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Letter

Observation of negative-parity high-spin states of ^{68}As

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Abstract. The neutron-deficient nucleus ^{68}As was populated at high spin in two experiments using the reaction ^{40}Ca(^{32}S, $3pn$) at beam energies of 105 and 95 MeV. A self-supporting and a gold-backed, highly enriched ^{40}Ca target were used. Gamma rays were detected with the EUROBALL array, combined with the charged-particle detector array EUCLIDES and the Neutron Wall. The ^{68}As level scheme was considerably extended, especially at negative parity and many previous spin-parity assignments were confirmed or rejected. The total-Routhian-surface (TRS) calculations find shape coexistence and γ softness for the negative- and positive-parity states, respectively.

PACS. 23.20.Lv γ transitions and level energies – 21.60.-n Nuclear structure models and methods

Coexistence of nearly spherical as well as well-deformed shapes has been discussed for many mass $A \approx 70$ nuclei, *e.g.* for ^{70}As and ^{72}As [1–3]. The structure of ^{68}As was interpreted in terms of rotational bands within the EXCITED VAMPIR approach [4], while multiplet-like sequences were discussed based on the interacting boson-fermion-fermion model [5]. However, the previous high-spin studies [4–6] resulted in several discrepancies concerning spin and parity assignments. While the yrast positive-parity sequences were observed up to relatively high spin ($\approx$ 15 $\hbar$), very little information exists concerning the negative-parity states. The aim of the present study was to remove the existing discrepancies, to extend the level scheme and search for negative-parity level sequences.

^{68}As was populated at high spin in two experiments, using the ^{32}S beam at energies of 105 and 95 MeV provided by the VIVITRON accelerator of IReS in Strasbourg, and two ^{40}Ca targets enriched to 99.9%. In the first experiment, the target was of a 860 μg/cm^2 self-supporting foil, while the second target consisted of a 1 mg/cm^2 ^{40}Ca layer evaporated onto a 15 mg/cm^2 gold backing. Gamma rays were detected with the EUROBALL array, combined with the EUCLIDES charged-particle detector array and the Neutron Wall. Experimental details were published in [7–9]. The level scheme of ^{68}As was constructed on the basis of neutron-gated γ-γ-γ cubes from both experiments. The resulting level scheme is shown in fig. 1 and the different parts are labelled A, B and C. Examples of doubly gated coincidence spectra extracted from the self-supporting target experiment are shown in fig. 2. DCO ratios were obtained from a neutron-gated γ-γ DCO matrix

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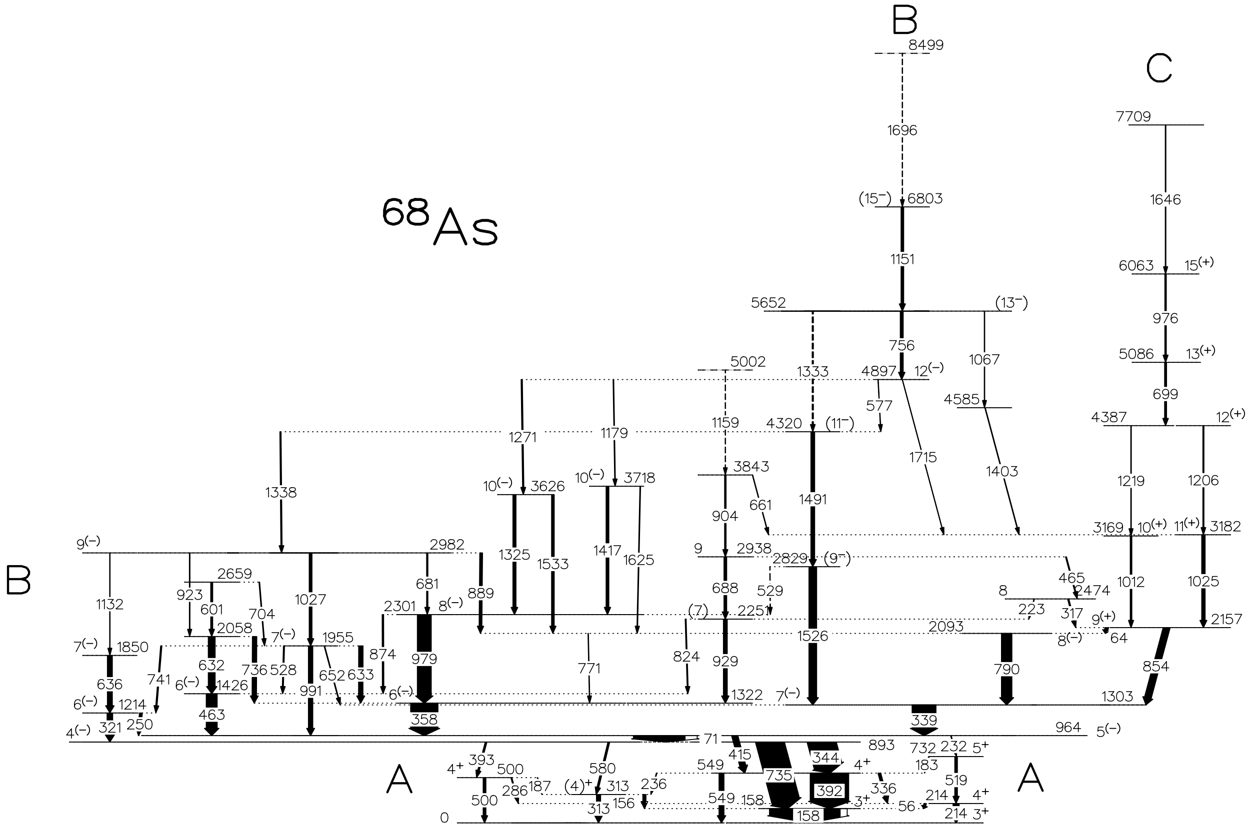

Fig. 1. Level scheme of ^{68}As deduced from the present experiment.

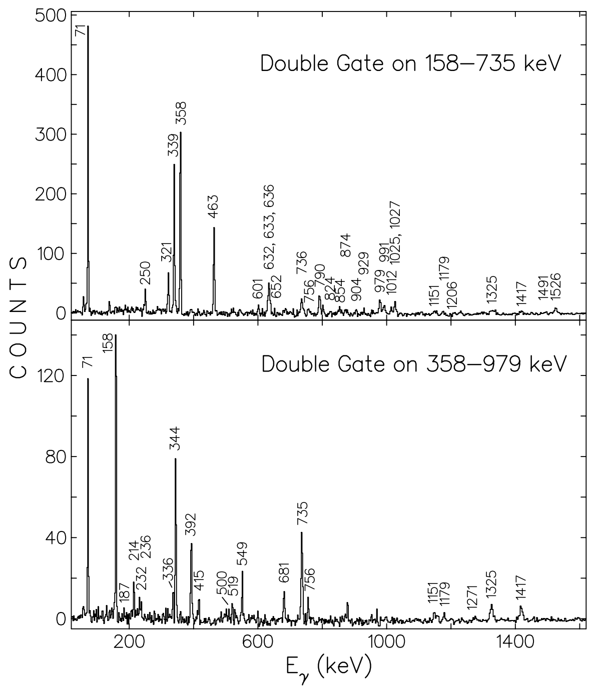

Fig. 2. Examples of doubly gated coincidence spectra extracted from the ν-γ-γ cube sorted from the self-supporting target experiment. Peaks labeled with their energy in keV are assigned to ^{68}As.

using mainly the backed-target data. In table 1, only DCO ratios of transitions with previously unknown, ambiguous or revised multipolarity are listed. DCO ratios of the transitions mainly used as a gate on the DCO matrix are also given.

In addition to the previous works [4–6], we extended the level scheme to higher spins and established new levels at 1850, 2659, 2982, 3626, 3718, 3843, 4320, (5002), 6803, 7709, and (8499) keV. In addition to the transitions depopulating those levels, the known part of the level scheme was complemented with the new 223, 528, 529, 577, 736, 741, and 824 keV transitions. We place the 874 keV transition on top of the 1426 keV level, parallel to the 632 keV transition instead on top of the 2058 keV level [4]. The DCO ratios rather point to $I^\pi = (4)^+$, $7^{(-)}$ and (13^-) for the levels at 313, 1955 and 5652 keV, respectively, than $I^\pi = 3^+$, (8^-) and (14^+) as given in [5]. An assignment of $I^\pi = 6^{(-)}$ was proposed to the 1214 keV level instead of $4, 5$ [6]. Based on the newly observed linking transitions and the quadrupole character of many of them, tentative parity assignments to most of the states were possible. For example, from the $\Delta I = 2$ character of the 991 and 1027 keV transitions, negative parity was assigned to the newly observed 2982 keV level, serving as a connecting point of 5 level sequences. From that negative parity to these sequences of states were tentatively assigned. Then, $I^\pi = 10^{(-)}$ was assigned to the 3626 and 3718 keV levels from the $\Delta I = 2$ character of the 1325 and 1417 keV transitions, respectively. The 1179 and

Table 1. DCO ratios obtained for γ-rays of ^{68}As with previously unknown, ambiguous or revised multipolarity as well as for the transitions mainly used as a gate on the DCO matrix.

E_γ $^{(a)}$ (keV)	$R_{\mathrm{DCO}}^{(\mathrm{b})}$	Gate$^{(c)}$	$\lvert\Delta I\rvert$, $\lambda^{(d)}$	$E_\mathrm{i}^{(\mathrm{e})}$ (keV)
236.1(1)	0.97(25)	338.2	0, $M1$	549.3
313.2(4)	0.55(16)	338.2	1, $M1$	313.2
320.8(2)	0.96(19)	343.8	2, Q	1213.9
339.0(1)	1.02(4)	343.8	2, $E2^{(\mathrm{f})}$	1302.9
343.8(2)	0.97(9)	338.2	0, D	893.1
358.1(1)	0.52(11)	343.8	1, D	1322.0
579.9(3)	0.80(28)	338.2	0, D	893.1
632.8(2)	1.14(34)$^{(\mathrm{g})}$	358.1	1, D	1954.8
635.6(2)	0.78(49)	320.8	1	1849.5
651.9(3)	1.08(19)	338.2	0, D	1954.8
681.1(2)	1.42(35)$^{(\mathrm{g})}$	358.1	1, D	2981.7
755.5(3)	0.78(26)$^{(\mathrm{h})}$	1025.1	(1, D)	5652.3
976.1(3)	1.03(47)	338.2	2, Q	6062.5
	1.17(31)$^{(\mathrm{g})}$	1025.4		
978.6(2)	1.70(26)	358.1	2, Q	2300.6
	2.40(60)$^{(\mathrm{g})}$	358.1		
990.9(2)	0.90(20)	343.8	2, Q	1954.8
1151.0(1)$^{(\mathrm{i})}$	1.20(29)$^{(\mathrm{g})}$	1025.1	2, Q	6803.3
1325.0(7)$^{(\mathrm{i})}$	1.29(50)$^{(\mathrm{g})}$	978.6	2, Q	3625.6
1417.3(5)$^{(\mathrm{i})}$	0.96(34)$^{(\mathrm{g})}$	978.6	2, Q	3717.9
1490.5(7)$^{(\mathrm{i})}$	1.40(33)$^{(\mathrm{g})}$	338.2	2, Q	4319.7
1526.3(5)$^{(\mathrm{i})}$	1.30(35)$^{(\mathrm{g})}$	343.8	2, Q	2829.2
1714.6(7)$^{(\mathrm{i})}$	0.59(21)$^{(\mathrm{g})}$	1025.1	1, D	4896.5

(a) γ-ray energy obtained from the experiment with the gold-backed target except where indicated otherwise.
(b) DCO ratio deduced from the n-γ-γ matrix sorted from the backed-target experiment except where indicated otherwise.
(c) Transition used as gate on the DCO matrix.
(d) Spin difference $\lvert\Delta I\rvert$ and multipolarity character compatible with the DCO ratio and the de-excitation mode.
(e) Energy of the initial state.
(f) Also from ref. [14].
(g) The DCO ratio was determined from the n-γ-γ matrix sorted from the self-supporting target experiment.
(h) May be a doublet. The DCO ratio may not be correct.
(i) γ-ray energy obtained from the experiment with the self-supporting target.

1271 keV transitions link these states with the 4897 keV $I = 12$ state, which point to the $E2$ character for them and, thus, negative parity for the 4897 keV state. This state is depopulated by the 1715 keV $\Delta I = 1$ transition to the $11^{(+)}$ state. Consequently, the 756 keV transition more likely does not change again the parity. The DCO ratio of 0.78(26) for this transition is compatible with the DCO ratios of the 636 and 790 keV transitions for which the corresponding level assignments point to $\Delta I = 1$ character. Thus, we suggest the $\Delta I = 1$ transition and $I^\pi = (13^-)$ for the 5652 keV state. However, an $E2$ character for the 756 keV transition and, thus, $I^\pi = 14^-$ for the 5652 kev state cannot be completely excluded, because of the large uncertainty of the DCO ratio. The suggested assignments of $I^\pi = 12^{(-)}$ and (13^-) for the

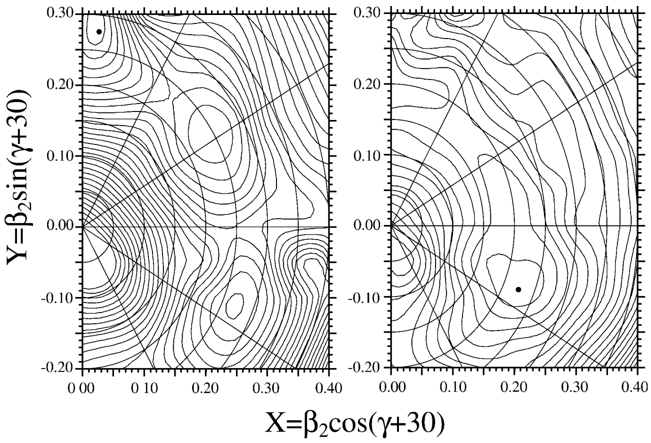

Fig. 3. Total Routhian surfaces for negative-parity states at $\hbar\omega = 0.39$ MeV, $I^\pi \approx 6^-$ (on the left) and for positive-parity states at $\hbar\omega = 0.39$ MeV, $I^\pi \approx 4^+$ (on the right).

4897 and 5652 keV states, respectively, are at variance with $I^\pi = (12^+)$ and (14^+) proposed in [5]. The present work revealed that except for the low-lying part A, the structure on top of the 2157 keV $9^{(+)}$ isomer (part C) and the states above the 929 keV level for which no parity could be assumed, all other states observed have probably negative parity. Additional support for the proposed negative parity for part B comes from the neighboring ^{66}Ge [7,10] and ^{68}Ge [10], where similar correlated parallel cascades between 5^- and 13^- were observed.

Extended total-Routhian-surface (TRS) calculations were performed [11,12]. The coexistence of oblate, prolate and nearly spherical shapes, and gamma softness is suggested in ^{68}As (see fig. 3). The TRS calculations describe the low-lying positive-parity states (part A in fig. 1) with slightly to moderately deformed configurations with dominant quasiparticle contributions having prolate and oblate noncollective shapes. At $\hbar\omega = 0$ MeV, $\beta_2 \approx 0.2$ and $\gamma = -120°$, the lowest $I = 3^+$ state is calculated with a $\pi p_{3/2}\nu p_{3/2}$ configuration. The negative-parity part of the level scheme (part B) revealed a complicated pattern similar to that in the heavier As isotopes and neighboring Ge isotopes. The TRS describes the complicated negative-parity pattern (up to spin 12 $\hbar$) as noncollective oblate sequences as well as bands built on differently aligned and probably mixed 2qp $(\pi p_{1/2}p_{3/2}f_{5/2};\nu g_{9/2})$ configurations causing a coexistence of oblate and prolate shapes.

A strongly collective positive-parity rotational band staggered in $M1$ energies and strengths connecting both signatures was observed above the 8_1^+ state in ^{72}As [2,13]. A collective band-like structure still persists in ^{70}As [1], although the $M1$ staggering becomes very strong. However, this band does not seem to exist in ^{68}As. The $9^{(+)}$ isomer (36 ns [14]) at 2157 keV is likely to be the lowest $\pi g_{9/2}\nu g_{9/2}$ state without an $E2$ band built on it. The first 8^+ state is expected above it from its energy trend in heavier As isotopes and may be the $I = 8$ state at 2474 keV. At $\hbar\omega = 0$ MeV and $I = 9^+$, a minimum corresponding to the $\pi g_{9/2}\nu g_{9/2}$ configuration appears in the TRS calculations with a noncollective oblate shape of $\beta_2 \approx 0.29$

and $\gamma \approx 52°$. The predicted oblate shape is also consistent with the isomeric character of this state [14]. The same basic configuration produces a sequence of collective states with $I^\pi = 10^+, 11^+, 12^+, 13^+, 15^+, 17^+, 19^+$, and so on at a triaxial deformation of $\beta_2 \approx 0.27$ and $\gamma \approx 22°$.

In conclusion, the extended and more complete level scheme of ^{68}As proposed in the present work partly matches the TRS calculations and offers a rich interplay of various shapes, but is far from being well understood. Lifetime measurements could reveal, which of the discussed structures are deformed and which feature the predicted softness in γ and β.

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