# IMPACT OF PHONON COUPLING ON THE GAMMA-RAY SPECTRA

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The E1 photon strength functions (PSF) of several Ni and Sn even-even isotopes have been calculated microscopically within the self-consistent version of the Extended Theory of Finite Fermi Systems, which includes the QRPA approach and, in addition, phonon coupling. These microscopically obtained PSFs have been used in the EMPIRE3.1 code to calculate the capture gamma-ray spectra. It has been shown that the phonon coupling contribution is rather important quantitatively and improves noticeably the agreement with experimental data as compared with the QRPA results. As a rule, our final results with phonon coupling in stable nuclei are in a better agreement with the known phenomenological variant Enhanced Generalized LOrentzian than with the QRPA values.

## 1. Introduction

As a rule, phenomenological approaches for nuclear level densities and photon strength functions (PSF) are based on experimental data for stable nuclei. However, the direct determination of these properties for short-lived radioactive target nuclei is impossible. In addition, as it was noted in RIPL-2 and RIPL-3 [1, 2], the phenomenological Lorentzian-based expressions for PSFs are unable to predict the observed structures in the pygmy-dipole resonance energy region and, therefore, in PSFs (if the Brink-Axel hypothesis is true).

For these reasons, since 2006, the microscopic self-consistent PSFs calculated within the Hartree-Fock-Bogolyubov method and Quasiparticle Random Phase Approximation (HFB+QRPA) have been included in RIPL2, RIPL3 and in modern nuclear reaction codes, like EMPIRE and TALYS. However, as discussed in [3] and as confirmed by several modern experiments, see for example [4], the HFB+QRPA approach is necessary but not sufficient. To be exact, it should be complemented by the effect describing the interaction of single-particle degrees of freedom with the phonon degrees of freedom, known as the phonon coupling (PC).

The PSF verification can be partially executed by the calculations of neutron capture gamma-ray spectra for different PSF sets. In this paper the neutron capture gamma-ray spectra are calculated using various PSF models. Our calculations have been performed with the use of two microscopic approaches – QRPA and, for the first time, Quasiparticle Time Blocking Approximation (QTBA) as well as, for comparison, with one of the phenomenological models – Enhanced Generalized LOrentzian (EGLO) [1].

## 2. Method

The E1 PSFs of several Ni and Sn even-even isotopes, such as $^{58,62,68,72}$Ni and $^{116,120,124}$Sn, have been calculated microscopically within the self-consistent version of the Extended Theory of Finite Fermi Systems [5] in the Quasiparticle Time Blocking Approximation [6] (ETFFS(QTBA)), hereinafter as QTBA, which includes the QRPA approach and, in addition, phonon coupling and discrete single-particle spectrum. The method of calculation of standard strength function, which is connected very simply with PSF, has been described in [7, 8]. Calculations have been carried out with the SLy4 parameterization of Skyrme force. The ground state is calculated within the HFB method using the spherical code HFBRAD [9]. In all PSF calculations we use the smearing parameter of 200 keV that effectively accounts for correlations beyond the considered PC, which do not show strong energy dependence. These microscopically obtained PSFs (see details in [3]) have been used in the EMPIRE 3.1 code [10] to calculate the capture gamma-ray spectra at various incident neutron energies. The Generalized Superfluid Model (GSM) for nuclear level density [1, 2] is used for calculations of gamma-ray spectra. The EGLO model was chosen for comparison with the microscopic PSF's because it is one of the popular variants of the Lorentzian-based PSFs.

## 3. Results

As can be seen from Fig. 1 and 2, the PC contribution is rather important for capture gamma-ray spectra: for stable isotopes the PC increases cross sections (as compared with the QRPA), as a rule, by a factor two or three in the gamma-ray energy interval of about (1.5-5) MeV. However, for unstable nuclei $^{67,71}$Ni, $^{123}$Sn that is not so. Our results with phonon coupling are in a better agreement with the known phenomenological variant EGLO than with the QRPA values, except for the cases of unstable nucleus $^{67,71}$Ni, $^{123}$Sn. Thus, as it should be expected, the phenomenological approach is not suitable for unstable nuclei, at least, for the considered cases. Therefore, it is necessary to use the microscopic self-consistent approach for unstable nuclei to describe PSFs and capture gamma–ray spectra.

In Ref. [11], neutron capture gamma-ray spectra of $^{117}$Sn and $^{119}$Sn have been measured. In order to compare with them, we multiplied their gamma-rays/MeV/capture data, taken from EXFOR, by the capture cross sections at $\langle E\rangle_n$=46 keV and $\langle E\rangle_n$ = 550 keV for $^{117}$Sn (Fig.3), $\langle E\rangle_n$ = 52 keV and $\langle E\rangle_n$=570 keV for $^{119}$Sn (Fig.4) . In other words, here we did not consider the incident neutron energy spectra and took the neutron average energies of 46 keV and 52 keV given by the authors [11]. The neutron cross sections used by us were calculated with EMPIRE3.1 for three theoretical models, EGLO, QRPA and QTBA. Then the obtained gamma-ray spectra data were calculated using EMPIRE3.1. The comparison with the experiment [11] is presented in Figs. 3 and 4.

One can see from Fig. 3 and 4 that EGLO and QTBA mainly reproduce experimental data better than QRPA. Moreover, the QTBA description is more preferable, on the whole, than the EGLO one because QTBA describes the structures better than EGLO, especially for $^{117}$Sn.

## 4. Conclusion

Our results show that the PC contribution is rather noticeable and, therefore, the account for PC is required to describe gamma-ray spectra both for stable and unstable nuclei. The fact that our results with PC, i.e. QTBA, are in a better agreement with the phenomenological EGLO model than with QRPA, indirectly confirms the necessity to take the PC effects into account. Some discrepancies between our calculations and experimental gamma-spectra data can probably be decreased if we consider the incident neutron energy spectra.

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## Bibliography


1. Handbook for calculations of nuclear reactions data-RIPL2, IAEA-TECDOC-1506, 2006.
2. R. Capote, *et al.*, Nuclear Data Sheets **110**, 3107 (2009). See also https://www-nds.iaea.org/RIPL-3.
3. O.I. Achakovskiy, A.V. Avdeenkov, S.P. Kamerdzhiev, this Seminar.
4. H.K. Toft, *et al.*, Phys. Rev. C **83**, 044320 (2011).
5. S. Kamerdzhiev, J. Speth, G. Tertychny, Phys. Rept. **393**, 1 (2004).
6. V. Tselyaev, Phys. Rev., C **75**, 024306 (2007).
7. Avdeyenkov, F. Gruemmer, S. Kamerdzhiev, *et al.*, Phys. Lett. B **653**, 196 (2007).
8. Avdeenkov, S. Goriely, S. Kamerdzhiev, S. Krewald, Phys. Rev. C **83**, 064316 (2011).
9. K. Bennaceur and J. Dobaczewski, Comp. Phys. Comm, **168**, 96 (2005).
10. M. Herman, *et al.*, Nucl. Data Sheets, **108** (2007) 2655-2715. See also http://www.nndc.bnl.gov/empire/index.html.
11. J.Nishiyama, M.Igashira, T.Ohsaki, J. Nucl. Sci. Technol. (Tokyo) **45**, 352 (2008).

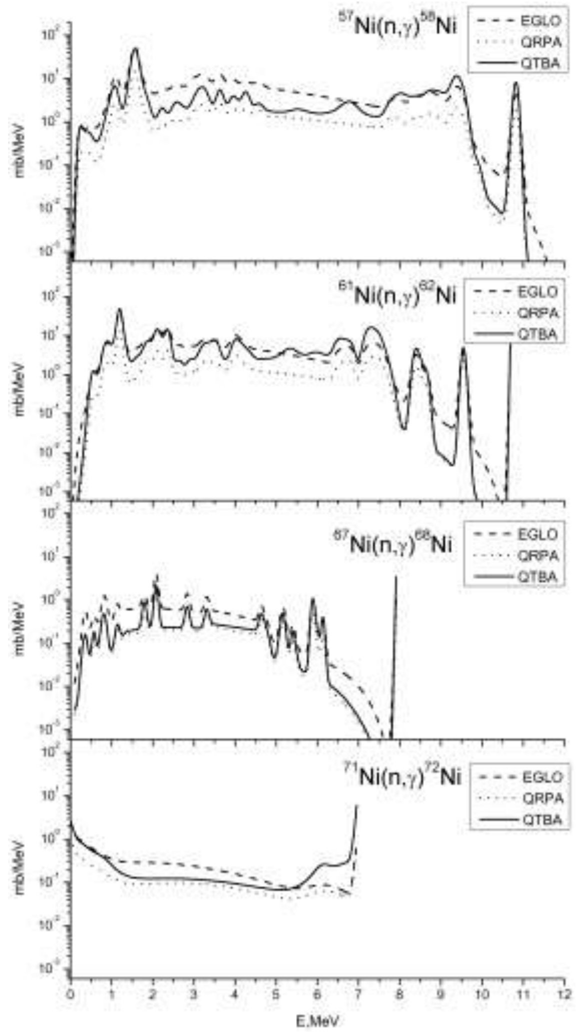


**Fig. 1.** Neutron capture gamma-ray spectra of Ni isotopes: microscopic QRPA (dots), and QTBA (solid line) and the phenomenological version EGLO (dashed). The incident neutron energy is 100 keV.

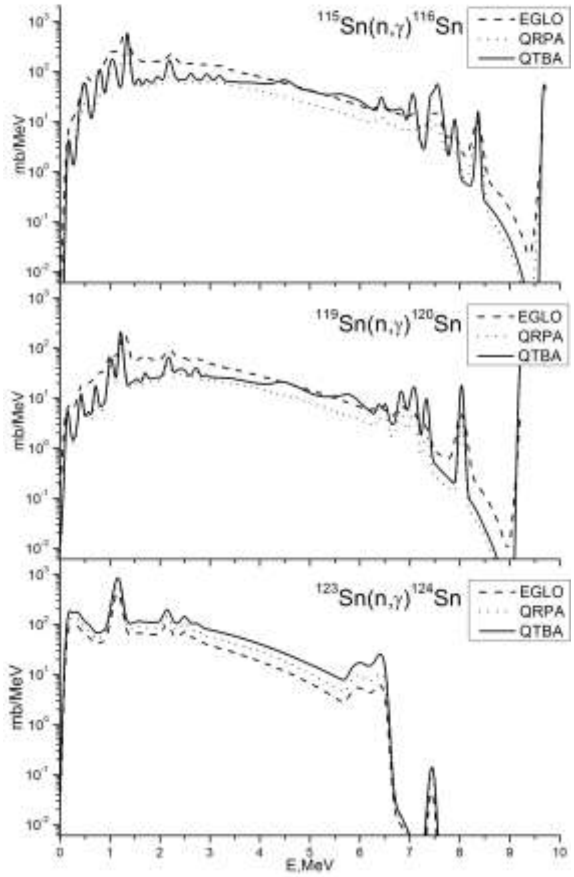


**Fig. 2.** The same as in Fig. 1 but for Sn isotopes.

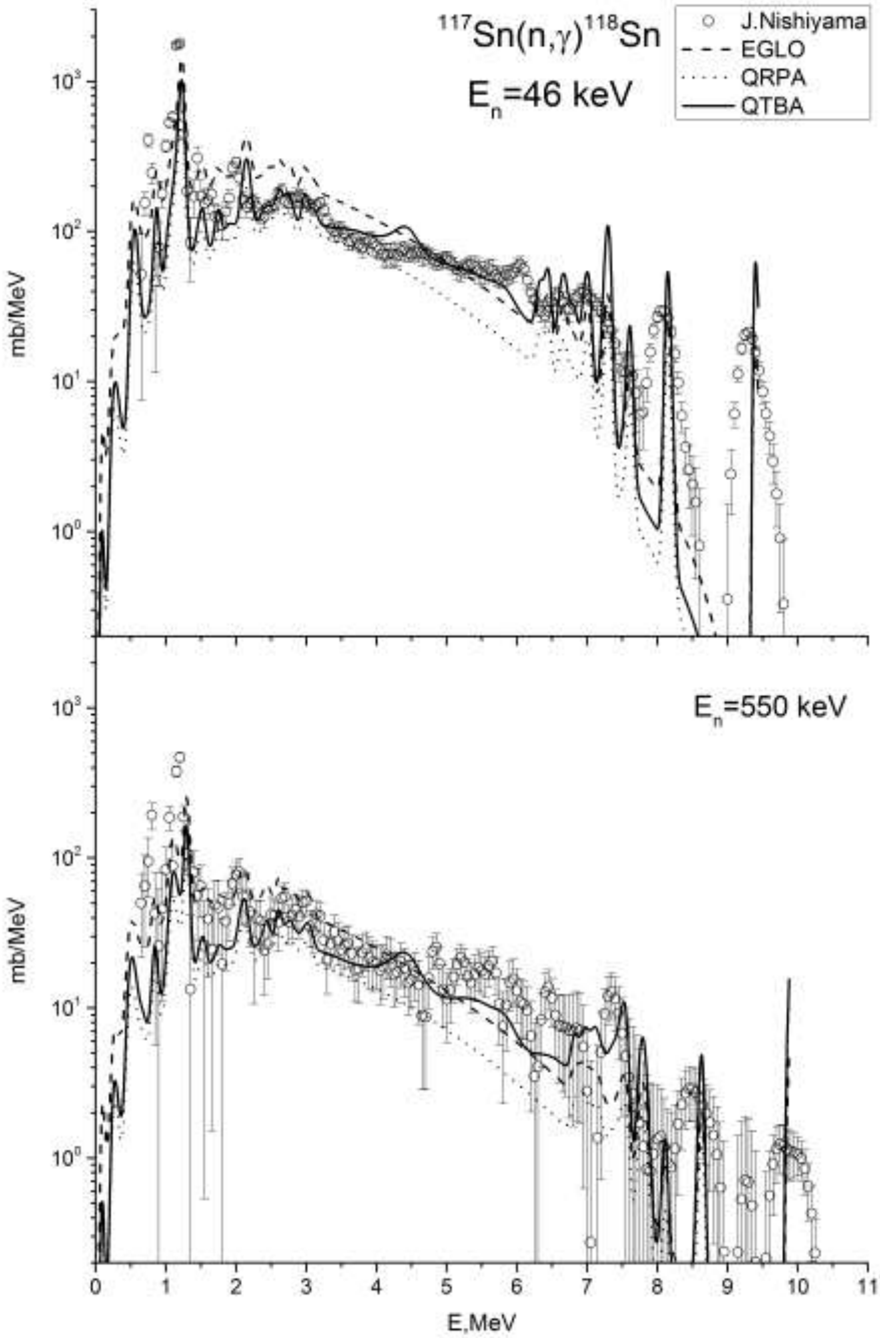


**Fig. 3.** Neutron capture gamma-ray spectra of $^{117}Sn$ at the average neutron energy of 46 keV and at 550 keV. Experimental data are taken from [11]. See text for details.

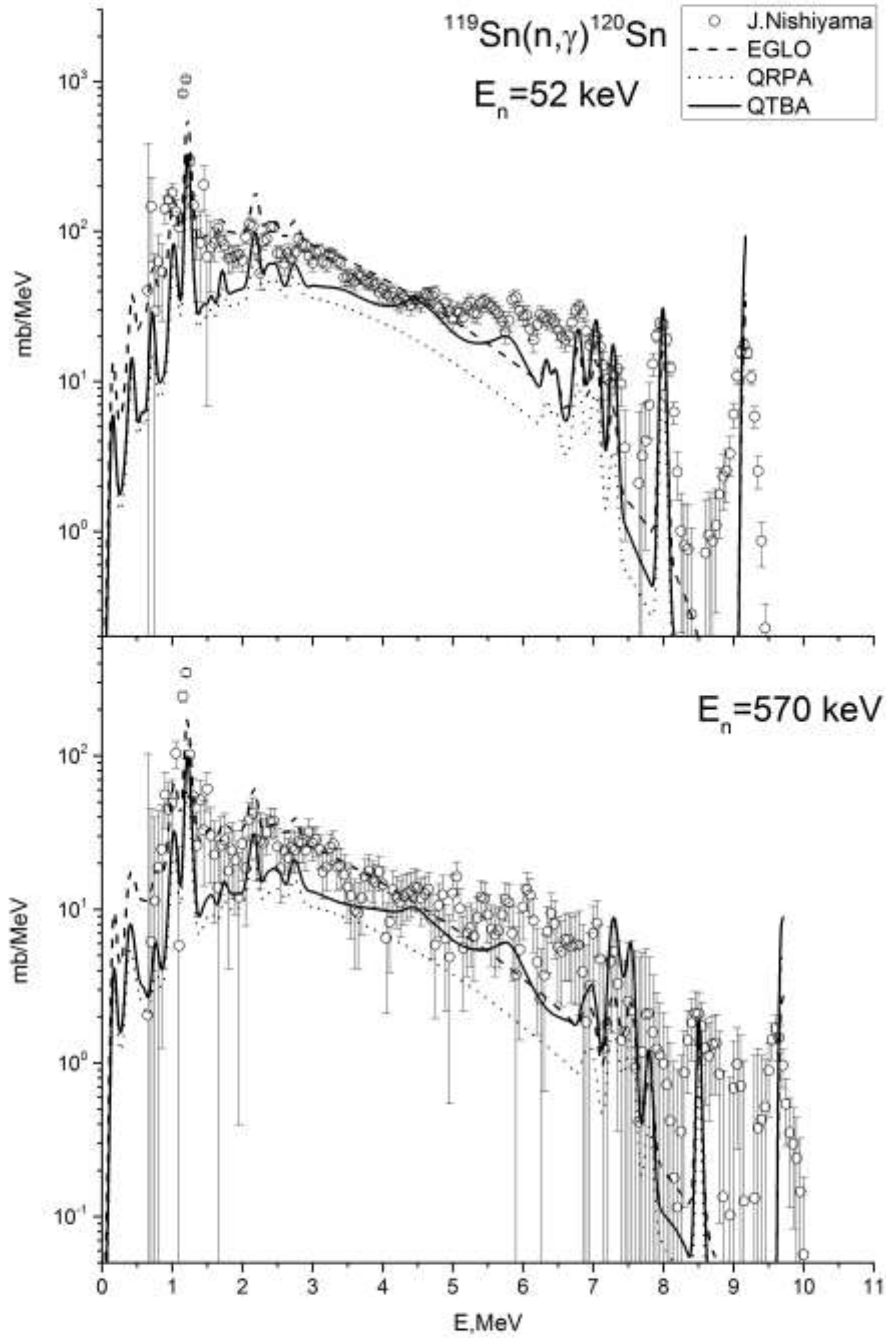


**Fig. 4.** Neutron capture gamma-ray spectra of $^{119}$Sn at the average neutron energy of 52 keV and at 570 keV. Experimental data are taken from [11]. See text for details.