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Identification and study of the very neutron deficient nuclide ^{111}I: search for octupole correlations in the region of N ≈ Z ≈ 56

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High-spin states in the neutron-deficient nuclide ^{111}I have been populated with the fusion reaction ^{58}Ni + ^{58}Ni at a beam energy of 210 MeV, in an experiment performed at the Tandem Accelerator of the Laboratori Nazionali di Legnaro. The gamma spectrometer GASP was used in time coincidence with the ISIS Si-ball and the CAMEL recoil mass spectrometer for the positive identification of the nuclide. Gamma transitions and structure details previously attributed to ^{111}I by other authors are only partially confirmed. The obtained level scheme includes new rotational bands and a new low lying structure which suggests the presence of octupole correlations at predicted rotational frequency values.

1. INTRODUCTION

Octupole correlations are expected to develop whenever two single-particle states differing by Δl=3 and Δj=3 lie close to each other and to the Fermi energy in the potential energy scale [1]. Favourable regions of the chart of nuclides for the observation of this effect are found at N or Z values around 34, 56, 88 and

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134. Detailed calculations performed for even-even nuclides with N~Z~56 [2] quantify the strong octupole deformation expected in this region, with the strongest effect occurring for ^{112}Ba. This nuclide (beyond the proton drip line) is practically out of reach for the experimentalists, yet other nuclides in this mass region can be studied. One interesting point is the observation that these octupole correlations can develop or be enhanced as a consequence of dynamical effects which cause an energy shift of the effective orbitals, like the deformation induced by rapid rotation of excited nuclei. This last mechanism has been in fact proposed to explain recently observed parity-symmetry breaking structures in light Te and Xe nuclides [e.g. 3-5 and refs therein].

In this work the structure of ^{111}I has been investigated up to high spin (I^{π} = 59/2$^-$), with the positive identification of the nuclide obtained for the first time. Partial results of this work are being published in ref. [6]. The deduced level scheme is basically in agreement with data published by another group [7], with additional substantial extensions. The results from ref. [8] are not confirmed.

2. THE EXPERIMENT

High spin states in the neutron deficient nucleus ^{111}I were populated using the reaction ^{58}Ni(^{58}Ni,αp)^{111}I at a beam energy of 210 MeV. The beam was delivered by the Tandem XTU accelerator of the Legnaro National Laboratory. Two targets have been used: the first consisted of a foil of isotopically enriched ^{58}Ni with a thickness of 1 mg/cm^2 on a 15 mg/cm^2 Au backing, the second was a 0.5 mg/cm^2 thick self-supporting ^{58}Ni foil. Double and higher fold γ-γ coincidences were acquired with the γ-spectrometer GASP [9], consisting of 40 Compton-suppressed HPGe detectors plus an inner calorimeter of 80 BGO detectors providing the γ-ray fold and sum energy. With a beam current of 8 pnA the events rate was ~2 kHz.

In order to improve the selectivity of the apparatus for reaction channels involving the evaporation of charged particles the 4π Si-ball ISIS [10] was mounted inside the GASP vacuum chamber. ISIS is composed of 40 ΔE-E silicon telescopes covering about 70% of the total solid angle. The mass identification was obtained using the recoil mass spectrometer CAMEL [11], with the thin target, in the GASP-linked configuration. The combined ISIS and CAMEL selection properties provide the unique identification of the nuclides in time coincidence with GASP.

3. THE RESULTS

One first new result is the positive identification of ^{111}I. The most intense low lying transitions assigned to ^{111}I are clearly visible in coincidence with the detection of one α particle and one proton in the ISIS Si-ball and not visible if the coincidence is required with 2α or 2p particles. The remaining ambiguity, with respect to the possible emission of neutrons, is removed by the mass measurement provided by CAMEL, which confirms the emission of a total of 5 nucleons. In the off-line analysis the events corresponding to the simultaneous detection of one α particle and one proton in the ISIS Si-ball were incremented into a symmetrized γ-γ matrix. In addition, triples data have been used to produce γ-γ matrices in coincidence with the proper γ transitions in ^{111}I.

Figure 1 shows two γ-ray spectra obtained from these two sorts of data: a) shows the full γ-spectrum in coincidence with the αp gate from ISIS and b) the γ-transitions in coincidence with the 415 keV and 555 keV lines assigned to ^{111}I. Position spectra at the CAMEL focal plane were extracted from a γ-x matrix by gating on γ-rays characteristic of the various evaporation residues. Figure 2 compares position spectra obtained: a) without conditions, b) and c) with gate conditions on known γ-rays of the A = 114 Xe and A = 113 I nuclides respectively,

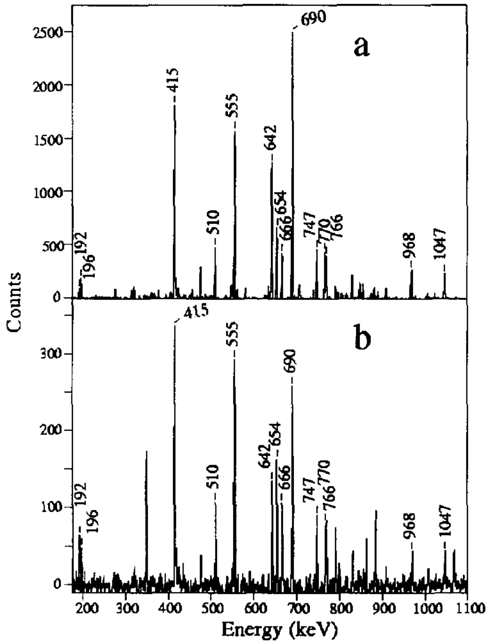

Figure 1. Gamma-ray spectra obtained: a) in coincidence with 1α+1p particles detected in the Si ball, b) by double gating on the 415 keV and 555 keV transitions here assigned to ^{111}I.

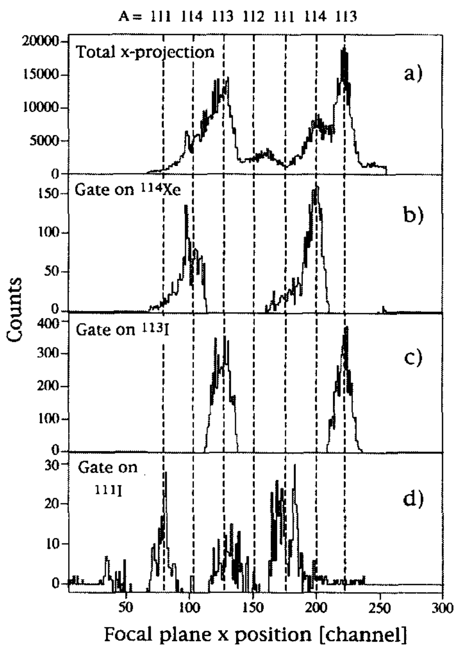

Figure 2. Position spectra at the CAMEL focal plane obtained for: a) no condition, b), c) and d) conditions imposed on γ-rays from ^{114}Xe, ^{113}I and ^{111}I respectively.

d) with a gate condition on the 415 keV line. Despite the low statistics related to the large angular dispersion of the αp reaction channel residues and consequent low CAMEL efficiency, the mass spectrum peaks at the expected positions for mass A = 111. Figure 3 shows the fold and sum energy measured by the BGO calorimeter when gating on γ-rays belonging to the 2p, 3p, αp and α2p reaction channels, leading to ^{114}Xe, ^{113}I, ^{111}I and ^{110}I respectively. For ^{111}I the 415 keV transition has been used as a reference. The centroid position of both the fold and sum energy distributions decreases as the number of evaporated particles increases, as expected. It can be observed that the centroid positions obtained by gating on the 415 keV γ-transition are located in between the values corresponding to the 2p and 3p distributions, thus further supporting the αp reaction channel assignment of this and coincident transitions.

The resulting level scheme for ^{111}I is shown in figure 4. Substantial new information has been obtained with respect to the decay scheme assigned to ^{111}I in ref. [7]. The observed γ-transitions have been ordered on the basis of their coincidence relationships and relative intensities. The spins and parities of the levels were deduced, where possible, from the analysis of the directional correlation ratios from oriented states (DCO) and from the decay patterns. Absolute spin and parity assignments are based on systematics considering that a ground state

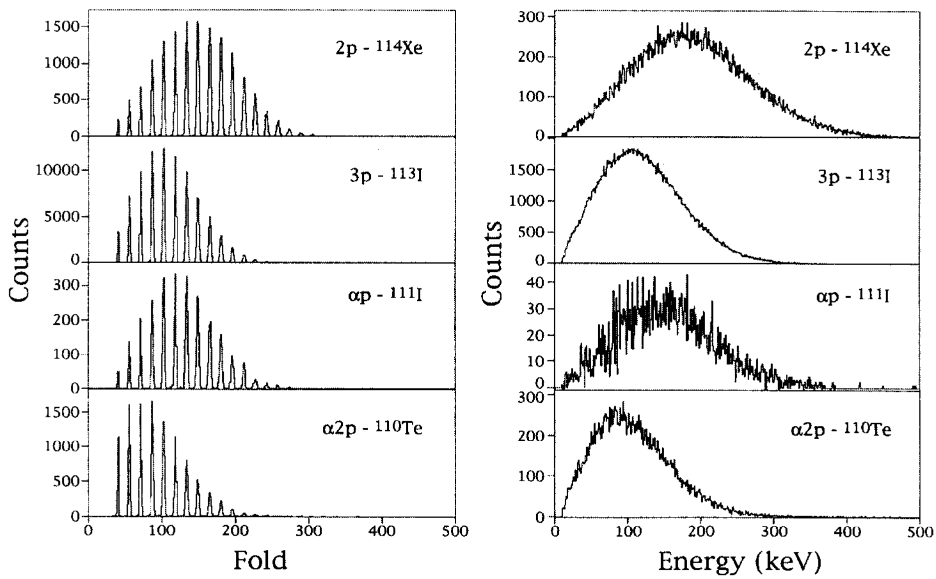

Figure 3. Gamma-rays fold and sum-energy distributions from the BGO ball, in coincidence with the shown reaction channels.

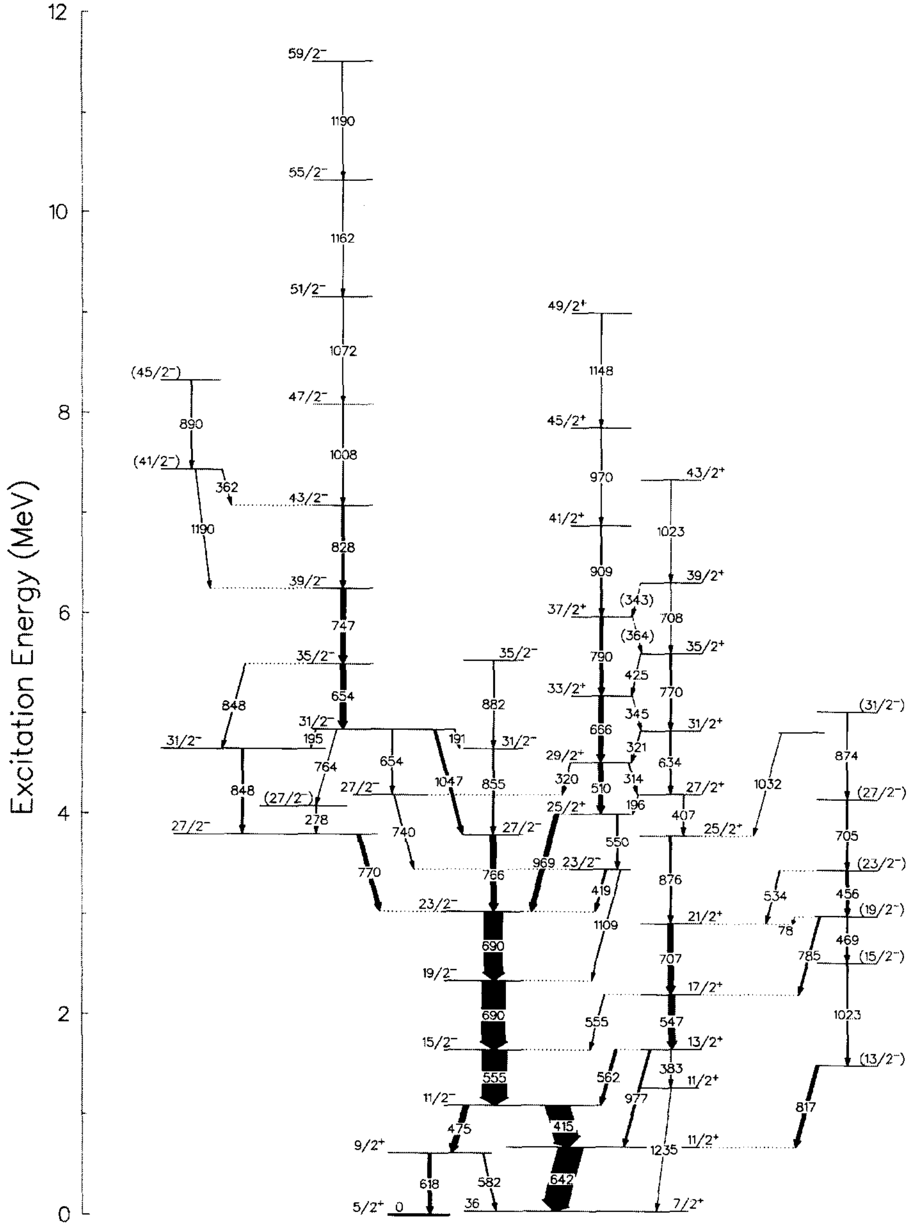

Figure 4. Proposed level scheme of ^{111}I. The energy labels are given in keV. The widths of the arrows are proportional to the relative intensities.

$5/2^+$ ($d_{5/2}$) and a low lying $7/2^+$ ($g_{7/2}$) state are expected. An $11/2^-$ state is also expected as the band head of the proton $h_{11/2}$ band and an $11/2^-$ assignment is indeed consistent with the DCO values deduced for the 1093 keV level. The deduced level scheme extends up to 11.5 MeV of excitation energy and up to spin $I^\pi = (59/2^-)$.

4. DISCUSSION

In the vicinity of ^{112}Ba the presence of octupole correlations at high spin has been related with the increased mixing between single particle states of opposite parity which approach each other with increasing rotational frequency. The favourable frequency for the onset of this effect depends on the energy position of the involved orbitals with respect to the Fermi energy level of the nucleus. For the present work Total Routhian Surface (TRS) calculations have been performed for ^{111}I [12]. Calculation results show (figure 5) a prolate reflection-asymmetric minimum in the energy surface at low rotational frequencies.

At low excitation energies the observed ^{111}I structure is characterized by single particle excitations of the odd proton involving the $d_{5/2}$ and $g_{7/2}$ orbitals, with couplings with the core phonons. Just above these energy levels a negative parity band built on the proton $h_{11/2}$ orbital is observed. Parallel to it an excited level sequence develops which de-excites via two γ-transitions of 562 keV and 555 keV to the $h_{11/2}$ band. DCO ratios and linear polarization results [13] extracted for the two connecting transitions are consistent with E1 character, resulting in a positive parity for the states of the side band. The presence of such opposite parity bands, connected by E1 transitions, is taken as evidence of octupole correlations at low spin which are expected to be

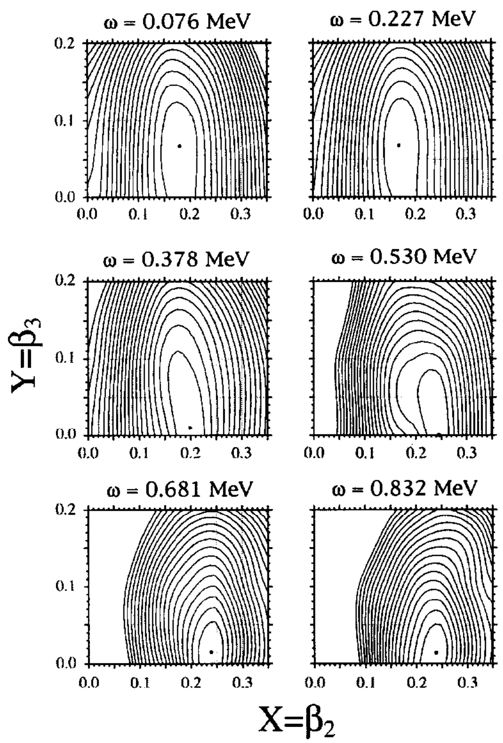

Figure 5. Total Routhian surfaces for axially symmetric shapes calculated at the shown rotational frequencies for ^{111}I.

based on a $\pi\,(d_{5/2}h_{11/2}) \times \nu\,(d_{5/2}h_{11/2})$ configuration. The transition energies are consistent with the shown calculation. At high spin three rotational structures characterize the decay: the negative parity decoupled band and two positive parity structures connected by several M1 transitions. These last two bands (one of which decays into the low lying positive parity structure mentioned above) could originate from the signature doublet of a rotational band based on a configuration $\pi\,h_{11/2}(g_{7/2}d_{5/2}) \times \nu\,h_{11/2}(g_{7/2}d_{5/2})$, which is consistent with the observed decay into the proposed octupole structure below.

5. CONCLUSIONS

The proton rich nuclide ^{111}I has been identified and studied using the GASP γ-spectrometer coupled to the ISIS charged particle detector and to the CAMEL recoil mass spectrometer. In the observed level scheme a low lying structure involving two connected opposite parity bands has been found, which is proposed as evidence of octupole collectivity enhanced by dynamical correlations, as predicted by the performed TRS calculations.

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