Lifetime measurements using the CLARA-PRISMA setup around the $^{48}$Ca doubly-magic nucleus.

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INTRODUCTION

Spectroscopic information on the neutron-rich side of the Segré chart is scarce due to the experimental difficulties to populate these nuclei. At Laboratori Nazionali di Legnaro (LNL), multi-nucleon transfer and deep-inelastic reactions have been used in combination with the CLARA-PRISMA setup [1, 2] to populate neutron-rich nuclei at different mass-regions [3–6].

The matrix elements for transitions between excited nuclear states provides conspicuous information on the behaviour of the nucleus and can be determined by measuring the lifetime $\tau$ of the decaying state. An accurate measurement of the lifetime of a nuclear state in the picosecond range can be achieved by using the Recoil Distance Doppler Shift method (RDDS) [7, 8].

In this manuscript we report on the first measurement of lifetimes around the $^{48}$Ca doubly-magic nucleus, using a novel method [9] to measure lifetimes of nuclei populated via multinucleon transfer reactions using the RDDS method in combination with the CLARA and PRISMA spectrometers.

EXPERIMENTAL METHOD AND RESULTS

A $^{48}$Ca beam at a bombarding energy of 310 MeV was delivered by the LNL Tandem-ALPI accelerator complex. The beam had an average intensity of 1µA. The target consisted of 1.0 mg/cm$^2$ of enriched $^{208}$Pb evaporated onto a 1.0 mg/cm$^2$ Ta support to accomplish the stretching of the target. A thick 4 mg/cm$^2$ Mg foil was used as an energy degrader of the recoiling ejectiles produced in the reaction. Different target-degrader distances, ranging from 20 µm to 3000 µm were employed during the experiment by using various metallic distance rings. The target/degrader combination, i.e. the plunger, was placed at the centre of the reaction chamber of the CLARA array in order to measure the lifetimes of the projectile-like ejectiles produced in the multinucleon transfer reaction by means of the RDDS method. In this experiment CLARA consisted of 12 Compton suppressed Clover detectors with a total photopake efficiency of the order of 1.2%. The detectors placed around 90° can not be used for the RDDS lifetime measurement, since the Doppler shift is close to zero for these detectors. The projectile-like products were selected with the magnetic spectrometer PRISMA placed at the grazing angle $\theta_{Grazing} = 49°$. See schematic view of the experimental setup in Fig. 1.

This novel method on one side allows to measure lifetimes of neutron-rich nuclei that were unaccessible before, and on the other hand it partially allows to overcome one of the limitations of the RDDS method, namely the evaluation of contributions from side-feeding.

The RDDS method coupled to a magnetic spectrometer can overcome the side-feeding problem present in RDDS singles measurements, since it is possible to gate on different Total Kinetic Energy Losses (TKEL), and by...
selecting a range of excitation energy the feeding intensities of the excited states can be studied in detail.

To prove the validity of this method, the known lifetime of the \(2^+ \to 0^+\) 1346-keV transition in \(^{46}\text{Ca}\) has been measured. Figure 2 shows Doppler-corrected \(\gamma\)-ray spectra corresponding to the 1346-keV transition in \(^{46}\text{Ca}\) for different target-degrader distances. The intensity ratio of the two components is a function of the target-degrader distance, the recoil velocity \(\beta_{\text{Before}}\) and the lifetime of the transition.

Figure 3 a) shows the Doppler-corrected spectrum for \(^{46}\text{Ca}\) where a gate on low TKEL has been set. Figure 3 b) shows the Doppler-corrected spectrum for \(^{46}\text{Ca}\) where a high TKEL gate has been set. In the latter spectrum can be noticed the larger percentage of the \(4^+\to 2^+\) 1229-keV transition, which directly contributes to the feeding of the \(2^+\) state. The preliminary measured lifetime of the \(2^+ \to 0^+\) 1346-keV transition in \(^{46}\text{Ca}\), when no gate on the TKEL is set, is \(9.02\pm0.16\) ps. This value is larger than the previously measured lifetime, \(5.24\pm0.54\) ps \([10]\) and \(6.6\pm1.5\) ps \([11]\), due to the feeding coming from the \(4^+\) state on top. However when a gate in the low TKEL value is set (Fig. 3 a), in such a way that the population of the low-spin states, mainly the \(2^+\) state is enhanced, the side-feeding is clearly reduced. The preliminary lifetime value obtained for the \(2^+ \to 0^+\) 1346-keV transition in \(^{46}\text{Ca}\) is \(\tau=5.50\pm0.17\) ps, which is good agreement with the previously measured values.

This novel method opens up new possibilities to measure lifetimes of neutron-rich nuclei populated via multi-nucleon transfer reactions, combining a gamma and a magnetic spectrometer, e.g. CLARA-PRISMA. This method allows to control the side-feeding, via TKEL gates, and therefore it might help us to overcome one of the limitations of the RDDS method. The analysis is ongoing and it will yield new lifetimes in the region of the doubly-magic \(^{48}\text{Ca}\) nucleus, such as the N=30 isotone \(^{50}\text{Ca}\) \([12]\).

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\[10\] M. Bini et al., Nuovo Cimento Lett. 5 913 (1972).