ELSEVIER

Nuclear Physics A682 (2001) 41c–47c

NUCLEAR PHYSICS A

www.elsevier.nl/locate/npe

In-beam study of the N=Z nucleus $^{66}_{33}As_{33}$ using the decay tagging technique

R. Grzywacz[a,b], C.H. Yu[c] Z. Janas[b,d], S.D. Paul[e] J. C. Batchelder[f] C. R. Bingham[a,c], T. N. Ginter[e], C. J. Gross[c,g] J. McConnell[c], M. Lipoglavsek[c], A. Piechaczek[h] D.C. Radford[c], J. J. Ressler[i] K. Rykaczewski[c,a], J. Shergur[i], W. B. Walters[i] E. F. Zganjar[h], C. Baktash[c], M.P. Carpenter[j] R.V.F. Janssens[j], C.E. Svensson[k] J.C. Waddington[l] D. Ward[k], E. Dragulescu[m]

[a]Dept. of Physics and Astr., University of Tennessee, Knoxville, Tennessee 37996
[b]Institute of Experimental Physics, Warsaw University, PL 00681, Warsaw, Poland
[c]Physics Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831
[d]Joint Institute for Heavy Ion Research, Oak Ridge, Tennessee 37831
[e]Dept. of Physics and Astr., Vanderbilt University, Nashville, Tennessee 37235
[f]UNIRIB, Oak Ridge Associated Universities, Oak Ridge, Tennessee 37831
[g]UNIRIB, Oak Ridge Institute for Science and Education, Oak Ridge, Tennessee 37831
[h]Dept. of Physics and Astr., Louisiana State University, Baton Rouge, Louisiana 70803
[i]Dept. of Chemistry, University of Maryland, College Park, Maryland 20742
[j]Physics Division, Argonne National Laboratory, Argonne, Illinois 60439
[k]Nuclear Science Div., Lawrence Berkeley National Laboratory, Berkeley, California 94720
[l]Dept. of Physics and Astr., McMaster University, Hamilton, Ontario, Canada L8S 4M1
[m]Nat. Inst. for Nucl. Physics and Eng., Bucharest-Magurele, P.O. Box MG-6, Romania

Several new prompt electromagnetic transitions have been identified in the N=Z nucleus ^{66}As using the Isomer Decay Tagging technique with the Recoil Mass Spectrometer and the Clarion array at ORNL. The observed gamma rays feed a microsecond isomeric state. The strongest cascade observed in this experiment has also been identified in a $p-\gamma\gamma\gamma$ data set from a Gammasphere experiment. No transitions bypassing the isomer were identified. The lifetimes of the two previously known isomeric states in ^{66}As were remeasured.

1. INTRODUCTION - ISOMERS IN ^{66}As

The discovery of two isomers in ^{66}As [1] gave the first insight into the structure of this N=Z odd-odd nucleus. The measurement reported in [1] provided information on excited states in this nucleus involving spin aligned or antialigned proton-neutron configurations: the positions of the low-lying $T = 0$ states with $J^\pi = 5^+$ and 9^+ and also the energy of the first excited $T = 1$, $J^\pi = 2^+$ level, which is the isobaric analog of the $J^\pi = 2^+$ state in ^{66}Ge. The proper theoretical reproduction of the energy levels and transition probablilities in the non-defomed midshell nucleus ^{66}As is a formidable problem for the nuclear shell-model, which must account for not only the nucleons in the *fp*-shell but also

0375-9474/01/$ – see front matter
PII S0375-9474(00)00620-5

in the $g_{9/2}$ orbital. This has been attempted for ^{62}Ga [2] but not for ^{66}As.

In parallel with the further study of the isomeric decay [3] using fusion-evaporation reactions, an effort was undertaken to identify prompt gamma rays above the known isomeric states at 1357 and 3024 keV. This article reports the first successful in-beam study of ^{66}As. It is one of the first results obtained with a new spectroscopic technique - Isomer Decay Tagging (IDT), which will be described here.

2. ISOMER DECAY TAGGING EXPERIMENT

The present experiment was performed at Oak Ridge National Laboratory (ORNL) using the Recoil Mass Spectrometer (RMS) [4] and a ^{28}Si beam accelerated in the electrostatic tandem to an energy of 85.3 MeV. This beam impinged on a 1 mg/cm^2 ^{40}Ca target sandwiched between two thin gold foils (500μg and 200μg, respectively). Up to 9.5 pnA of ^{28}Si beam was used. The ions and prompt radiation of ^{66}As were identified with the IDT technique - a variation of the well established RDT (Recoil Decay Tagging) technique [5] which uses the characteristic particle (proton, alpha) decay of the nucleus to identify in-beam gamma radiation. The IDT technique uses the gamma radiation from the decay of isomeric states detected after mass separation to tag the radiation emitted near the production target. A variation of this method has been applied by Cullen *et al.* [6] to identify rotational bands in ^{138}Gd in conjunction with the gas-filled RITU recoil separator.

Fig. 1 shows the apparatus utilized in this experiment. For detection of the prompt radiation the HRIBF Clarion array was used. The Clarion photopeak efficiency was about 2% at 1.3 MeV and 12% at 122 keV. The isomer detection station at the final focus of the RMS consisted of a germanium clover detector placed inside a BGO detector. An active ion catcher, a square silicon detector, was placed inside the BGO very close to the front of the clover detector. In this geometry the BGO+Clover setup covers a solid

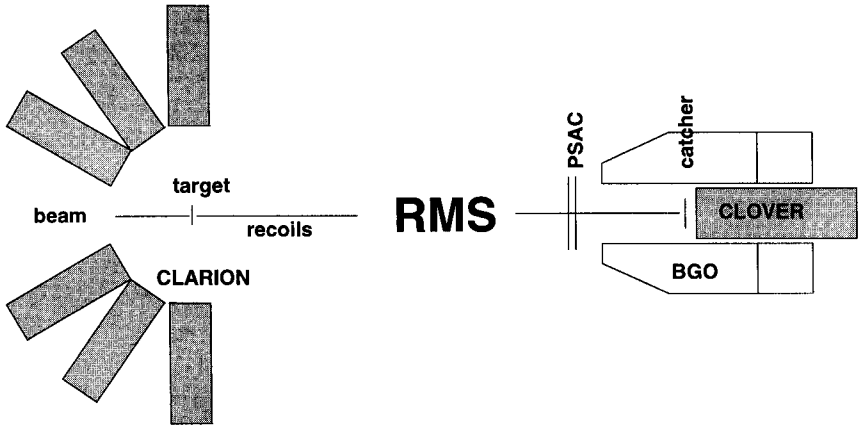

Figure 1. Experimental setup used in the experiment.

angle of nearly 4π for the detection of the isomeric γ radiation. The RMS was tuned to transmit recoils with mass number A=66, energy 19.84 MeV and charge state 13^+. This charge state was found experimentally to provide the best RMS transmission efficiency and least contribution of lighter recoils with similar A/q values. A Position Sensitive Avalanche Counter (PSAC) was placed in the mass dispersive plane, about 1 m upstream from the ion catcher. Vertical slits were placed in front of the PSAC in order to block the unwanted ions with mass numbers other than A=66. The slits proved crucial for the purity of the gamma tagging, by eliminating unwanted ions which would contaminate the gamma tagging system. The time signal from the PSAC opened a time gate of 32 μs in which isomeric decay radiation was recorded. Each ion arriving at the final focus and detected by the PSAC, caused the conversion of signals detected in the final focus detector for about 32 μs after ion arrival. The PSAC signal was also correlated within a window of 250 ns with the delayed timing signals of prompt gamma radiation originating from the Clarion array at the target position.

There are two isomeric states in ^{66}As known from the fragmentation type experiment [1]: at 3024 keV, and at 1357 keV (see Fig. 5). Each known decay path of the isomer has a multiplicity of five. The clover efficiency for detecting at least one of the discrete transitions is about 29%, which we assume to be "clean" tagging efficiency. The total clover tagging efficiency was about 67%. The isomer decay spectrum detected in the clover is presented in Fig. 2 (lower part).

The low resolution BGO detector was used to supplement the low efficiency of the clean tagging. All gammas detected in this detector were used for tagging purposes – see Fig. 2 (upper part). The BGO detector provided a very good detection efficiency so that on average two gamma rays were registered for each isomer deexcitation.

The results illustrating the power of tagging are shown in Fig. 3. Nine different gamma lines which feed the upper isomer were identified in the present experiment. Part a) of Fig. 3 shows the prompt gammas recorded in delayed coincidence with recoils detected in the PSAC. It is essentially that the ^{66}Ge spectrum is [7,8]. When the requirement of a delayed gamma detected within 30 μs in final focus BGO is imposed on the prompt-data, spectrum 3b) is generated where several new lines appear with intensity equal to the ^{66}Ge lines. These are lines in ^{66}As deexciting the states above the upper isomer. The appearance of ^{66}Ge in-beam lines is due to the random correlation of the BGO-detected background lines with mass gated prompt radiation. The same delayed gating done with the final focus clover produces spectrum 3c) which shows much less contribution from ^{66}Ge, because this detector is better shielded from background radiation. Gating on discrete ^{66m}As levels 3d) eliminates the unwanted ^{66}Ge background almost completely.

The spectrum presented in Fig. 4 shows the sum of 3b) and 3c) with a properly renormalized mass gated spectrum 3a) subtracted. The newly identified gamma lines are labeled. We observe that the 1207 keV peak is broader than the neighboring lines at 1131 keV and 1262 keV. This line detected in the 90 degree detector is broader and shifted as compared to the same line observed in the 131 and 154 degree detectors. Such an angular dependence effect can be produced e.g. if there is a closely spaced doublet of E2 and E1/M1 lines near 1207 keV.

Multipolarities of the strongest transitions were measured using angular assymetries. They indicate that the lines 722, 840, 894, 1262 and 1461 keV are of quadrupole type. The

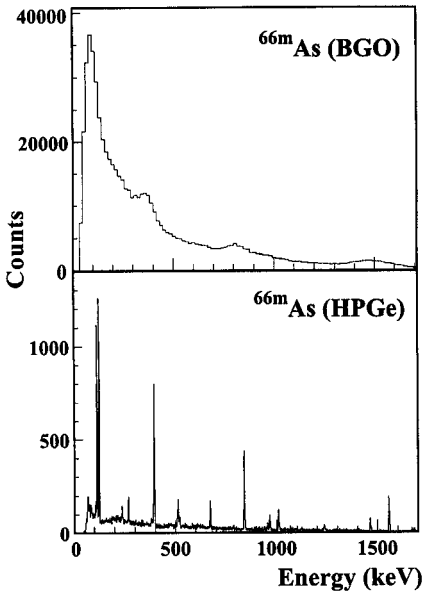

Figure 2. Gamma radiation detected at the final focus of the RMS.

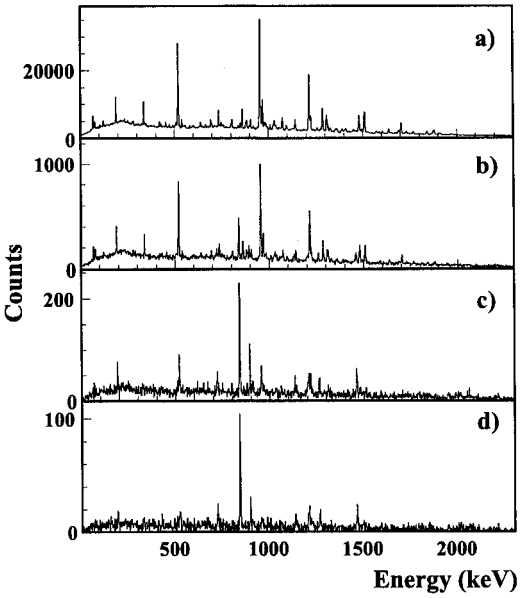

Figure 3. Gamma radiation detected with the Clarion array gated by a) PSAC, b) PSAC-BGO, c) PSAC-clover, and d) PSAC-clover on discrete isomeric transitions.

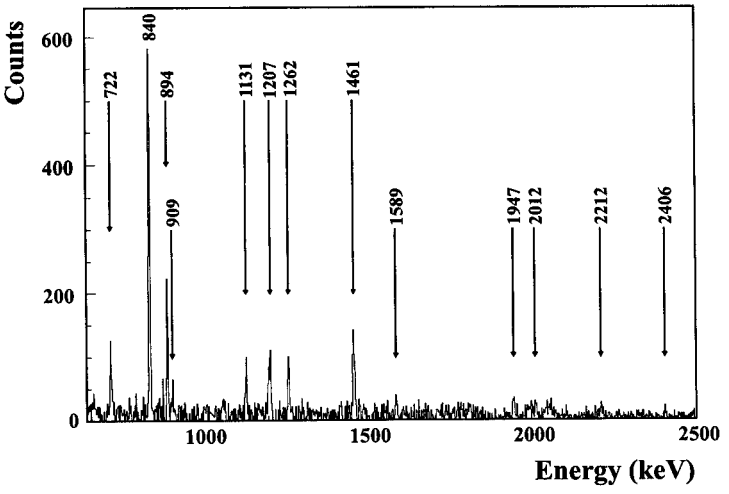

Figure 4. The isomer gated spectrum after subtracting the randomly correlated ^{66}Ge lines.

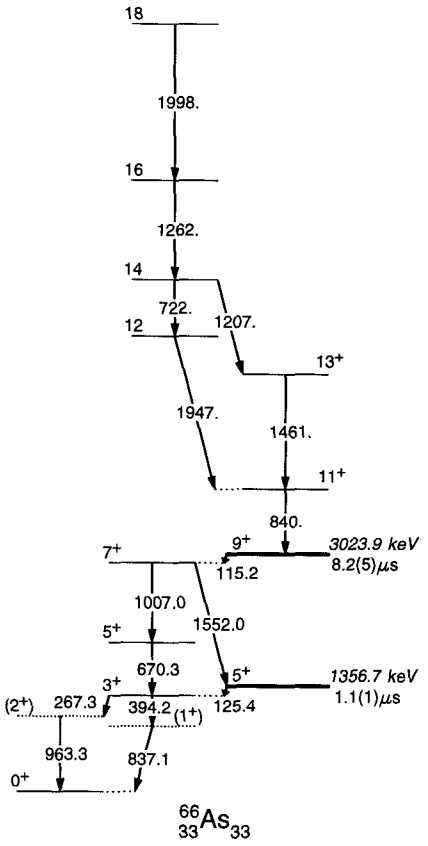

Figure 5. Level scheme of ^{66}As showing the new states above the 8.2 μs isomer reported here. All spins and parities are tentative.

1207 and 1131 keV lines show distributions characteristic of a dipole, but a quadrupole assignment cannot be excluded.

The experimental results allow us to propose the extension of the ^{66}As level scheme as shown in Fig. 5. All transitions observed in this experiment were placed above the 3024 keV isomer. We were not sensitive to isomeric levels with lifetimes between 1 ns and 100 ns in this and in the fragmentation experiment [1]. Having the knowledge of the gamma energies observed and unambigously identified in the IDT experiment we also examined the data obtained from a Gammasphere experiment at Argonne National Laboratory. This experiment was performed with ^{32}S at 140 MeV beam on 0.4 mg/cm^2 thick ^{40}Ca target. The Microball particle detector was used to select channels involving proton or alpha emission. In the Gammasphere $p - \gamma\gamma\gamma$ coincidences data we have found some of the transitions observed in the IDT spectra.

3. RESULTS AND INTERPRETATION

Based on combined Clarion and Gammasphere coincidence data we were able to build 1998-1262-1207-1461-840 keV and 1998-1262-722-1947-840 keV cascades. We could not place the 894 transition which was observed very strongly in almost all Gammasphere gates, but not in coincidence with 1207 keV line. Some transitions, like the relatively strong 1133 and 1589 keV and the weaker 909-, 2012-, 2212-, and 2406-keV were not found in the Gammasphere data.

In this experiment we have remeasured some of the isomeric properties known from the previously published data [1]. We found that the isomeric lifetimes are not $T_{1/2}$=17 μs and $T_{1/2}$=1.9 μs but $T_{1/2}$=8.2(5) μs and $T_{1/2}$=1.1(1) μs for the upper and lower isomeric levels, respectively. These discrepancies can be very likely explained by a calibration and data evaluation mistake in the data of Ref. [1].

The proposed decay scheme has a sparse number of transtions with energies of about 1 MeV and higher, not unlike ^{64}Ge [9], ^{68}S [10] the even-even neighbors of ^{66}As at low excitation energies. We could not identify transitions which would link the states above the isomer with those below in the Gammasphere data. This observation indicates that the isomer at 3024 keV has to be high-spin ($J > 7$), and is a waiting point for each decay path near the yrast line. We did not observe the bypassing 2787 keV transition which suggests that the spin of the 5811 keV level must be at least three units larger then the spin of the isomer. Assuming the E1/M1 character of the 1207 keV and E2 for other transitions we can tentatively assign the spins to the states above the isomer to be as shown on fig. 5.

Based on the IBFFM formalism developed in [11,12] we attempted to reproduce high-spin properties of ^{66}As. So far, we could reproduce fairly well the positions of the 5^+ and 9^+ isomeric levels, with the composition of the wave functions as suggested in Ref. [1]. The calculated high-spin yrast levels above the isomer have a simple structure with 9^+ proton-neutron spin aligned pair coupled to multiple boson excitations with spins 2^+, 4^+, 6^+. The level spacing is about 1 MeV - as observed experimentally. The results of these calculations, which attempt to interpret the experimental data on odd-odd systems ^{62}Ga, ^{66}As and ^{70}Br will be published separately [13].

4. SUMMARY

In summary, we have identified several new levels in the N=Z nucleus ^{66}As feeding the 3024-keV microsecond isomeric state. The observed transitions are strikingly similar to those between low lying yrast levels in the neighboring even-even nuclei. We have remeasured the isomeric lifetimes finding that they are shorter than previously reported.

Nuclear physics research at the University of Tennessee is supported by the U. S. Department of Energy through Contract No. DE-FG02-96ER40983. ZJ was partially supported by the Polish Committee for Scientific Research KBN, contract KBN 2 PO3B 086 17.

REFERENCES

1. R. Grzywacz *et al.*, Phys. Lett. B429 (1998) 247
2. S. Vincent *et al.*, Phys. Lett. B437 (1998) 264
3. A. Piechaczek *et al.* Contribution to the conference Perspectives in Nuclear Physics, edt. J.H. Hamilton, World Scientific (1998) p. 201
4. C.J. Gross *et al.*, NIM A450 (2000) 12
5. R.S. Simon *et al.*, Z. Phys. A325 (1986) 197 and E.S. Paul *et al.*, Phys. Rev. C51 (1995) 78
6. D.M. Cullen *et al.*, Phys. Rev. C58 (1998) 58
7. U. Hermkens *et al.*, Z. Phys. A343 (1992) 371
8. M.R. Bhat NDS 83 (1998) 789
9. P.J. Ennis *et al.* Nucl. Phys. A535 (1991) 392
10. S. Skoda *et al.* Phys. Rev. C58 (1998) R5
11. V. Paar *et al.* Z. Phys. A327 (1987) 291
12. S. Brant *et al.* Z. Phys. A319 (1984) 355
13. E. Dragulescu, to be published