

Study of neutron-deficient mercury isotopes

Preliminary results on ^{189}Hg

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Abstract. The mercury isotopic chain is depicted as one of the best fields to observe many phenomena related to collectivity evolution as, for instance, shape transition, shape coexistence or shape staggering. In this context, the ^{189}Hg presents several interesting aspects and is still relatively unexplored. The nucleus has been studied at the Laboratori Nazionali di Legnaro using a fusion-evaporation reaction and the γ rays emitted have been detected by the GALILEO array, coupled with Neutron Wall and the GALILEO plunger. The presorting and the preliminary results are presented.

1 Introduction

The mercury isotopic chain has been and is still an important region of the nuclear chart for the understanding of the evolution of nuclear structure through spectroscopic studies. Being just two protons away of the $Z=82$ shell closure, it is a perfect playground for testing the effective nuclear force near the magic numbers and it presents many phenomena such as shape transition, shape coexistence and shape staggering [1]. The latter one was observed for the first time via optical pumping experiments [2], by polarizing the spins of the nuclei and then observing its polarization via the angular asymmetry of the β decay: an impressive isotope shift between $A = 185$ and $A = 187$ was observed, later understood thanks to the evidences of a rotational band built on an excited 0^+ state given by in-beam γ -ray spectroscopy [3]. Recently, a study on the characterization of the shape-staggering effect in the mercury nuclei has confirmed the measurement of Bonn et al. and further extended the systematic [4].

In addition, the neutron-deficient mercury isotopes are known to present two structures close in energy, one oblate and one prolate deformed, that compete to form the ground-state of the nucleus when approaching to the neutron mid-shell [1]. In this region, theoretical calculations predict the ground states of the Hg isotopes to be weakly oblate deformed, while the intruder band, that reaches its minimum for the ^{182}Hg nucleus, is expected to be prolate deformed. Then, for lighter isotopes, the excitation energy of the minimum increases and the shape mixing becomes less significant. At last, the ground state is expected to reach a more spherical shape in ^{176}Hg [5]. The presence

of a region where these two shapes coexist is established and it is predicted to go from ^{180}Hg to ^{188}Hg [6].

While for the even mercury isotopes a wealth of studies have been published, both theoretical and experimental, for the odd isotopes the literature is scarcer. From Strutinsky shell correction calculations [7], the shape of the $^{181,183,185}\text{Hg}$ nuclei is predicted to be prolate deformed, while for the heavier isotopes $^{187,189}\text{Hg}$ is expected to become oblate deformed. These results seems to be confirmed also by more recent calculations with Hartree–Fock–Bogoliubov method employing the Skyrme SIII, SkI3 and SLy4 forces [5].

Among the mercury isotopes, the ^{189}Hg nucleus presents some interesting aspects. A $13/2^-$ isomeric states at 140 keV with a lifetime of 8.7(2) min [8] is presented as the head of a high spin band. From spectroscopic and γ -ray directional correlations (DCO) studies, the level scheme of the ^{189}Hg was established and its structure was interpreted as a ^{190}Hg core coupled to a $\nu i_{13/2}$ quasi-particle hole [9]. In addition, since the work of [11], the presence of a superdeformed band in ^{189}Hg has been demonstrated. This is in agreement with the systematics of the Hg region and the $A=190$ and with the theoretical predictions [10]. Several calculations [12, 13] have been performed to identify the spin of the state that forms the band head of the superdeformed band, leading to mismatching results. A new experiment was performed in order to obtain direct measurements of the lifetimes of the excited states in ^{189}Hg .

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2 Experimental details

The experiment was performed at the Laboratori Nazionali di Legnaro and the beam was provided by the Tandem-ALPI accelerator complex. The γ rays produced in the reactions were studied using GALILEO [14], an array of 25 high-purity germanium detectors (HPGe), of which 15 were placed at backward angles with respect to the beam direction, arranged in 3 different rings (152° , 129° and 119°), and 10 in a ring at 90° . Every HPGe detector was surrounded by a Bismuth Germanate (BGO) crystal that acted as an anti-Compton shield. A thorough study of the effect of the Compton suppression and on the efficiency of GALILEO can be found in Ref. [15]. The channel of interest, expected in coincidence with neutrons, was selected by using Neutron Wall [16], an array of 45 liquid scintillators used for the detection of neutrons. In fact, thanks to the characteristic of the detectors, it was possible to perform a neutron-gamma discrimination to reject the events due to the Coulomb excitation and obtain a cleaner spectrum. More details about the selection of neutrons can be found in Ref. [17, 18]. Finally, the lifetime measurement were performed via Recoil Distance Doppler-Shift (RDDS) technique using the plunger device [19]. The GALILEO plunger is designed for lifetime measurement of the range of 1 ps to 1 ns, allowing the variation of target-stopper distances from few micrometers to millimeters with a sub-micrometer precision.

The main goal of the experiment was the study of the ^{188}Hg nucleus and the channel of interest was populated via two different fusion-evaporation reactions:

- ^{34}S beam at the energy of 185 MeV impinged onto $600 \mu\text{g}/\text{cm}^2$ of ^{160}Gd target ($2.5 \text{ mg}/\text{cm}^2$ thick ^{181}Ta fronting);
- ^{34}S beam at the energy of 165 MeV impinged onto $600 \mu\text{g}/\text{cm}^2$ of ^{158}Gd target ($2.5 \text{ mg}/\text{cm}^2$ thick ^{181}Ta fronting).

Such reactions were chosen in order to maximise the population probability of the ^{188}Hg , according to previous measurements [11, 20, 21] and to PACE4 estimations [22]. Furthermore, with the first reaction, the ^{189}Hg channel was also populated with a significant intensity, making a study of this nucleus feasible.

In order to study ^{189}Hg , the average velocity of the evaporated residue (ER) was extracted from the Doppler shift of the $17/2^+ \rightarrow 13/2^+$ transition at the different angles of the GALILEO rings, as shown in Figure 1. For a more precise estimation of the fragment velocity, a kinematic reconstruction would be necessary [23]. However, considering the large mass of the compound nucleus with respect to the evaporated particles, the difference between the direction of the beam and of the flying ER is negligible, so the average velocity can be considered a good approximation. The ratio between the shifted (in-flight) and unshifted (stopped) component E_γ/E_0 is plotted as a function of the ring angle θ and the data are fitted via the following equation:

$$\frac{E_\gamma}{E_0} = \frac{\sqrt{1 - \beta^2}}{1 - \beta \cos(\theta)} \quad (1)$$

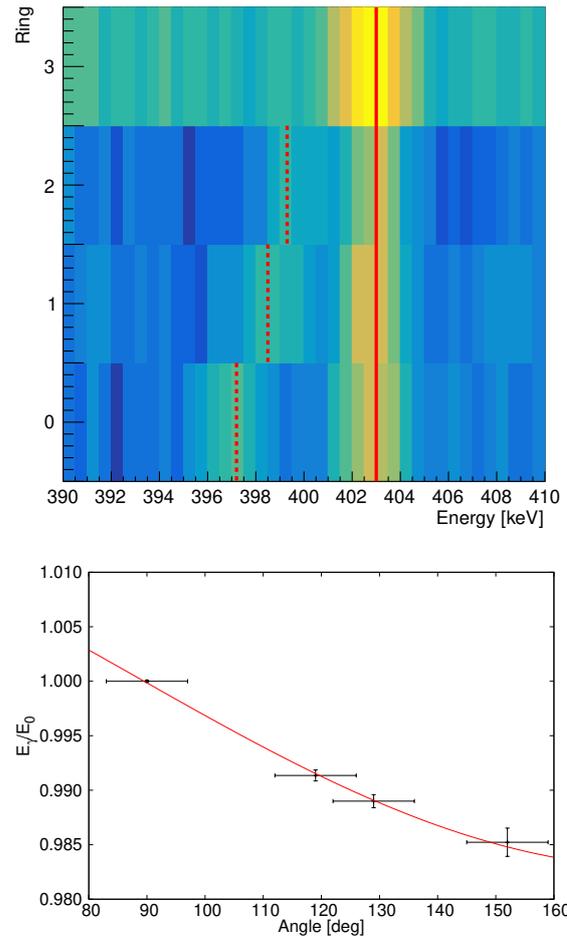


Figure 1. (top) In-flight (dashed) and stopped (solid) components of the $17/2^+ \rightarrow 13/2^+$ transition at 403 keV for the four different rings of the GALILEO array (152° , 129° , 119° and 90° respectively) at the plunger distance of $400 \mu\text{m}$. No Doppler shift is observed at 90° . (bottom) The ratio E_γ/E_0 as a function of the ring angle, fitted with Eq. 1 with β as a free parameter. The velocity resulted to be 1.7(6)%.

where β , the velocity, is a free parameter and resulted to be 1.7(6) %.

3 Preliminary results

A γ -ray energy spectrum of the ^{189}Hg nucleus was obtained by requiring the coincidence with at least one neutron, gating on the $17/2^+ \rightarrow 13/2^+$ transition at 403 keV and subtracting the background. To get rid of the in-flight and stopped components of the peaks due to the RDDS technique, only the detectors at 90° were used. The spectrum is shown in Figure 2 (left) and the identified transitions are highlighted. A partial level scheme, reconstructed with the identified γ -ray transitions, is also shown in Figure 2 (right).

A lifetime measurement of the $17/2^+$ was also attempted via RDDS technique. Six target-stopper distances were investigated. A gate on the in-flight component of the feeding transition $21/2^+ \rightarrow 17/2^+$ at 626 keV and a background subtraction was performed in order to remove any

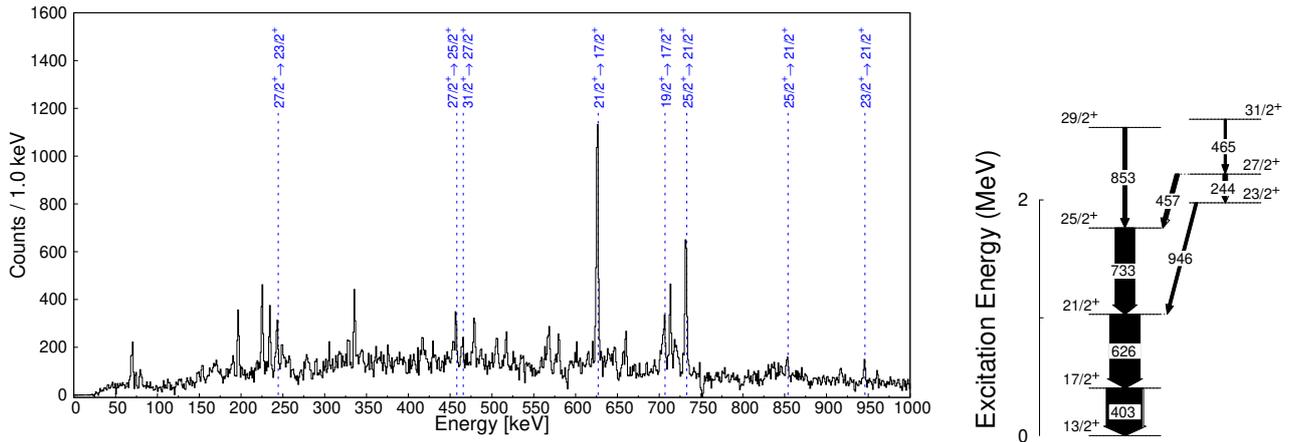


Figure 2. (left) Background-subtracted γ -ray energy spectrum of the ^{189}Hg obtained by requiring the coincidence with at least one neutron and by gating on the $17/2^+ \rightarrow 13/2^+$ transition at 403 keV. The identified transitions are highlighted in blue. (right) Partial level scheme reconstructed with the identified transitions. The efficiency-corrected intensity of the transitions is represented by the thickness of the arrows.

possible contamination from side feeders. The results for four target-stopper distances are shown in Figure 3 for detectors at 152° . The in-flight and stopped components are clearly separated and marked with a dashed and solid line respectively. The integral of the two component depends on the velocity of the nucleus, on the distance between the target and the plunger stopper and on the lifetime, that can be extracted by using the integration over time of the Bateman equation. A decay curve can be obtained and the lifetime of the state extracted.

4 Conclusions

The ^{189}Hg was produced via a fusion-evaporation reaction at the Laboratori Nazionali di Legnaro, employing the γ spectrometer GALILEO coupled with the Neutron Wall array and the GALILEO plunger. Many transitions have been identified and a preliminary level scheme has been reconstructed. Moreover, a first attempt to measure the previously lifetime of the $17/2^+$ has been made: the in-flight and stopped component are clearly distinguishable and a decay curve can be obtained. The higher lying states are still under investigation.

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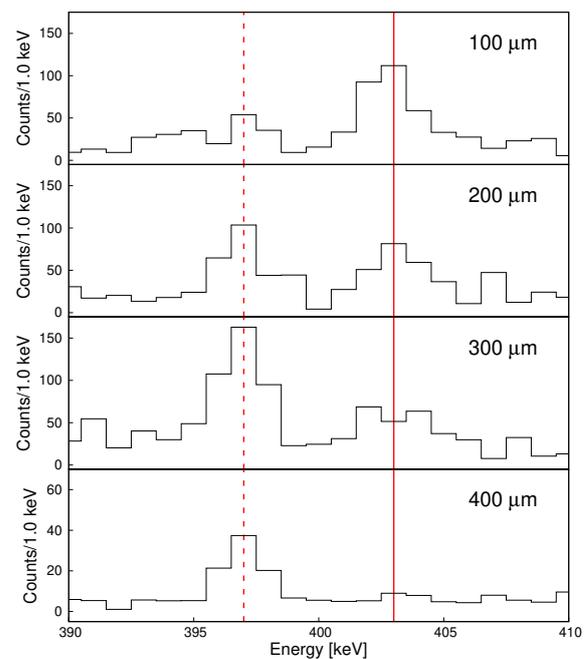


Figure 3. Background-subtracted γ -ray energy spectra of ^{189}Hg , obtained by requiring the detection of at least one neutron in Neutron Wall and the coincidence with the in-flight component of the $21/2^+ \rightarrow 17/2^+$ transition at 626 keV. The spectra are shown for 4 different target-to-stopper distances and for the GALILEO detectors at 152° . The stopped (solid line) and in-flight (dashed line) of the $17/2^+ \rightarrow 13/2^+$ transition are marked.

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