Coulomb excitation of ^{116}Te: a study of collectivity above the $Z = 50$ shell gap

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Abstract

We propose to study the nature and collectivity of low-energy excitations in ^{116}Te. We aim to measure transition probability of the $0^+ \rightarrow 2^+$ transition by means of Coulomb excitation, employing REX-ISOLDE and MINIBALL. The proposed study aims to probe systematics of $B(E2)$ values in light Te nuclei, which lie in the region of the nuclear chart where unusual phenomena and development of collectivity have been observed. Moreover, the proposed study will shed light on the role of the residual proton-neutron interactions in the development of collectivity when approaching the $N = Z$ line.

Introduction

Nuclei near closed proton or neutron shells exhibit a rich variety of phenomena. In such regions of the nuclear chart, a small change in the number of constituent nucleons can introduce dramatic changes in the structures of observed states. For instance, in the neutron-deficient Sn and Cd nuclei around the neutron mid shell at $N = 66$, excited 0_2^+ states based on the intruding structures have been observed and associated with proton particle-hole excitations across the $Z = 50$ shell gap [1]. In neutron-deficient Te nuclei the situation regarding intruder structures is more ambiguous, although similar intruding 0_2^+ states based on the proton particle-hole excitations have been observed [1] along with the candidate intruder bands in ^{118}Te [2].

The origin of the observed phenomena can be studied through quantities such as level energies and reduced transitions probabilities, the latter rendering it possible to extract precise knowledge of nuclear wavefunctions. Indeed such studies have been carried out in the neutron-deficient Te nuclei. Figure 1 illustrates the systematics of observed level energies and $B(E2)$ values in Te nuclei. The energies of the first excited 2^+ and 4^+ states reveal vibrational patterns almost throughout the isotopic chain. The 2^+ and 4^+ states minimise their energies near the neutron mid shell at $N = 66$ and consequently a large $B(E2)$ value from the 2^+ state has been observed in ^{120}Te (see Fig. 1). The measured $B(E2; 2^+ \rightarrow 0^+)$ value for ^{118}Te, albeit with rather large error bars, may suggest weakening of collectivity with decreasing N.

In Ref. [7] $B(E2)$ values have been calculated for the Te isotopic chain in the framework of the microscopic configuration mixing approach with the Gogny D1S effective nucleon-nucleon interaction. The method spans the whole quadrupole collective space, taking into account axial and triaxial quadrupole vibrations together with rotation. The potential energy surface indicates (see Fig. 7 of Ref. [7]) the γ softness of ^{116}Te without any deep minima. The measured $B(E2)$ values down to ^{120}Te have been reproduced remarkably well (see Fig. 5 of Ref. [7]). The $B(E2)$ values for the $2^+ \rightarrow 0^+$ transitions are predicted to follow a parabolic behaviour around the neutron mid shell, reaching their maximum at ^{116}Te. Interestingly, deviations from such a parabolic behaviour have been recently observed in neutron-deficient Sn isotopes, in which $B(E2; 2^+ \rightarrow 0^+)$ values remain almost constant when moving from the neutron mid shell towards the doubly-magic ^{100}Sn, pointing towards the weakening of the $N = Z = 50$ shell closure [8, 9]. However, information on the transition probabilities in Te nuclei with $N < 66$ is lacking.

Moreover, spectroscopic studies may indicate a sudden onset of collectivity when approaching the $N = 50$ shell closure. A decrease in level energies of the first 2^+ and 4^+ states has been observed starting at ^{112}Te (see Fig. 1). Similar behaviour has also been observed in neutron-deficient I [10] and Xe isotopes [11] (see Fig. 1). Such unusual effect has been suggested to arise from increased octupole correlations [12] or from isoscalar proton-neutron interactions as N approaches Z [11].

The objectives of the proposed study are:

1. To provide detailed information of the wavefunctions in ^{116}Te, in which the $B(E2; 2^+ \rightarrow 0^+)$ value is predicted to reach the maximum.
2. To push the experimental limits of Coulomb excitation studies in Te isotopes at REX-ISOLDE towards the $N = 50$ shell closure through required target and beam developments.

Proposed experiment

Radioactive beam of ^{116}Te could be produced using the fibrous ZrO_2 primary target and the hot plasma ion source [13]. Spallation of the ≈ 1.5 mass% hafnium impurities in the ZrO_2 target will produce ^{116}Te as it was noted in Ref. [13]. It was also recommended that HfO_2 or CeO_2 would be suitable target materials for the production of neutron-deficient Te beams. Indeed target development would enhance the scope of the present proposal and allow Coulomb excitation studies of Te nuclei to be extended towards the $N = 50$ shell closure in order to probe the above mentioned sudden onset of collectivity. Therefore, beam time for a test measurement is

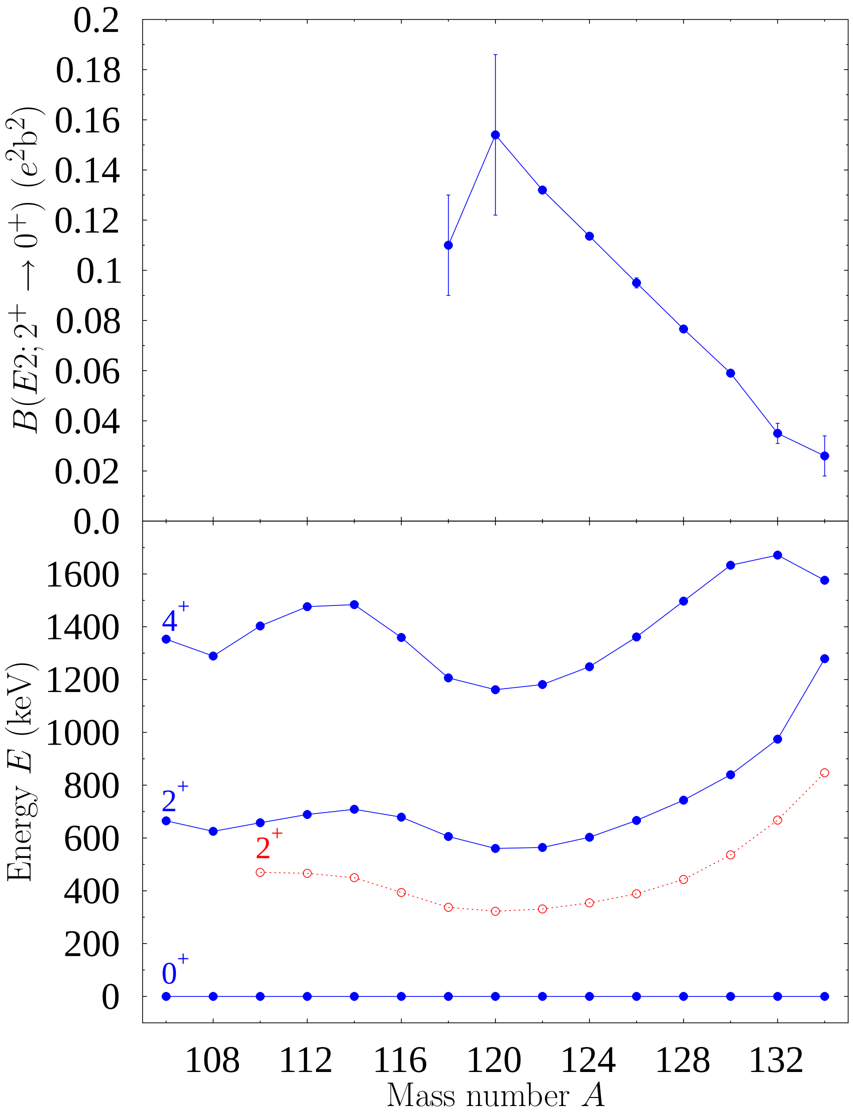

Figure 1: Reduced transition probability $B(E2;2^+ \rightarrow 0^+)$ (top panel) and level-energy (bottom panel) systematics for even-mass Te isotopes. In the bottom panel the 2^+ level energies for even-mass Xe nuclei (open symbols) are also plotted. The data are taken from Refs. [3, 4] except tentative levels for ^{106}Te are taken from Ref. [5] and the $B(E2)$ value for ^{118}Te from Ref. [6].

requested. Nevertheless, the following conservative estimate will demonstrate that the objectives of the present proposal can be achieved with the ^{116}Te beam produced as described in Ref. [13].

The required charge state to accelerate ^{116}Te beam up to 2.95 MeV/u with

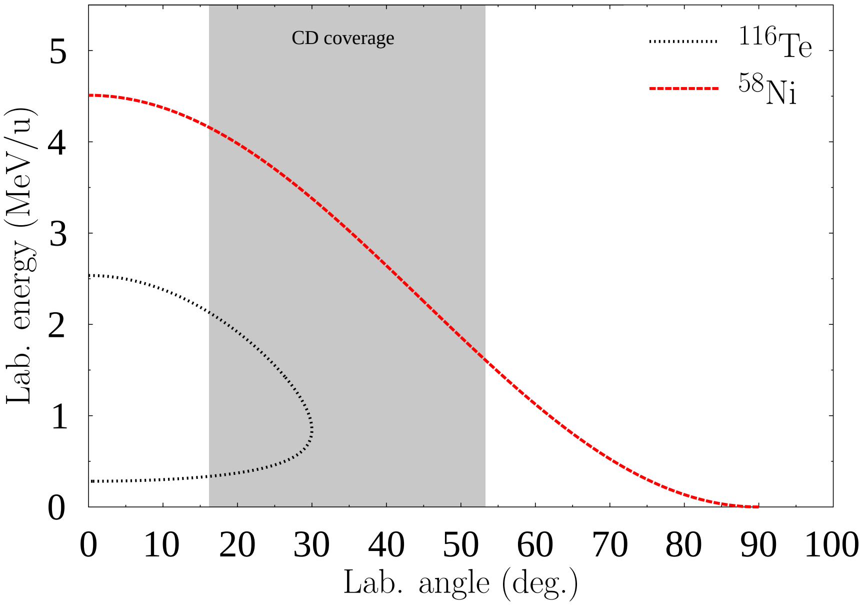

Figure 2: Kinematic plot for the 2.95-MeV/u ^{116}Te beam impinging on the 2-mg/cm^2 ^{58}Ni target. The grey area denotes the angular coverage of the CD detector.

the REX-ISOLDE linear accelerator will be obtained with the REX-EBIS charge breeder. Post-accelerated ^{116}Te beam will be delivered to MINIBALL target position where it will be Coulomb excited using the secondary 2-mg/cm^2 thick ^{58}Ni target ($E_{2^+} = 1454$ keV). The MINIBALL Ge-detector array, with a photopeak efficiency of $\approx 7\%$ for 1.3 MeV γ rays, will detect γ rays de-exciting the first 2^+ state in ^{116}Te ($E_{2^+} = 678.4$ keV) under investigation. Both scattered projectiles and target recoils will be detected using an annular double sided silicon strip detector (CD) positioned on the beam axis after the secondary target. The CD detector covers the angular range from 16° to 53° with respect to the beam direction.

In Fig. 2, the scattering of a ^{116}Te projectile impinging on the 2-mg/cm^2 thick ^{58}Ni target is shown. It is evident that the target nuclei can be clearly distinguished from the projectile nuclei within the angular coverage of the CD detector. One should note that the reaction kinematics for the proposed study are similar to that used in the previous Coulomb excitation studies in this mass region [9], in which the $B(E2; 2^+ \rightarrow 0^+)$ values have been extracted for ^{106,108}Sn.

The final beam energy of 2.95 MeV/u is well below the the safe bombarding energy of $\approx$ 3.4 MeV/u [14]. Therefore, a ‘safe’ Coulomb excitation measurement can be performed and the $B(E2)$ value for the $0^+_{\mathrm{g.s.}} \rightarrow 2^+_1$ transition can be extracted from the measured γ-ray yield.

The target Coulomb excitation γ-ray yield information is required in order to carry out a relative measurement to extract the $B(E2)$ value from the ^{116}Te γ-ray yield. However, the mass separated radioactive beam may contain isobaric impurities introducing additional target excitations. One should note that the halflives of $A = 116$ isobars in the vicinity of ^{116}Te are much shorted than that of ^{116}Te ($t_{1/2}$=2.5 h). This fact favours the extraction of ^{116}Te from the ion source. One of the objectives of the requested test measurement is to ascertain the level of isobaric impurities in the ^{116}Te beam. Should issues from the isobaric contaminants arise, use of selective laser ion source RILIS is requested.

On the other hand, in the analysis of Coulomb excitation data, triple coincidences between target particles (^{58}Ni) and beam particles (^{116}Te) observed in CD and the known $2^+ \rightarrow 0^+$ γ ray of ^{116}Te observed with MINIBALL can be required. From such a γ-ray spectrum the target excitation γ-ray yield introduced solely by ^{116}Te can be unanimously extracted. This is a standard procedure in the analysis and has been successfully applied for the Hg data (IS452). Hence, beam impurities should not pose a problem for the proposed experiment.

Yield estimate and beam time request

In Ref. [13] a primary ISOLDE yield of 10^6 ions/μC for ^{116}Te is reported. Assuming 1% transmission efficiency of REX, 10^4 pps will be delivered to the MINIBALL target position. Coulomb excitation γ-ray yield can be estimated with the Coulomb excitation code GOSIA [15]. A conservative estimate for the reduced matrix element for the $2^+ \rightarrow 0^+$ transition in ^{116}Te is taken, being half of that in ^{120}Te [4], *i.e.* $\langle 0^+_{\mathrm{g.s.}}||O(\hat{E}2)||2^+_1\rangle = 0.39\ e^2\mathrm{b}^2$. Based on these assumptions, 170 γ-ray events *per 8 hour shift* would be recorded with MINIBALL for the 678.4-keV $2^+ \rightarrow 0^+$ transition. Therefore, in order to record spectra with sufficient statistics, we request **9 shifts** of beam time for the Coulomb excitation study of ^{116}Te. An additional **3 shifts** are requested for the set up of REX.

While the above estimate is carried out for ^{116}Te, it is anticipated that HfO_2 or CeO_2 primary targets would be more favourable for the production of ^{116}Te. In order to verify the primary yields with these targets, a further **3 shifts** of beam time is requested for the yield and contamination test prior the actual Coulomb excitation measurement of ^{116}Te. The beam time request is summarised in Table 1.

The proposed experiment forms a part of the experimental programme to study the evolution of collectivity above the $Z = 50$ shell gap near the $N = 50$ shell closure. Experiments to probe level lifetimes in ^{108,110,112}Te are being carried out at the University of Jyväskylä (spokespersons B. Cederwall and R. Wadsworth). To provide complementary information to those studies through the Coulomb excitation programme of neutron-deficient Te nuclei at REX-ISOLDE, further beam development, as noted in Ref. [13], would be required.

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Table 1: Summary of the beam time request. Yield estimates for the $0^+ \rightarrow 2^+$ transitions in ^{58}Ni (target excitation) and ^{116}Te are also given.

Beam	Target	Ion source	Shifts	^{116}Te γ-ray yield	^{58}Ni γ-ray yield
^{116}Te (test)	$ZrO_2/HfO_2/CeO_2$	Hot plasma/RILIS	3		
REX set-up	$ZrO_2/HfO_2/CeO_2$	Hot plasma	3		
^{116}Te	$ZrO_2/HfO_2/CeO_2$	Hot plasma	9	1500	140
Total			**15**		

[3] Data extracted using the NNDC On-Line Data Service from the ENSDF database, file revised as of 30.11.2009. M. R. Bhat, *Evaluated Nuclear Structure Data File (ENSDF)*, **Nuclear Data for Science and Technology**, page 817, edited by S. M. Qaim (Springer- Verlag, Berlin, Germany, 1992).

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