Proposal
Lifetime measurement of short-lived states of ^{150}Gd

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Abstract

We propose to measure short lived low-spin states of ^{150}Gd with the Doppler Shift Attenuation Method (DSAM). The excited low-spin states will be populated via the ^{147}Sm(α,n)^{150}Gd fusion-evaporation reaction at a beam energy of 17.5 MeV. γ-rays will be detected with an array of lanthanum bromide (LaBr$_3$) and high-purity germanium (HPGe) detectors at forward- and backward-angles.

1 Motivation and physics case

An important source of information on the proton-neutron interaction in collective nuclei are proton-neutron mixed-symmetry states (MSSs)[1, 2, 3]. The fundamental MSS is the isovector quadrupole excitation of the valence shell ($2^+_{1,ms}$). The wave functions for one-quadrupole phonon excitations in the Q-phonon scheme show the close relationship to the first 2^+:

$$|2^+_1\rangle \propto [Q_\pi + Q_\nu]\,|0^+_1\rangle \tag{1}$$

$$|2^+_{ms}\rangle \propto \left[\frac{Q_\pi}{N_\pi} - \frac{Q_\nu}{N_\nu}\right]|0^+_1\rangle\,, \tag{2}$$

where $Q_{\pi,\nu}(N_{\pi,\nu})$ denotes the proton and neutron quadrupole operators (boson numbers) and $|0^+_1\rangle$ is the ground state of an even-even nucleus.

^{150}Gd is a nearly spherical nucleus near the neutron shell-closure at N=82. In such nuclei we typically find phonon excitations at low energies. Dominant fragments of the one-phonon $2^+_{1,ms}$ state are typically located at an excitation energy of about 2 MeV. The 2^+_{ms} state can be identified by a strong $M1$ matrix element ($\langle 2^+_1|\,M1\,|2^+_{ms}\rangle \sim 1\,\mu_n$) and a "weakly-collective" $E2$ transition to the ground-state ($\sim 1\,W.u.$). Due to its isovector character this state has a short lifetime of typically < 100 fs.
Up to date not a single lifetime of a low-spin state of ^{150}Gd is known in the Nuclear Data Sheets (from 2013, [11]). This lifetime will be measured using the Doppler Shift Attenuation Method (DSAM). To identify the mixed-symmitry state one also need the $E2/M1$ multipole-mixing ratio from angular correlations.

Mixed-symmetry states are well known especially in the N=52,54 isotones (see Ref [5]) and there are ongoing studies at N=80 [7, 5, 8]. Not much is known for heavier isotopes with N$>$ 82 and Z$>$ 62.
We intend to locate the one-phonon 2^+_{ms} state in ^{150}Gd, or its strongest fragments, for the first time.

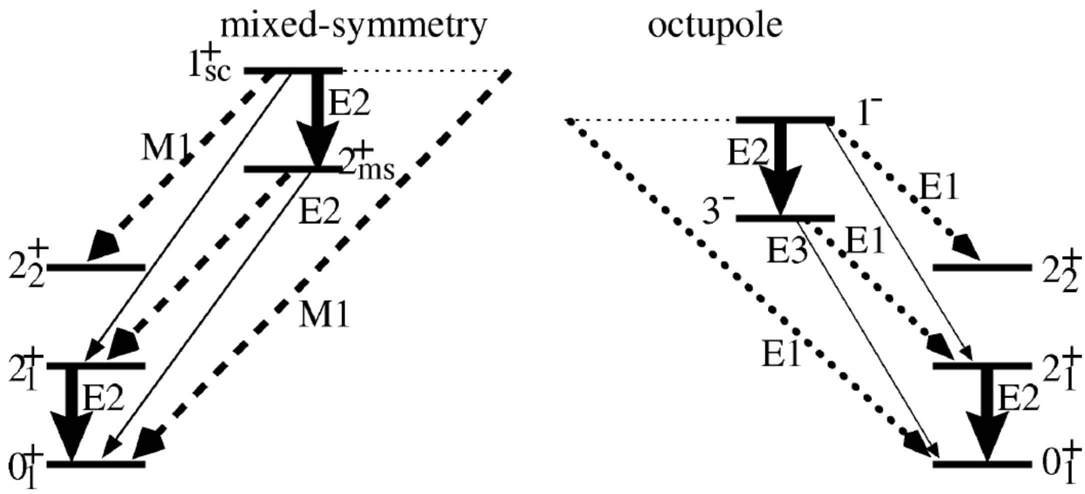

Figure 1: Expected decays of fundamental one-phonon states in the sdf-IBM-2. Taken from [9].

The main candidates for the fundamental MSS are the 2^+-states at 1518 keV and at 2091 keV. They both decay mainly by an $E2$-transition to the ground-state, a $M1$-transition to the first 2^+-state and a $E1$-transition to the first 3^--state. An enhanced $E1$-transition to the 3^-_1-state is an addtional signature for the $2^+_{1,ms}$-state [10].

Furthermore, we want to search for members of the $2^+_1 \otimes 2^+_{ms}$ two-phonon multiplet ($j^\pi = 0^+, ..4^+$) which should be accessible in such a light ion reaction around the Coulomb-barrier. One should expect them close to the sum energy of the one-phonon states, i.e. the 2^+_1-state and the $2^+_{1,ms}$-state. Members of this two-phonon structure have previously been observed in (α,n$\gamma\gamma$)-reactions in the A$\sim$ 90 region, e.g. in ^{94}Mo [4], but no example is known near N=82.

In addition, ^{150}Gd lies in a region with strong octupole correlations, e.g. the 3^-_1 state of ^{148}Gd at 1273.5 keV is known to have a $E3$ decay transition strength of $\sim 40\,W.u.$ to the ground state [11]. If the transition strength is of the same order for the decay of the 3^-_1-state to the ground-state of ^{150}Gd, one can obtain a first approximation for the lifetime of the 3^-_1-state of ^{150}Gd using:

$$\frac{1}{\tau} = \sum_{\pi\lambda} 8\pi \frac{\lambda+1}{\lambda((2\lambda+1)!!)^2} \left(\frac{E_\gamma}{\hbar c}\right)^{2\lambda+1} \cdot B(\pi\lambda; I_i \to I_f), \tag{3}$$

with the lifetime τ, the multipolarity π, the angular momentum λ and the transition strength $B(\pi\lambda)$. The lifetime should be approximately two-times the lifetime of the 3^-_1 of ^{148}Gd, i.e. $\sim$70 ps, because the 3^-_1-state of ^{150}Gd lies at a lower energy (1134.3 keV) in comparison to ^{148}Gd.
Figure 1 shows the decay scheme for the fundamental one-phonon states [9].

With $LaBr_3$-detectors in the array, we can also use Fast-Timing to determine lifetimes in the region of a few ten picoseconds [14]. Lifetimes of the one-phonon octupole excitation and of the first excited 0^+ state are expected to be in the range of 10s of picoseconds, and would be accessible through fast timing methods using the Bucharest $LaBr_3$-array. This, in addition to the determination of decay multipolarities, will allow the study of octupole correlations and, hence, the phonon structure of ^{150}Gd.
In addition, our study of 0^+_2 lifetimes in the Gd isotopic chain, which crosses from spherical to well deformed isotopes across N=90, will be complemented by its most vibrational member above N=82.

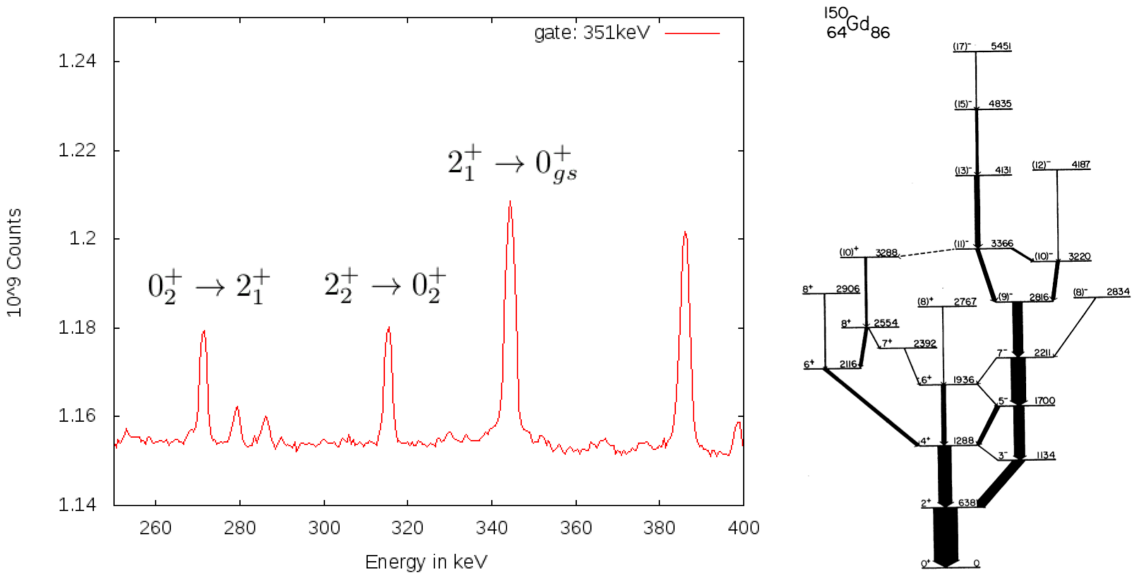

Figure 2: On the left side a gated energy spectrum of ^{149}Sm(α,n)^{152}Gd and on the right side a levelscheme of ^{150}Gd [13].

2 Experiment

For the measurement of the lifetime of the 2^+_{ms} in the fs-region we intend to use DSAM. The produced γ-rays will be detected with HPGe-detectors in forward and backward direction to observe the Doppler-shift of the order of a few keV in the relevant transitions. The RoSphere detector array should allow us to determine angular correlations.

A CASCADE calculation has been done to choose the optimal beam energy for this experiment, compare Fig.3. With 17.5 MeV beam energy we are below the threshold of the 2n channel and above the Coulomb barrier of about 16 MeV. The cross section for ^{150}Gd is approximately 200 mb.
In a recent experiment at Bucharest we were able to populate the second 0^+ state of ^{152}Gd with an (α,n) reaction, compare Fig.2.

We propose to start taking a few hours of excitation-function data at different beam energies around the Coulomb-barrier in order to optimize for low spin-transfer and cross-section.
After measuring with a 5 mg/cm^2 ^{147}Sm Au-backed Target for 7 days we ask for an additional few hours of ^{13}C beam on a thin ($\approx$ 1 mg/cm^2) ^{140}Ce target to test the ^{140}Ce(^{13}C,3n)^{150}Gd reaction. This reaction could be used in a follow-up plunger experiment to measure lifetimes on the order of picoseconds, especially the hitherto unknown yrast band state lifetimes.

3 Summary

- α-beam at 17.5 MeV
- Target: 5 mg/cm^2 of ^{147}Sm on 10 mg/cm^2 Au
- $LaBr_3$ detectors for Fast-Timing and HPGe-detectors under forward and backward angles for DSAM
- 2 days for energy/time calibration runs and excitation-function production runs
- 7 days for taking data with Gold backed ^{147}Sm-DSAM target
- 1 day for the test of ^{140}Ce(^{13}C,3n)^{150}Gd reaction with thin target

CASCADE Calculation LaTeX Output © F. Seiffert												
code vers.: F. Pühlhofer, Nucl.Phys.A 280(1977)267										Target: **147Sm**		Projectile: **4He**
Date of calc: 20140731				Compound Nucleus:151Gd				Vcoul.= 17.23 MeV			Lcrit.= 17$\hbar$	
E	[MeV]	12.00	13.00	14.00	15.00	16.00	17.00	18.00	19.00	20.00	21.00	22.00
Cl0	$\hbar$	1.00	1.00	1.00	1.00	1.00	1.37	4.04	5.79	7.10	8.17	9.10
Nuc.	chan.	σ / mb										
151Gd	γ	0.05	0.04		0.01	0.02	0.04	0.07	0.09	0.11	0.11	0.09
150Gd	n	0.29	1.16	4.24	14.76	47.83	126.69	250.01	364.51	471.01	581.47	450.55
149Gd	2n								21.61	43.81	48.22	281.64
147Sm	α								0.24	0.41	0.57	0.62
146Sm	nα											0.04
σ_{fusion}		0.34	1.20	4.24	14.77	47.87	126.78	250.23	386.52	515.48	630.68	733.26

Figure 3: CASCADE calculation for ^{147}Sm(α,n)^{155}GD.

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