Title
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A STUDY OF THE BETA-DECAY ENERGIES OF HIGHLY NEUTRON-DEFICIENT INDIUM ISOTOPES


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June 1981

This work was supported by the Director, U.S. Office of Energy Research, Division of Nuclear Physics of the Office of High Energy and Nuclear Physics, and by Nuclear Sciences of the Basic Energy Sciences Program of the U.S. Department of Energy under Contract No. W-7405-ENG-48.
A Study of the Beta-Decay Energies of Highly Neutron-Deficient Indium Isotopes*


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Abstract

Following on-line mass separations, the decay energies of 103-105In were measured by $\beta$-$\gamma$ coincidence spectroscopy. The deduced masses of 103-105In are compared to the predictions of different available mass models. For 103In an interesting deviation of -1 MeV from the trends of many theoretical systematic predictions is observed. A broad survey of the masses of the indium isotopes between the closed $N=50$ and $N=82$ shells is presented.

1. Introduction

The study of the nuclind mass surface in the vicinity of the doubly magic nucleus $^{100}$Sn is of fundamental interest in providing information on the strength of the shell closure when

\[ Z-N=50. \]  

A comparison of measured mass excesses with currently available model mass predictions can determine the accuracy with which the various models include the effects resulting from shell closures. Figure 1 presents a section of the chart of the nuclides in the vicinity of $^{100}$Sn, depicting those nuclides with measured masses.

As a further step in the extension of the known mass surface, we report here the masses of 103-105In as calculated from our measured $\beta$-endpoint energies and the known decay schemes. The decay of 102In was also observed, but with inadequate statistics up to now to determine an accurate endpoint energy. [The decay of this nucleus has only very recently been identified.] A comparison of the decay energies and deduced masses with different model

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predictions will be presented. In addition the systematics of the known ground state masses of the indium isotopes between the N=50 and 82 shells will be discussed.

2. Experimental

The indium isotopes of interest and various β-calibration sources were produced with the mass separator RAMA-88, located on-line at the Lawrence Berkeley Laboratory 88-inch cyclotron. This separator is novel in that reaction product recoils from the bombardment of multiple targets are thermalized in 1.5 atmospheres of helium and transported via a helium-jet to the hollow cathode ion source of the separator, operating at ~1600°C (see fig. 2). After mass analysis, the separated activities were collected on mylar tape and rapidly transported to a detector station for β-γ coincidence spectroscopy. The β-telescope, positioned facing the radioactive source side of the tape, consisted of a 10 mm diameter and 1 mm thick NE102 plastic scintillator as a ΔE detector (for γ-ray rejection) and a large cylindrical NE102 plastic scintillator, 11.4 cm in both diameter and length, as an E detector. The γ-ray detector, located on the opposite side of the tape, was a large 15% Ge(Li) counter which was positioned within 1.0 cm of the ΔE-E detector to achieve high coincidence detection geometry. Standard fast-slow coincidence networks were set up between all three detectors with a final coincidence timing of 5 ns (FWHM) between the two scintillators and 20 ns (FWHM) between the β-E scintillator and the Ge(Li) counter.

Positron spectra obtained by gating these coincidence spectra with known transitions in the daughter nuclei were corrected for the finite energy resolution of the E detector using the procedure of Rogers and Gordon5). The response function of this detector was assumed to be that of a Gaussian curve, whose width varied with energy as VΔE5). This width was determined to be 200 keV using the 976 keV conversion electrons from 207Bi. Energy endpoint determinations were obtained from weighted linear least-squares fits to Fermi-Kurie plots of the spectra. The Fermi-Kurie plot of the positron spectrum

Fig. 2 Schematic view of the on-line mass separator RAMA.
Table I. Calibration Nuclei

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Half-life</th>
<th>Gate (keV)</th>
<th>E\text{max} (MeV)</th>
<th>Ref.</th>
<th>Reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>38\text{K}</td>
<td>7.6 min.</td>
<td>2168</td>
<td>2.724±0.002</td>
<td>7</td>
<td>24\text{Mg}^{16}\text{O,(p,n)}</td>
</tr>
<tr>
<td>62\text{Cu}</td>
<td>9.7 min.</td>
<td>511</td>
<td>2.927±0.005</td>
<td>7</td>
<td>52\text{Cr}^{12}\text{C,(p,n)}</td>
</tr>
<tr>
<td>123\text{Cs}</td>
<td>9.9 hr.</td>
<td>98</td>
<td>3.410±0.122</td>
<td>7,22</td>
<td>nat\text{Cd}^{14}\text{N,xn)</td>
</tr>
<tr>
<td>66\text{Ga}</td>
<td>9.8 hr.</td>
<td>511</td>
<td>4.153±0.004</td>
<td>7</td>
<td>52\text{Cr}^{16}\text{O,(p,n)}</td>
</tr>
<tr>
<td>124\text{Cs}</td>
<td>31 sec.</td>
<td>354</td>
<td>4.573±0.150</td>
<td>7,22</td>
<td>nat\text{Cd}^{14}\text{N,xn)}</td>
</tr>
</tbody>
</table>

of 62\text{Cu} (one of the calibration nuclei) is presented in figure 3 as an example. An energy calibration as determined using the calibration activities listed in Table I and the assumed response function was found to give a good linear fit. Table I also lists for each calibration activity the y-gate employed to obtain the B spectrum and the reaction used for its production.

In order to study 103-105In, 14\text{N} beams from 90 to 105 MeV and 16\text{O} beams from 90 to 130 MeV were directed onto 80\% enriched 92\text{Mo} and natural Mo targets. All targets were 2 mg/cm\text{2} thick; the average beam intensity varied between 2 and 4 electrical \text{A}.

3. Results
The Fermi-Kurie analysis of the positron spectrum from 105\text{In} in coincidence with the 131 keV y-transition in the 105\text{Cd} daughter is shown in figure 4. About 27\% of the decay is known to feed this 313 keV level directly, while the next strongly fed levels lie at 770 keV and 799 keV with branches of 8\% and 9\%, respectively (ref. 8). One can see the contribution of these higher levels from the change in slope of the Fermi-Kurie plot at ~3.0 MeV.

In the case of 104\text{In}, 22\% of the y-decay goes to the 4\textsuperscript{+} level at 1492 keV, while the 2\textsuperscript{+} level is not fed directly (ref. 9). This allows the use of both the 834 keV (4\textsuperscript{+} \rightarrow 2\textsuperscript{+} transition) and the 658 keV (2\textsuperscript{+} \rightarrow 0\textsuperscript{+} transition) as coincidence gates. Strong B-branches to levels at 2370, 2435 and 2492 keV are also present. This restricts the energy range for the least-squares fit to the data in the Fermi-Kurie plot to 1 MeV in the case of 104\text{In}.

Figure 5 presents a Fermi-Kurie analysis for the 103\text{In} positron spectrum in coincidence with the 188 keV transition in the 105\text{Cd} daughter. Concerning the y-decay of 103\text{In}, a 720 keV y-ray decaying with the proper half life was present in the y-spectra in addition to the 188 keV and 202 keV y-rays mentioned in ref. 10. The relative intensity of this y-ray compared to the 188 keV y-ray is 18\%3\%. Meyer et al.11 determined the level scheme of 103\text{Cd} from the 94\text{Mo}^{12}\text{C,3n} reaction. According to their work the 720 keV y-ray depopulates the 11/2\textsuperscript{+} level at 908 keV and feeds the
7/2^+ level at 188 keV. Taking into account the relative intensities of the observed γ-rays, the β-branch to the level at 908 keV is about 5 times smaller than the branch to the first excited state at 188 keV. The linearity of the Fermi-Kurie plot is not affected seriously by the small β-feeding of the 11/2^+ level as can be seen in figure 5.

A summary of our results on the 103-105In beta-decay energies is given in table II along with the coincident γ-rays used for the gating. For comparison the QEC values reported previously in the literature are also included. The uncertainties quoted in our decay energies include the contribution from the energy calibration of the E-teloscope. The decay energies for 103-104In obtained in this work agree quite well with the literature values and provide a significantly more precise QEC value for 103In. A QEC value for 105In was not previously available.

To investigate the β-decay of 102In, γ-γ coincidence measurements were carried out on mass 102 activities made in the reaction of 130 MeV 160 on 92Mo. In addition to known 102Ag γ-rays, two equal intensity γ-rays at 777.2±0.5 keV and 862.1±0.5 keV were present in the γ-spectra. The half-life of these γ-rays was 21±7 sec according to our measurements. Very recently the decay of 102In was also studied by Béraud et al. The results of their study, which will be presented in this conference, are in agreement with our observations. A preliminary experiment to measure the endpoint energy of 102In has too low statistics to determine a decay energy with a reasonable precision. A further investigation is in progress.

4. Discussion

Information from the decay energy measurements of 103-105In can be used to delineate features of the mass surface in this region of nuclei. A comparison of the measured QEC values with the predictions of the available model masses can highlight which models are more successful in predicting the curvature of the mass surface. Converting the QEC values to mass excesses using the known cadmium masses also allows a direct comparison of the measured masses of 103-105In with the mass predictions.

Figure 6 shows the differences between the measured decay energies and the different model QEC predictions. To deduce systematic trends, this comparison extends to 108In. Each arrow in the figure is labeled by a number corresponding to the QEC prediction of a model as summarized in ref. 12 (the QEC predictions of Möller and Nilsson and of Monahan and Serduke are also included. From figure 6 it is apparent that for 105-108In good agreement exists between the experimentally determined QEC values and the calculated values of the shell model formula of Liran and Zeldes and the mass formulas based on the relationships of the Garvey-Kelson type: Jänecke, Comay and Kelson, Jänecke and Eynon and Monahan and Serduke). By 103In, however, the QEC predictions of these mass formulas are systematically 1 MeV too high. The deviations between the QEC values, calculated with the droplet models of Myers, Groote et al. and Seeger

Table II. Summary of the QEC Determinations

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Gate (keV)</th>
<th>Level in daughter (keV)</th>
<th>This Work QEC (MeV)</th>
<th>Literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>103In</td>
<td>188</td>
<td>188</td>
<td>5.41±0.19</td>
<td>5.8±0.5 (ref. 10)</td>
</tr>
<tr>
<td>104In</td>
<td>658,834</td>
<td>658,1492</td>
<td>7.41±0.20</td>
<td>7.1±0.2 (ref. 9)</td>
</tr>
<tr>
<td>105In</td>
<td>131</td>
<td>131</td>
<td>5.16±0.16</td>
<td>----</td>
</tr>
</tbody>
</table>
7. Mc,lc

Fig. 6 Comparison of experimentally determined QEC values with the predictions of selected model mass formulas.

and Howard [12c] and Möller and Nix[13], and the experimental values are larger than for the other mass formulas. In addition, until 103In, these droplet model predictions are systematically too low.

Table III shows the mass-excess values for 103-105In, determined from the measured QEC values, using the experimentally known masses of the cadmium isotopes [ref. 15-17]. The differences between the measured masses and the available mass predictions are also given in Table III. The mass of 105In is predicted adequately by the Liran-Zeldes[12d], Comay-Kelson[12f] and Janecke-Eynon[12g] mass formulas, taking into account the error in the calculated masses of 105In, quoted in ref. 12f: 350 keV. For the mass of 103In the predictions of the Liran-Zeldes and Garvey-Kelson type mass formulas are systematically about 1 MeV too high, as already noted for the QEC values.

By also considering the available data on the neutron-rich indium isotopes, one can observe the broad systematics of their ground state mass behavior as a function of the neutron number between the shell closures at N=50 and N=82. Aleklett et al. [18] studied the masses of 120In-129In. The mass of the N=82 nucleus 131In can be deduced from the recently reported QEC values of 131In (ref. 19) and 131Sn (ref. 20) and the experimentally-determined mass of 131Sb (ref. 21).

Figures 7 and 8 show comparisons of the predictions of the known indium masses with selected representatives of the different mass theories which are available. Those masses calculated according to the mass relations of the Garvey-Kelson type and those calculated from the shell model formula of Liran-Zeldes agree very well with the experimental results from 106In to 125In (fig. 7). For each of these mass models the root-mean-square deviation of theory from experiment for these nuclides is less than 200 keV. For the more neutron-rich In isotopes, approaching the closed N=82 shell, these mass predictions diverge and the deviations from the experimental value QEC values; an exception is the predictions of Comay and Kelson, which reproduce fairly well the experimental masses. On the neutron-deficient side of figure 7, at 103In, a strong deviation of about 1 MeV of the experimental value from the predictions of Liran-Zeldes and the different Garvey-Kelson type mass formulas suddenly appears. The model of Comay-Kelson (ensemble averaging of mass values using the Garvey-Kelson transverse relation) exhibits the best predictive qualities for the indium isotopes over the A=103 to 131 mass range: the root-mean-square deviation from the experimental data is only 240 keV. In the case of the Liran-Zeldes, Janecke, Janecke-Eynon and Monahan and Serduke models, root-mean-square values of 330, 320, 640 and 340 keV, respectively, are obtained.

Table III. Summary of Experimental Mass Excesses and Comparison with Different Model Mass Predictions.

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Mass excess (MeV)</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>e</th>
<th>f</th>
<th>g</th>
<th>h</th>
<th>i</th>
</tr>
</thead>
<tbody>
<tr>
<td>103In</td>
<td>-75.21±0.19</td>
<td>0.70</td>
<td>-0.99</td>
<td>0.59</td>
<td>-0.70</td>
<td>-1.17</td>
<td>-0.78</td>
<td>-0.78</td>
<td>-1.10</td>
<td>-0.72</td>
</tr>
<tr>
<td>104In</td>
<td>-76.31±0.20</td>
<td>1.00</td>
<td>-0.50</td>
<td>1.29</td>
<td>-0.11</td>
<td>-0.58</td>
<td>0.18</td>
<td>-0.07</td>
<td>-0.19</td>
<td>0.26</td>
</tr>
<tr>
<td>105In</td>
<td>-79.18±0.16</td>
<td>1.25</td>
<td>-0.06</td>
<td>1.92</td>
<td>0.48</td>
<td>0.28</td>
<td>0.59</td>
<td>0.40</td>
<td>0.28</td>
<td>0.58</td>
</tr>
</tbody>
</table>

a) Myers; b) Groote et al.; c) Seeger-Howard; d) Möller-Nix; e) Liran-Zeldes; f) Janecke; g) Comay-Kelson; h) Janecke-Eynon; i) Monahan-Serduke.
The predictions of those liquid drop models considered here differ more from the experimentally observed mass behavior than the results of calculations based on the Garvey-Kelson relations (see figure 8). For the models of Myers, Groote et al., Seeger-Howard and Möller-Wix the root-mean-square deviation from all the indium mass data is 1070, 830, 780 and 630 keV, respectively. As was noted for those mass models displayed in figure 7, a sudden change in the systematic differences between the experimental and calculated masses also sets in for 103In in the comparison with the liquid drop model predictions shown in figure 8.

In conclusion, according to our results, 103In is about 1 MeV more bound than predicted by the Liran-Zeldes and the different Garvey-Kelson type mass formulas, which reproduce very well the heavier indium mass data. A similar effect is not present for the neutron-rich indium isotopes in the vicinity of the N=82 closed shell. An extension of this study to the lighter indium isotopes and other investigations of the mass surface near 100Sn will show whether the observed deviation from the systematics for 103In might have any possible relationship with the nearby double-shell closure.

Fig. 7 A comparison of known indium masses with the predictions of the Liran-Zeldes and the Garvey-Kelson type mass equations.
Fig. 8 A comparison of known indium masses with the predictions of different liquid drop model mass equations.

References

12 a) W. D. Myers, At. Data Nucl. Data Tables 17 (1976) 411.
   c) P. A. Seeger and W. M. Howard, ibid. 428.
   d) S. Liran and N. Zeldes, ibid. 431.
   e) J. Jänecke, ibid. 455.
f) E. Comay and I. Kelson, ibid. 463.

g) J. Jänecke and B. P. Eynon, ibid. 467.


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