Half-life Measurement of the $i_{13/2}$ State in $^{209}_{83}$Bi

O.J.Roberts[1], A.M.Bruce[1], F.Browne[1], P.H.Regan[2], Zs.Podolyák[2], T.Alexander[2], N.Mărginean[3], D.Bucurescu[3], Gh.Căta-Danil[3], I.Căta-Danil[3], D.Deleanu[3], D.Filipescu[3], I.Gheorghe[3], D.G.Ghiţă[3], T.Glodariu[3], R.Lica[3], C.Mihai[3], R.Mărginean[3], A.Negret[3], T.Sava[3], L.Stroe[3], S.Toma[3], R.Suvaila[3], N.V.Zamfir[3], K.Mulholland[4], J.F.Smith[4], and P.J.R.Mason[5]

[1]University of Brighton, Brighton BN2 4GJ, UK
[2]University of Surrey, Guildford, Surrey GU2 7XH, UK
[3]IFIN-HH, R-76900, Bucharest, Romania
[4]University of the West of Scotland, Paisley PA1 2BE, UK
[5]STFC Daresbury Laboratory, Daresbury, Warrington WA4 4AD, UK

October 2012

Abstract

This proposal is an extension of a previous one entitled "Lifetime Measurements of Single Particle States in $^{209}_{83}$Bi", which was awarded 10 days of beam-time at the PAC meeting in March 2012. The aim is to study the influence of the single-particle and collective modes in $^{209}_{83}$Bi, and in July 2012 we measured the half-life of the $i_{13/2}$ level at E_x=1.608 MeV as 150±25 ps. However this is not sufficiently accurate to give a unique interpretation of the level. We now request to complete this study and extend our findings from the previous experiment in two steps; by using the fast timing, ROSPHERE array of cerium-doped lanthanum bromide ($LaBr_3$(Ce)) and high-purity germanium (HPGe) detectors to acquire more statistics to reduce the uncertainty in the half-life, and to perform an angular distribution measurement in order to determine the B(E3) and B(M2) mixing ratio of the depopulating transition to the $\frac{9}{2}^-$ level.

1 Motivation

In March 2012, the PAC awarded us 10 days of beam-time to measure the half-lives of three levels (E_x=1.608 MeV ($\frac{13}{2}^+$), 2.443 MeV ($\frac{1}{2}^+$) and 2.987 MeV ($\frac{19}{2}^+$)), populated using the ^{208}Pb(^{7}Li,α2nγ)^{209}Bi proton transfer reaction. For the level scheme please refer to Figure 1. The single-particle

$\frac{13}{2}^+$ state is formed from the coupling of the $\pi 1i_{13/2}$ single particle to the ^{208}Pb core, previously calculated by Mottelson [1] to have a half-life of 0.27±0.18 ns based on the measurement of B(E3)↑=1.5±0.4 e^2fm^6[2], and mixing ratio (δ) of 0.33±10 assigned previously by Beene et al. [3] for the depopulating 1.609 MeV ($i_{13/2} \rightarrow h_{9/2}$) transition. The half-lives of the $\frac{1}{2}^+$ $[(\pi 3s_{1/2})^{-1} \otimes ^{210}Po(0^+)]$ and $\frac{19}{2}^+$ $[(\pi 1h_{9/2} \otimes ^{208}Pb(5^-)]$ had been measured previously to be 10 ± 2 and 18 ± 1 ns by Ellegaard et al. [4] and Beene et al. [3] respectively.

During the experiment in July, we ran at two different time-to-amplitude converter (TAC) settings; a TAC setting of 50 ns was used to determine the half-lives of the $\frac{13}{2}^+$ and $\frac{19}{2}^+$ states, and 200 ns was used to determine the half-life of the $\frac{1}{2}^+$ level. While all three levels were populated successfully, not enough statistics were acquired over both TAC ranges (10 days) to determine the $i_{13/2}$ level half-life (found to be 150 ± 25 ps), with great accuracy. However despite the large uncertainty, the half-life is not consistent with the current mixing ratio of δ=0.33 (which suggests the de-populating 1609-keV transition is 92% M2 and 8% E3), and calculations by Mottelson [1] using the measured B(E3) from Coulex studies [2]. This means that either the mixing ratio or B(E3) value is incorrect, and thus it is necessary to ask for more statistics in order to accurately establish the half-life of this $i_{13/2}$ level. The mixing ratio will also be measured along with the half-life so that one can figure out which of the previous studies was incorrect, and provide a clearer picture of the structure of this nucleus.

In order to give a better understanding of the nature of the $\frac{13}{2}^+$ level, we propose to remeasure its half-life so that the uncertainty of its value can be reduced. The value of the half-life will be combined with a value of δ from an angular distribution measurement. This will allow us to gain a more complete understanding of the amount of admixture seen in this level. The half-lives of the $\frac{19}{2}^+$ and $\frac{1}{2}^+$ states are still currently under analysis.

2 Experimental Overview

We propose to populate ^{209}Bi using the same reaction as in the previous proposal; ^{208}Pb(^{7}Li,α2nγ)^{209}Bi, at an energy of 31.5 MeV which is just around the Coulomb barrier. This reaction and its mechanism are well documented[5], and have been used before to populate the state of interest[6]. 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[7, 8, 9].

The γ-rays produced will be detected in the ROSPHERE fast-timing array in Bucharest, which consists of 14 HPGe and 11 $LaBr_3$(Ce) detectors. HPGe detectors will be used to gate on transitions within the nuclei of interest and produce relatively clean $LaBr_3$(Ce)-$LaBr_3$(Ce) coincidence spectra. The centroid shift method, used in cases where the half-life is too short to see the exponential decay, will be used. Using this method, the half-life 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 ± 2 ps half-life of the 14^+ level in ^{138}Ce [10].

The left panel in Fig. 1 shows gated γ-ray spectra from the $LaBr_3$(Ce) (a.) and HPGe (b.)

detectors, which were collected during the first five days ($\sim$ 140 hours) using a TAC setting of 50 ns. The gated γ-ray $LaBr_3$(Ce) spectrum in Fig. 1a. shows very clean transitions above and below the level of interest. By carefully selecting gates on feeding transitions in the germanium detectors and taking the time difference between the 992- and 1609-keV transitions, the half-life of the 1609-keV state can be obtained. Other γ-ray combinations might also be used to measure the half-life in order to boost the number of statistics. A preliminary measurement of the half-life is shown in Fig. 2. Selecting five transitions in the HPGe detectors (140-,167-,225-,246- and 413-keV), and taking the time difference between the feeding (992-keV) and de-exciting (1609-keV) γ-rays in the $LaBr_3$(Ce) detectors using data from both TAC settings, a half-life of $\sim$150$\pm$25 ps was obtained. Statistics using the feeding 1132-keV transition along with the de-exciting 1609-keV transition results in lower statistics due to the reduction in detection efficiency and intensity of the gamma-ray (68%). Thus using both combinations (992+1609 and 1132+1609) together to try and reduce the error is not sufficient enough to get an error of less than 10% for the half-life, and why more time is needed to collect additional statisitics.

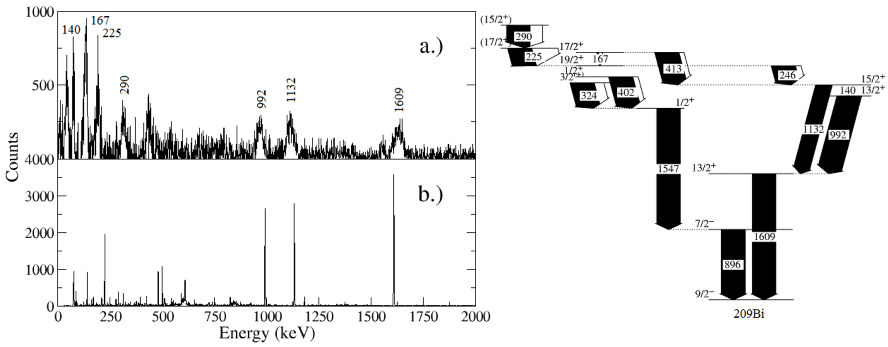

Figure 1: Right: A partial level scheme showing the levels of interest in ^{209}Bi. Left: Gated γ-ray spectra from the $LaBr_3$(Ce) (a) and HPGe (b) detectors obtained in coincidence with the feeding 246- and 413-keV transitions in ^{209}Bi after five days of data taking.

3 Beam-Time Request

A 31.5-MeV ^{7}Li beam with a current of 4-5 pnA (12-15 enA) impinged on an isotopically enriched (99%) 20 mg/cm^2 ^{208}Pb target in the July run to populate levels in ^{209}Bi. The time spectrum of the depopulating 1.609-keV γ-ray from the $i_{13/2}$ in this measurement is shown in Fig. 2. We found that using five gates in the HPGe to select the feeding γ-rays needed to determine the time difference of the 1609-keV level, 351$\pm$19 counts were recorded in the 10 day run. This equates to $\sim$35 counts per day. The ROSPHERE array has now been modified so that the $LaBr_3$(Ce) detectors are roughly a factor of two closer. Therefore, another week of beam-time will add an addtional factor of 3 more statisitics to the existing data, will give an overall factor of 4 increase in the number of counts observed in the timing spectrum. Thus we expect to halve the error in the experimental measurement to 10 ps.

We also aim to measure the B(E3)/B(M2) mixing ratio of the 1609-keV transition. To determine a rate estimate for this, we used one Compton-suppressed HPGe detector in ROSPHERE during the initial July run. It was found that with a beam current of 4.5 pnA and 290 s of "actual acquisition time" running in "singles-mode" (dead time of 3-4%), we had a background subtracted counting rate of $\sim$ 3 cps. This means that after an hour we will have $\sim$ 10,800 counts, and after 3 hours at each angle, we will have sufficient statistics to obtain intensities with errors of $<1\%$. We aim to measure at least six angles in total by moving a HPGe detector around a table, and thus ask for 3 days to measure the maximum number of angles possible in order to get a precise value for the mixing ratio.

In total, we request 10 days of beam-time to fully determine the nature of the $i_{13/2}$ level in ^{209}Bi; 7 days for the measurement of the half-life, and 3 days to determine a new mixing ratio based on angular distribution measurements at several angles.

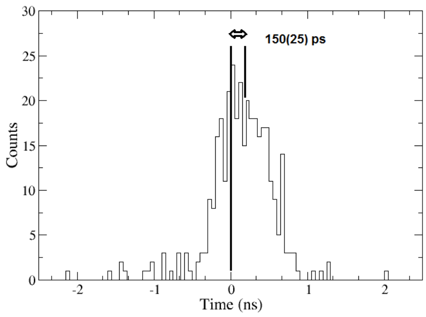

Figure 2: A time distribution spectrum showing the time difference between the centroid of the forward time spectrum and the prompt position of gamma rays feeding and de-exciting the level of interest. Five gates were used to select the 992- and 1609-keV transitions. After using data from both TAC settings, $\sim$350 counts were obtained in 10 days. Preliminary analysis of this time difference indicates a half-life of $\sim$150 ps for the $i_{13/2}$ level.

References

[1] A.Bohr and B.R.Mottelson. *Nuclear Structure, Vol II: Nuclear Deformations*. World Scientific Publishing Co., 1998.

[2] J.W.Hertel et al. *Phys. Rev. Lett.*, 23:488, 1969.

[3] J.R.Beene et al. *Phys. Rev. C*, 17:4:1359, 1978.

[4] C.Ellegaard et al. *Nuclear Physics A*, 302:125–133, 1978.

[5] O.Häusser et al. *Physics Letters*, 38B(2):75–77, 1972.

[6] O.Häusser et al. *Nuclear Physics A*, 194:113–139, 1972.

[7] W.Y.So. et al. *Phys. Rev. C*, 76:024613, 2007.

[8] P.H.Stelson et al. *Phys. Lett. B*, B205:190, 1988.

[9] P.H.Stelson et al. *Phys. Rev. C*, 41:1584, 1990.

[10] T.Al-Harbi et al. Paper Submitted.