Title
Level Structure of {sup 73}Kr

Authors
Moltz, Dennis M.
Robertson, J.D.
Norman, E.B.
et al.

Publication Date
1989-11-28

LBL-28098
Preprint

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

Submitted to Physical Review C

Level Structure of ^{73}Kr

D.M. Moltz, J.D. Robertson, E.B. Norman, J. Burde, and C.W. Beausang

November 1989

NUCLEAR SCIENCE DIVISION

Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098.

DISCLAIMER

LBL - 28098

D.M. Moltz, J.D. Robertson*, E.B. Norman, J. Burde†, and C.W. Beausang

Nuclear Science Division, Lawrence Berkeley Laboratory,
University of California
Berkeley, California 94720, USA

Level Structure of ^{73}Kr

November 1989

This work was supported by the Director, Office of Energy Research, Division of Nuclear Physics of the Office of High Energy and Nuclear Physics of the U.S. Department of Energy under Contract DE-AC03-76SF00098

Level Structure of ^{73}Kr

D.M. Moltz, J.D. Robertson*, E.B. Norman, J. Burde†, and C. W. Beausang

Nuclear Science Division

Lawrence Berkeley Laboratory

University of California

Berkeley, CA 94720

We have used the ^{40}Ca(^{36}Ar, 2pn) reaction to study the previously unknown low-lying structure of ^{73}Kr. By utilizing a bombarding energy at the Coulomb barrier, the relative cross section for this channel was enhanced to a few percent of the total reaction cross section. Levels in ^{73}Kr were assigned based primarily upon observed neutron-gamma-gamma coincidences and upon comparisons of these newly assigned transition cross sections with those from known nuclei.

The neutron deficient nuclei between the $1f_{7/2}$ and $1g_{9/2}$ shells have become the focus of much study in recent years. Although experimental studies have been hampered by the low production cross sections of nuclei near the proton drip line, the existence [1,2] of an island of very deformed nuclei ($|\beta_2| > .3$) has created a number of possibilities for studying the effects of nuclear shape changes. Systematics for many traditional nuclear structure quantities have now been determined as a function of the shape changes within chains of isotopes and isotones. How these changes affect a very fundamental quantity in nuclear physics, the atomic mass, is not at all delineated, however. Although the paucity of reliable mass measurements in this region has contributed toward this knowledge gap, sorting out various known effects (e.g., the Wigner energy, volume energies, isospin effects, etc.) is not always straightforward. Two sets of studies have been performed in an attempt to obtain systematic mass measurements in this region. Originally, masses of all beta-stable, neutron-deficient rubidium isotopes were measured[3] using a direct mass measurement technique. Subsequent measurements[4] attempted to derive masses (based upon these prior results) for several of the krypton isotopes by measuring the beta endpoints of the corresponding rubidium isotope. A reevaluation of the original direct mass measurements[5], however, required the utilization of direct transfer reactions to measure the masses of $^{74-77}$Kr[6,7] because of revised uncertainties in the final values. Unfortunately, all of these measurements have tended to suggest additional puzzles rather than yield a coherent set of answers. For instance, many formulae tend to correctly predict the masses of even-Z nuclei like Kr but seriously mispredict those of several odd-Z Rb nuclei (e.g., ^{76}Rb is much more stable than any prediction[4]).

The macroscopic-microscopic model of Möller and Nix[1] seems to give the best overall results for deformed nuclei in the $N \approx Z \approx 40$ region. One could attribute this to the inclusion of shape dependences in the model. Checking this shape inclusion solely by examination of the mass surface is made difficult because the masses of all nuclei measured to date have either spherical or prolate ground states. Thus, to further check this and later mass models which include shapes (e.g., ref. 8), it is important to measure the mass of a nuclide with an oblate ground state. Earlier predictions[9,10] suggested that Kr nuclei with A<74 could be excellent candidates for oblate ground states. Therefore, we decided to search for the totally unknown low-lying level structure in ^{73}Kr. Ideally one could use beta decay into the proposed nucleus for both the shape and mass measurements. Unfortunately, ^{73}Rb is proton unbound. Thus, we decided to divide the experiment into an in-beam gamma-ray study of ^{73}Kr and a beta-endpoint determination of the mass difference between ^{73}Kr and ^{73}Br. In this paper we report results of the former.

It was decided to utilize the cold fusion technique[11] used in the study of ^{77}Sr. By producing a compound nucleus just at the Coulomb barrier in a symmetrical nuclear reaction, one can limit the product channels to those with 2–3 evaporated particles. We chose to study products of the ^{36}Ar + ^{40}Ca (4 mg/cm^2 target) reaction with the HERA array[12] at the Lawrence Berkeley Laboratory 88-Inch Cyclotron. Prior to this measurement we performed a series of excitation function measurements[13] to identify a few major transitions in ^{73}Kr. Subsequently, a preliminary measurement[14] by another group showed that our primary assignments were indeed in mass 73. In the present experiment the 0° gamma ray detector of HERA was replaced with a small neutron detector, permitting collection of n-γ-γ events in addition to the standard γ-γ coincidences with the remaining twenty Compton suppressed germanium detectors. The total projections of the γ-γ and n-γ-γ matrices obtained are shown in Figs. 1a and 1b, respectively.

The 95 MeV ^{36}Ar bombarding energy was chosen to eliminate essentially all four-particle evaporation channels. This nuclear reaction, in conjunction with the neutron gate, almost solely selects the desired 2pn evaporation channel (two-particle-out channels are severely reduced at this energy) because the p2n channel leads to the unbound nucleus ^{73}Rb and the 3n channel (^{73}Sr) is at least two orders of magnitude down in cross section. The α,n evaporation channel (^{71}Kr) should be produced in lower yield at this energy (x 1/20) and has not been directly identified. The efficacy of this neutron gating technique can be seen in Fig. 1 by the strong presence of ^{49}Cr produced in the ^{16}O (^{36}Ar, 2pn) reaction (oxygen is an omnipresent contaminant of calcium targets).

The strong transitions in Fig. 1 which belong to ^{73}Br have been used to corroborate the evidence reported in ref. 15. Principal transitions labelled in Fig. 1 which do not belong to ^{73}Br or which we assign to ^{73}Kr are taken from various references and are listed in Table 1. Table 1 additionally gives the ALICE[16] prediction for the production cross sections (limited to $\sigma \geq 1$mb) and the percentage of events in the neutron-gated spectrum (ratio of net n-γ-γ/γ-γ events). This last criterion is extremely sensitive to the numbers of neutrons (if any) emitted and to the kinematic focusing in the ^{36}Ar + ^{16}O reaction. Using all of this information permitted the identification of several transitions which we attribute to ^{73}Kr. Figure 2 shows a typical coincidence projection from the n-γ-γ matrix for a transition assigned to ^{73}Kr. Subsequent generation of coincidence intensities from this n-γ-γ matrix at 95 MeV were utilized in constructing the preliminary decay scheme shown in Fig. 2. The first two more strongly populated sequences are well-defined. However, due to the low intensities of its transitions, we cannot decide for sure that sequences 3 and 4 are even in ^{73}Kr; their crude excitation functions are also not inconsistent with that of the αn channel (^{71}Kr). In addition, because of the lack of connecting transitions between the sequences, we do not know their relative positions. It is not, however, unreasonable to suggest that the two states at 1003 keV could indeed be the same state. The proposed spins for band 1 in Fig. 2 are entirely based upon the E = (A) (J) (J + 1) rule. Although many other transitions have been identified which may belong to ^{73}Kr, inconsistencies between the n-γ-γ and the hundred-fold greater data in the γ-γ spectra make it difficult to place them.

Results for the six lines seen at the Rochester RMS[14] are in general agreement with our observations (statistics in their measurement were insufficient for coincidence work). Two notable exceptions exist for lines at 455 and 87 keV. Neither gamma ray is strongly coincident with any transition assigned to ^{73}Kr or ^{73}Br; the former is also extraordinarily close in energy to the main transition in ^{74}Kr and exhibits no enhancement in the neutron-gated spectrum, while the latter transition does exhibit a minor neutron-gate enhancement but in our spectrum is primarily attributed to ^{47}V from the ^{16}O(^{36}Ar, αp) reaction.

Prior predictions[9,10] have shown that ^{72}Kr should be the first even Kr isotope to exhibit strong oblate deformation. Since ^{76}Kr and ^{74}Kr both have prolate ground states[25] and exhibit shape coexistence with nearly spherical bands, results of studies of the odd-neutron nuclei ^{77}Kr and ^{75}Kr may not extrapolate correctly to ^{73}Kr. A later prediction by Leander[26] suggested that ^{73}Kr would also have an oblate ground state. Unfortunately, we feel that Leander's unpublished results must be independently verified before conclusions can be drawn from our data. Additionally, our results for ^{73}Kr look similar to those for ^{75}Kr [27]; ^{75}Kr is prolate. It is hoped that these results near the proton drip line will initiate theoretical interest in solving this important shape dependence question.

We wish to thank the staff of the 88-Inch Cyclotron for the excellent ^{36}Ar beams and to J. Äystö and M. Hotchkis for initial help in the excitation function work. We especially wish to thank R.M. Diamond, M.A. Deleplanque and F.S. Stephens for help on the experiment and for critically reading this paper.

Table 1. Nuclides produced in ^{36}Ar + ^{40}Ca, ^{16}O reactions at E_{Ar} = 95 MeV

Nuclide	Production Channel	Relative[a)] σ	Principal Transition(s) (keV)	Percentage[b)] of Main Peaks in Neutron Gate	Reference
^{73}Kr	2pn	8	This study	0.75–0.85	This study
^{73}Br	3p	40	177,188	0.15–0.25	15
^{74}Kr	2p	2	456	~0.2	17
^{72}Se	4p	17	862	~0.2	18
^{72}Br	3pn	<1(3.5@100MeV)	654,583	~0.8	19, 23
^{71}Br	αp	1		—	—
^{70}Se	α2p	10	945	~0.2	20
^{49}Cr	2pn	132	272, 8.3	~1.3	21
^{50}Cr	2p	335	783, 1098	~0.2	22
^{49}V	3p	43	102	~0.2	21
^{47}V	αp	70	87.5, 58.2, 260	~0.2	24

a)From the statistical compound nucleus evaporation code ALICE.[16]

b)Ratio of n-γ-γ/γ-γ events. See text.

Figure Captions

Fig. 1. Composite sum of 20 Compton suppressed Ge detectors with the following gating criteria: a) any gamma with any gamma; b) a) plus any neutron for 1) ^{73}Kr, 2) ^{73}Br, 3) ^{74}Kr, 4) ^{72}Se, 5) ^{72}Br, 6) ^{70}Se, 7) ^{49}Cr, 8) ^{50}Cr, 9) ^{49}V, 10) ^{47}V.

Fig. 2. Coincidence spectrum projection from the n-γ-γ matrix for the 128.6 keV transition assigned to ^{73}Kr.

Fig. 3. Proposed partial level structure for ^{73}Kr.

References

*Present Address: Department of Chemistry, University of Kentucky, Lexington, KY 40506
†Permanent Address: The Racah Institute of Physics, The Hebrew University of Jerusalem, Israel

[1]P. Möller and J.R. Nix, Nucl. Phys. A361, 117 (1981).

[2]J.Eberth et al., Proc. of the Fifth Int. Conf. on Nuclei Far From Stability, Rossea Lake, Canada, AIP Conf. Proc. 164, 268 (1988).

[3]M. Epherre, G. Audi, C. Thibault, R. Klapisch, G. Huber, F. Touchard, and H. Wollnik, Phys. Rev. C 19, 1504 (1979).

[4]D.M. Moltz, K.S. Toth, F.T. Avignone III, H. Noma, B.G. Ritchie, and B.D. Kern, Phys. Lett. 113B, 16 (1982).

[5]G. Audi, M. Epherre, C. Thibault, A.H. Wapstra, and K. Bos, Nucl. Phys. A378, 443 (1982).

[6]D.M. Moltz, K.S. Toth, R.E. Tribble, R.E. Neese, and J.P. Sullivan, Phys. Rev. C 26, 1914 (1982).

[7]D.M. Moltz, A.C. Betker, J.P. Sullivan, R.H. Burch, C.A. Gagliardi, R.E. Tribble, K.S. Toth, and F.T. Avignone III, Phys. Rev. C 35, 1275 (1987).

[8]P. Möller, W.D. Myers, W.J. Swiatecki, and J. Treiner, Proc. of the 7th Int. Conf. on Atomic Masses and Fundamental Constants (AMCO-7), Darmstadt-Seeheim, West Germany, 457 (1984).

[9]W. Nazarewicz, J. Dudek, R. Bengtsson, T. Bengtsson, and I. Ragnarsson, Nucl. Phys. A435, 397 (1985).

[10]I. Ragnarsson and R.K. Sheline, Phys. Scripta 29, 385 (1984)..

[11]C.J. Lister, B.J. Varley, H.G. Price, and J.W. Olness, Phys. Rev. Lett. 49, 308 (1982).

[12]R.M. Diamond, in "Nuclei Off the Line of Stability", R.A.Meyer and D.S.Brenner, eds., ACS Symposia Series 324, American Chemical Society, Washington, D.C. (1986) p. 341.

[13]D.M. Moltz, E.B. Norman, M. Hotchkis, and J. Äystö, Bull. Am. Phys. Soc. 30, 1257 (1985).

[14]M. Satteson, J. Boyle, T.M. Cornier, E. Dafni, A.V. Ramayya, and C.Y. Wu, University of Rochester Nuclear Structure Research Laboratory Annual Report, 78 (1987).

[15]J. Heese, K.P. Lieb, L. Lühmann, S. Ulbig, B. Wörmann, D. Alber, H. Grawe, H. Haas, and B. Spellmeyer, Phys. Rev. C 36, 2409 (1987).

[16]M. Blann and J. Birplinghoff, Lawrence Livermore National Laboratory, Report UCID-19614 (1976).

[17]J.H. Hamilton, et al., Proc. of the 4th Int. Conf. on Nuclei Far From Stability, Helsingør, Denmark, 391 (1981).

[18]H.P. Hellmeister, E. Schmidt, M. Uhrmacher, R. Rascher, K.P. Lieb, and D. Pantelica, Phys. Rev. C 17, 2113 (1978).

[19]G. Garcia Bermudez, C. Baktash, A.J. Kreiner, and M.A.J. Maricotti, Phys. Rev. C 25, 1396 (1982).

[20]A. Ahmed et al., Phys. Rev. C 24, 1486 (1981).

[21]L.R. Medsker, L.H. Fry, Jr., and D.C. Wilson, Phys. Rev. C 18, 2584 (1978).

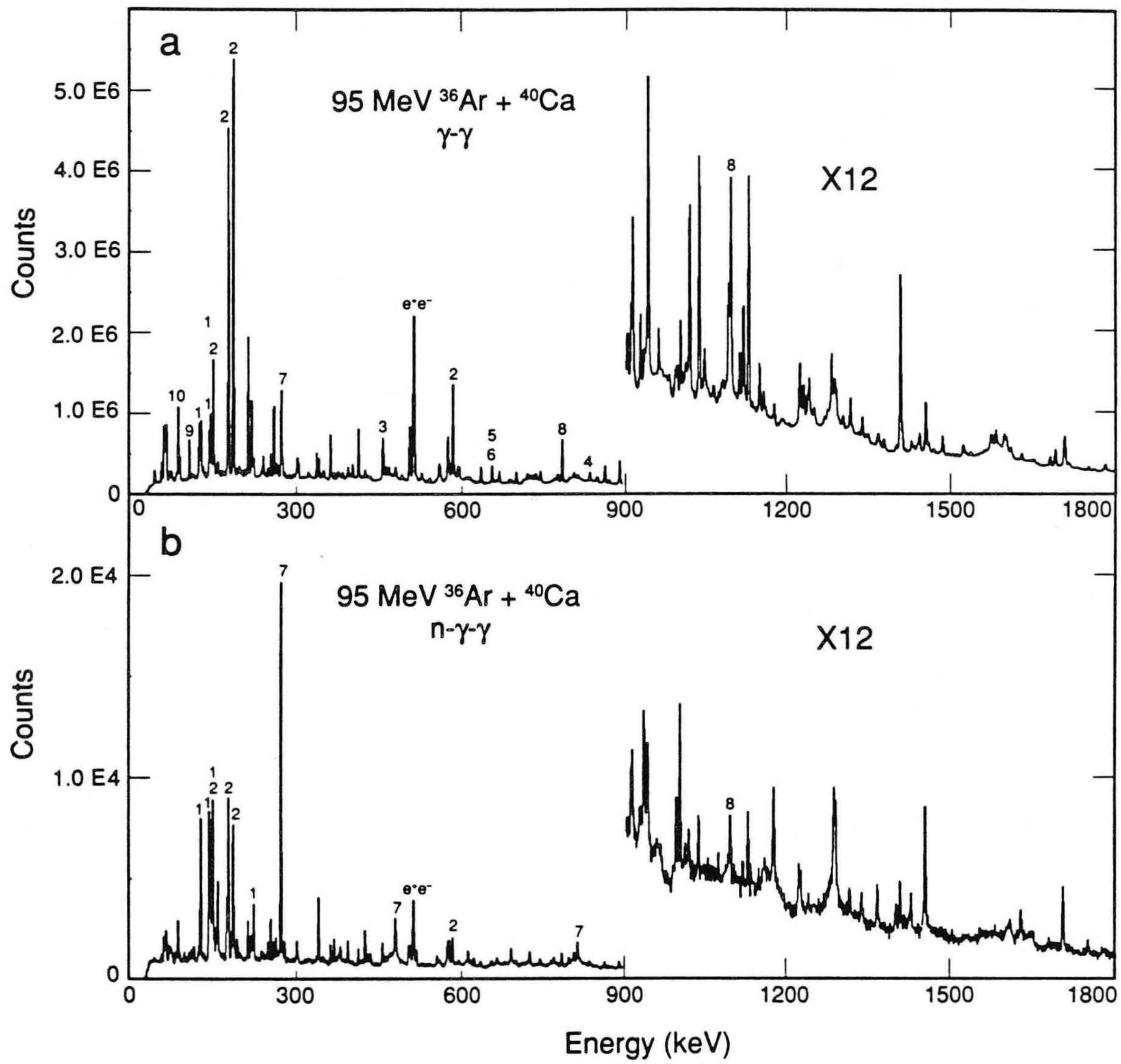
[22]W. Dehnhardt, O.C. Kistner, W. Kutshera, and H.J. Sunn, Phys. Rev. C 7, 1471 (1973).

[23]S. Ulbig, et al., Z Phys. A 329, 51 (1988).

[24]M. Schrader, K. Buccholz, and H.V. Klapdor, Nucl. Phys. A213, 173 (1973).

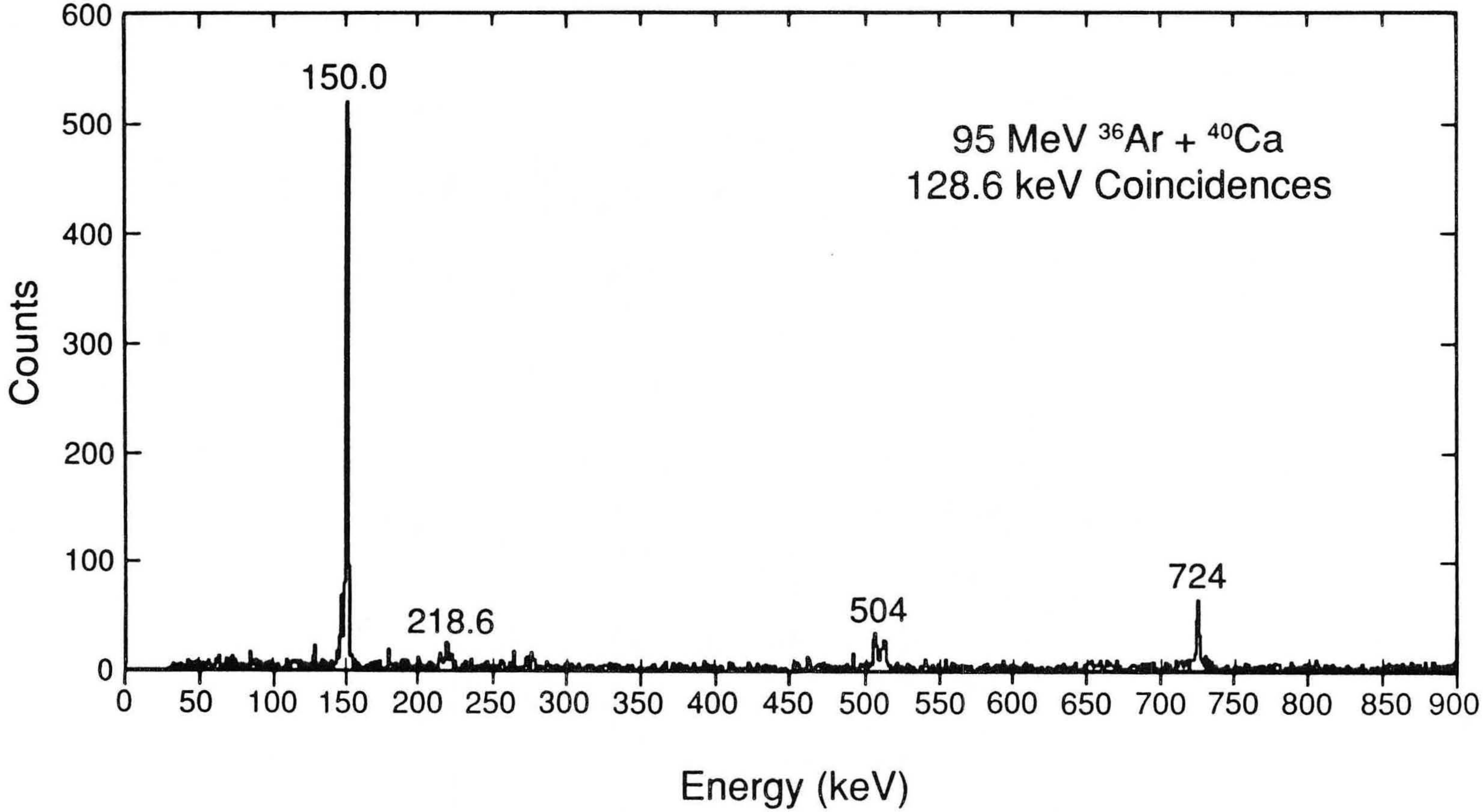
[25]R.B. Piercey, et al., Phys. Rev. Lett. 47, 1514 (1981).

[26]G. Leander, private communication.

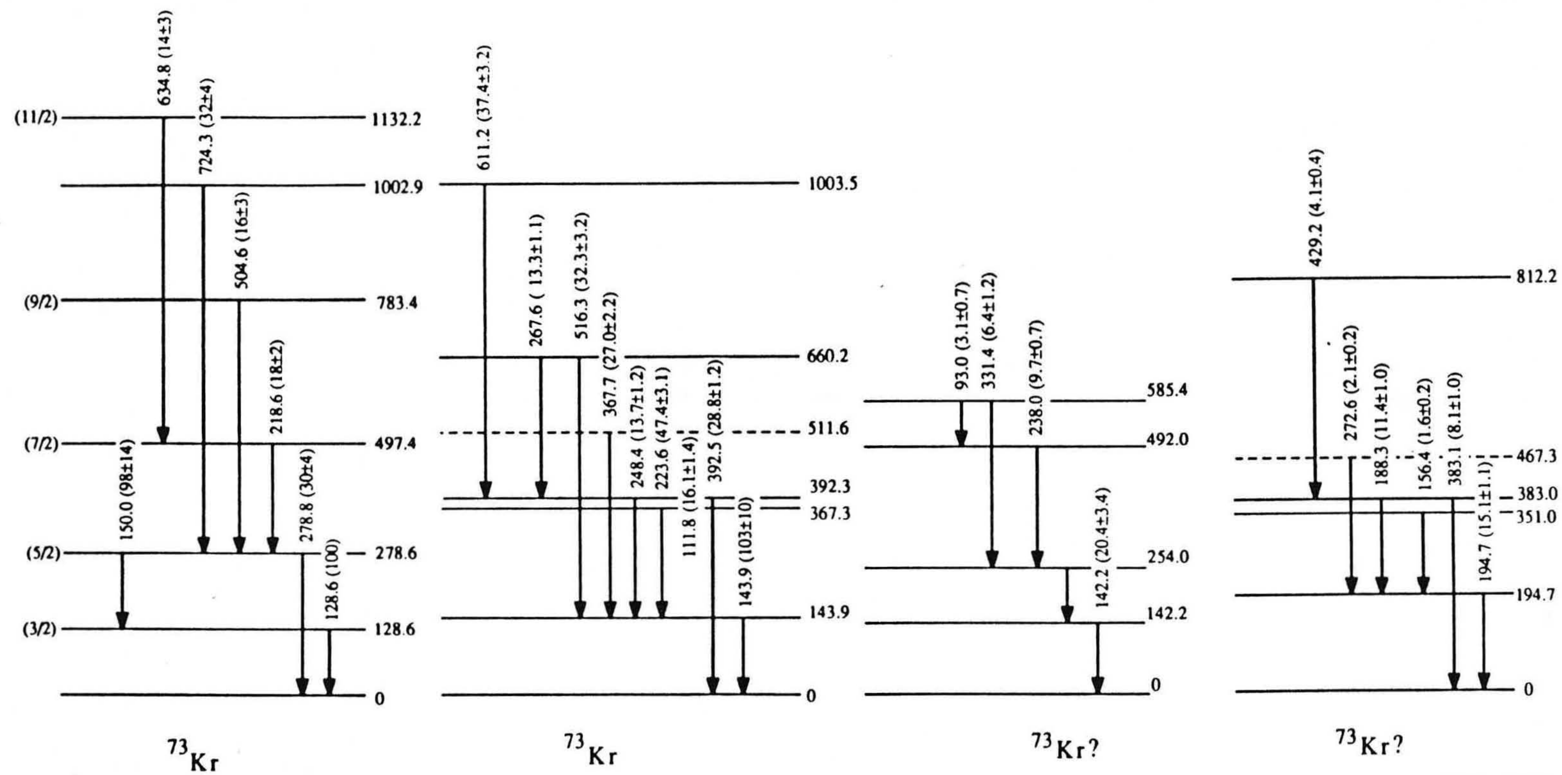


a
95 MeV ^{36}Ar + ^{40}Ca
γ-γ
X12
Counts
5.0 E6
4.0 E6
3.0 E6
2.0 E6
1.0 E6
0
e+e-
b
95 MeV ^{36}Ar + ^{40}Ca
n-γ-γ
X12
Counts
2.0 E4
1.0 E4
0
0
300
600
900
1200
1500
1800
Energy (keV)

XBL 898-6971



XBL 8911-7324



XBL 8911-4330

LAWRENCE BERKELEY LABORATORY
TECHNICAL INFORMATION DEPARTMENT
1 CYCLOTRON ROAD
BERKELEY, CALIFORNIA 94720