Microscopic calculations of the photon strength functions in magic and semi-magic nuclei

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Plan

- Aims of work
- Microscopic self-consistent calculations of photon strength functions (PSFs) in magic and semi-magic nuclei to account for phonon coupling (PC) effects
- Calculations of radiative neutron capture cross sections and average radiative widths with EMPIRE 3.1 using our microscopic PSFs
- Conclusion
Aims of calculations:

We want to investigate the specificity of the radiative characteristics in magic and semi-magic nuclei:

- To take self-consistency into account. (such an approach has a higher predictive power as compared with phenomenological approaches (SLO, MLO, EGLO etc.))
- To describe structures of E1 photon strength functions (PSFs) microscopically with both QRPA and phonon coupling effects
- To compare ($^3$He, $^3$He’ γ) Oslo exp. data, the (γ, γ’) and (p, p’) results for $^{208}$Pb
- To calculate radiative neutron capture cross sections and average radiative widths for corresponding nuclei
Extended Theory of Finite Fermi Systems in the QTBA approximation

ETFFS(QTBA) contains:
1. (Q)RPA
2. Phonon coupling
3. Single-particle continuum (in discretized form)
4. Self-consistency

and uses the known Skyrme forces to calculate simultaneously the mean field, effective interaction and phonon characteristics self-consistently

No new parameters!

Method:

Some our articles:
Kamerdzhiev et al., JETP Lett., 101, No. 11, 725 (2015)
Achakovskiy et al., JETP Lett., 104, No.6 (2016)
Features of the self-consistent approaches

• Self-consistency:
  Mean field (ground state) is determined by the first derivative of the **density functional**.
  Effective ph- and pp-interactions for phonons are the second derivative of the **same functional**.

• Individual approach to each nucleus due to its single-particle and phonon spectra. Therefore, the individual PSF structures can be described.

• Parameters of the Skyrme forces or functional are universal for all nuclei except for light ones ("first principle" approach).

• Great predictive power.
Continuum TBA

This method

- is improved fully self-consistent **method TBA**
- uses the additional (to QTBA) Coulomb and spin-orbital forces
- automatically takes into account the spurious $1^{-}$ state
- account more consistently the single–particle spectrum
- was developed recently *only for double-magic nuclei*

Comparison of these two methods with experiment for double-magic nuclei allows to check and choose the method

Predictions of PDR for $^{70}$Ni (QTBA)

All Ni isotopes are calculated with Skyrme forces BSk17

$$S_n = 7.31 \text{ MeV} \quad \Delta = 200 \text{ keV}$$

For energy interval 4–8 MeV
QRPA: $\langle E \rangle = 6.74 \text{ MeV}, 0.24 \% \text{ of EWSR}$,
QTBA: $\langle E \rangle = 6.92 \text{ MeV}, 1.0 \% \text{ of EWSR}$.

For energy interval 8–14 MeV
QRPA : $\langle E \rangle = 12.3 \text{ MeV}, 20.6 \% \text{ of EWSR}$,
QTBA : $\langle E \rangle = 12.2 \text{ MeV}, 27.7 \% \text{ of EWSR}$.

Theor. calc.: Achakovskiy et al., JETP Lett., 104, No.6 (2016)
Exp. data: S. N. Liddick et al., PRL 116, 242502 (2016)
Predictions of PSF for $^{66}$Ni (QTBA)

Preliminary results! 

PC give additional (as compared with QRPA) PSF structures and allow us to describe structures in PDR energy region

$S_n = 8.95$ MeV \hspace{1cm} $\Delta = 200$ keV

For energy interval 4–8 MeV
QRPA: $\langle E \rangle = 6.49$ MeV, 0.14 % of EWSR,
QTBA: $\langle E \rangle = 6.75$ MeV, 0.84 % of EWSR.

For energy interval 8–14 MeV
QRPA: $\langle E \rangle = 12.26$ MeV, 16.5 % of EWSR,
QTBA: $\langle E \rangle = 12.14$ MeV, 23.9 % of EWSR.
PSF for $^{208}$Pb (CTBA)

Calculated with CTBA with new Skyrme SV-m56k6

$S_n = 7.37 \text{ MeV} \quad \Delta = 400 \text{ keV}$

The improved approach describes the reanalyzed data better at $E>5 \text{ MeV}$

Exp. data:
Oslo group - N.U.H. Syed et al., PRC 79, 024316 (2009), private communication (reanalyzed data)
PSF for $^{208}$Pb: comparison of experimental data sets

The PSF structures at $E<4.84$ MeV may be only caused by the (M1?) transitions between excited states.

Some additional transitions between excited states at $E>5$ Mev?

$(\gamma, \gamma')$ - N. Ryzeaeva, et al., PRL 89, 272502 (2002)
$(p, p')$ - S. Bassauer, et al., PRC 94, 054313 (2016)
$(^3\text{He}, ^3\text{He}' \gamma)$ - N.U.H. Syed, et al., PRC 79, 024316 (2009), private communication (reanalyzed data)
PSF for $^{132}$Sn (QTBA)

Exp. data: P. Adrich et al., PRL 95, 132501 (2005)

Skyrme forces – SLy4

$S_n = 7.34 \text{ MeV}$

$\Delta = 200 \text{ keV}$
PSF for $^{56}\text{Ni}$ (QTBA and CTBA)

$S_n = 16.64\text{ MeV}$

Neutron capture for $^{207}\text{Pb}$

Very large difference between the results obtained with the traditional GSM and others NLD models (Enhanced GSM and combinatorial HFB).

Difference between the results obtained with CRPA and CTBA for one NLD model is much smaller than for different NLD models.
Neutron capture for $^{131}$Sn and $^{55}$Ni
## Average radiative width

<table>
<thead>
<tr>
<th>Nuclei</th>
<th>NLD model</th>
<th>EGLO</th>
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For \(^{208}\)Pb:
- \(D_0\) (GSM) = 0.00441 keV
- \(D_0\) (EGSM) = 32.0 keV
- \(D_0\) (HFB) = 37.6 keV
- \(D_0\) (exp) = 30 (8) keV

It turned out that the contribution of the **M1 resonance** (Bohr model) is rather small

Conclusions

• Our results showed the necessity of inclusion both the QRPA and PC effects for description of radiative nuclear data for magic and semi-magic nuclei, first of all for PSFs. A reasonable agreement with experiment due to PC has been already obtained for $^{208}$Pb and Sn isotopes.

• We have more pronounced PSF structure for double magic nuclei than for semi-magic nuclei.

• For $^{208}$Pb and $^{132}$Sn the contribution of PC to radiative neutron capture cross sections and average radiative widths is not so noticeable as compared with the semi-magic nuclei.

• For $^{208}$Pb in PDR region transitions between excited states also could be measured by Oslo group.

• GSM NLD model in EMPIRE is not suitable for description of characteristics in double-magic nuclei.
Acknowledgements:

• We acknowledge Oslo group for their experimental data and support
• We acknowledge Dr. N. Lyutorovich for collaboration
• The work has been supported by the grant of Russian Science Foundation (project № 16-12-10155)

Thanks you for your attention!