Lifetime Measurement of the 4^+ state in $^{132}_{52}$Te

O J. Roberts*

University of Brighton, Brighton BN2 4GJ, UK

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Abstract

We propose to measure the half-life of the $I^\pi = 4^+$ state in ^{132}Te using the fast timing LaBr$_3$(Ce) and HPGe detector set-up in Bucharest. We aim to investigate the trend in collectivity around N = 82, an area of interest in this mass region due to anomalies of B(E2) strengths and low 2^+ excitation energies in neighbouring even-even isotopes. An estimate of the half-life of the 4^+ state in ^{132}Te has been calculated to be $\sim$ 90 ps [1].

We will use the ^{130}Te(^{7}Li,αp)^{132}Te reaction at a beam energy of 22 MeV ($\sim$ 2 MeV above the Coulomb barrier), to perform an induced transfer reaction to populate states in ^{132}Te. A pulsed beam will be set-up so that the decay from the isomeric ($T_{1/2}$ = 145(6) ns) $I^\pi = 6^+$ state can be measured out of beam. Realistic count-rate estimates are presented which indicate that 10 days of beam time will be needed to measure the lifetime of the $I^\pi = 4^+$ state.

1 Motivation

The region around doubly magic ^{132}Sn has been studied extensively. Of particular interest, are the values for ^{136}Te B(E2) strengths, which do not show the expected increase when compared to the N = 82 nucleus ^{134}Te [2]. Similar systematics have been observed for the 2^+ level energies, contradicting the expectation that the 2^+ energy should be highest, and the B(E2;$0^+ \rightarrow 2^+$) lowest, at the N = 82 closed shell. This has been identified as a dependence of the pairing energy on the single-particle level density by Terasaki et al [3]. Previous studies by Jungclaus et al. [4] have probed the shell structure of ^{132}Te, and have shown that there is quadrupole deformation of a predominately spherical shape due to the Fermi level lying above the Z = 50 shell closure.

Figure 1 shows the partial level scheme of ^{132}Te [5]. This figure indicates that there are three low-lying isomeric states with $I^\pi = 10^+$, 7^- and 6^+ at energies of 2723, 1925 and 1775 keV respectively. Figure 1 also shows that there is feeding into the 28.1 μs isomeric 7^- level from both the long lived 3.7 μs 10^+ isomer, and the 8^+ state. For the decay from the 10^+ level, the branching ratio is unknown. However, for the 8^+ level, the 775 and 926 keV transitions have been observed to be of equal intensity [5]. The 6^+ level is not only populated by the 8^+, but also by the long-lived 7^- isomeric state ($T_{1/2}$ = 28.1 μs) via an extremely hindered ($[\nu 1h_{11/2} 2d_{3/2} \rightarrow \pi(g^2_{7/2})] \sim 10^{-9}$ W.u. [6]) E1 transition.

Figure 2 displays the energy systematics of the low spin states in N = 80 isotonic nuclei (left), and in various Te isotopes (right). The figure on the right shows an increase in the energies of the 4^+, 2^+_2, and 2^+_1 levels as the N = 82 shell closure is approached. The figure on the left shows that low lying 2^+ states in N = 80 nuclei, show a similar trend of increasing excitation energy as the Z = 50 proton shell closure is approached. However, the excitation energies of the 4^+ in Z = 52 and 54 nuclei exhibits a decrease in their level energies.

^{126}Te and ^{134}Te are the only Te isotopes with known lifetimes for their 4^+ levels, with values of 2.8(1) ps [7] and 1.4(1) ns [8] respectively. The longer lifetime of ^{134}Te is consistent with the N = 82 nucleus having a closed shell structure. Shell model calculations suggest a $T_{1/2}$ of 86 ps for the 4^+ state in ^{132}Te [1].

We propose to measure the half-life of this 4^+ state not only to test the underlying physics, but to also use as a comparison between measurements of the same level at the ILL and GSI.

*On behalf of the DESPEC Fast Timing Collaboration

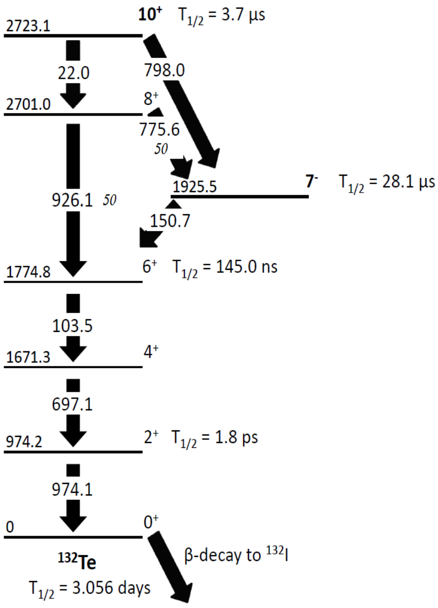

Figure 1: A partial level scheme of ^{132}Te showing all the known levels populated in the decay of the I^{π} = 10^{+} and 7^{-} isomers. Known γ-ray branching ratios are given in italics by the corresponding γ-ray energy [5].

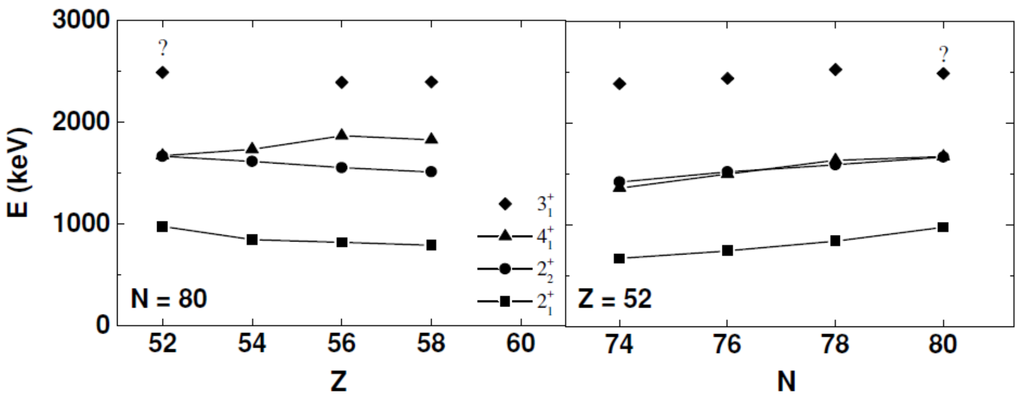

Figure 2: The left panel shows the energies of various low-lying states in N = 80 isotopes. The right panel shows the same low-lying level energies but for Te isotopes [6].

2 Experimental Overview

We propose to populate ^{132}Te using the ^{130}Te(^{7}Li,αp)^{132}Te reaction, with a beam energy of 22 MeV (within $\sim$ 2 MeV of the Coulomb barrier). This reaction is thought to be a mixture of incomplete fusion and low energy transfer, and has been performed successfully in previous experiments at Bucharest to populate the 2n transfer channel. In particular, the ^{124}Sn(^{7}Li,αp)^{126}Sn reaction was used to populate states in ^{126}Sn with an estimated cross-section of 1-2 mb. A similar cross-section is anticipated in the proposed reaction. Previous "two neutron transfer" reactions with ^{7}Li reveal that the maximum spin that is likely to be populated is six. Thus it is anticipated that for ^{132}Te, the 7^{-} will be very weakly populated and the 10^{+} will not be populated at all.

Since the 6^{+} level has a $T_{1/2}$ = 145(8) ns (well suited to the natural frequency of the beam pulsing at 5 MHz), a pulsed beam will be used to isolate the decay from this isomer, resulting in clean out-of-beam spectra. A 1-2 ns pulsed beam with a 200 ns interval will be used, and the DAQ trigger will be set to register when two $LaBr_3$(Ce) detectors fire, within a time interval of 40 - 180 ns after the beam pulse [9].

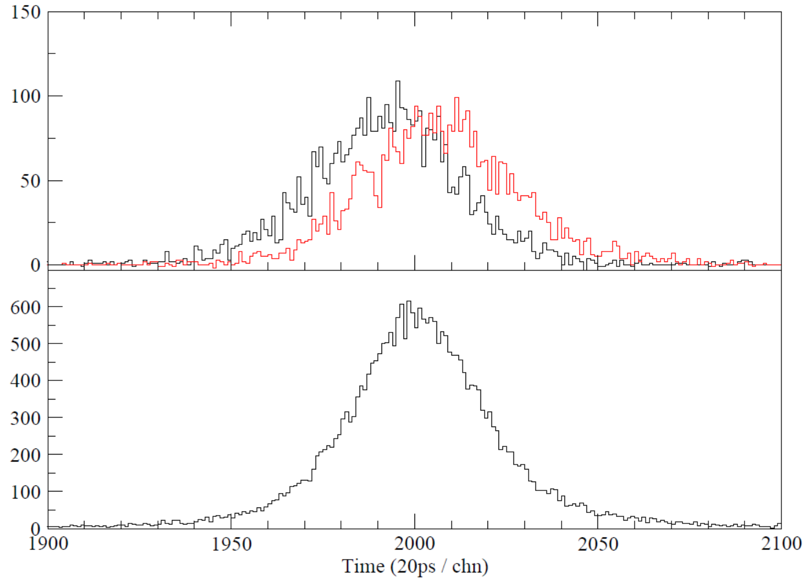

Figure 3: Spectra from a recent measurement of the lifetime of the 14^+ level in ^{138}Ce. In the top panel, the two spectra show the time difference obtained by reversing the first and second gates. The lifetime is measured from the relative shift between the centroids of the two time spectra. The bottom panel shows the time distribution of a prompt coincidence between transitions of similar energies as used in the panel above. The half-life for the 14^+ was found to be $\sim$ 100 ps [10].

We intend to measure the lifetime of the 4^+ state in ^{132}Te by taking the time difference between the $6^+ \rightarrow 4^+$ (103 keV) and the $4^+ \rightarrow 2^+$ (697 keV), and $2^+ \rightarrow 0^+$ (974 keV) transitions shown in figure 1. The lifetime will be measured using the centroid shift method, used in cases where the lifetime is too short to see the exponential decay. Using this method, the lifetime is measured from the relative shift between the centroids of the forward and backward time spectra, made by slicing a $LaBr_3$(Ce)-$LaBr_3$(Ce)-Δt matrix, which enhances the sensitivity of measurements in the 100 ps range. Time spectra are created by setting gates on the γ rays expected above and below the state of interest, and projecting out along the time difference axis. This method was used recently at Bucharest to measure the lifetime of the 14^+ level in ^{138}Ce, as shown in figure 3. In this experiment, it was found that in order to make an accurate centroid shift measurement at the $\sim$ 100 ps level, 10^4 counts were required in the spectrum.

Figure 1 shows that ^{132}Te is not stable ($T_{1/2}$ = $\sim$ 3 days), and β-decays to ^{132}I, producing two strong transitions with energies of 228.2 and 49.7 keV. ^{132}I itself is not stable ($T_{1/2}$ = 2.2 hours), producing two strong transitions with energies of 772.6 and 667.7 keV in its decay to stable ^{132}Xe. The energies of these transitions are not expected to interfere with our measurements.

3 Beam-Time Request

The Coulomb barrier for the ^{7}Li + ^{130}Te reaction is $\sim$ 20 MeV. The population of ^{132}Te via the 2n fusion-evaporation channel is expected to be weak and will be in competition with fusion evaporation channels producing ^{135}Cs (2n), and ^{134}Cs (3n). At energies above 25 MeV, previous work by T.Koike et al [11] shows that both the 3n and 4n channels are strongly populated for a similar ^{7}Li + ^{130}Te reaction[1]. At a beam energy of 22 MeV, the reaction cross-sections of the 3n and 2n channels calculated by PACE4 [12] are 90.5 mb and 9.1 mb for ^{134}Cs and ^{135}Cs respectively, at least an order of magnitude larger than the anticipated $\sim$ 1 mb cross-section of the 2n transfer reaction channel. Both ^{135}Cs and ^{134}Cs have low-lying isomeric levels ($T_{1/2}$ = 53 minutes and 2.9 hours respectively [13]) which will contribute to the out-of-beam spectrum. We propose to measure an excitation function between 20 and 22 MeV to

[1]The population of ^{132}Te was not discussed in this study.

minimise the population of levels in ^{135}Cs and ^{134}Cs, and maximise the yield of ^{132}Te ions. For this, we will use the Ge and LaBr$_3$(Ce) singles with a pulsed beam. We request two shifts of beam time for this measurement.

Calibration measurements made previously with the array of 8 LaBr$_3$(Ce) detectors and a ^{137}Cs source revealed an efficiency of ~ 1.5 % for the entire array. This is in good agreement with the value of 1.2% from the simulations, and thus provides a bench mark by which we can confidently predict the performance of this set-up. The efficiency of the Bucharest fast timing array is expected to be increased by the addition of more LaBr$_3$(Ce) detectors; including three 1.5″x1.5″ detectors provided by the DESPEC collaboration. This will bring the total number of LaBr$_3$(Ce) detectors to be used in the final set-up to 12 and will increase the expected coincidence efficiency to 0.04% at 662 keV.

Simulations of the initial fast timing set-up were performed to look at the full-energy peak efficiencies and singles spectra. The energy resolutions were calculated by incorporating a ″smearing factor″ into the simulations based on previous studies by Ciemala et al. [14]. The simulations also included the internal conversion of the E1 $7^- \rightarrow 6^+$ (α = 0.62(9)), and more importantly, the E2 $6^+ \rightarrow 4^+$ (α = 1.504(21)) transitions [15]. The internal conversion of the M1 $3^+ \rightarrow 4^+$ transition in ^{132}I was also included (α = 5.62(8)) [15]. The results of these simulations are shown in figure 4. The spectrum was generated with the existing array of 8 LaBr$_3$(Ce) detectors and includes the β-decay to ^{132}I, and the fusion evaporation channels ^{135,134}Cs. These channels have been included in the simulations with relative populations based on the expected cross-sections (^{132}Te $\sim$ 1 mb, ^{135}Cs $\sim$ 9 mb, and ^{134}Cs $\sim$ 90 mb). Figure 4 also demonstrates the cleanliness of the spectrum acquired with the pulsed beam set-up, where the $4^+ \rightarrow 2^+$ (697 keV) and $2^+ \rightarrow 0^+$ (974 keV) transitions in ^{132}Te are clearly visible. The $6^+ \rightarrow 4^+$ transition (103 keV) is obscured in the singles spectrum, but will be clean in the coincidence matrix.

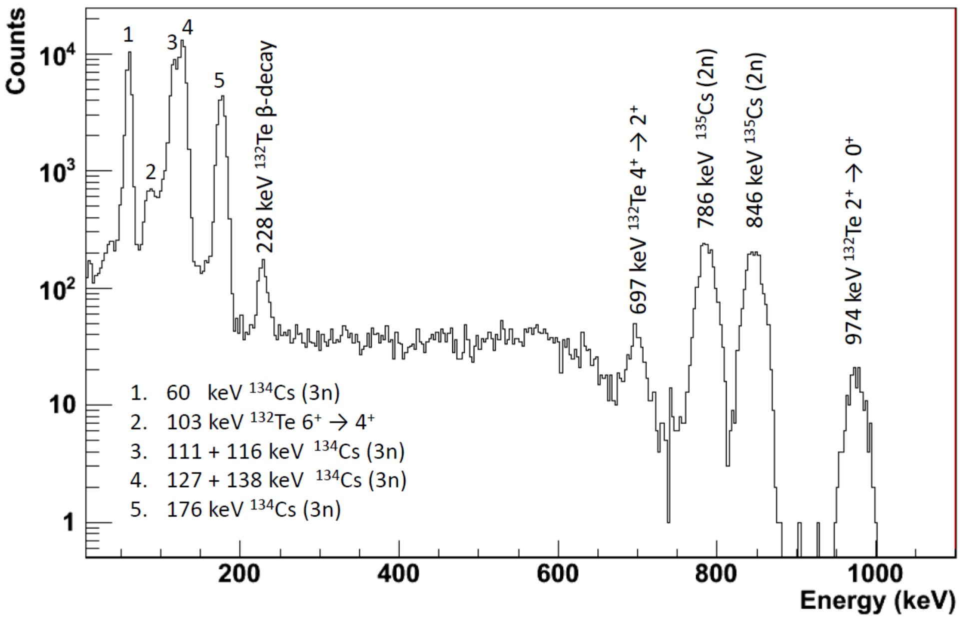

Figure 4: The simulated out-of-beam singles spectrum.

The cross-section for this reaction is anticipated to be $\sim$ 1 mb, and a beam current of $\sim$ 5 pnA on a 1 mg/cm^2 ^{130}Te target will create 142 ^{132}Te ions/s. A lower limit on the count rate can be calculated by assuming 50 % of the ions feed into each of the 6^+ and 7^- isomers. Calculations indicate that $\sim$ 40 % of the 6^+ and $\sim$ 2.5 % of the 7^- isomeric decays will occur within the DAQ window (40-180 ns), giving 30 ^{132}Te ions/s. Using $4 \cdot 10^{-4}$ for the γ-γ efficiency gives $\sim$ 1100 γ-γ coincidences a day. Therefore, with 10 days of beam time, it is estimated that we will obtain $>$ 10,000 LaBr$_3$(Ce)-LaBr$_3$(Ce) coincidences, necessary to measure the half-life of the 4^+ state.

We request a total of 11 days of beam time; 1 day to measure an excitation function, and 10 days to measure the half-life of the 4^+ state in ^{132}Te with an array of 12 LaBr$_3$(Ce) detectors and 22 MeV ^{7}Li pulsed beam set-up.

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