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γ(γ)-spectroscopy and lifetime measurements in the 132 Sn region following (p,2p) reactions

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Compared to studies of neutron-rich nuclei (A,Z) employing isomeric decay or Coulomb excitation which require the isotope of interest as secondary beam or spectroscopy following β-decay which even requires the more neutron-rich (A,Z-1) isotope, (p,2p) reactions start from the less exotic isotope (A+1,Z+1). This reaction mechnism has been exploited successfully already in the SEASTAR campaign with the liquid hydrogen target MINOS at RIBF. Also the population via alternative reaction paths, e.g. (p,pn), can be investigated. The reaction mechanism itself, hence the extracted cross sections, offers additional sensitivity on the structure of the populated states.
The nuclei in the region of 132 Sn are just at the heavy border of what can be done at RIBF. Various decay studies with EURICA, but also in-beam spectroscopy, e.g. of 136 Te, have been done. New experimental information will challenge modern nuclear theory calculations, the shell model as well as beyond-mean-field approaches.
Cd isotopic chain
Cd lies two protons below of Sn. The Cd isotopes up to 132 Cd (N=82) have been investigated by mass measurements, laser spectroscopy and decay spectroscopy, however in-beam studies are scarce and B(E2) values have often large errors. The level schemes of the odd isotopes from 123 Cd and heavier have to be revised as mass measurement revealed a wrong placement of the 11/2 - isomers. No excited states in odd isotopes are known above N=82.
The Cs isomers will be populted from the (A+1) In isotones. The production cross section for 130 In is about 10 -2 mb. In the same setting Sn isotopes are strong side channels giving access to In isotopes.
Sn isotopic chain above 132 Sn
The 6+ seniority isomers in 134,136,138 Sn have been studied with EURICA. Below the isomers, only the B(E2, 0 ⟶ 2) value in 134 Sn has been measured with a large error. For the odd isotopes, no excited states are known for 135 Sn and above. The Sn isotopes will be populated from the (A+1) Sb isotones.The lightest Sb isotope with published production cross section is 139 Sb (about 10 -4 mb). In the same setting there will be Te side channels giving acces to Sb isotopes.
Embryonic rate estimate … feasible at all?
10 pnA 238 U and a 3 mm Be primary target results in 2.3·10 5 part/s secondary beam for 0.1 mb production cross section. Assuming MINOS with 10 cm thickness and a cross section for (p,2p) of 1 mb, 10 5 part/s result in 20 reactions/s. With 5% efficiency the γ(γ)-rates are 3600(180)/h. For the quite rare channel 138 Sn, these numbers would result in about 100 counts/day γ-rate.
Extraction of lifetimes
Electromagnetic transition matrix elements are of paramount importance for the understanding of the nuclear structure. The high velocities at RIBF naturally cause that the point of emiison of the decay g-ray is not the reaction vertex for lifetimes above some 10 ps. This can be exploited to extract lifetimes. The better energy resolution compared to DALI2 allows for lifetime measurements in the region of about τ = 10 ps -100 ps. The exponential decay curves are folded with distribution of reaction vertices along the target
and the slowing down (within the target) before decay. The analysis is similar to DSAM.
Some examplary lieftimes of the first 2 + states in even-even isotopes in the region of interest are given in Table 1.
126
E(2 +)[keV]
τ [ps]
Cd

652
128
Cd
646
1
130
Cd
618
2
134
Sn
726
136
Sn
688
2
138
Sn
715
3
14.9
19.9
67.7
42.9
24.6 3
12.9 2
59.1 3
64.5 3
Table 1: 1 direct lifetime measurement; 2 B(E2) from Coulomb excitation; 3 theory predictions
The result of a simple and very schematic simulation is shown in Fig. 1. Assumed is a MINOS target of 10cm length and a distance of the detector from the centre of MINOS of 20 cm. No uncertainties for the direction and the velocity of the incoming beam, entrance windows, straggling inside the target (constant dE/dx is assumed), background, intrinsic resolution and opening angle (θ Lab =45°, infinite position resolution) of the γ-detector are included. More realistic simulations e.g. with APCAD have to confirm the region of sensitivity.
Fig. 1: Doppler-shifted γ-ray energy for reactions at the centre of MINOS ± 5 mm (E γ0 =600 keV, E beam =200 MeV/u, A=128). Shown are lineshapes for τ =10 ps, 25 ps, 50 ps and 100 ps with 10 6 events each.

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