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Beta decay of ^{61}Ga

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Abstract. The β decay of ^{61}Ga to its mirror nucleus ^{61}Zn has been measured for the first time by using on-line mass separation and β-delayed gamma-ray spectroscopy. The observed decay strength to the ground state implies superallowed character in accordance with the systematics of the mirror decays in the sd and fp shell. The β feedings observed to four excited states in ^{61}Zn are consistent with earlier spin-parity assignments based on in-beam experiments. The ground-state spin and parity for ^{61}Ga were determined to be $3/2^-$.

PACS. 21.10.Hw Spin, parity, and isobaric spin – 23.40.Hc Relation with nuclear matrix elements and nuclear structure – 27.50.+e $59 \leq \mathrm{A} \leq 89$

1 Introduction

Nuclei with $\mathrm{Z} \geq \mathrm{N}$ above mass 60 are weakly bound or even unbound due to increasing strength of the Coulomb interaction. Therefore, these nuclei are more sensitive to effects of deformation as well as to charge-dependent effects of nucleon-nucleon interaction. Especially, the proton-neutron interaction plays an enhanced role for nuclei with $\mathrm{Z} \sim \mathrm{N}$, because the protons and neutrons populate the same shell-model orbitals. Due to these effects, mirror states provide a unique possibility to study systematic trends along the $\mathrm{Z} = \mathrm{N}$ line.

Maximum β-decay energies of nuclei with $\mathrm{M_T} = (\mathrm{N} - \mathrm{Z})/2 = -1/2$ are usually determined by Coulomb-energy differences between the mirror states in the initial and the final nucleus. The transition between these states is of mixed Fermi and allowed Gamow-Teller type and, as a consequence, the half-life of the parent state is short and most part of the decay proceeds through this ground state to ground state transition. Large $\mathrm{Q_{EC}}$ values near the proton drip-line also allow Gamow-Teller strength studies for a large excitation region. Deformation has been predicted to shift the energy of the Gamow-Teller Resonance; this effect, which affects the β-feeding pattern, might be used to deduce an experimental fingerprint of a particular deformation [1, 2].

Theoretical efforts to study the Gamow-Teller strength in β decays between the mirror nuclei in the fp shell by the shell model have reached ^{57}Cu [3–5]. Experimentally, the ground-state GT matrix elements have been determined with high accuracy for all mirror transitions in the $1\mathrm{f}_{7/2}$ subshell from ^{41}Sc to ^{55}Ni [6–11]. For heavier nuclei, information on the Gamow-Teller strength has been reported for ^{57}Cu [4] and ^{59}Zn [12] in the $2\mathrm{p}_{3/2}$ subshell and for ^{67}Se [13] and ^{71}Kr [14] in the $1\mathrm{f}_{5/2}$ orbital. β-decay half-lives have been measured for ^{61}Ga, ^{63}Ge, and ^{65}As without any detailed spectroscopic information [15, 16]. β-delayed proton decay has been studied for ^{67}Se, ^{71}Kr, and ^{75}Sr [17]. In addition, particle stability has been observed for the isotopes up to ^{91}Pd [18] except for ^{69}Br, ^{73}Rb, ^{81}Nb and ^{85}Tc, which are unbound [15, 19, 20, 21].

In this paper we report on the observation of the mirror β decay of the nucleus ^{61}Ga by β-delayed γ-ray spectroscopy using the On-Line Mass Separator at GSI. This study was carried out as an addendum to a main experiment devoted to the decay study of ^{56}Cu.

2 Experimental method

^{61}Ga was produced, together with neighbouring neutron-deficient isotopes, in a fusion-evaporation reaction using

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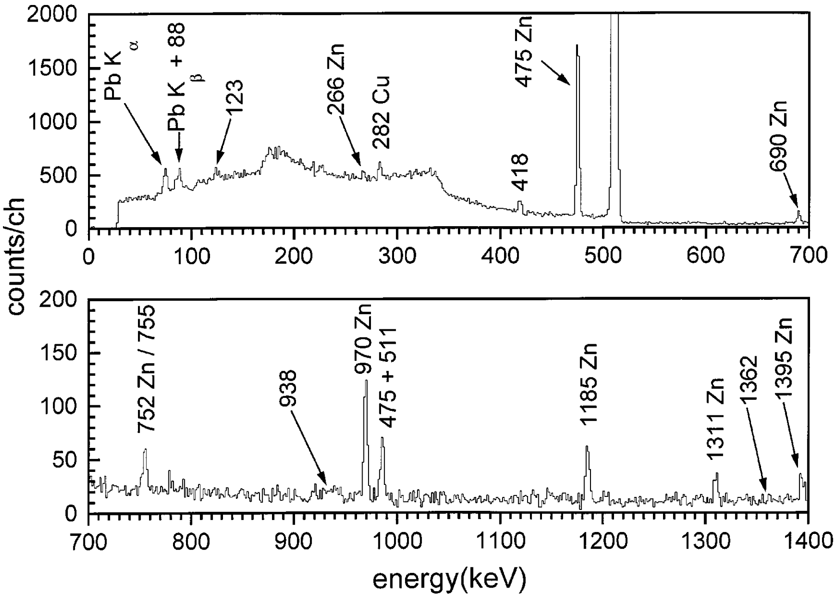

Fig. 1. β-coincident γ-ray spectrum obtained for A = 61. Peaks originating from the decay of ^{61}Ga are marked by their energy in keV

a 121 MeV ^{36}Ar-beam from the heavy-ion accelerator UNILAC and a 1.9 mg/cm^2 $^{\mathrm{nat}}$Si-target. The intensity of the ^{36}Ar beam was typically 80 particle-nA. Evaporation residues were stopped in a graphite catcher mounted inside a FEBIAD-B2-C ion source [22]. The products, extracted as singly-charged ions, were mass separated by means of the GSI On-Line Mass Separator and implanted into a movable collection tape. In order to suppress the amount of the long-lived contaminants ^{61}Zn and ^{61}Cu, the tape was moved periodically after every 0.8 s collection period. The implantation position was shielded by a lead block against γ radiation from sources collected during previous implantations. Collected source was viewed by two germanium detectors for the detection of γ rays. In addition, it was surrounded by a hollow cylindrical plastic scintillator with the collection point in its center for the detection of positrons and by a 2 mm thick plastic scintillator in front of one of the germanium detectors for the detection of positrons. The measurement electronics provided an event trigger for each pair of detector responses. The recorded event, consisting of 8 parameters, included energy and time signals of each detector. The time intervals were stored with respect to both the trigger and the beginning of the counting period. In this way, the time distribution of events could be used for a half-life analysis. The relative detection efficiency of the germanium detector used for gamma-intensity determination was obtained by using sources of ^{56}Ni and ^{56}Co produced on-line. By using a calibrated standard ^{60}Co-source, the absolute efficiency was determined to be $\varepsilon_{\mathrm{abs}} = 0.95(5)\%$ at 1.332 MeV. The efficiency of the cylindrical scintillation detector was determined to be 46(4)% by comparing the photopeak intensities of ^{58}Cu γ rays in singles and in coincidence with this β detector. The ^{58}Cu ions were produced in separate on-line experiments using the reactions ^{32}S + $^{\mathrm{nat}}$Si and ^{36}Ar + $^{\mathrm{nat}}$Si.

The measuring time for ^{61}Ga was 4 h. Limited duration corresponds to the period where the experimental conditions were optimised for ^{61}Ga production, most of the run being used for ^{56}Cu production. The production rates measured at the implantation position were 78, 4.2×10^4, and 5.1×10^5 atoms/s for ^{61}Ga, ^{61}Zn, and ^{61}Cu, respectively. These rates show the dominance of the 2pn- and 3p-reaction channels as compared to the p2n channel leading to ^{61}Ga. The strongest contamination in the γ-ray spectrum was due to the ^{61}Zn decay as can be seen in Fig. 1, whereas the ^{61}Cu activity was suppressed effectively by the short collection time.

3 Results

Figure 1 shows the β-gated γ-ray spectrum recorded for A = 61. Four γ transitions of 88, 123, 418, and 755 keV were assigned to the β decay of ^{61}Ga based on the known γ transitions in ^{61}Zn (Table 1). Due to the relatively low production rate of ^{61}Ga and the strong ground-state feeding of its decay, only the strongest γ transition de-exciting a certain ^{61}Zn level was observed. The complex de-excitation pattern is known from detailed studies of ^{61}Zn states up to excitation energies of 2.3 MeV [23, 24, 25]; these nγ and $\gamma\gamma$ angular correlation measurements yielded relative γ intensities, conversion coefficients for low-energy transitions, and spin/parity assignments. The β-decay branching ratios deduced in the present work are based on the previously known γ-branching ratios from the populated states and the β- and γ-intensities determined from our β-decay data.

The determination of the intensity of the 88 keV transition was disturbed by K_β X-rays originating from the lead shielding. However, this contribution could be subtracted via the intensities observed in the calibration spectrum at A = 56. The transition has been measured to be highly converted with $\alpha_{\mathrm{tot}} = 0.59(48)$ [25]. Unfortunately

Table 1. Energies and relative intensities of the γ transitions observed in the β decay of ^{61}Ga. Only upper limits are indicated in the cases of the 938 and 1362 keV transitions. These γ rays de-excite known levels with E_x, J^π in ^{61}Zn to the $3/2^-$ ground state. Half-life estimates are also given if allowed by the statistics

E_γ (keV)	E_x [b] (keV)	J^π	$T_{1/2}$ [a] (ms)	I_γ [a] (rel. units)
87.6(10) [a]	88.40(10)	$1/2^-$	<430	250(70)
122.9(10) [a]	123.75(10)	$5/2^-$	–	120(30)
418.4(8) [a]	418.10(15)	$3/2^-$	140(70)	100(14)
754.5(12) [a]	756.02(18)	$5/2^-$	<130	79(13)
938	937.7(4)	$1/2^-$	–	<11
1362	1362.3(4)	$3/2^-$,$5/2^-$	–	<13

[a] Present work
[b] Reference [25]

Table 2. Branching ratios, log ft values and the corresponding Gamow-Teller matrix elements for the ^{61}Ga β decays feeding levels with the excitation energy Ex in ^{61}Zn. Absolute uncertainty in intensity has been used for E_x the ground state decay

E_x(keV)	J^π	I_β(%)	log ft	$\lvert\langle\sigma\tau\rangle\rvert$
0	$3/2^-$	84(20)	3.70(14)	0.35(34)
88.40(10)	$1/2^-$	9(4)	4.66(22)	0.29(7)
123.75(10)	$5/2^-$	2.5(8)	5.20(16)	0.15(3)
418.10(15)	$3/2^-$	0.6(6)	5.8(5)	0.08(5)
756.02(18)	$5/2^-$	4.6(6)	4.76(10)	0.25(3)
937.7(4)	$1/2^-$	<1.1	>5.3	<0.13
1362.3(4)	$3/2^-$,$5/2^-$	<0.7	>5.4	<0.12

the large uncertainty in α_{tot} introduces an additional uncertainty into the β feeding. The 752/755 keV doublet is due to γ transitions following the β decays of ^{61}Zn and of ^{61}Ga, respectively. The intensity of the 752 keV peak was obtained by using the 690 keV peak from the β decay of ^{61}Zn as a reference. The final intensity for the 755 keV peak of ^{61}Ga was obtained after subtracting this contribution from the total intensity of the 752/755 keV doublet.

The observed γ transitions following the β decay of ^{61}Ga are given in Table 1. The intensities were determined from the γ-ray spectrum gated by the cylindrical scintillator. Additional anticoincidence was required with the thin plastic scintillator in front of this germanium detector in order to obtain the final spectrum free from positron summing. Only upper limits could be determined for the intensities of the expected 938 and 1362 keV transitions. Table 1 includes also the half-lives extracted, using a least squares fit in the background-subtracted grow-in intensity curves of the β-delayed γ transitions. The deduced uncertainties in half-lives and γ intensities correspond to one standard deviation following from the fitting procedures used. Additional uncertainty contributions in the case of γ intensities have been included using the law of error propagation. Although the accuracy of the half-life data remains modest due to low statistics, it is sufficient to unambiguously distinguish the new short-lived ^{61}Ga activity from the long-lived contaminant activities ^{61}Zn and ^{61}Cu, whose half-lives are 89.1(2) s and 3.41(1) h, respectively [25]. A half-life value of 140(70) ms was obtained for 61Ga using the 418 keV transition. As this result is less accurate than the previously obtained value of 150(30) ms [16], we use the previous result for further discussion. Similarly, the more accurate level energies adopted from reference [25] are used in Fig. 3 and the tables.

In order to determine the absolute intensity of β branchings in the ^{61}Ga decay, the time spectrum of the signals from the cylindrical scintillator was fitted with a two component grow-in curve with the fixed half-lives for ^{61}Ga and ^{61}Zn and a constant background due to the long-lived ^{61}Cu activity. The time spectrum and the fitted components for the three activities are shown in Fig. 2. Integrals of these components also gave the relative β-decay intensities of these two isotopes. The absolute β-decay intensity for ^{61}Ga was obtained from the known absolute intensity of ^{61}Zn derived from the 475 keV γ-ray peak. This procedure resulted in β branching ratio of 0.84(20) to the ground state of ^{61}Zn. The large uncertainty is absolute and includes the uncertainty from the total intensity determination i.e. uncertainties of the half-life of ^{61}Ga [16] and the fitting procedure. This uncertainty in the total β intensity is 20%. The β-decay branching ratios, listed in Table 2, have been deduced from the observed γ-transition intensities compiled in Table 1, and from the relative intensities of the in-beam work [23, 25]. The log ft value and the Gamow-Teller matrix element for the ground-state feeding in Table 2 and Fig. 3 include the absolute uncertainty.

4 Discussion

In the 1995 atomic-mass evaluation, Audi & Wapstra [26] predict a β-decay energy $Q_{EC} = 9.0(2)$ MeV for ^{61}Ga from systematics. A shell-model calculation for Coulomb-energy differences, including isospin nonconserving (INC) interaction, yields a slightly higher value, i.e. $Q_{EC} = 9.262(50)$ MeV [27]. The latter value is in close agreement with the other two commonly used mass predictions of Jänecke-Masson [28] and Möller-Nix [29], which give values of 9.220 and 9.330 MeV, respectively. Also, the half-life calculated for the pure $0^+ \rightarrow 0^+$ Fermi decay of ^{62}Ga using the Q_{EC} from the Coulomb-energy calculation of [27] is in good agreement with the measured value. Based on this good agreement, the Q_{EC} value from [27] has been adopted. An accurate experimental determination of the Q_{EC} value for ^{61}Ga would be very desirable in the future.

The decay strength for an allowed β transition can be calculated using the well-known expressions

$$\mathrm{B(F)} = \mathrm{T(T+1)} - \mathrm{M_{Ti}M_{Tf}} \qquad (1)$$

$$\mathrm{B(GT)} = \left(\frac{g_A}{g_V}\right)^2 \langle\sigma\tau\rangle^2 \qquad (2)$$

$$(1+\delta_r)\mathrm{ft} = \frac{C}{\mathrm{B(F)}(1-\delta_C) + \mathrm{B(GT)}} \qquad (3)$$

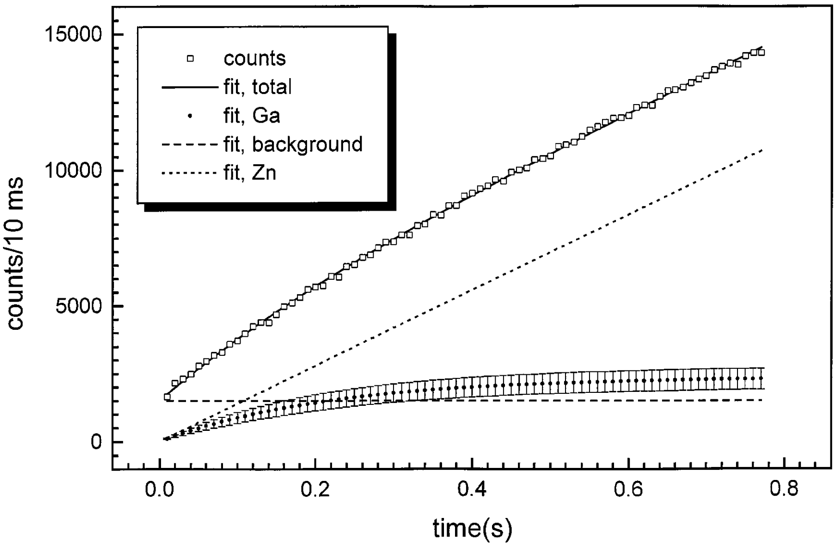

Fig. 2. Determination of the relative intensities of ^{61}Ga and ^{61}Zn. The time spectrum of β particles was fitted with a two-component grow-in curve with fixed half-lives for ^{61}Ga and ^{61}Zn plus a constant background. Integrals of these curves were used to determine the relative total intensities of the activities. Statistical uncertainties in the measured data points are smaller than the symbol. Uncertainties due to the fitting procedure are illustrated by the error bars in the case of ^{61}Ga

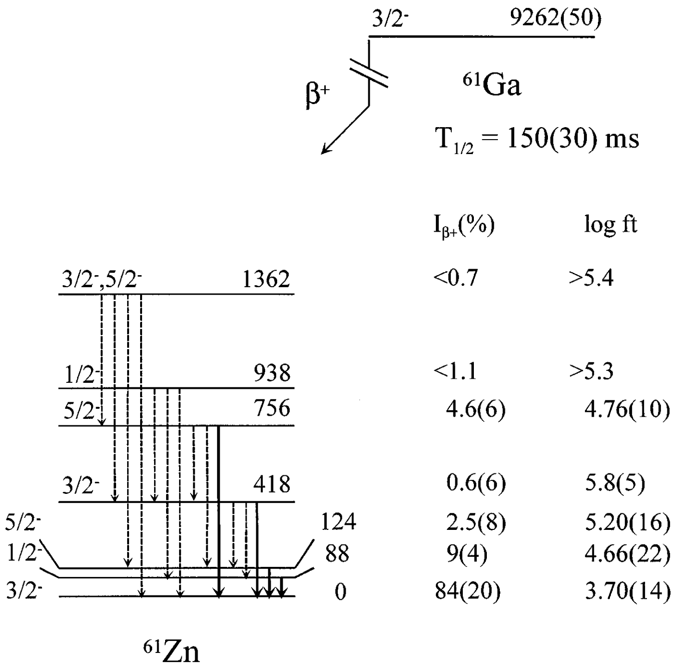

Fig. 3. Proposed partial decay scheme for ^{61}Ga. The given values are taken from this work, except for the Q_{EC} value which stems from a Coulomb-shift calculation [27], the level energies and the β-decay half-life [16] which was obtained by using intermediate-energy fragmentation reactions. Transitions that were observed in-beam [23, 24], but not in the present β-decay study, are indicated by dashed lines. An absolute uncertainty has been given for the β-decay ground-state feeding and log ft value

where $(1-\delta_C)$ is the correction for isospin impurity taken as 0.997(3) [30], $(1+\delta_r)$ is a radiative correction equal to 1.026 [31, 14], C = 6145(4) s [32], and $g_A/g_V = -1.266(4)$ [33]. The values for the Fermi integral f have been taken from the tabulation of Dessagne and Miehe [34]. The pure Fermi strength for mirror decays has the value of B(F) = 1. Using the above expression, the GT-matrix element for the ground-state transition results in $|\sigma\tau| = 0.35(34)$. The large uncertainty is induced by the modest accuracies in the branching ratio, half-life and β-decay energy.

The total integrated GT strength is only about 10% of the sum rule limit of $\sum_f \langle\sigma\tau_+\rangle^2 > 3$ for T = 1/2 mirror nuclei. Similar values have been obtained for other fp-shell mirror nuclei in the region A = 45–71. However, any solid conclusions about the integrated GT strength are difficult to draw, since most experiments have been performed by using β-delayed γ-ray spectroscopy, which detects the strength only in the low-excitation region. The data on β-delayed proton spectroscopy suited for the study of higher-excitation region have been restricted to ^{59}Zn [12], ^{67}Se [17] and ^{71}Kr [17, 14]. The GT strength deduced for proton-unbound states in ^{59}Cu is around 50%, corresponding to an absolute feeding of only 0.23% [12]. In the case of ^{61}Ga, the proton separation energy of the daughter nucleus ^{61}Zn is fairly high, i.e. $S_p = 5290(16)$ keV, in comparison with $S_p = 3418(1)$ keV for ^{59}Cu. Thus, the probability for β-delayed proton emission for ^{61}Ga is expected to be lower than for ^{59}Zn. Using a simple estimate for β-delayed proton branching based on phase-space and binding-energy considerations only, one can estimate the β feeding to proton unbound states in ^{61}Zn to be 0.03%.

Short-lived isomeric states with half-lives in the μs region have been found in many nuclei in the upper fp shell [35] mainly due to the presence of the $1g_{9/2}$ orbital. No evidence for isomerism was found in this work. On-line mass separation technique used in this work restricted the search for isomerism to states with half-lives longer than milliseconds.

The decay scheme proposed for ^{61}Ga is shown in Fig. 3. The observed feedings to the $1/2^-$ state at 88 keV and to the $5/2^-$ states at 124 and 756 keV fix the ground-state spin and parity of ^{61}Ga to be $J^\pi = 3/2^-$, as expected from the mirror ground-state of ^{61}Zn. This is also in agreement with the extreme single-particle shell-model. The high relative intensity of the 418 keV peak compared to the small β feeding to the 418 keV level is explained by a strong population of this level from the 756 keV level by a 338 keV γ transition, as is deduced from the known branchings [23, 25] of the 756 and 338 keV transitions. The observation of this transition is prevented by the high background due to the 511 keV Compton edge around 340 keV. The low β branching ratio to this $3/2^-$ state indicates some hindrance of the allowed GT transition.

The decay scheme shown in Fig. 2 is in agreement with the known mirror decays in the fp shell, i.e. it is dominated by strong ground-state feeding. All observed transitions possess allowed character. The GT-matrix element $|\sigma\tau| = 0.35(34)$ for this transition can be compared to an extreme single-particle estimate. Assuming a $2p_{3/2} \rightarrow 2p_{3/2}$ transition, one obtains $|\sigma\tau|_{SP} = 1.29$ [36]. The observed reduction of the strength of the Gamow-Teller matrix element for the ground-state to ground-state transition, which is typical for fp-shell nuclei, has its origin in configuration mixing. Shell-model calculations for the light zinc isotopes $^{62-68}$Zn, using the MSDI interaction, have been performed by Van Hienen et al. [37]. In these calculations, ^{56}Ni was used as an inert core and the MSDI two-body matrix elements were adjusted to reproduce the energy levels of nickel and copper isotopes with A = 57–68. In these calculations, the occupation numbers of the ground states of zinc isotopes show increasing configuration mixing between the $2p_{3/2}$, $1f_{5/2}$, and $2p_{1/2}$ orbits, when going towards the N = Z line. We have extended these calculations to ^{61}Zn, obtaining occupation probabilities of 0.55, 0.30, and 0.15, respectively, for the above orbitals in the $J^\pi = 3/2^-$ ground state.

As a summary, β decay of ^{61}Ga to the mirror nucleus ^{61}Zn has been studied using β-delayed gamma spectroscopy at the On-line Mass Separator at GSI. In addition to the strong transition to the mirror daughter ground state, four transitions to excited levels have been observed. Spin and parity of the ground state in ^{61}Ga have been established to be $3/2^-$ on the basis of the allowed character of the observed transitions. The presence of an isomeric state in ^{61}Ga can not be ruled out by our experiment. Limited statistics due to large background activity do not allow an accurate determination of the ground-state Gamow-Teller matrix element. However, the extracted result together with the large mixing of single-particle states revealed by our shell model calculation are consistent with the systematical trend of the Gamow-Teller matrix elements of mirror decays in the upper fp shell.

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References

1. F. Frisk, I. Hamamoto and X. Z. Zhang, Phys. Rev. C**52**, 2468 (1995)
2. I. Hamamoto, to be published in *Proceedings of the International Symposium on New Facet of Spin Giant Resonances in Nuclei, Tokyo, Japan, 1997*
3. H. Miyatake, K. Ogawa, T. Shinozuka and M. Fujioka, Nucl. Phys. A**470**, 328 (1987)
4. D.R. Semon, M.C. Allen, H. Dejbakhsh, C.A. Cagliardi, S.E. Hale, J. Jiang, L. Trache, R.E. Tribble, S.J. Yennello, H.M. Xu, X.G. Zhou and B.A. Brown, Phys. Rev. C**53**, 96 (1996)
5. G. Martinez-Pinedo, A. Poves, E. Caurier and A.P. Zuker, Phys. Rev. C**53**, R2602 (1996)
6. H. Wilson, R.W. Kavanagh and F.M. Mann, Phys. Rev. C**22** (1980) 1696
7. J. Honkanen, V. Koponen, H. Hyvönen, P. Taskinen, J. Äystö and K. Ogawa, Nucl. Phys. A**471**, 489 (1987)
8. P. Hornshøj, J. Kolind and N. Rud, Phys. Lett. B**116**, 4 (1982)
9. T.W. Burrows, J.W. Olness and D.E. Alburger, Phys. Rev. C**31**, 1490 (1985)
10. J. Honkanen, V. Koponen, P. Taskinen, J. Äystö, K. Eskola, S. Messelt and K. Ogawa, Nucl. Phys. A**496**, 462 (1989)
11. J. Äystö, J. Ärje, V. Koponen, P. Taskinen, H. Hyvönen, A. Hautojärvi and K. Vierinen, Phys. Lett. B**138**, 369 (1984)
12. J. Honkanen, M. Kortelahti, K. Eskola and K. Vierinen, Nucl. Phys. A**366**, 109 (1981)
13. P. Baumann, M. Bounajma, A. Huck, G. Klotz, A. Knipper, G. Walter, G. Marguier, C. Richard-Serre, H. Ravn, E. Hagebö, P. Hoff and K. Steffensen, Phys. Rev. C**50**, 1180 (1994)
14. M. Oinonen, A. Jokinen, J. Äystö, P. Baumann, F. Didierjean, A. Honkanen, A. Huck, M. Huyse, A. Knipper, G. Marguier, Yu. Novikov, A. Popov, M. Ramdhane, D.M. Seliverstov, P. Van Duppen, G. Walter and the ISOLDE Collaboration, Phys. Rev. C**56**, 745 (1997)
15. M.F. Mohar, D. Bazin, W. Benenson, D.J. Morrissey, N.A. Orr, B.M. Sherrill, D. Swan and J.A. Winger, Phys. Rev. Lett. **66**, 1571 (1991)
16. J.A. Winger, D. Bazin, W. Benenson, G.M. Grawley, D.J. Morrissey, N.A. Orr, R. Pfaff, B.M. Sherrill, M. Thoennessen, S.J. Yennello and B.M. Young, Phys. Rev. C**48**, 3097 (1993)
17. B. Blank, S. Andriamonje, S. Czajkowski, F. Davi, R. Del Moral, C. Donzaud, J.P. Dufour, A. Fleury, A. Grewe, R. Grzywacz, A. Heinz, Z. Janas, A. Junghans, M. Lewitowicz, A. Musquère, M.S. Pravikoff, M. Pfützner and J.E. Sauvestre, Phys. Lett. B**364**, 8 (1995)
18. K. Rykaczewski, R. Anne, G. Auger, D. Bazin, C. Borcea, V. Borrel, J. Corre, T. Dörfler, A. Fomichov, R. Grzywacz, D. Guillemaud-Mueller, R. Hue, M. Huyse, Z. Janas, H. Keller, M. Lewitowicz, S. Lukyanov, A. C. Mueller, Yu. Penionzhkewich, M. Pfützner, F. Pougheon, M. Saint-Laurent, K. Schmidt, W. D. Schmidt-Ott, O. Sorlin, J. Szerypo, O. Tarasov, J. Wauters and J. Zylicz, Phys. Rev. C**52**, R2310 (1995)
19. B. Blank, S. Andriamonje, S. Czajkowski, F. Davi, R. Del Moral, J.P. Dufour, A. Fleury, A. Musquère, M.S.

Pravikoff, R. Grzywacz, Z. Janas, M. Pfutzner, A. Grewe, A. Heinz, A. Junghans, M. Lewitowicz, J.-E. Sauvestre and C. Donzaud, Phys. Rev. Lett. **74**, 4611 (1995)

20. A. Jokinen, M. Oinonen, J. Äystö, P. Baumann, F. Didierjean, P. Hoff, A. Huck, A. Knipper, G. Marguier, Yu. N. Novikov, A. V. Popov, M. Ramdhane, D. M. Seliverstov, P. Van Duppen, G. Walter and the ISOLDE collaboration, Z. Physik A**355**, 227 (1996)
21. Z. Janas, C. Chandler, B. Blank, P.H. Regan, A.M. Bruce, W.N. Catford, N. Curtis, S. Czajkowski, Ph. Dessagne, A. Fleury, W. Gelletly, J. Giovinazzo, R. Grzywacz, M. Lewitowicz, C. Longour, C. Marchand, Ch. Miehe, N.A. Orr, R.D. Page, C.J. Pearson, M.S. Pravikoff, A.T. Reed, M.G. Saint-Laurent, J.A. Sheikh, S.M. Vincent, R. Wadsworth, D.D. Warner and J.S. Winfield, to be published (1998)
22. R. Kirchner, O. Klepper, D. Marx, G.-E. Rathke and B. Sherrill, Nucl. Instr. and Meth. in Phys. Res. A**247**, 265 (1986)
23. J.M. Thirion, G. Chouraqui, T.H. Muller and M. Port, Z. Physik A**317**, 329 (1984)
24. R.B. Schubank, J.A. Cameron and V.P. Janzen, Phys. Rev. C**40**, 2310 (1989)
25. Z. Chunmei, Nucl. Data Sheets **67**, 271 (1992)
26. G. Audi and A.H. Wapstra, Nucl. Phys. A**595**, 409 (1995)
27. W.E. Ormand, Phys. Rev. C**55**, 2407 (1997)
28. J. Jänecke and P.J. Masson, At. Data. Nucl. Data Tables **39**, 265 (1988)
29. P. Möller, J.R. Nix, W.D. Myers and W.J. Swiatecki, At. Data Nucl. Data Tables **59**, 185 (1995)
30. D.H. Wilkinson, A. Gallmann, D.E. Alburger, Phys. Rev. C**18**, 401 (1978)
31. G.T. Ewan, E. Hagberg, P.G. Hansen, B. Jonson, S. Mattsson, H.L. Ravn and P. Tidemand-Petersson, Nucl. Phys. A**352**, 13 (1981)
32. I.S. Towner, E. Hagberg, J.C. Hardy, V.T. Koslowsky and G. Savard, in Proceedings of the 1st International Conference on Exotic Nuclei and Atomic Masses ENAM-95, Arles, France, 1995
33. K. Schreckenbach, P. Liaud, R. Kossakowski, H. Nastoll, A. Bussiere and J.P. Guillaud, Phys. Lett. B**349**, 427 (1995)
34. P. Dessagne and C. Miehé, CRN Report No. CRN PN 87-08, 1987 (unpublished)
35. R. Grzywacz, R. Anne, G. Auger, D. Bazin, C. Borcea, V. Borrel, J.M. Corre, T. Dörfler, A. Fomichov, M. Gaelens, D. Guillemaud-Mueller, R. Hue, M. Huyse, Z. Janas, H. Keller, M. Lewitowicz, S. Lukyanov, A.C. Mueller, Yu. Penionzhkevitch, M. Pfützner, F. Pougheon, K.Rykaszewski, M.G. Saint-Laurent, K. Schmidt, W.-D. Schmidt-Ott, O. Sorlin, J. Szerypo, O. Tarasov, J. Wauters and J. Zylicz, Phys. Lett. B**355**, 439 (1995)
36. A. Bohr and B.R. Mottelson, Nuclear Structure, Vol. I, p.346 (W.A. Benjamin, Inc., New York, Amsterdam 1969)
37. J.F.A. Van Hienen, W. Chung and B.H. Wildenthal, Nucl. Phys. A**269**, 159 (1976)