

Measurements of shape co-existence in $^{182,184}\text{Hg}$ using Coulomb excitation

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Abstract

We propose to exploit the unique capability of ISOLDE to provide post-accelerated $^{182,184}\text{Hg}$ ions from the REX facility to enable the lowest states of these nuclei to be Coulomb excited. By measuring the γ -ray yields using the MINIBALL array we can measure the transition and diagonal E2 matrix elements for these states. This will give quantitative information about the nature of the shape coexistence in these nuclei and allow the sign of the quadrupole deformation to be determined for the first time. We require **24 shifts** to fulfil the aims of the experiment.



Physics Case

The evolution and microscopic origin of quadrupole collectivity and shape coexistence at low excitation energies in neutron mid-shell nuclei near the $Z = 82$ shell closure are still not fully understood (for recent review, see [1]). The shape coexistence phenomenon in neutron-deficient nuclei close to $Z = 82$ was first observed when isotope shift measurements at ISOLDE for Hg nuclides revealed a sharp transition between ^{187}Hg and ^{185}Hg [2]. This change was interpreted as a transition from a weakly oblate shape [3] to a more deformed prolate structure [4, 5]. Nowadays there exists a large body of experimental information supporting the coexistence of different shapes at low excitation energies in mercury isotopes. Similarly, in neutron deficient even-mass Pb isotopes intruder states were first identified in α - and β -decay studies using on-line isotope separators [6]. The low-lying excited 0^+ states associated with weakly deformed oblate proton $2p$ – $2h$ intruder structures have been observed in α -decay in several Pb isotopes with $N \geq 106$ [7, 8], and prolate deformed bands built upon $4p$ – $4h$ excitations have also been identified in separate experiments (e.g. [9]). The lowest excited states in ^{186}Pb were found to have spin and parity 0^+ and are associated with oblate and (predicted) more deformed prolate shape respectively [10].

While much has been learnt in recent years concerning the behaviour of the light Hg and Pb nuclei, several key questions remain outstanding, such as the degree of mixing between the various different configurations. We propose to embark on a study of the mid-shell nuclei $^{182,184}\text{Hg}$ since for these isotopes the co-existing configurations lie closest to each other (see figure 1) [1] and the radionuclides are readily obtainable from

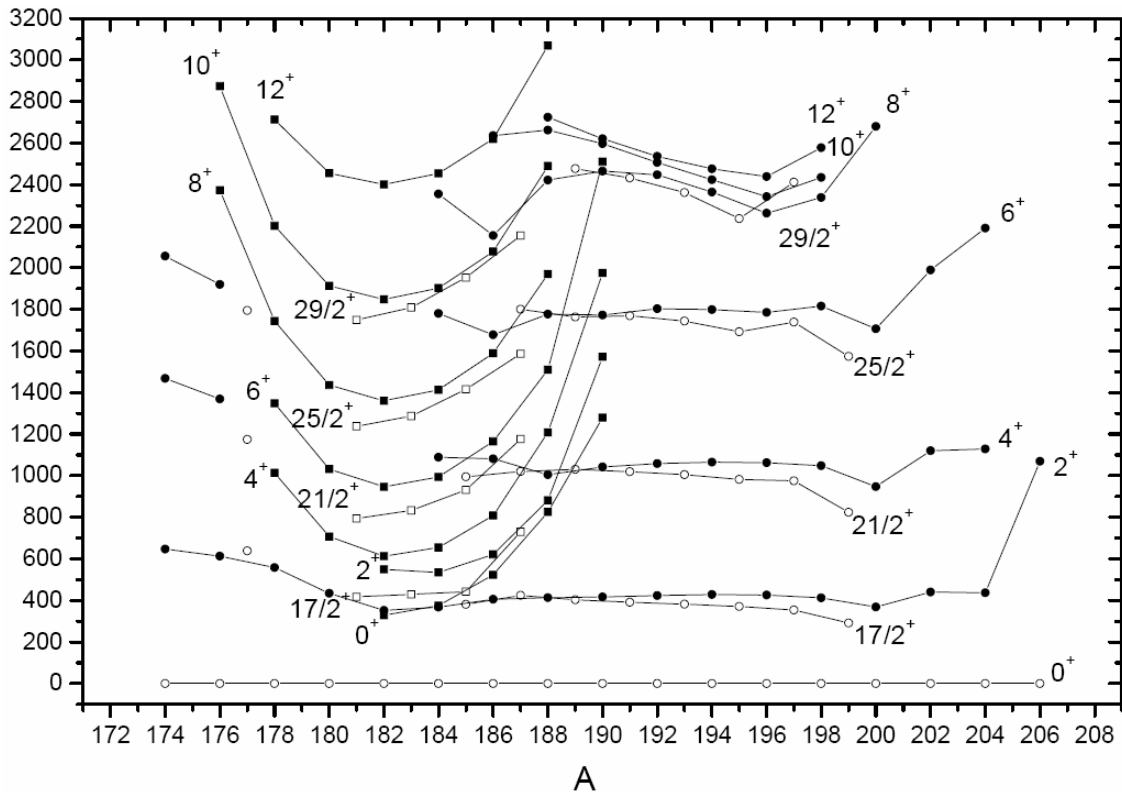


Figure 1: level systematics of Hg isotopes, taken from reference [1]. Full (open) circles and squares represent the oblate and prolate deformed structures in even-N (odd-N) Hg nuclei, respectively.

the REX-ISOLDE facility. The ground states are predicted [11] to be weakly deformed $2h$ oblate states ($\beta \sim -0.15$) whereas the $4p$ – $6h$ prolate ($\beta \sim 0.25$) band heads are expected

to lie at about 300-400 keV. The availability of accelerated radioactive heavy ions at REX and the application of Coulomb excitation (Coulex) allow a number of unique observations to be made: (i) Coulex will preferentially excite states strongly coupled to the ground state so the oblate excited states will be readily observed and identified; (ii) as we have recently successfully demonstrated for ^{70}Se accelerated by REX [12], low energy Coulex will measure the sign of the diagonal quadrupole matrix element and hence distinguish between prolate and oblate excitation; (iii) the degree of mixing between the oblate and prolate structures is determined directly from the transition matrix elements.

Structure of $^{182,184}\text{Hg}$ and Coulex yields

The experimentally observed low-lying structure of $^{182,184}\text{Hg}$ relevant to sub-barrier Coulomb studies is shown in figure 2 [13-16]. The α -decay hindrance factors are also given where these have been observed [13, 14]. The supposition is that the ground state is oblate, whereas the excited 0^+ state at ~ 350 keV is the bandhead of a prolate deformed band having a π (4p-6h) configuration. A band-mixing analysis leads to the conclusion that there is little mixing ($< 4\%$) between the bandheads, whereas an analysis of the α hindrance factor data suggests a mixing of $\sim 20\%$ [13, 14]. An analysis of the E0 strength in ^{184}Hg gives a mixing of 0.5% [17]. For the lowest 2^+ states, the band-mixing seems to be substantial. It is notable that the observed hindrance to the 2^+ member of the ground state band is rather large as compared with heavier, more deformed nuclei.

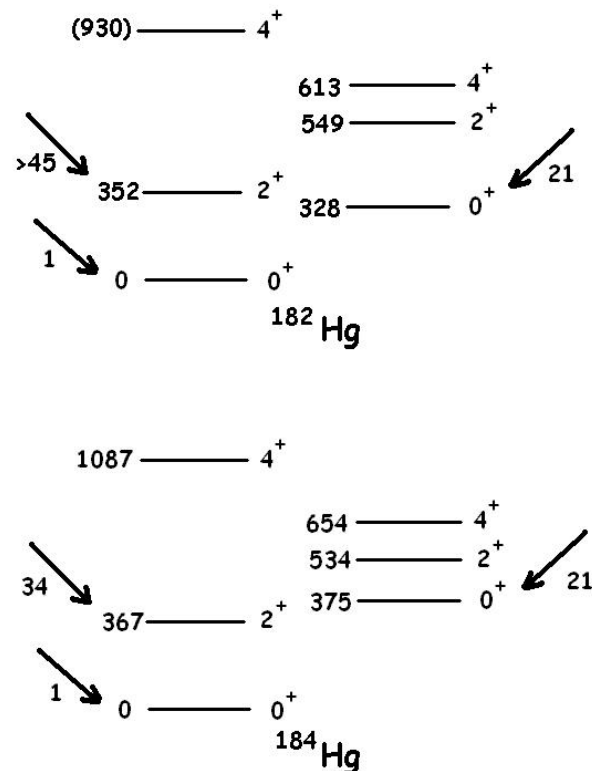


Figure 2: Low lying states in $^{182,184}\text{Hg}$. The arrows represent observed α -decay for which the measured hindrance factors are given.

It is also interesting that an earlier application of a two band mixing model led to the conclusion that the observed branching ratios for E2 decays in ^{184}Hg is best fitted if the sign of the deformation of the two bands is the same [18].

The Coulex γ -ray yields for a 2.75 MeV/u Hg beam onto a 1 mg/cm² ^{120}Sn target can be calculated with a number of assumptions and are given in table 1 for ^{182}Hg :

transition	transition energy (keV)	matrix element trans./diag. (eb)	γ -ray yields
$2^+_{1-}0^+_{1-}$ oblate	352	-1.32/1.57	57800
$2^+_{1-}0^+_{1-}$ prolate	352	1.32/-1.57	45800
$4^+_{2-}2^+_{1-}$ oblate	578	-2.13/2.02	1360
$2^+_{2-}0^+_{1-}$ prolate	549	0.13/-1.57	200

Table 1: Estimated γ -ray yields following the Coulomb excitation of 3 MeV/u ^{182}Hg on 1 mg/cm² ^{120}Sn target. For details of the calculation, see text.

The above assumes an efficiency of 0.1 for γ -ray detection (see below), and 100 hours of 5.10^4 ions/s irradiation (see below). The in-band matrix elements assume the following: (i) rotational model values for $\beta=0.15$, (ii) the ground state and 2^+_{1-} states are pure, and (iii) an arbitrary reduction by a factor of 10 for the inter-band matrix element. Note that for ^{184}Hg the lifetimes of the 2^+_{1-} , 4^+_{2-} (and higher) states have been measured [19], suggesting a deformation of $\beta=0.15$ or larger.

Experimental set-up

ISOLDE is unique world-wide in having the capability of providing sufficient primary intensity ($> 5 \times 10^6$ ions/s) that will give the minimum 5.10^4 ions/s delivered at the target for γ -ray transition yield measurements using MINIBALL for 3 MeV/u Hg beams. It has already been demonstrated that the required charge state necessary for post-acceleration can be achieved at the REX-EBIS charge breeder with a reasonable efficiency (few %). In order to reach $A/q \sim 4.5$ the Hg atoms have to be charge bred to an ionisation state 43^+ . Tests carried out recently at REX (F. Wenander, priv. comm.) have demonstrated that ^{238}U ions with a charge state of 52^+ ($A/q = 4.6$) were extracted from the REX mass separator with a total efficiency of 4.3%. In these tests the breeding time was 500ms, so the small repetition rate will benefit from development of slow extraction that is currently making good progress (J. Cederkäll, priv. comm.).

The ISOLDE primary yields for $^{182,184}\text{Hg}$ (measured at the SC) are respectively 8.10^6 and $1.3.10^8$ /s for a molten Pb target and plasma ion source with heated line. A yield of 8.10^6 /s ^{182}Hg ions has been extracted from the PS Booster [20]. We anticipate that a post-accelerated ion intensity of 5.10^4 /s should be easily available, possibly with a shorter breeding time of 200ms.

The secondary target, ^{120}Sn ($E_{2^+} = 1171$ keV) will be surrounded by the MINIBALL array containing 8 triple cluster of 6-fold segmented Ge detectors [21], which has an efficiency of 7% for 1.3 MeV photons. Both scattered projectiles (maximum laboratory angle $\sim 40^\circ$) and target recoils will be detected using the DSSD CD detector which subtends an angular range $16^\circ - 53^\circ$.

Aim of experiment and request for beam time

The primary aims of the experiment are to determine the matrix elements, for both nuclei, between the ground state, (oblate) 2^+ state, (oblate) 4^+ state, and second (prolate) 2^+ state, as well as the diagonal matrix element and sign of the lowest 2^+ state. As a full set of matrix elements cannot sometimes be obtained independently from yield measurements alone, the Coulex yield measurements will be complemented by lifetime measurements (spokesperson T. Grahn) that are being carried out at the University of Jyväskylä. Such measurements should be possible for the yrast states that are strongly populated by (HI,xn) reactions, using the tagged-RDDS method recently developed at Jyväskylä. Using table 1 as a guide, we estimate that **6 shifts** will be sufficient for yield measurements of transitions in ^{184}Hg , **12 shifts** for ^{182}Hg , as well as **3 shifts** for setting up REX. In addition, **3 shifts** are required in a separate run to ascertain the isobaric purity of the Hg beam. As Z separation cannot be achieved using an ionisation counter, the radioisotopic content will be assayed by measuring the γ -ray activity and α -decay activity at the beam dump and at the CD detector respectively. In total **24 shifts** are requested. Note that the presence of ^{178}W ($T_{1/2} = 22\text{d}$) in the α -branch decay chain of ^{182}Hg will lead to a maximum activity of 10^5 decays/s (2.6 μCi) activity at the low-energy end of REX; this may have consequences for the scheduling of this experiment.

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