

## THE DECAYS OF NEUTRON DEFICIENT $^{103}\text{In}$ AND $^{102}\text{In}$

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### Abstract

Using an on-line mass isotopic separator operating on nuclear reactions induced by heavy ions,  $^{102}\text{In}$  [ $T_{1/2} = 24 + 4$  seconds] has been identified for the first time. Gamma-rays observed in the decays of  $^{103}\text{In} \rightarrow ^{103}\text{Cd}$  and  $^{102}\text{In} \rightarrow ^{102}\text{Cd}$  complement previous in-beam experiments on  $^{103}\text{Cd}$  and  $^{102}\text{Cd}$ . The partial level scheme deduced for  $^{102}\text{Cd}$  has been included in the systematics of ground bands of the even cadmium isotopes.

### 1. Introduction

This paper deals with the investigation of the short-lived very neutron-deficient isotopes of indium in the vicinity of  $^{100}\text{Sn}$ , the spherical double closed shells far from stability which always represents an exciting experimental challenge. It is interesting to study the lighter cadmium nuclei reached by the indium's decays to extend the experimental systematics available on the heavier ones and to compare the situation to the theoretical predictions. Indeed, in this region, constrained Hartree-Fock calculations including pairing correlations and performed with the SIII Skyrme effective force have been used to determine the deformation energy curves of  $^{98-102-106-110}\text{Cd}$  (1). With this description,  $^{98}\text{Cd}$  appears spherical and the even heavier cadmiums present a small prolate deformation. Then, from self-consistent calculations, the neutron and proton quasi-particle states are extracted at equilibrium deformations and injected in a rotor-plus-quasi-particle model to describe the odd-A cadmium nuclei. The development of several bands as the  $h_{11/2}$ ,  $g_{7/2}$  and  $d_{5/2}$  ones is predicted. Moreover, these calculations do not predict a prolate-oblate shape coexistence at low energy for odd-A isotopes.

Experimentally, the in-beam gamma-ray spectroscopy applied to heavy-ion reactions is a classical tool to investigate neutron-deficient isotopes. Unfortunately, the very neutron deficient compound nuclei reached present a complicated deexcitation, with many evaporation exit channels. More or less collective structures are easily identified in the final nuclei but, in general, from excitations functions, their Z and A identification is ambiguous.

If the cross-section of the final products is not too low, the on-line mass separation is a powerful technique to identify the isotopes by a few low-energy excited states and also to observe isomers which could be eventually correlated to a shape transition.

As experimental in-beam results were available in our laboratory on  $A = 103, 102$  (2) chains a complementary study has been undertaken with on-line isotopic separation for a Z determination. It is reported in this paper.

### 2. Experimental technique

The experiments were carried out using the 5-10 MeV/nucleon heavy-ion beams from the Grenoble variable energy cyclotron and the mass separator operating on-line. The details concerning this new possibility will be described elsewhere but few points typically related to the indium separation are reported here.

The Nier-Bernas-Charvet type ionization ion-source of the magnetic separator (3), with a vertical arc perpendicular to the extracted ion-beam direction, has been modified to use the recoil of the nuclei produced in the target by the heavy-ion reaction. A photography and a schematic view of the modified ion source are presented in figures 1 and 2, respectively.

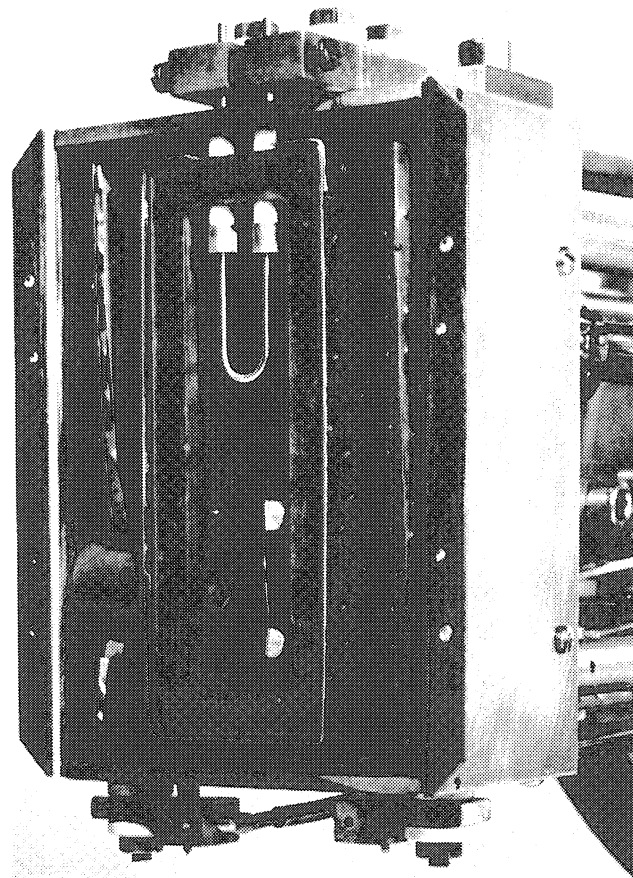


Figure 1 - Photography of the ion-source

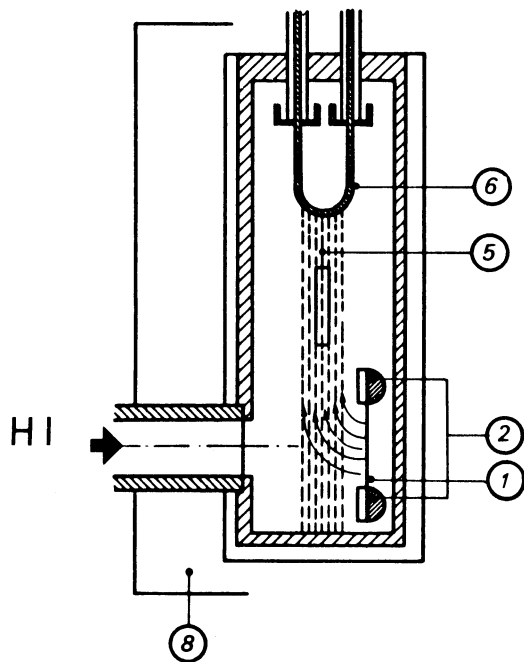


Figure 2 - Schematic view of the target-ion-source system

- 1 graphite catcher
- 2 electrical connections
- 5 arc of the ion-source
- 6 cathode
- 8 colded external chamber

For the production of indium isotopes, the best results have been obtained with a natural molybdenum target (roughly  $5 \text{ mg} \times \text{cm}^{-2}$  thick) placed in the front of a graphite catcher (Papiex N from Carbone Lorraine, 0.15 - 0.3 mm thick), operating with 800 nA to  $3 \mu\text{A}$   $^{14}\text{N}^{4+}$  beams delivered by the accelerator. The catcher was heated at a temperature of 1600-1700°C to diffuse out the recoiled isotopes inside the ionization chamber. The extraction of indium has been carefully studied on  $^{106}\text{In}$  produced by  $^{14}\text{N}$  beams on natural molybdenum targets. Then, on the basis of the Alice Code predictions, the production of  $^{103,102}\text{In}$  has been improved at different beam energies for both the  $^{92}\text{Mo} + ^{16}\text{O}$  and the  $^{92}\text{Mo} + ^{14}\text{N}$  reactions. The latter reaction was found to be the most efficient at 80 MeV for  $^{103}\text{In}$  and at 86 MeV for  $^{102}\text{In}$  respectively. These productions have been compared with the ones obtained at Isocele 2, with light particle projectiles (figure 3).

The mass separated products were collected and transported in front of detectors. The identification of the isotopes was mainly based on the  $\gamma$  and X-ray singles measurements with intrinsic Ge detectors. The half-lives were determined by a classical multispectrum analysis consisting of 8 time subgroups (2K channels each).

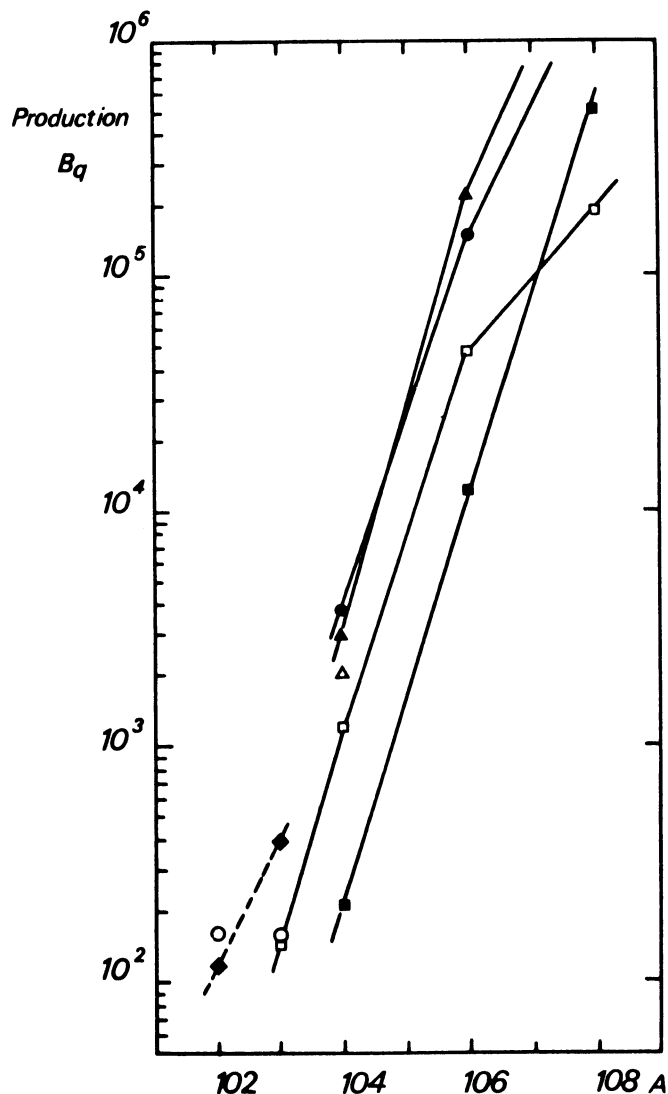


Figure 3 - Productions of indium isotopes

- |                        |         |                                       |        |
|------------------------|---------|---------------------------------------|--------|
| ● Sn + p               | 210 MeV | □ nat <sub>Mo</sub> + <sup>14</sup> N | 80 MeV |
| ▲ Sn + <sup>3</sup> He | 270 MeV | ◆ <sup>92</sup> Mo + <sup>14</sup> N  | 80 MeV |
| ■ Sn + α               | 218 MeV | ○ <sup>92</sup> Mo + <sup>14</sup> N  | 86 MeV |
| △ Ag + <sup>3</sup> He | 270 MeV |                                       |        |

Isocele II

Grenoble

### 3. Experimental results

#### 3.1. The $^{103}\text{In}$ isotope

Before this investigation,  $^{103}\text{In}$  was the highest known indium isotope, identified at Louvain by Lhersonneau et al <sup>4</sup>). In the present experiment, a half-life of 1.0 minute has been found, in good agreement with the previous one ( $T_{1/2} = 1.08 \pm 0.11$  minute). In addition, several new  $\gamma$ -rays have been assigned to the  $^{103}\text{In} \rightarrow ^{103}\text{Cd}$  decay (Table 1). The strongest lines correspond to the ones at 188 keV, M1 ( $7/2^+ \rightarrow 5/2^+$ ) and 720 keV, E2 ( $11/2^+ \rightarrow 7/2^+$ ) already placed in  $^{103}\text{Cd}$  by in-beam investigations on the  $^{94}\text{Mo}(^{12}\text{C}, 3n\gamma)$  reaction <sup>5</sup>). Up to now, the other new transitions have not been unambiguously inserted in the  $^{103}\text{In} \rightarrow ^{103}\text{Cd}$  decay scheme and complementary coincidences measurements have to be performed on  $^{103}\text{In}$  separated samples after the energy improvement

of the Grenoble accelerator. Nevertheless, combining these preliminary data with in-beam results the most probable spin assignment for  $^{103}\text{In}$  is  $9/2^-$ .

### 3.2. The $^{102}\text{In}$ isotope

In the multispectrum analysis performed on the  $A = 102$  mass separated products excited in the  $^{92}\text{Mo} + ^{14}\text{N}$  reaction at a beam energy of 86 MeV, in addition to the well-known  $\gamma$  lines of the  $\text{Cd} \rightarrow \text{Ag} \rightarrow \text{Pd}$  chain, four new  $\gamma$ -rays at 776.8, 861.4, 593.0 and 396.5 keV have been found to decay with an average half-life  $T_{1/2} = 24 \pm 4$  seconds, as shown in figure 4. Relative intensities of the gamma transitions have been reported in Table 1.

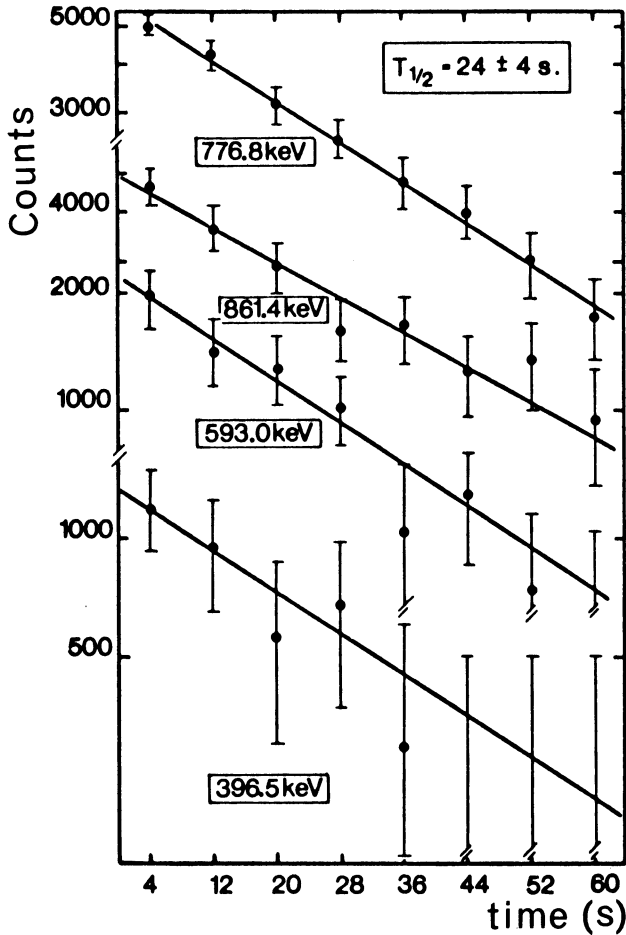


Figure 4 - Decay curves of the  $\gamma$ -lines ascribed to the  $^{102}\text{In} \rightarrow ^{102}\text{Cd}$  decay

Table 1 : Relative gamma-ray intensities observed in the  $^{102}\text{In}$  and  $^{103}\text{In}$  decays.

$^{102}\text{In}$		$^{103}\text{In}$	
$E_\gamma$	$I_\gamma$	$E_\gamma$	$I_\gamma$
(156.6)	10	188.0	100
396.5	12	202.1	17
593.0	30	(699.5)	10
776.8	100	720.0	32
861.4	96	739.9	19
(923.7)	10		

Due to the presence of an enormous amount of K-X lines associated with the  $^{102}\text{Ag} \rightarrow ^{102}\text{Pd}$  decay ( $\text{Ag/In}$  production ratio  $> 10^3$ ), K-X rays characteristic of Cd element have not been observed. Nevertheless the four lines never seen before belong necessarily to the  $^{102}\text{In} \rightarrow ^{102}\text{Cd}$  decay for the following reasons. The  $A = 102$  mass chain starts at the indium element through the  $^{92}\text{Mo} + ^{14}\text{N}$  reaction and these lines have also been observed in in-beam experiments leading to the excited states of  $^{102}\text{Cd}$  produced in the  $^{92}\text{Mo} + ^{12}\text{C}$  reaction at 50 MeV and the  $^{102}\text{Pd} + ^3\text{He}$  reaction at 35 MeV. In these cases their intensities are in agreement with those of the  $\gamma$ -rays of the daughter activity ( $\text{Cd} \rightarrow \text{Ag}$ ) measured after the beam cut-off.

From  $\gamma$ - $\gamma$  coincidences and angular distribution measurements performed in-beam<sup>2)</sup>, the 777-861-503 keV transitions form a  $\Delta I = 2$  cascade and connect the  $0^+$ ,  $2^+$ ,  $4^+$ ,  $6^+$  excited levels (figure 5). Due to the relative intensities of the  $\gamma$ -rays in both in-beam and decay experiments, the 776.8 keV transition is placed at the bottom of the sequence but the reversed order (861-777) is not excluded.

According to the observed cascade, the spin of the  $^{102}\text{In}$  identified by isotopic separation should be  $> 5$ .

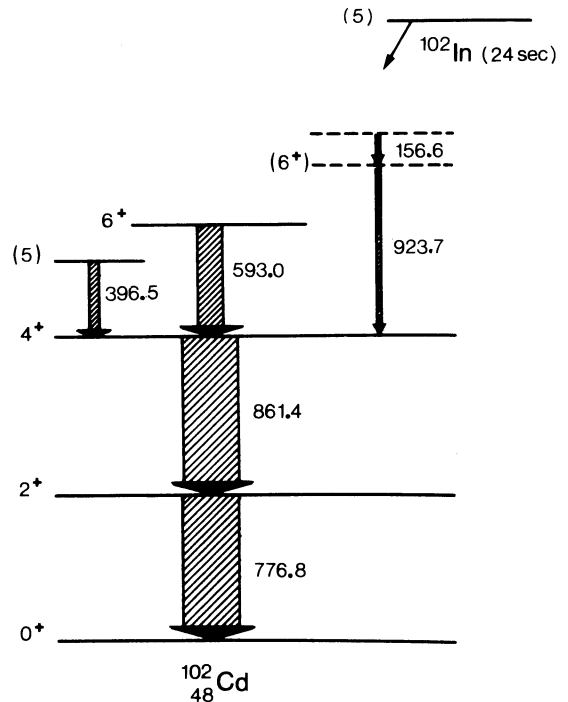


Figure 5 - Partial decay scheme of  $^{102}\text{In} \rightarrow ^{102}\text{Cd}$

### 4. Discussion

Using the new ground state band identified in  $^{102}\text{Cd}$ , the systematics of the  $2^+$ ,  $4^+$  states in even cadmium nuclei can be extended (figure 6). A sudden rising of these levels is found in  $^{102}\text{Cd}$  in comparison with the heavier isotopes and indicates an important decrease of the deformation. This observation is in agreement with the Hartree-Fock calculations performed on these even cadmiums<sup>1)</sup>. Indeed, from this treatment, the  $\beta_2$  parameter associated with a prolate deformation varies from  $\beta_2 \approx 0.17$  in  $^{110}\text{Cd}$  to  $\beta_2 \approx 0.10$  in  $^{102}\text{Cd}$ . The quadrupole moments have not been measured for these lighter even cadmiums and the prolate shape is only confirmed

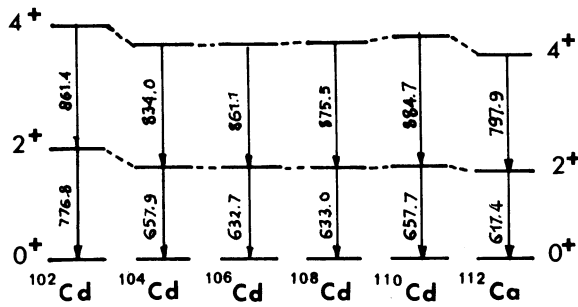


Figure 6 - Systematics of the  $2^+$  and  $4^+$  levels in light even Cd nuclei.

experimentally by the characteristics of the collective structures observed by in-beam spectroscopy in the neighbouring odd-A isotopes <sup>5)</sup>.

Another theoretical approach has been made for the <sup>102</sup>Cd nucleus in the frame of a shell model calculations around the doubly closed shells <sup>100</sup>Sn isotope <sup>6)</sup>. A very good agreement is observed for the calculated and experimental <sup>2)</sup> ground bands and also for a second  $6^+$  level identified at 2561 keV in the <sup>92</sup>Mo(<sup>12</sup>C, 2n) reaction

#### References

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#### DISCUSSION

*A.C. Müller:*

1) Cadmium isotopes: We have measured hyperfine structures and isotope shifts for the sequence of Cd-isotopes between  $102 \leq A \leq 120$ . Extracting deformation from our data we see a gradual decrease in deformation approaching lower neutron numbers consistent with what you have shown.

2) Barium isotopes: The isotope shift data measured by fast-beam laser spectroscopy at the ISOLDE separator we have presented in the talk given by Prof. Otten. He showed a transparency for the derived deformations in the range from <sup>122</sup>Ba to <sup>146</sup>Ba.

*J. Eberth:* I would like to comment on your statement that it is difficult to study <sup>102</sup>Cd by in-beam  $\gamma$ -spectroscopy. We have investigated the reaction <sup>12</sup>C + <sup>92</sup>Mo with the neutron multiplicity technique which I presented in my talk of this morning. As you see from the transparency in the two-fold neutron gated  $\gamma$ -spectrum there are two weak neutron exit channels enhanced, namely the 2n-channel to <sup>102</sup>Cd and the p2n-channel to <sup>101</sup>Ag. All transitions assigned by your work to <sup>102</sup>Cd can be identified with a good peak-to-background ratio. The 861.1 keV transition has about twice the intensity of the 776.6 keV line in our spectrum. As there is no evidence for a doublet, 861.1 keV might be the energy of the ground state transition and 776.6 keV the  $4^+ \rightarrow 2^+$  transition. But still one has to be careful if the 861.1 keV line has not partially to be assigned to <sup>101</sup>Ag which we will prove by a n- $\gamma$  coincidence measurement.

*W. Andrejtscheff:* A confirmation of many two-quasiparticle assignments in <sup>106</sup>Cd are the five new isomers in the nanosecond region we found recently in reactions with <sup>16</sup>O on the Rutgers tandem.

*J. Stachel:* I do not yet see how you get your evidence for triaxiality in Ba-isotopes; are you sure that it is not possible to reproduce your data by coupling an odd particle to a  $\gamma$ -unstable core?

*A. Gizon:* I can only say that we have used a special model to reproduce our in-beam measurements and that we know that different models are able to do the same thing.