Lifetime Measurements of Single Particle States in $^{209}_{83}$Bi

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Abstract

We propose to study nuclei around the ^{208}Pb region in order to understand the influence of the single particle model and collective states in this region. In clarifying the behaviour of these nuclei, we aim to precisely measure half-lives in the longer lived $\frac{19}{2}^+$,$\frac{13}{2}^+$,$\frac{1}{2}^+$ states in ^{209}Bi using the fast timing $LaBr_3$(Ce) and HPGe detector set-up in Bucharest. We aim to populate these levels using the ^{208}Pb(^{7}Li,α2nγ)^{209}Bi proton transfer reaction.

1 Motivation

Low energy states of A = 209 nuclei are described as single-particles coupled to the ^{208}Pb ground state or collective excitations (e.g. 3^- at 2.6 MeV in ^{208}Pb).[1]. Previous studies have compared shell model calculations using wave-functions based on the weak coupling model to experimental data of this nucleus, where γ-ray transitions are found to be sensitive to small admixtures in the wave functions[2]. Present information on the electro-magnetic (EM) properties of states in and around ^{208}Pb were largely determined from inelastic electron scattering[3], Coulomb excitation[4, 5, 6, 7, 8], direct decay time[9, 10, 11] and multi-nucleon transfer reactions[1, 12].The best measure of the collectivity in ^{209}Bi is to look at the reduced transition probability B(π,λ) between two states, where π and λ denote the parity and multi-polarity of the transition operator. The B(π,λ) is a good indication of collectivity in nuclei as this reduced transition probability only depends on the wave-functions of the initial and final states. Reduced transition probabilities of the multiplets of levels formed by coupling the single-particle configurations to the collective states of the ^{208}Pb core have been previously studied by Broglia et al.[13]. However, lifetimes of the levels associated with this multiplet have been measured using the Doppler shift attenuation method (DSAM), and are thus not within the scope of the fast timing array ($<$ 5 ps). We aim to initially measure the known half-lives of the $\frac{13}{2}^+$ (0.27 $\pm$ 0.18 ns), $\frac{1}{2}^+$ (10 $\pm$ 2 ns) and $\frac{19}{2}^+$ (18 $\pm$ 1 ns) states in ^{209}Bi, previously extracted from Coulomb excitation measurements[1, 14]. It is hoped that with more statistics, improvements in the measured half-lives of other states, such as the $\frac{7}{2}^-$ (9.7 $\sim$ 1.1 ps[13]) and $\frac{3}{2}^+$ ($\sim$ 31 ps[13]) can also be measured. Although these low-lying states in ^{209}Bi have been studied previously in nucleon-transfer reactions[1], the small recoil velocities produced in these reactions make these nuclei unsuitable for studies with the DSAM. Advances in both scintillator ($LaBr_3$) and electronic technologies mean that significant improvements to known lifetimes and tentative spin and parity assignments can be made in this region.

2 Experimental Overview

We propose to populate ^{209}Bi using the ^{208}Pb(^{7}Li,α2nγ)^{209}Bi reaction at an energy of 31-32 MeV, which is just around the Coulomb barrier. This reaction and its mechanism are well documented[12], and have been used before to populate the states of interest[1]. The reaction cross-section is predicted to be around 100-120 mb, and is based on calculations of the threshold energies for direct and fusion reaction cross-sections[15, 16, 17].

The γ-rays produced will be detected in the Bucharest fast-timing array, which consists of 8 HPGe and 12 $LaBr_3$ detectors. HPGe detectors will be used to gate on transitions within the nuclei of interest and produce relatively clean $LaBr_3$-$LaBr_3$ coincidence spectra. 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. This method was used recently at Bucharest to measure the 66 $\pm$ 2 ps lifetime of the 14^+ level in ^{138}Ce [18]. In this experiment, it was found that in order to make an accurate centroid shift measurement at the $<$ 100 ps level, 10^4 counts were required in the spectrum.

Fig. 1 shows the γ-ray spectra which were collected during a short 45 minute test of this reaction at Bucharest in November 2011. The γ-ray spectrum in the bottom left of Fig. 1 shows transitions coincident with the 245 keV transition which depopulates the $\frac{19}{2}^+$ level at 2987 keV. This spectrum shows very clean 1132 and 1608 keV transitions and indicates that a gate on the 245 keV transition would enable the lifetime of the 1608 keV state to be obtained by measuring the relative times of the 1132 and 1608 keV transitions in the $LaBr_3$ detectors. Similarly, the γ-ray spectrum shown in the top left of Fig. 1 shows transitions which are coincident with the 1546 keV transition depopulating the $\frac{1}{2}^+$ level at 2442 keV. The cleanliness of this spectrum indicates

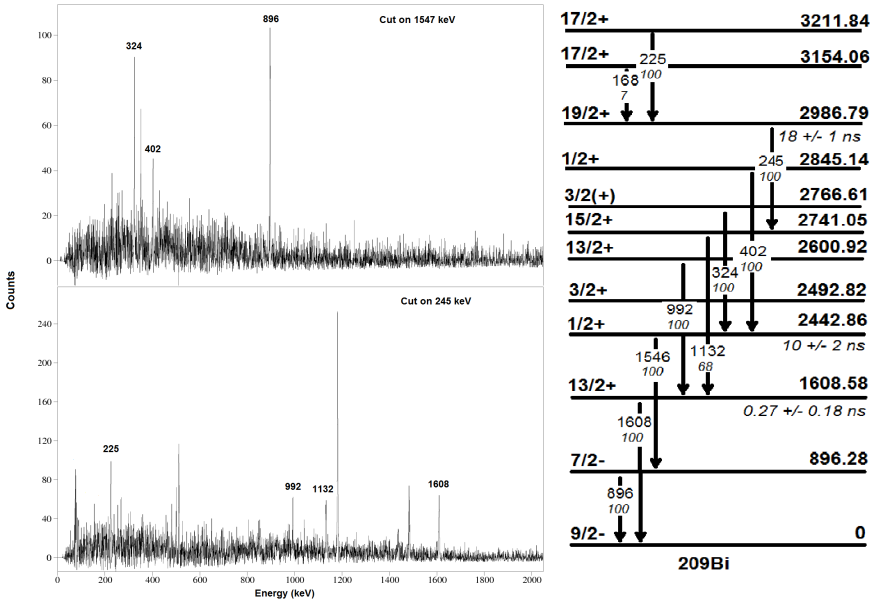

Figure 1: Left: γ-ray spectra obtained in coincidence with (top) the 1546 and (bottom) 245 keV transitions in ^{209}Bi. Right: A partial level scheme showing the levels of interest.

that time correlated events between the 1546 and the 324/402 keV transitions could be used to measure the lifetime of the 2442 keV ($\frac{1}{2}^+$) level. The lifetime of the 896 ($\frac{7}{2}^-$) level is known to be very short, τ = 9.7 $\pm$ 1.1 ps[1] and therefore probably outside the scope of this experiment. Other γ-ray combinations will be used to measure the lifetimes of the $\frac{19}{2}^+$ level at 2986 keV and the $\frac{3}{2}^+$ level at 2493 keV.

3 Beam-Time Request

A short ($\sim$ 45 minutes) test of this reaction used a 20 mg/cm^2 Pb target which was isotopically pure, and a 31.5 MeV, 4 pnA (12 enA) ^{7}Li beam. In the test, the $\frac{19}{2}^+$ state at 2987 keV was observed to be populated, where 39 γ-γ (Ge-$LaBr_3$) coincidences were detected. This equates to 1176 γ-γ coincidences a day, or 11,760 γ-γ coincidences over a period of 10 days for the highest spin state of interest. However, HPGe-$LaBr_3$-$LaBr_3$ (γ-γ-γ) coincidences will need to be performed as the γ rays needed to make the gates in the $LaBr_3$ spectrum are not as clearly seen as in the HPGe spectra. An estimate of the γ-γ-γ coincidence rate was obtained by measuring the number of 896 keV transitions in a symmetrised $LaBr_3$ matrix gated on the 1546 keV transition in the HPGe detectors. During the 45 minute test 45 counts were obtained, equating to 14,400 γ-γ-γ coincidences over a period of 10 days. This gives us enough statistics to measure the lifetime down to the 100 ps range. However, we will need to use two TAC ranges (50 and 200 ns settings) in order to measure the lifetimes in this proposal, and thus would have to perform lifetime measurements of the quicker and slower levels over a time period of 5 days each.

In total, we request 11 days of beam time; 1 day to measure the excitation function and make calibrations, and 10 days of beam on target; 5 days with the TAC setting at 50 ns and 5 days at 200 ns. This will allow us to make precise lifetime measurements at the rates presented in this proposal with a suitable amount of statistics.

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