GAMOW-TELLER RESONANCES IN THE COMPOUND-NUCLEUS ^{118}Sb: PUZZLES OF THE SAROV'S EXPERIMENT

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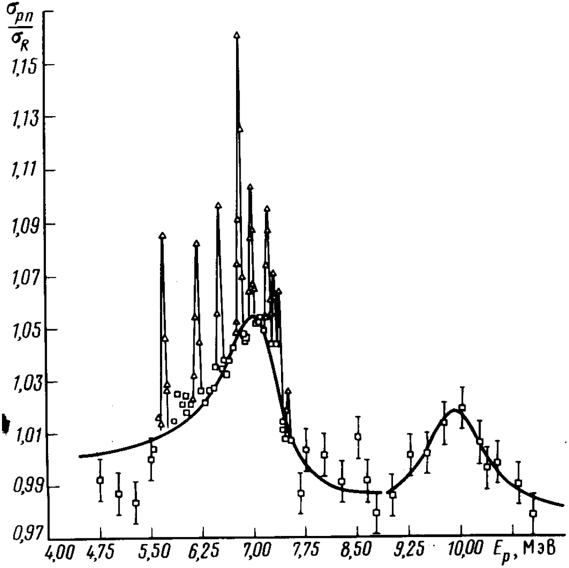
Outline

1 Experimental studies of the GTR in ^{118}Sb

1.1 The unique experiment on observation of two rather narrow resonance structures in the excitation function of the $^{117}Sn(p, n_{tot})$-reaction has been performed more than 30 years ago (the "Sarov's experiment", Guzhovskii, Protopopov, Dzyuba, JETP Lett., 1984). Being highly experienced in studies of IARs by the same type reactions, supposing that IAR and GTR have the similar microscopic structure (monopole excitations of the proton-neutron-hole-type), being based on GTR systematic, the authors have:

(i) assigned the observed resonance structures to the GTRs built correspondingly on the ground state and, in fact, on the two-quasiparticle ($d_{3/2}\ s^{-1}_{1/2}$) excited state of the parent nucleus ^{118}Sn (GTR_1 and GTR_2, respectively);

(ii) deduced the parameters of these resonances with reasonable accuracy (Fig. 1. and Table 1.).



$\frac{\sigma_{pn}}{\sigma_R}$
1,15
1,13
1,11
1,09
1,07
1,05
1,03
1,01
0,99
0,97
4,00
4,75
5,50
6,25
7,00
7,75
8,50
9,25
10,00
E_p, МэВ

Exciting points:

- Observation of a two-bump GTR (GTR_1 and GTR_2) with anomalously small (1 MeV) width as the resonances in the compound-nucleus.
- To that time the GTR has been observed only by means of the direct charge-exchange reactions (p, n), $(^3\mathrm{He}, t)$ performed with not-too-high resolution, as the resonance in the final (product) nucleus.

	E_x, MeV	E_r, MeV	Γ, MeV	Γ_{p_0}, keV	Δ, keV
GTR_1	12.06	7.173 ± 0.057	0.99 ± 0.12	$50 \pm 20\%$	170 ± 20
GTR_2	14.83	9.927 ± 0.064	1.09 ± 0.42	125 ± 64	-

1.2 The Sarov's experiment stimulated the MEPhI group, having been in close contacts with Guzhovskii and his collaborators in connection with IAR studies, to a theoretical description of the GTR in open-shell nuclei. Unexpectedly, the group found the effect of the GTR splitting into two components ($\mathrm{GTR}_<$ and $\mathrm{GTR}_>$) for some nuclei, having strong neutron pairing (Guba, Nikolaev, U., Phys. Lett. B, 1989). As applied to Sb isotopes (especially for the $A \approx 118$ region), we'll discuss this effect in Sect. 2.

1.3 This theoretical work was one from the reasons for the Jänecke's group (Michigan, Ann Arbor) to perform the systematical experimental study of the GTR in even Sn parent nuclei with $A = 112 - -124$ by means of the Sn($^3\mathrm{He}, t$)-reaction (Phys. Rev. C 1993. 1995).The mean excitation energy and the total width for each (one-bump!) GTR have been deduced from the experimental data.

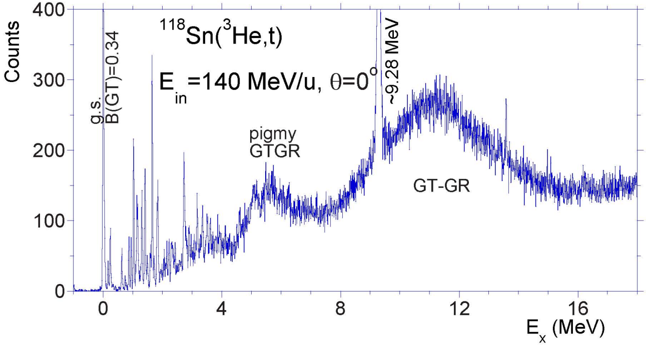
The GTR splitting near $A \approx 118$ has been not directly found. The indirect indications are:

(i) the anomalously large GTR total width (5.7 MeV for ^{118}Sn parent nucleus;

(ii) non-monotonous A-dependence of the GTR and IAR energy difference.

It should be noted that the experimental total width of the GTR in ^{208}Bi is markedly lesser (3.75 MeV. Akimune et al,. Phys. Rev. C, 1995) .

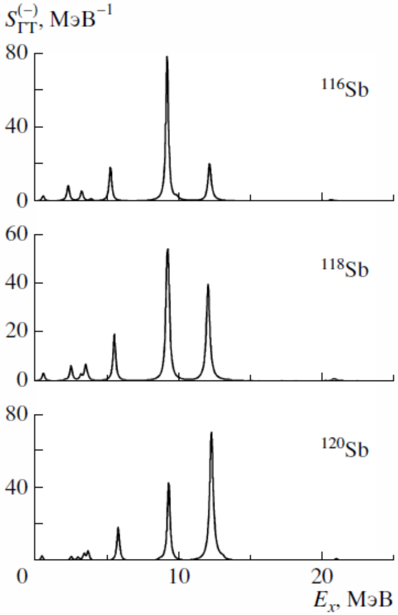
Performed rather recently the high-energy-resolution experimental study of the ^{118}Sn($^3\mathrm{He}, t$)-reaction (Fujita, 2009) didn't show a gross structure of the GTR in ^{118}Sb (Fig. 2).



Conclusion: the experimental data concerned with the GTR in ^{118}Sb are found to be rather contradictive.

This effect has been initially found in 1989 within the simplified theoretical scheme based on the "charge-exchange"-continuum-RPA (pn-cRPA) with taking pairing and the spreading effect into account in a simplified way. The splitting takes place for neutron-open-shell nuclei, where the single-neutron level with highest for the last shell angular momentum is filling ($1h_{11/2}$ for Sn isotopes). The relatively large energy of the spin-flip transition $1h^{n}_{11/2} \to 1h^{p}_{9/2}$ proves to close to the energy of the GTR formed by monopole $(n \to p)$-transitions from levels, having a rather small spin-orbit splitting. The GTR splitting appears as a result of the solution of this two-level problem. It was found for the GTR in ^{118}Sb that the calculated splitting energy, E_{spl}, is close to the energy difference between the GTRs observed in the Sarov's experiment.

Being motivated by the above-described contradictive experimental data, by first attempts to understand these data, and (that is the main point) by intentions to repeat and essentially extend the Sarov's experiment (Sect. 3), we turned again to theoretical studies of the GT strength functions in Sb isotopes (Igashov, Rodin, U.. Phys At., Nucl., 2013). Exploited early for description of $2\nu\beta\beta$-decay a realistic version of the (pn-cQRPA) has been used. The model parameters are taken from independent data except of the Landau-Migdal parameter g', which determines the strength of the particle-hole interaction in the spin-isospin channel. This parameter is adopted to reproduce in calculations the GTR mean excitation energy deduced from data of the Jänecke's group. The GT strength functions calculated within the (pn)-cQRPA (i. e., without taking the spreading effect into account) for the ^{116,118,120}Sn parent nuclei exhibit clearly splitting of the main GTR component into two resonances, $GTR_<$ and $GTR_>$.



$S^{(-)}_{ГТ}$, МэВ$^{-1}$
80
40
0
^{116}Sb
60
40
20
0
^{118}Sb
80
40
^{120}Sb
0
10
20
E_x, МэВ

Some conclusions can be done from this theoretical consideration.

(i) The strongest splitting effect (the GT strengths of both components are comparable) is found for the GTR in ^{118}Sb. The calculated GTR$_>$ energy, $E_{x,>} = 12.11$ MeV, is surprisingly close to the energy of the GTR$_1$, $E_{x,1} = 12.06$ MeV, deduced from the Sarov's experiment.

(ii) The total ("natural") proton width (FWHM) calculated for the high-energy GTR component, $\Gamma_{p,>} = 80$ keV, is in a qualitative agreement with the elastic proton width $\Gamma_{p_0,1} = (50 \pm 20\%)$ keV of the GTR$_1$.The calculated total proton width $\Gamma_{p,<} = 5$ keV is small due to decreasing the Coulomb barrier penetrability for excitation of the GTR$_<$ by captured protons. This point allows one to understand "non-observation" of this resonance in the Sarov's experiment.

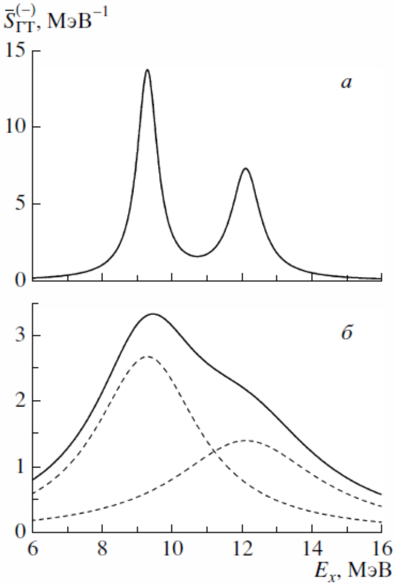
(iii) The calculated energy of the lowest two-quasiparticle excited state ($d_{3/2}$, $s_{1/2}$) of the ^{118}Sn parent nucleus, $E_x^* = 2.78$ MeV, was found occasionally close to the calculated splitting energy $E_{spl} = 2.82$ MeV. Using the known Brink's hypothesis, one gets the energies of the GTR* components (i.e., of the GTR built on the mentioned excited state), $E^*_{x,>,<} = E_{x,>,<} + E^*$. That means:

- $E^*_{x,>} = 12.11 + 2.78 = 14.89$ (hereafter, in MeV) (surprisingly close to the GTR$_2$ energy, 14.83);
- $E^*_{x,<} = 12.11 - 2.82 + 2.78 = 12.08$ (occasionally close the GTR$_1$ energy, 12.06).

From pp. (i)-(iii) follows:

- the energies of the GTRs observed in the Sarov's experiment can be theoretically described with taking the configurational splitting effect into account; this effect allows one to understand the difference between the GTR excitation energy deduced from the direct reaction and the GTR_1 energy;
- there is a hope to describe quantitatively the partial (elastic) proton width for these GTRs (Sect. 3).

The GTR total width is mainly determined by the spreading effect. The latter can be described only in a phenomenological way. In particular, the GTR components, found in the calculated within the pn-cQRPA GT strength function for the ^{118}Sb compound-nucleus (Fig. 3), can be presented as a superimposition of two Lorenzians with the total widths (about 3 and 5 MeV, respectively) adopted to reproduce the observable total width (about 6 MeV) of the one-bump GTR studied by means of the direct reaction (Fig. 4).



$\bar{S}^{(-)}_{ГТ}$, МэВ$^{-1}$
15
10
5
0
а
3
2
1
0
б
6
8
10
12
14
16
E_x, МэВ

Therefore, the same resonance (GTR_1 and $GTR_>$) studied via the RESONANCE and DIRECT reactions has noticeably different total width (about 1 MeV and 5 MeV, respectively).
That is the main puzzle of the Sarov's experiment!
The point, that the total width of the $GTR_>$ exceeds the total width of the having markedly larger excitation energy GTR in ^{208}Bi (3.75 MeV) is also not clear.

3 Perspectives of experimental and theoretical studies of the GTR(s) in Sb isotopes

3.1 If the GTR spreading width is really rather small, then, as in case of IAR, experimental studies of the GTR via the resonance reactions with protons give the unique information. It concerns mainly to decay properties (partial proton widths, asymmetry parameters, spreading width) of the GTRs built on the ground and simple excited states of a parent nucleus. This info would be a challenge for the nuclear theory.

3.2 From this point of view, intentions to repeat and essentially extend the Sarov's experiment are quite reasonable. There is a plan (Abramovich, Zvenigorodskii, Yad. Fiz. Eng., 2013) to study the resonance Sn(p, p')- and Sn(p, n_{tot})-reactions for tin isotopes with $A = 116 - -118, 120, 122$. In particular, the study of the angular distribution in the $^{117}\mathrm{Sn}(p, p_0)$-reaction accompanied by excitation of the GTR_1 allows one to prove that this resonance corresponds to the monopole excitation (the distribution should be isotropic). The study of the mentioned reactions for even tin isotopes allows one to get info about GTRs built on single-quasiparticle states of the corresponding odd parent nuclei. Confirmation that the GTRs excited in the resonance reactions with protons have a relatively small total (spreading) width (1–2 MeV) remains the main question to results of the planned experiments.

3.3 Obtained and planned to be obtained the experimental data on the parameters of GTRs in Sb isotopes stimulate the further theoretical studies of high-energy charge-exchange excitations in open-shell spherical nuclei. The points of this study, which is an extension of both the particle-hole dispersive optical model and its "pole" version formulated for closed-shell nuclei (U.; Phys. Rev. C, 2013 and Nucl. Phys. A, 2008, respectively) might be the following.

- Extension of the pn-cQRPA for description of the excitations built on single- and two-quasiparticles states relatively even-even "core". The shortest way here is the use of the spectral expansion of the 4×4 matrix two-quasiparticle Fermi-system Green function.
- Formulation of the pn-cQRPA non-standard version, which allows one to describe direct-nucleon-decay properties of pn-two-quasiparticle-type excitations. This formulation is possible for high-energy excitations, when the matrix of the two-quasiparticle Green functions can be reduced up to its particle-hole component.

- A phenomenological description of the spreading effect. In the "pole" approximation (i.e., in a vicinity of the given giant resonance) it can be done by substitution of the current excitation energy E_x by $E_x + iI(E_x) - P(E_x)$ in equations of the pn-cQRPA standard and nonstandard versions. Here, $I(E_x)$ is the properly parameterized imaginary part of an effective optical-model potential, while the corresponding real part, $P(E_x)$, is determined by a dispersive relationship.

Realization of this program will allow one to describe the main properties of any charge-exchange giant resonance in open-shell spherical nuclei. In case of the GTR, these properties are: the mean excitation energy, partial proton widths (in case of a large total width – the partial probabilities for direct proton decay), asymmetry parameters. Known from IAR studies, this parameter is proportional to the so-called mixing phase, which is the difference between the phases for "background" and resonant proton scattering.

The main puzzle of the Sarov's experiment is the anomalously small total (spreading) width of the GTR. Waiting for confirmation (or rejection) of this result, one can try to find the reasons for suppression of GTR coupling to many-quasiparticle configurations. An approximate conservation of the spin-isospin SU(4)-symmetry in nuclei might be responsible for this suppression. Considering the spin-orbit term in nuclear mean field as the main source for violation of this symmetry, one can try to estimate the GTR spreading width by the method used rather recently for evaluation of the IAR spreading width (Gorelik, Rykovanov, U., Phys. At. Nucl., 2010). This width is strongly suppressed due to approximate conservation of the isospin SU(2)-symmetry.

4 Summary

- Suggested by the Guzhovskii's group the method of experimental study of the GTR by means of resonance reactions with protons opens unique possibilities to get info about properties of this giant resonance. Intentions to repeat and extend the Sarov's experiment (Abramovich et al.,) look very promised.
- The theory should be also extended to describe the energy and direct-proton-decay properties of the GTRs built on ground and simple excited states of neutron-open-shell nuclei. First steps in this direction look also promised.

At the moment, the question WHY THE GTR TOTAL (SPREADING) WIDTHS DEDUCED FROM THE DIRECT AND RESONANCE REACTIONS ARE SO DIFFERENT? has no answer and stimulates further investigations!
One can hope that new info concerned with proton-induced resonance reactions accompanied by GTR excitation in Sb isotopes will be announced at the next (Nucleus-2016) Conference.

MANY THANKS FOR YOUR ATTENTION

GAMOW-TELLER RESONANCES IN THE COMPOUND-NUCLEUS ^{118}Sb: PUZZLES OF THE SAROV'S EXPERIMENT

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More than 30 years ago, two rather narrow ($\Gamma \approx 1$ MeV) resonance structures have been observed in the excitation function of the ^{117}Sn (pn$_{tot}$)-reaction [1]. The use of the methods successfully exploited early by the Guzhovskii's group (Sarov) in experimental studies of IAR allowed this group to deduce with a high accuracy the parameters of the mentioned structures associated by the authors with the Gamow-Teller resonances (GTRs) in the compound-nucleus ^{118}Sb. Up to now these unique experimental results are not reasonably explained. This point, and intention to essentially extend experimental studies of excitations functions of the (pp')- and (pn$_{tot}$)-reactions with a number of tin target-nuclei [2] stimulate us to come again to experimental and theoretical studies of the GTR in antimony isotopes. We plan to discuss: (i) a comparison of the results of Ref. [1] with the corresponding data obtained by means of the direct (^{3}He,t)-reaction [3]; (ii) attempts to understand the mentioned experimental results from the theoretical point of view with inclusion into consideration of the specific structure effect – the GTR splitting in antimony isotopes near A = 118 [4,5]. A number of open questions and possible theoretical studies are planned to be discussed. The main puzzle is the noticeable difference the GTR total width deduced from the direct and resonance reactions. The small GTR total width might be a signature of an approximate spin-isospin SU(4)-symmetry conservation in nuclei.

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