole resonance (IVGSMR$^{(-)}$) in ^{208}Bi [5]. The unique experiment on excitation of the GTGR in ^{118}Sb with the resonance ^{117}Sn(p,n$_{tot}$)-reaction [6] should be also mentioned. Along with the anomalously small total width ($\simeq$ 1 MeV), the partial (elastic) proton width of the mentioned GTGR has been measured as well.

Using the modern version of the SMAGR [1–3], in the present work we revise the previous calculations of the partial direct-proton-decay probabilities performed in [7] for the GTGR in ^{208}Bi. The new elements of our analysis are: (i) taking the spreading effect on the escaped-proton wave function into account; (ii) the use of the energy-averaged decay-channel strength function (instead of the Breit-Wigner parametrization of the proper cRPA strength function); (iii) the use of the proton optical-model penetrability (instead of the penetrability calculated for a schematic single-particle potential). The method and results briefly described in Sect. 2 will be published soon together with the study of the GT strength distribution in a wide excitation energy interval [8].

[a] e-mail: safonov@theor.mephi.ru

2 Direct-proton-decay probabilities for the GTGR in ^{208}Bi

As applied to description of charge-exchange excitations, the cRPA radial equations for the basic quantities are given in [7]. Extension of these equations on taking the spreading effect into account is described in [2, 3] in a rather schematic form. As applied to the semi-microscopic description of 0^+ charge-exchange excitations (including IAR), the radial equations for the energy-averaged basic quantities are explicitly given in [9]. These quantities are: the effective field $\tilde{V}^{(-)}(x, \omega)$ and strength function $S^{(-)}(\omega)$, corresponding to an external single-particle field $V^{(-)} = V(r)\tau^{(-)}$ (ω is the excitation energy counted off the ground-state energy of the parent (even-even) nucleus); the proton-escape amplitude $M_\nu^{(-)}(\omega)$ and partial proton-decay-channel strength function $S_\nu^{(-)}(\omega) = |M_\nu^{(-)}(\omega)|^2$ ($\nu = n_r, (\nu)$ is the full set of the quantum numbers of a neutron-hole state, populated after direct proton decay, $(\nu) = j_\nu, l_\nu$). In the semi-microscopic description of the 1^+ charge-exchange excitations we suggest to use, for short, the equations of Ref. [9] after the following substitutions:

$$\tau^{(-)} \to \sigma_M \tau^{(-)}, \qquad V(r) \to 1, \qquad F' \to G'. \quad (1)$$

$$\sum_{(\pi)} n_\nu (2j_\nu + 1)\delta_{(\pi)(\nu)} \to \frac{1}{3}\sum_{(\pi)} n_\nu \langle(\pi)\|\sigma\|(\nu)\rangle^2. \quad (2)$$

In Eq. (1) σ_M are the spherical Pauli matrices; $F' = Cf'$, $G' = Cg'$ ($C = 300$ MeV fm^3) are the intensities of the isovector part of the Ladau–Migdal particle-hole interaction: $F(x_1, x_2) \to (F' + G'\boldsymbol{\sigma}_1\boldsymbol{\sigma}_2)\boldsymbol{\tau}_1\boldsymbol{\tau}_2\delta(\mathbf{r}_1 - \mathbf{r}_2)$. In Eq. (2) $(\pi) = j_\pi, l_\pi$ are the single-proton quantum numbers linked to (ν) via the corresponding selection rules; n_ν are the neutron occupation numbers. The partial proton-decay-channel strength functions for the GTGR are properly modified: $S_\nu^{(-)}(\omega) = \sum_{(\pi)} S_{(\pi),\nu}^{(-)}(\omega)$. These strength functions determine the corresponding partial direct-proton-decay branching ratios as follows:e

$$b_\nu^{(-)}(\delta) = \frac{\int S_\nu^{(-)}(\omega)d\omega}{\int S^{(-)}(\omega)d\omega}, \qquad (3)$$

where integration is performed over the resonance. It is noteworthy that almost the same equations determine within SMAGR the partial branching ratios for direct proton decay of the IVGSMR$^{(-)}$. The difference is in the choice of the radial dependence of the external field $V(r) \to R^2 - \eta$, where the scaling parameter η is chosen from the condition of "non-exciting" the GTGR [3, 10].

A mean field and particle-hole interaction together with the imaginary part $W(r, \omega)$ of the effective optical-model potential are the input quantities for calculations within the SMAGR the giant-resonance strength function. The partial direct-nucleon-decay branching ratios are then calculated without the use of additional model parameters. In our calculations a phenomenological mean field and Landau–Migdal interaction are used. The mean-field parameters (together with the parameter f') are found, as described in [11] but with the use of another mean-field geometrical parameter $r_0 = 1.21$ fm. In calculations of the strength function of the GTGR in ^{208}Pb we used two adjustable parameters: the intensity g' of the Landau–Migdal interaction to reproduce in calculations the observed GTGR energy; the intensity of $W(r, \omega)$ to reproduce in calculations the total width of the considered GTGR. The calculated strength function $S^{(-)}(\omega)$ is shown in figure 1.

Before comparing the calculated partial direct-proton-decay branching ratios $b_\nu^{(-)}$ of Eq. (3) with the corresponding experimental values, we recalculate the partial proton-decay-channel strength functions $S_{(\pi),\nu}^{(-)}$ to take into account two points: (i) the difference of the experimental neutron-hole state excitation energies $\mathcal{E}_\nu^{exp}$ of the product nucleus ^{207}Pb from the calculated energies $\mathcal{E}_\nu = \varepsilon_\nu^{calc} - \varepsilon_{p_{1/2}}^{calc}$ (ε_ν^{calc} are determined by the mean field); (ii) the difference of the experimental spectroscopic factors S_ν for the mentioned one-hole states from unity. (Both of these differences are shown in Table 1). In view of the discussed points we recalculate the partial proton-decay-channel strength functions to the following effective values:

$$\check{S}_{(\pi),\nu}^{(-)}(\omega) = S_\nu S_{(\pi),\nu}^{(-)}(\omega) T_{(\pi)}(\varepsilon^{exp}) \Big/ T_{(\pi)}(\varepsilon^{calc}) \ . \qquad (4)$$

Here, $\varepsilon = \varepsilon_\nu + \omega$ is the escaped-proton energy; $T_{(\pi)}(\varepsilon)$ is the optical-model penetrability (the seizure coefficient) for the partial proton wave. Because of changing over the GTGR the potential-barrier penetrability for escaped protons, the energy dependence of the calculated decay-channel strength functions $\check{S}_\nu^{(-)}(\omega)$ is noticeably different from that of the giant-resonance strength function $S^{(-)}(\omega)$ (figure 1). The proton branching ratios $\check{b}_\nu$ calculated for the GTGR in ^{208}Bi in accordance with Eqs. (3), (4) for the energy interval $\omega = 12$–26 MeV are found in a reasonable agreement with the corresponding experimental data (Table 1).

In conclusion of this Section we note, that the similar description of the partial (and total) direct-proton-decay branching ratios for the IVGSMR$^{(-)}$ in ^{208}Bi leads to different results [3, 10]. The total branching ratios (about 50%) is in reasonable agreement with the experimental data of [5], while the calculated and experimental distributions of the partial branching ratios over decay channels are noticeably different: population of deep neutron-hole states in ^{207}Pb has been unexpectedly observed in [5]. Up to now there is no explanation of this observation.

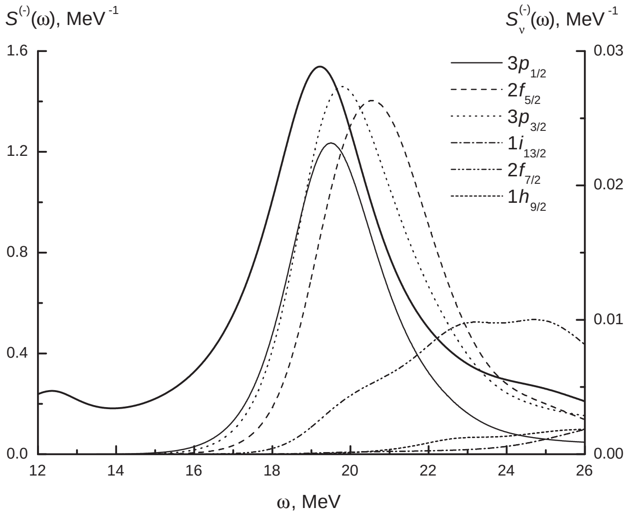

Fig. 1. The giant-resonance strength function (thick line) and partial proton-decay-channel strength functions calculated for the GTGR in ^{208}Bi.

Table 1. The calculated partial direct-proton-decay branching ratios for the GTGR in ^{208}Bi in a comparison with the experimental data. Some characteristics of the decay channels are also given.

ν^{-1}	S_ν [11]	$\mathcal{E}_\nu^{calc}$, keV*	$\mathcal{E}_\nu^{exp}$, keV** [4]	$\check{b}_\nu(\delta)$, %	b_ν^{exp}, % [4]
$3p_{1/2}$	1.0	0	0	1.0	1.8 (5)
$2f_{5/2}$	0.98	895	570	1.3	2.7 (6)
$3p_{3/2}$	1.0	1078	898	1.4	
$1i_{13/2}$	0.91	2011	1633	0.05	0.2 (2)
$2f_{7/2}$	0.5	3614	2340	0.7	0.4 (2)
$1h_{9/2}$	0.61	4373	3413	0.1	
$\sum_\nu$				4.55	4.9 (1.3)

$^*\mathcal{E}_\nu^{calc} = \varepsilon_{3p_{1/2}}^{calc} - \varepsilon_\nu^{calc}$, $\varepsilon_{3p_{1/2}}^{cac} = -7.55328$ MeV.

$^{**}\mathcal{E}_\nu^{exp} = -\varepsilon_\nu^{exp} - B_N^{exp}(^{208}\mathrm{Pb})$,

$B_N^{exp} = 7.36787$ (5) MeV (Nuclear Data Sheets).

3 Conclusive remarks

Within the semi-microscopic approach to description of giant resonances in closed-shell nuclei the reasonable description of the experimental data on direct proton decay of the Gamow-Teller giant resonance in ^{208}Bi is obtained. Extension of experimental studies of direct proton decay of the GTGR and its overtone for other nuclei seems to be necessary together with generalization of the semi-microscopic approach on description of giant-resonance damping for open-shell nuclei.

Acknowledgement

This work is partially supported by the Russian Foundation for Basic Research under grant no. 12-02-01303-a.

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