COULOMB EXCITATION OF ^{118}Sn

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Abstract

We propose to perform a Coulomb excitation measurement on ^{118}Sn to determine the shape of this nucleus. The main goal of this proposal is to measure the signs and the magnitudes of the quadrupole moments for the excited 2^+ states at 1229.6 keV, 2042 keV and 2403.2 keV respectively. In addition the transitional matrix elements between the low-lying states inside the ground state and the intruder rotational band will be measured. The determination of the signs and magnitudes of the quadrupole moments in ^{118}Sn, as well as the transitional matrix elements between the low lying states, especially for the excited 2^+_3 (2403 keV) and 0^+_3 (2496 keV) states is crucial to understanding the nuclear structure of ^{118}Sn. The measurement will be performed at the Heavy Ion Laboratory. The ^{118}Sn target nuclei will be Coulomb excited by a 188 MeV ^{58}Ni beam from the U-200P Warsaw cyclotron. The de-exciting γ-rays will be measured by the EAGLE array in coincidence with the backward scattered ions. The Coulex chamber equipped with 48 PIN diodes will be used for particle detection. Results derived from this measurement will yield a detailed picture of the ^{118}Sn properties and are extremely useful for theoretical interpretations. The previous measurement using ^{32}S beam was performed in June 2017.

1. Physics Case

Numerous experimental and theoretical studies are currently focused on nuclear shell structure far from the line of stability [1] . In particular, the evaluation of nuclear properties, e.g., the energy of the first excited 2^+ state and the reduced transition probabilities across closed shell Z = 50 are the area of great interest. Nuclei near the closed proton or neutron shells exhibit a rich variety of phenomena. In this region of nuclear chart, a small change in the number of constituent nucleons can introduce dramatic changes in the structure. In recent years the region in the vicinity of tin isotopes has been intensively investigated both from experimental and theoretical perspectives.

Previously, ^{120,122,124}Te isotopes were Coulomb excited [3] using the same experimental set-up. Since, the collective strength of the Z = 52 nuclei are considerably larger than for the Z = 50 nuclei, higher-lying states were also populated and transition matrix elements could be determined. Surprisingly, they are well reproduced by a triaxial nuclear shape. Already measured quadrupole moments of the ^{122,124}Te isotopes support this investigation [4,5]. Though, microscopic calculation (using the Skryme effective interaction) performed point towards a vibrational structure with a mean value of $\gamma\sim30°$. The most sensitive probe to characterize a nuclear excitation is via the measurement of quadrupole moments.

Hence, for investigating the second order effects (diagonal matrix elements) in ^{120}Te, an experiment was performed at Heavy Ion Laboratory, where particle detectors are in the backward direction enabling a more precise and sensitive measurement of the quadrupole moments [6]. The measurement was carried out using a highly enriched ^{120}Te target and a ^{32}S @100 MeV beam from the U-200P cyclotron at HIL. A multi-step Coulomb Excitation of ^{120}Te was observed up to 4^+ state in the g.s. band.

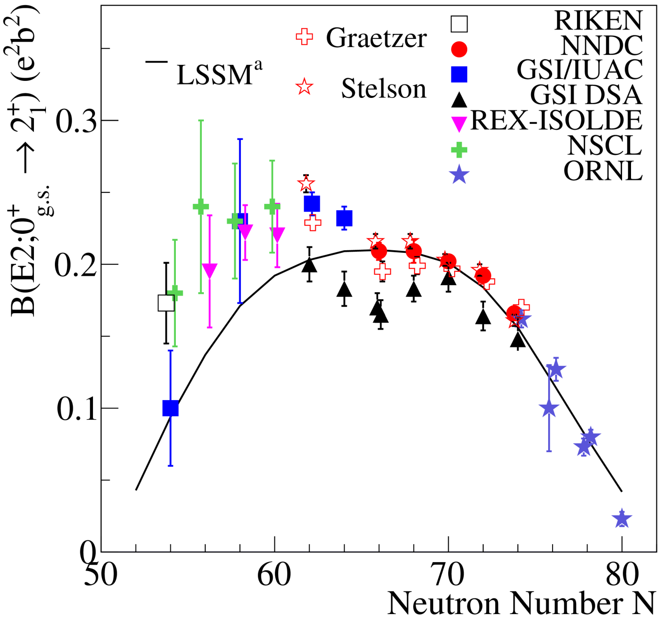

Fig 1. Evolution of B(E2↑) values values for Sn isotopes. An increasing deviation from ^{104}Sn to ^{112}Sn is visible for the latest Coulex results and the DSA measurements on stable nuclei. Shell model calculations using a ^{100}Sn core are shown for comparison. Values labeled with NNDC are the adopted ones from Ref. [17].

In order to understand the dramatic change from the tin isotopes to the neighboring tellurium isotopes, we propose a Coulomb Excitation measurement on ^{118}Sn (Z =50). This nucleus is an isotone of ^{120}Te. By measuring the diagonal matrix elements of the low lying excited 2^+ states, we hope to find the missing link in the significant change of nuclear structure.

The measurement of the quadrupole moments represents one of the most sensitive probes to study the nuclear structure. In ^{118}Sn the electric quadrupole moment was measured by Coulomb excitation many years ago [7]. It was found to be $Q(2^+) = -0.05\pm0.14$ b. The authors stated that their experimental values were slightly smaller than those obtained from earlier measurements. The recent measurement by Allmond et al [8] produced a value of $Q(2^+)$ for ^{118}Sn equal to +0.07(9).

The Sn isotopes (Z = 50) also provide a good laboratory for study of the phenomenon of shape coexistence in nuclei and have attracted extensive experimental and theoretical interest. The coexistence of both spherical and prolate shapes has been systematically observed in even-even Sn isotopes. Spherical states are interpreted to arise from the influence of the shell gap, low-lying deformed states are known to exist in Sn isotopes, which result in collective rotational bands. This structure is associated with a two proton excitation, where a pair of $g_{9/2}$ protons is excited to the down sloping $g_{7/2}$ levels above the Z = 50 closed shell. These $(\pi g7/2)^2\times(\pi g9/2)^{-2}$ bands have been observed from ^{112}Sn to ^{118}Sn [9].

To obtain a quantitative understanding of shape coexistence it is necessary to measure spectroscopic properties that are related to the nuclear shape for both yrast and non yrast states Coulomb excitation is an ideal tool for such experiments, since the excitation cross sections give access to electromagnetic matrix elements that can be directly related to the nuclear shape. Low energy Coulomb excitation can populate many excited states in a multi step process Allows to extract spectroscopic quadrupole moments utilising second order terms in the excitation process and to obtain complete sets of electromagnetic matrix elements connecting all low lying states.

The low-lying excited states in Sn isotopes were previously studied in a Coulomb Excitation experiment using ^{16}O beam at 48 MeV [10]. They performed a γ-γ coincidence measurement and determined E2 transition probabilities. For ^{118}Sn, the value of $B(E2;\ 4_1^+ \rightarrow 2_1^+)$ was measured ~ 0.058(10) e^2b^2 and the value of $B(E2;\ 2_2^+ \rightarrow 2_1^+)$ was about ~ 0.02(5) e^2b^2. The rather large values for the transition probabilities suggested a more vibrational character for the 4^+ state. The intra band E2 transition $2_2^+ \rightarrow 0_1^+$ was found to be rather strongly retarded. They could not excite 2^+_3 state in ^{118}Sn isotope.

A. Backlin et.al [11] measured the E2 transitional probabilities from the excited second 0^+ state to the 2_1^+ by means of Coulomb excitation. They performed a γ-γ coincidence measurement and determined E2 transition probabilities. The $0_2^+ \rightarrow 2_1^+$ E2 transition was found to be rather enhanced with the value of $B(E2;\ 0_2^+ \rightarrow 2_1^+)$ ~ 18(3) W.u. indicating a collective character of the 0_2^+ state. In ^{116}Sn isotope, it was reported [12] that the E2 transition probability of the $2_2^+ \rightarrow 0_2^+$ transition corresponded to a deformation β_2 of about 0.13, suggesting the 0_2^+ state as the band head of a possible intruder rotational band. It was also stated that similar characteristics also exist in ^{118}Sn nuclei.

The positive parity bands in ^{112,114,116,118}Sn were excited and its properties were studied using the Cd(α, 2nγ)Sn reactions [9]. The main goal of the experiment was to search for collective bands in Sn nuclei. It was pointed out that in ^{118}Sn the 0^+ band heads originate from 2p-2h excitations in the Z = 50 proton shell.

More recently, the excited states in ^{118}Sn nuclei were investigated via the ^{116}Cd(^{7}Li,1p4n) reaction [13]. The excited 0^+_2 state at 1758 keV was interpreted as proton pair excitation across the Z = 50 shell gap leading to a deformed state, co-existing with the spherical ground state. This rotational band was extended up to I = 16^+ state.

There is no reported quadruople moment measurement for any other excited states in ^{118}Sn using Coulomb excitation or any other method. Also the past Coulomb Excitation experiments were performed by light ion beams and the E2 transition probabilities were determined using a γ-γ coincidence measurement, rather than a p-γ coincidence measurement which yields higher precision results.

No Coulex data exits for the reduced transitional probabilities of the excited 0^+_3 state at 2496 keV and 2^+_3 state at 2403 keV . We are interested in determination of the electromagnetic structure of ^{118}Sn in these states.

In summary, the main goal of this experiment is to study of collectivity in ^{118}Sn by investigating the signs and magnitudes of quadrupole moments of the excited low lying 2^+ states and the reduced transition probabilities of the low lying states, via multi-step Coulomb excitation. Such information is crucial to study the nuclear structure of ^{118}Sn isotope.

The previous measurement using ^{32}S beam as projectile was already performed in June 2017. This new measurement will be a continuation of our studies on ^{118}Sn nuclei. In the present measurement, we plan to Coulomb excite ^{118}Sn isotope using a different projectile. We shall use ^{58}Ni, which has a higher Z =58 in comparison to Z=32 in Sulphur. A higher Z beam will allow us

to have larger statistics for the measured gamma rays and also to populate higher spin states. The analysis of the first measurement is in progress. After obtaining the new data with the higher Z beam, we shall be able to extract complete set of electromagnetic matrix elements for the low-lying states in ^{118}Sn.

2. Proposed Coulomb excitation experiment

We propose to perform Coulomb excitation of ^{118}Sn isotope using **^{58}Ni** beam @ 188 MeV energy from the U-200P cyclotron at Heavy Ion Laboratory. The beam energy for the present projectile–target combination was chosen to fulfil the Cline's "safe energy" criteria [14] to ensure a purely electromagnetic interaction between the colliding nuclei.

The measurement will be carried out using a highly enriched ^{118}Sn target of 1 mg/cm^2 thickness. The de-exciting gamma rays emitted by the ^{118}Sn recoils after Coulomb excitation will be detected by the EAGLE array in coincidence with the back scattered **^{58}Ni** beam ions. The EAGLE gamma-ray spectrometer [15] consists of 15 HPGe detectors equipped with BGO anti-Compton shields. A compact Coulex chamber (the so-called Munich Chamber), equipped with 48 PIN-diodes of 0.5 x 0.5 cm^2 active area, will be used for the detection of backscattered **^{58}Ni** beam ions to select particle-gamma coincidences in order to perform event-by- event Doppler shift correction. The PIN-diodes will be placed at angles from 110 to 152 degrees for which the probability of multi-step excitation is enhanced. For the same reason, the beam energy was chosen to be as high as possible, while still ensuring a purely electromagnetic interaction between the collision partners.

The main goal of the proposed experiment is to

- determine the signs and the magnitudes for the diagonal matrix elements 2^+_2 and 2^+_3 states at 2042 keV, and 2403.2 keV respectively, and reduced transition probabilities for 0^+_3 state decay.
- also determine the relative signs and magnitudes of transitional electromagnetic matrix elements between the low-lying states inside the ground state band and the intruder rotational band to validate the shape co-existence scenario.
- The statistics in the proposed experiment will allow also for model independent determination of the quadrupole deformation parameters for the low lying excited states in the ground state and the intruder rotational bands.
- Re-measure the quadrupole moment for the first excited 2^+ state.

In the proposed experiment, several levels will be populated in the Coulomb excitation of ^{118}Sn. Expected experimental yields were calculated using the GOSIA code [16], assuming 1pnA ^{58}Ni beam of energy 188 MeV, bombarding a 1 mg/cm^2 ^{118}Sn target. The total photo-peak efficiency of the EAGLE array is 0.5% for 1.332 MeV gamma-ray energy. Matrix elements were calculated from the known B(E1), B(E2) and B(M1) values given in NNDC data base [17]. With this set of matrix elements all known lifetimes, branching ratios and multipole mixing ratios were accurately reproduced. Calculation results are presented in tab. 1. The calculated yields are also compared for ^{32}S beam Coulomb exciting ^{118}Sn target. As presented in the table, with ^{58}Ni beam we will have a chance to observe transitions upto 6^+ spin in the yrast band. Additionally, the yield for $0^+_3 \rightarrow 2^+_1$ transition is four times larger than with ^{32}S beam. Also we have a favorable chance to excite the rotational side band with the band head at 0^+ (at 1758 keV), up to second 2^+ level.

The gamma-rays expected to be observed in the proposed experiment together with the low-lying states populated in the calculations are presented in fig. 2.

Summarizing, in order to achieve the goals of the proposed experiment we request **12 days** of beam time. Namely, **36 shifts of data taking and 2 shift for the beam optimization and the in-beam tests of the experimental setup.** The ^{58}Ni beam of 1pnA intensity and 188 MeV energy will allow us to fulfill the goals of the proposed measurement.

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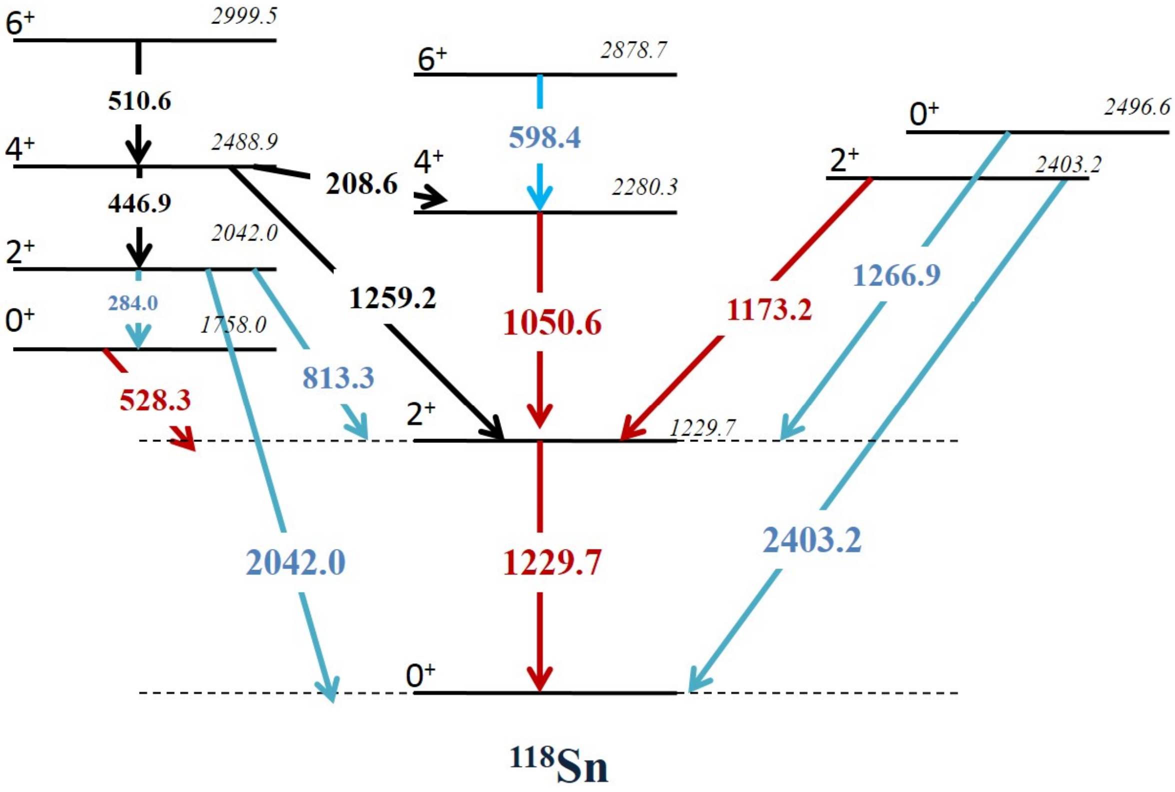

Figure 2: The partial level scheme of ^{118}Sn isotope. The transitions marked in red are the γ-rays observed with ^{32}S beam. The transitions marked in blue are planned to be observed in addition with the ^{58}Ni beam in the proposed measurement.

Table 1: Expected γ-ray yields in ^{118}Sn calculated with GOSIA code. Known level lifetimes and branching ratios are taken from NNDC data base. The yields are compared for two different projectiles, ^{58}Ni (proposed measurement) and ^{32}S(previous measurement). (for 1mg/cm^2) (these are as per new yields calculated, without efficiency)

Level energy [keV]	Halflife [ps]	Transition	Eγ [keV]	Counts for 12 days (^{58}Ni)	Counts 5 days (^{32}S)
1229.7	0.485	**$2^+ \rightarrow 0^+_{(g.s.)}$**	**1229.7**	**6.1×10^5**	**3.1×10^5**
1758.0	21	**$0^+ \rightarrow 2^+$**	**528.3**	**9.4×10^3**	**2.34×10^3**
2042.0	2.9	$2^+_2 \rightarrow 0^+_2$ **$2^+_2 \rightarrow 2^+_1$** **$2^+_2 \rightarrow 0^+_{(g.s.)}$**	284.0 **813.3** **2042.0**	14 **~370** **~500**	~ 5 **~100** **~140**
2280.3	0.76	**$4^+ \rightarrow 2^+_1$**	**1050.6**	**1.2×10^4**	**3.2×10^3**
2403.2	0.18	$2^+_3 \rightarrow 0^+_2$ **$2^+_3 \rightarrow 2^+_1$** **$2^+_3 \rightarrow 0^+_1$**	645.2 **1173.5** **2403.2**	~5 **6.0×10^3** **3.4×10^3**	~1 **1.8×10^3** **1.0×10^3**
2496.6	-	**$0^+_3 \rightarrow 2^+_1$**	**1266.9**	**~320**	**~70**
2878.7	-	**$6^+ \rightarrow 4^+_1$**	**598.4**	**230**	**~ 50**

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