

Half-lives of heavy nuclei through α tagging

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Abstract. Neutron-rich isotopes around lead, beyond $N=126$, have been studied exploiting the fragmentation of a ^{238}U beam at 1 GeV/u, at the FRS-RISING setup at GSI. In order to study the half-lives of populated nuclei both α and β correlations have been exploited.

1 Introduction

The β decay of neutron-rich nuclei around $Z=82$ is of particular interest for astrophysical purposes: since the rapid neutron-capture process path lies very far away from accessible nuclei, astrophysical models have to extrapolate extensively in order to predict production rates in stellar environments [1, 2]. Experimental inputs are, therefore, highly demanded to set constraints to these models.

In this paper we describe a recent analysis of an experiment in which nuclei with $N>126$ were populated by relativistic fragmentation of a ^{238}U beam at 1 GeV/u on a 2.5 g/cm² Be target. Fragmentation products were transported and analyzed by the FRagment Separator of the GSI laboratory, and then brought to rest in a Si stopper consisting of 9 Double Sided Silicon Strip Detectors, surrounded by the RISING γ -detector array. Details of the experiment and arrays can be found in [3–5].

A number of isotopes for each nuclear species, ranging from Au ($Z=79$) to Po ($Z=84$), were populated and implanted, as shown in Fig. 1: the left panel shows all the nuclei produced by the fragmentation reaction, while the right panel shows only nuclei implanted in the Si array. A very good resolution, both in mass and Z , is achieved for these heavy nuclei.

The details of the ad-hoc technique developed to study long-time β correlations can be found in refs. [3, 6], where the measurement of the half-lives for $^{211-213}\text{Tl}$ and $^{218,219}\text{Bi}$ is reported. In this paper we will describe a different analysis which, by exploiting the tagging on α particles, allowed us to extend our studies also to species not directly populated by the reaction.

2 Analysis of α correlations

In Fig. 2 we show the typical α energy spectrum registered in our Si detectors. Many discrete lines are visible and the corresponding mother nucleus is indicated. The discrete energies of the α particles ensure a correct identification of the decay, and this is confirmed by the measured half-lives and delayed γ ray spectra. The peaks corresponding to the decay of $^{212-213}\text{Po}$, characterized by lifetimes

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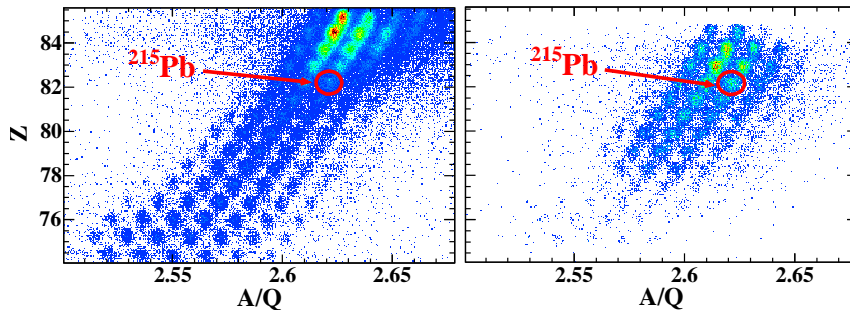


Figure 1. Particle identification plot of nuclei produced in the fragmentation reaction (left panel), and nuclei finally implanted in the Si array (right panel).

shorter than 100 μs , show a continuous tail extending to higher energies, corresponding to the pile-up of the β decay of the progenitor and the α particle.

Since the α range in silicon is only of 30-60 μm , correlations can be restricted to the pixel where the implantation of the progenitor occurred, keeping the correlation efficiency close to 100%. The presence of other fragments decaying to the same α -emitter contribute as a random background and form an exponential time distribution with a decay constant given by the frequency of implantation of the contaminant species, typically $1\text{-}5 \times 10^{-4} \text{ s}^{-1}$.

3 Half-lives determination

We take the decay of ^{215}Pb as benchmark of this analysis. This decay has been recently reported to have a half-life of 147(12) s with a decay mainly proceeding through the ground state [7]. The value found in this analysis deviates largely from the general trend of Pb isotopes, having, generally, longer half-lives. Recent DF3-cQRPA calculations based on Fayans energy-density functionals predict a half-life of 165 s, quite in agreement with the measured value, while the FRDM microscopic-macroscopic approach predicts a half-life of 282.5 s (see ref. [7]). An independent confirmation of the found half-life is therefore demanded.

Though the nucleus ^{215}Pb is indeed populated in the fragmentation reaction, the extraction of a reasonable half-life and decay scheme from this dataset can hardly be made since it is implanted in the Si detectors of the first row, which suffer from a high background coming from heavier elements implanted either in the same stopper, or in the matter layers just in front of it.

We therefore tried to bypass this problem by tagging on the α decay from ^{215}Po : as it shown in Fig. 3, ^{215}Pb undergoes two successive β decays prior the formation of the α -emitter ^{215}Po . The α decay of ^{215}Po is characterized by the emission of a α particle of 7526.3(8) keV which connects the ground state (g.s.) of ^{215}Po to the g.s. of ^{211}Pb with a half life of 1.781(4) ms [8]. This line is well resolved in the spectrum in Fig. 2.

Once the β electron emitted by ^{215}Bi is identified, it is correlated back in time with the first implantation of ^{215}Pb registered in the pixel fired by the α particle. As a result, the time behaviour of the ion- β correlations can be expressed in terms of the decay constants of ^{215}Pb and ^{215}Bi through the Bateman equations. Since this α particle is emitted immediately after the β decay of ^{215}Bi , we correctly find only multiplicity one β events in the correlation time gate. The correlation time window extends to 5 half-lives.

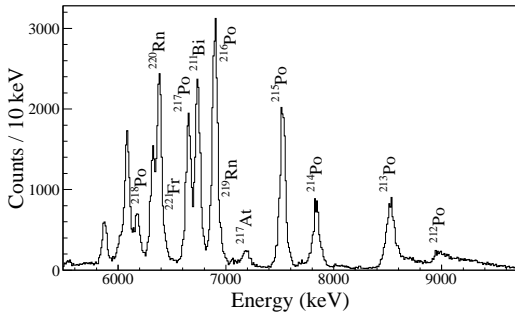


Figure 2. Energy spectrum measured in the active stopper focusing in the energy region of α decay. Labelled peaks correspond to known α lines.

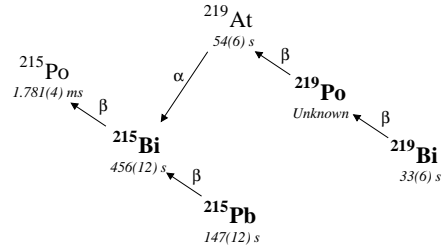


Figure 3. The decay series to ^{215}Po . Nuclei in bold characters are fragmentation residues implanted in the active stopper.

As one can see from fig. 3, there are other decays that can contribute to the formation of ^{215}Po : ^{215}Bi and ^{219}Bi , which are produced and implanted in the fragmentation reaction. ^{215}Bi produces ^{215}Po via a direct β decay. Its half life is reported in the literature as 456(12) s [9]. Recent studies on this nucleus [10] also reveal the existence of a high spin β -decaying isomer of 36.9 s built on a valence neutron excitation in the $1\nu i_{11/2}$ orbital. The other nuclei form a decay chain in which ^{219}Bi decays by β emission to ^{219}Po that β decays to ^{219}At . This nucleus emits an α particle and forms ^{215}Bi , which, in turns, β decays to ^{215}Po . In this case the population of ^{215}Po occurs through the population of ground state of ^{215}Bi . Lifetimes for ^{219}Bi and ^{219}At are 33(6) s [3] and 54(6) s [11], respectively. The half life of ^{219}Po has not been measured yet, though FRDM+QRPA calculations estimate it around 17 s [12].

An important issue is whether the presence of all these decay chains can hinder a direct measurement of the half-life of ^{215}Pb . The analysis suggests that we can establish a safe correlation if the time elapsed between α particles is longer than, at least, three times the total decay time of the ^{215}Pb chain ($T_{1/2}(^{215}\text{Pb}) + T_{1/2}(^{215}\text{Bi}) \sim 600$ s). By restricting the correlated time differences to the pixels where this condition is fulfilled, contributions from other fragments are highly suppressed. Furthermore, contributions from implantations of ^{215}Bi are eliminated to a large extent by requiring a unique implantation of ^{215}Pb within this time gate. The remaining background can be described by an exponential time distribution function with the decay constant given by the frequency of implantation of the contaminant residues, as stated before.

Figure 4, left panel on top row, shows the experimental decay curve of ^{215}Pb . The dots represent the measured half-life of the daughter ^{215}Bi relative to the implantation of ^{215}Pb fragments. The fit, corresponding to a superposition of the Bateman equations plus an exponential background, is shown in continuous black line. The measured value is 160(40) s, in excellent agreement with the recently reported half-life of 147(12) s.

We tested this procedure also for other known nuclei. In the case of $^{215-216}\text{Po}$ and ^{217}At we exploited $\alpha - \alpha$ correlations, using the first α as a clock for the start of the decay. One has to note that in these cases the mother nuclei, $^{219-220}\text{Rn}$ and ^{221}Fr , are not implanted in our Si array, but they are populated via successive β decays. In the case of $^{215-217}\text{Bi}$ we, instead, exploited a $\alpha - \beta$ correlation, by first recognizing the final α decay and then correlating it back in time with the β decay from the known ion. Results are shown in fig. 4. Dots are experimental data and lines are the results of the fit with a double exponential function. In all cases, the uncertainty of the measurements reflects both the statistic and systematic errors related to the analytical fit and the bin size, respectively.

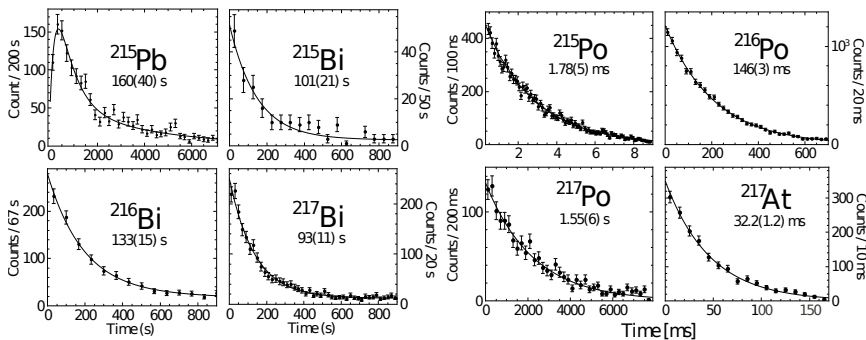


Figure 4. Time distribution of ^{215}Pb , $^{215-217}\text{Bi}$, $^{215-217}\text{Po}$ and ^{217}At , as obtained by means of the α tagging technique.

All results are in agreement with previously published data, apart from the half-life of ^{215}Bi , for which we cannot distinguish between the decay from the ground state (with a half-life of 7.6 min.) and from the $(25/2^-)$ isomeric state (with a half-life of 36.4 s) [10]. The measured half-life and a least-square fit to the time-correlated spectrum allows us to extract an isomeric ratio for the high-spin isomer of 50(8)%.

4 Conclusions

In this proceeding we described a new analysis of experimental data from relativistic fragmentation of a ^{238}U beam at 1 GeV/u on a Be target, to extract half-lives in the region of heavy Pb-Bi-Po isotopes. α and β correlations have been exploited to extract such half-lives and delayed spectra. Despite the presence of many contributing decay chains we could extract and confirm the lifetimes of many nuclei. This is important for future work in which unknown lifetimes and level schemes will be extracted for the first time.

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