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Study of the γ decay of high-lying states in ^{208}Pb via inelastic scattering of 17O ions

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Abstract. A measurement of the high-lying states in ^{208}Pb has been made using ^{17}O beams at 20 MeV/u. The gamma decay following inelastic excitation was measured with the detector system AGATA Demonstrator based on segmented HPGe detectors, coupled to an array of large volume LaBr3:Ce scintillators and to an array of Si detectors. Preliminary results in comparison with (γ,γ') data, for states in the 5-8 MeV energy interval, are presented.

1 Introduction

The giant dipole resonance (GDR), a collective oscillation of the protons against the neutrons, dominates the electric dipole response of nuclei. The study of this mode allowed to extract relevant information on the nuclear structure and on the effective nucleon-nucleon interaction, as well as on the bulk properties of nuclear matter (see e.g. [1]). Results of different experiments (see e.g. [2-9]) performed with stable and unstable neutron rich nuclei evidenced the presence of an accumulation of electric dipole strength at energies around the particle threshold, larger than that due to the low energy tail of the GDR. This is commonly denoted as the Pygmy Dipole Resonance (PDR, see e.g. [2]). The hydro-dynamical model describes the PDR as originating from the collective oscillation of the neutron skin against a symmetric proton-neutron core. The study of the PDR is not only interesting as a

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phenomenon associated to the nuclear structure, it has also astrophysical implications and it is expected to provide information on the neutron skin and thus on the symmetry energy of the equation of state [10-13]. From an experimental point of view, by comparing results of photon scattering, proton scattering and alpha scattering experiments a clear selectivity in the population of these PDR states has been observed (e.g. [8,14]). Experiments performed with different probes are found to be complementary, altering the relative population of the different states, in particular it is interesting to study PDR states using a probe interacting mainly at the surface of the nucleus. In this contribution an experiment to study the gamma decay of E1 states (in the PDR region) via inelastic scattering of ^{17}O ions accelerated at 20 MeV/u [15] is described and some preliminary results discussed.

2 Experimental technique and setup

The use of heavy ions inelastic scattering at approximately 20 MeV/u to study highly excited states is a good tool when the measurement of the subsequent gamma decay is also performed with high resolution. In the experiment described in this contribution an ^{17}O beam at the energy of 20 MeV/u in the laboratory frame, provided by PIAVE-ALPI accelerator system of the Legnaro National Laboratories, was used together with a ^{208}Pb target. The left and central panels of Fig.1 display in a schematic way and with a picure the experimental setup. ^{17}O has been chosen since it is loosely bound (4.1 MeV), and thus it allows to have a γ-spectrum mainly containing target de-excitation: if excitation energy larger than 4.1 MeV is transferred to the projectile, the neutron emission channel becomes dominant and thus the outgoing nucleus becomes ^{16}O which is well separated by ^{17}O in the particle detector system. The detection of the scattered ^{17}O ions was performed with two segmented ΔE-E silicon telescopes (pixel type), prototypes from the TRACE project [16]. An example of a two-dimensional histogram displaying the Total Kinetic Energy (TKE) of ^{17}O ions measured in one pad of the ΔE-E silicon telescopes versus the energy deposit measured in the ΔE pad is shown in the right panel of Figure 1. From this figure one sees a good separation of the different oxygen isotopes. In addition the excitation energy transferred to the target nucleus is measured with medium resolution (1.2-1.5 MeV).

The gamma-ray detection system consisted of the AGATA (Advanced GAmma-ray Tracking Array) Demonstrator [17,18], namely the first step of the new generation segmented HPGe gamma-ray spectrometer AGATA, and by an array of 8 large volume (3.5" x 8") $LaBr_3$:Ce scintillators from the HECTORplus array [19,20]. These scintillators are characterized by the best properties typical of inorganic scintillators (high efficiency, subnanosecond time resolution) and by an energy resolution surpassed only by that of germanium detectors.

Fig. 1. Left panel: schematic representation of the experimental setup including silicon detectors at small angles (13 degrees) and the gamma detectors covering a wide angular range . Middle panel: picture of the detection systems used to measure gamma rays in the experiment (AGATA Demonstrator and $LaBr_3$:Ce array). Right panel: Two-dimensional histogram of the Total Kinetic Energy (TKE) measured in one pad of the TRACE telescopes versus the energy deposit measured in the ΔE pad. The black line shows the separation of the oxygen isotopes.

3 Preliminary results

In panel a) of Figure 2 the gamma spectrum obtained with the AGATA array is displayed in the 5-8 MeV region. This spectrum is obtained after selecting the inelastically scattered ^{17}O events and with the additional requirement that the energy of the gamma rays equals the Total Kinetic Energy Loss (TKEL) values within a window ±1.5 MeV wide. This latter quantity is extracted using the energy of the ^{17}O detected in the Si telescopes. In addition Doppler correction of the gamma spectrum was also performed to account for the speed of the ^{208}Pb recoils (0.5% of the speed of light). In fact, while this value appears quite small it is enough to cause a shift of more than 10 keV for high-energy gamma rays. Although the gamma-ray spectrum in the 5-8 MeV energy range is dominated by E1 transitions, some E2 transitions are also present. In the panel b) of Figure 2 the B(ρλ) (from previous Nuclear Resonance Fluorescence (NRF) experiments [7,20]) are displayed for the E1 and E2 states in red and blue color respectively. It is therefore important to have the possibility to separate the two contributions through the different angular distribution of the emitted gamma rays. In the case of the AGATA Demonstrator it is possible to measure the emission direction of each gamma ray with a remarkable precision (~ 1°), thanks to the Pulse Shape Analysis and tracking algorithms. We considered for each event the angle ($\theta_{\gamma,recoil}$) between the gamma-ray emission direction and the ^{208}Pb recoil velocity vector (reconstructed using the information from the silicon telescope pad which detected the ^{17}O ion). The panels c) and d) of Figure 2 display the angular distributions obtained for the two transitions at 5512 keV and 6194 keV respectively. In both cases the measured variation in intensity ($W(\theta_{\gamma,recoil})$) as a function of angle is well reproduced with the expected trend for the E1/E2 transition, allowing for an unambiguous determination of the multipolarity. The spectrum of Figure 2 (panel a)) clearly shows that the PDR states have been populated. The E1 component, shown on the red spectrum as inset was selected using angular gate: 65°<θγ,rec<115° (solid black lines indicate transitions already observed in previous NRF experiments). The preliminary analysis shows a selectivity in the population of these states as compared to photon scattering results. The observed behavior is similar to what was found in other nuclei using the *(α,α'γ)* reaction [8,14], a number of states are better populated via (^{17}O,^{17}O'γ) reaction indicating the presence of a dominant isoscalar character.

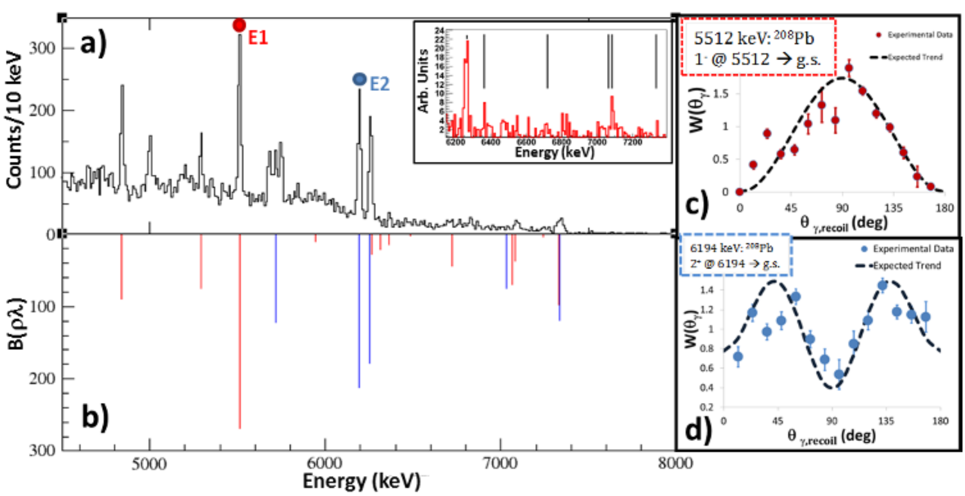

Fig. 2. Panel a) and the inset, respectively show the gamma spectrum obtained with the AGATA array displayed in the 5-8 MeV region and the spectrum of the E1 component, selected with gate on the angular range 65°<θγ,rec<115°. Panel b): B(ρλ) values measured in previous Nuclear Resonance Fluorescence (NRF) experiments are displayed for the E1 and E2 states in red and blue color respectively. Panels c) and d): the angular distributions of the two transitions at 5512 keV (E1) and 6194 keV (E2).

4 Conclusions

High-lying states in the ^{208}Pb nucleus were populated via inelastic scattering of a ^{17}O beam at bombarding energy of 20 MeV/u. Their subsequent gamma decay was measured with the detector system AGATA Demonstrator based on HPGe detectors, coupled to an array of large volume $LaBr_3$:Ce scintillators. The multipolarity of the observed gamma transitions was determined with remarkable sensitivity thanks to angular distribution measurements. The interesting result obtained from the preliminary data analysis concerns the E1 response in the pygmy resonance region. Similarly to what was found using the *(α,α'γ)* reaction at high resolution in other nuclei, also in this case the results seem to indicate a selectivity in the population of specific pygmy states as compared to photon scattering results.

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