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Lifetime measurements of excited states in neutron-rich 16C and 18C isotopes: a test of the three-body forces

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1. The physics case

We propose an experiment with the AGATA array coupled to the PRISMA spectrometer, to investigate excited states in n-rich B, C, N, O and F nuclei, populated by deep-inelastic reactions induced by an ^{18}O beam on a ^{198}Pt target. For these nuclei, limited spectroscopic information is available in terms of the lifetimes of the excited states.

The focus of the experiment will be on exotic C isotopes. In these nuclei, ab initio calculations provide a description of the excited states and predict a strong sensitivity of the electromagnetic transition probabilities to the details of the nucleon-nucleon interactions, especially in connection with the role played by the three-body (NNN) forces [For13,Vos12]. Among the most interesting cases are ^{16}C and ^{18}C, for which ab initio calculations without and with inclusion of the NNN term predict B(E2) and B(M1) of the second 2^+ states to vary by a factor of 2 to 5. For example, for ^{16}C, the calculated lifetime of second 2^+ state with two-body (NN) forces, only, is equal to 230 fs versus 80 fs with NN+NNN forces included. Similar calculations for 18C provide a lifetime of ~1 ps versus ~2 ps considering NN or NN+NNN, respectively. Therefore, precise measurements of the lifetimes of the second 2^+ states in these systems are needed, which require techniques able to extract information in the time intervals from one hundred femtosecond to few picoseconds.

The present experiment is a follow up of a 2017 measurement performed at GANIL with the AGATA+VAMOS+PARIS setup, employing an 18O-induced reaction (at 7 MeV/A) on a thick ^{181}Ta target (6.6 mg/cm^2). After developing a novel Doppler Shift Attenuation Method for assessing tens-to-hundreds femtoseconds state lifetimes, using deep-inelastic reactions, the lifetime of the 2^+ state was determined in ^{20}O and an estimate was provided for the second 2^+ state lifetime in ^{16}C [Cie20,Cie21]. It was shown that this type of experimental setup and analysis approach are well suited for these measurements, which could be further pursued at LNL, exploiting a better angular coverage of AGATA (including 90° HPGe detectors, which are crucial for a precise gamma-ray energy determination, not Doppler affected) [Cie21]. At LNL, a thick 198Pt target will be employed, and the PRISMA spectrometer will be placed at the most forward possible angles (between 20° and 35°, depending on the distance of AGATA from the target), in order to take advantage of the enhanced cross sections of deep-inelastic processes, with respect to the grazing angle. Furthermore, the DSAM method developed for the GANIL experiment [Cie21] will be extended in order to cover the 10's fs –few ps lifetime interval. For this purpose, a thick degrader will be used at close distance from the target, as discussed later.

2. Experimental details and beam time estimation

The main aim of the present proposal is to measure the second 2^+ state lifetime in the ^{16}C and ^{18}C, which are located at 3979 and 25157 keV, respectively, as illustrated in Fig. 1.

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Figure 1. Partial level schemes for ^{16}C [Cie20]) and ^{18}C [Vos12].

The nuclei of interest will be populated in deep-inelastic processes induced by a ^{18}O beam (at ~7 MeV/A, i.e., about 50% above the Coulomb barrier) on a ^{198}Pt target, 10 mg/cm^2 thick. The reaction grazing angle is θg ~54° and the projectile-like fragments will have v/c~10%. State lifetimes of the order of tens-to-hundreds fs, corresponding to decays in flight inside the target, will be assessed employing the DSAM method developed for the GANIL experiment [Cie21]. This is the case of the second 2^+ state of ^{16}C. Sensitivity to state lifetimes of the order of 1 to 2 ps (which will partially decay after the target, as expected for the second 2^+ state of ^{18}C) will be gained by placing a ^{93}Nb degrader, 10 mg/cm^2, at ~15 μm from the target.

The evaluation of the expected reaction cross-section for ^{16}C and ^{18}C can be based on Deep Inelastic Transport (DIT) model calculations, reported in Ref. [Ste18] and illustrated in Fig. 2. Such calculations refer to a similar reaction employing a ^{18}O (8.5 MeV/A) on a 238U target, and give a reasonable account for the statistics collected in the previous ^{18}O+^{181}Ta experiment of GANIL. According to the DIT model, at slightly forward angles with respect to the grazing angle, the cross section is ~1 mbarn/sr for ^{16}C, and ~0.01 mbarn/sr for ^{18}C ions. A 10% probability can be assumed for the population of the second 2^+ in both cases. The PRISMA solid angle coverage is 80 msr, and the transmission efficiency for the light ion of interest is about 10%. Based on the previous 2017 experiment, performed in GANIL, the beam current should not exceed 1 pnA, in order to limit the pileup in the AGATA crystals. With the abovementioned conditions and with AGATA placed in close geometry (i.e., 18 cm from the target), the statistics collected in 10 days in the main gamma transition depopulating the 2_2^+ state of 16C and 18C (i.e., the 2217-keV and 932-keV gamma rays shown in Fig. 1) should be of the order of 9000 and ~200 counts, respectively. Such a statistics will be sufficient to precisely determine the lifetime in the case of ^{16}C, while for ^{18}C the sensitivity will probably be limited to distinguish between lifetimes of ~1 ps and 2 ps, as predicted by ab initio calculations assuming NN+NNN or NN interactions.

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Figure 2. Cross section calculations, as a function of angle, for the deep-inelastic reaction ^{18}O (8.5 MeV/A)+^{238}U target, green for the NNCLE +NRV model (green) and in DIT +Gemini++approach (blue) [Ste18]. The red symbol corresponds to the experimental point measured close to 0° with the LISE spectrometer at GANIL.

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