

Lawrence Berkeley National Laboratory

Recent Work

Title

DECAY OF A NEW ISOTOPE, Si: A TEST OF THE ISOBARIC MULTIPLY MASS EQUATION

Permalink

<https://escholarship.org/uc/item/86120440>

Author

Aysto, J.

Publication Date

1978-12-01

Submitted to Physics Letters

LBL-8578
Preprint

RECEIVED
LAWRENCE
BERKELEY LABORATORY

JAN 19 1979

LIBRARY AND
DOCUMENTS SECTION

DECAY OF A NEW ISOTOPE, ^{24}Si :
A TEST OF THE ISOBARIC MULTIPLY MASS EQUATION.

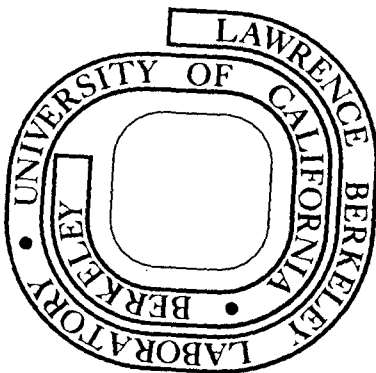
J. Äystö, D. M. Moltz, M. D. Cable, R. D. von Dincklage,
R. F. Parry, J. M. Wouters and Joseph Cerny

December 1978

Prepared for the U. S. Department of Energy
under Contract W-7405-ENG-48

TWO-WEEK LOAN COPY

This is a Library Circulating Copy
which may be borrowed for two weeks.
For a personal retention copy, call
Tech. Info. Division, Ext. 6782



LBL-8578-18
e

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

DECAY OF A NEW ISOTOPE, ^{24}Si :

A TEST OF THE ISOBARIC MULTIPLY MASS EQUATION.*

J. Aystö[†], D. M. Moltz, M. D. Cable, R. D. von Dincklage[‡],
R. F. Parry, J. M. Wouters and Joseph Cerny

Department of Chemistry and
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

ABSTRACT

Observation of beta-delayed protons from the decay of the mass separated $T_z = -2$ nuclide ^{24}Si ($t_{1/2} \sim 100$ ms) establishes the mass excess of the lowest $T = 2$ (0^+) state in ^{24}Al (5.903 ± 0.009 MeV). An excellent fit to the quadratic form of the isobaric multiplet mass equation is obtained.

* This work was supported by the Nuclear Physics and Nuclear Sciences Divisions of the Department of Energy.

[†] On leave from: University of Jyväskylä, Finland.

[‡] On leave from: University of Göttingen, West Germany.

Recent developments in nuclear instrumentation techniques have made possible the detection of exotic light nuclei up to the proton drip line. Such measurements have also led to the completion of the mass 8 and 20 isospin quintets [1,2] as well as to the observation of four members of the mass 32 and 36 quintets [3,4], thereby extending the tests of the isobaric multiplet mass equation (IMME) beyond the very well-studied isospin quartets [5]. The masses of analog states of an isospin multiplet are given in first order by the IMME as:

$$M(A,T,T_z) = a(A,T) + b(A,T) \cdot T_z + c(A,T) \cdot T_z^2,$$

where the coefficients a, b and c are related to diagonal reduced matrix elements of the charge dependent part of the Hamiltonian.

Although this quadratic form of the IMME fits the vast majority of the data on known isospin quartets, a persistent deviation has been reported in the mass 9 quartet. In addition, the mass 8 isospin quintet also shows a deviation from the simple IMME, so that tests at higher masses have become imperative to establish comparable systematics for quintets. Such deviations from the quadratic form are generally represented by additional terms $d(A,T) \cdot T_z^3$ and $e(A,T) \cdot T_z^4$, in which the d and e coefficients can be derived from second order perturbation theory. Deviations from the quadratic form in cases of the A = 9 quartet and the A = 8 quintet have been explained as resulting from an expansion of the radial wavefunctions due to strong Coulomb repulsion as well as to isospin mixing [1,5].

Since, in general, the most experimentally inaccessible mass in the $A = 4n$ isospin quintets is that of the 0^+ , $T = 2$ state in the $T_z = -1$ nuclide, we have initiated a program to characterize these states by observing the beta-delayed proton decay of the mass-separated $T_z = -2$ nuclei [2]. Mass analysis is of critical importance due to the presence of other, copiously produced, strong delayed particle emitters; it is accomplished with a helium-jet fed, on-line mass separator system, RAMA, described in ref. 6. In particular, we wish herein to report the observation of the decay of ^{24}Si (whose accurate mass has not yet been determined). The lowest $T = 2$ state in ^{24}Al is expected to be fed via a pure Fermi (superallowed) transition from the ground state of ^{24}Si . Accurate measurement of the energy of the subsequent isospin-forbidden proton decay from this ^{24}Al state yields a precise value for its mass. Inasmuch as all members of the mass 24 multiplet are bound to isospin-allowed particle decays, an exacting test of the isobaric multiplet mass equation using four members of the mass 24 quintet is now possible.

Beams of 70 MeV ^3He ions of intensity 3-5 μA from the Lawrence Berkeley Laboratory 88-inch cyclotron were used to produce ^{24}Si nuclei via the $^{24}\text{Mg}(^3\text{He}, 3n)$ reaction. A special target system, consisting of three 1.2 mg/cm² Mg targets, was constructed to optimize the yield of the low cross section and short-lived ^{24}Si . Reaction products, recoiling from each target and stopping in 1.3 atm of helium, were collected by four adjacent capillaries spaced evenly over a distance of the maximum recoil range ($\sim 3\text{cm}$). This 12-unit multiple capillary system fed a single 6 m stainless steel capillary (1.27 mm i.d.), which transported activity to the skimmer-ion source region. The average total transport time was approximately 250 ms. Ethylene glycol was employed as an additive in the helium to build up high molecular weight aerosols; nuclides attached to these aerosols possess

excellent transport and skimming properties. After skimming, the reaction products were ionized in a hollow cathode ion source operated at about 1800 °C. Ionized species were subsequently extracted and accelerated to 18 keV for magnetic mass separation. Total efficiency of the system (target to focal plane) for Si was about 0.01%.

The detection system for delayed protons on the focal plane of the separator consisted of a counter telescope subtending a solid angle of $\sim 30\%$ of 4π sr. This telescope consisted of a $42 \mu\text{m}$ ΔE detector and a $300 \mu\text{m}$ E detector, each 1.5 cm in diameter. Mass separated ion beams of interest were implanted on a $50 \mu\text{g}/\text{cm}^2$ carbon foil placed just before the ΔE counter. Given this high detection geometry and the large area detectors, a decreasing detection efficiency is obtained with decreasing proton energy; the minimum observable energy was approximately 1.5 MeV.

Having $J^\pi = 0^+$ and $T = 2$, ^{24}Si is expected to undergo superallowed β^+ decay to the 0^+ ($T=2$) analog state in ^{24}Al in addition to strong allowed transitions to lower-lying 1^+ states, predicted by shell model calculations [7]. The quadratic IMME prediction and the proton binding energy in ^{24}Al lead one to expect ~ 3.9 MeV laboratory energy for the proton transition from the analog state to the ground state of ^{23}Mg . Calibration of the telescope was accomplished by detecting the well-known beta-delayed proton emitter ^{25}Si [8], produced in much higher yield in the $^{24}\text{Mg}(^3\text{He}, 2n)$ reaction. A proton spectrum arising from the decay of 220 ms ^{25}Si is shown in fig. 1(b); the groups at 4089 ± 2 keV and 5403 ± 2 keV provided convenient calibration points. These calibration energies were derived from the most recent value of the excitation energy of the lowest $T = 3/2$ state in ^{25}Al [9]. Events in the shaded areas in both spectra are due to the simultaneous detection of a proton and its preceding positron in this high geometry telescope.

The proton spectrum arising from the decay of ^{24}Si after bombardment for 560 mC is shown in fig. 1(a). Only one peak is evident in the spectrum; it occurs at a laboratory energy of 3.914 ± 0.009 MeV. Possible lower energy groups arising from positron decay to 1^+ states were not observed, a result partly due to the low detection efficiency of the telescope below 3 MeV. A half-life of 100^{+90}_{-40} ms was estimated for the observed peak by comparing the ^{24}Si focal plane yield to the yields of ^{20}Na ($t_{1/2} = 446$ ms), ^{24}Al (2.07s), ^{24m}Al (129ms) and ^{25}Si (220ms). Relative cross sections for these nuclides were estimated by using the overlaid ALICE code as well as by the relative experimental cross section value for the previously studied $^{20}\text{Mg} - ^{21}\text{Mg}$ case [2]. The weak beta-delayed alpha emitter ^{24}Al [10] also served as a very convenient monitor during the ^{24}Si experiment. It should be noted that the peak attributed to the decay of ^{24}Si can not arise from the possible beta-delayed proton decay of ^{24}Al or ^{24m}Al , since the maximum available proton energies in these latter decays are 2.1 and 2.5 MeV, respectively.

The proposed decay scheme for ^{24}Si is shown in fig. 2, in which the 3.914 MeV proton group [fig. 1(a)] is attributed to the isospin-forbidden proton decay of the lowest 0^+ , T=2 state in ^{24}Al . Since the superallowed transition to this ^{24}Al state has a calculated log ft-value of 3.18, allowed beta decay to other states near this excitation energy of 5.955 MeV would lead to considerably lower intensities in the proton spectrum. Taking the center of mass proton energy together with the ^{23}Mg mass excess [11], one obtains a mass excess of 5.903 ± 0.009 MeV for the 0^+ (T=2) analog state in ^{24}Al . Since the ^{24}Si ground state mass has not yet been measured, a mass excess of 10.750 ± 0.016 MeV was predicted using the quadratic IMME. The decay energy and estimated half-life combined with the calculated log ft-value yield a branching ratio of $7 \pm \frac{6}{4}\%$ for the superallowed beta transition.

Experimental mass values for the four known members of the $A = 24$ isospin quintet are given in Table I [12-15]. These four accurate masses provide a good test of the validity of the quadratic isobaric multiplet mass equation as shown also in Table I. In addition, calculations with a cubic form for this mass equation are presented. Both sets of IMME coefficients show clearly the insignificance of the cubic term. The value of a possible d -coefficient, -0.9 ± 2.5 keV, is consistent with zero, reflecting the absence of higher order charge dependent effects. This result is in good agreement with the results for the other quintets, in which four or more members are known, the only exception being mass 8 as noted earlier. In the mass 8 system nonzero d and e coefficients are obtained, a result attributed to the strong Coulomb repulsion associated with particle unbound members and isospin mixing effects, especially in the $T_z = 0$ member of the quintet. Since isospin quintets with $A = 24, 32$ and 36 now have four members known in each, accurate measurements of the fifth members of these multiplets, although a difficult experimental task, would clearly be of substantial value.

REFERENCES

1. R. G. H. Robertson, W. S. Chien and D. R. Goosman, Phys. Rev. Lett. 34 (1975) 33; R. G. H. Robertson, W. Benenson, E. Kashy and D. Mueller, Phys. Rev. C13 (1976) 1018.
2. D. M. Moltz, J. Äystö, M. D. Cable, R. D. von Dincklage, R. F. Parry, J. M. Wouters and J. Cerny, LBL Report-8372 to be published.
3. E. Hagberg, P. G. Hansen, J. C. Hardy, A. Huck, B. Jonson, S. Mattsson, H. L. Ravn, P. Tidemand-Petersson and G. Walter, Phys. Rev. Lett. 39 (1977) 792.
4. R. E. Tribble, J. D. Cossairt and R. A. Kenefick, Phys. Rev. C15 (1977) 2028.
5. W. Benenson and E. Kashy, to be published in Rev. Mod. Phys. (1979).
6. J. Cerny, D. M. Moltz, H. C. Evans, D. J. Vieira, R. F. Parry, J. M. Wouters, R. A. Gough and M. S. Zisman, Proc. of the Isotope Separator On-Line Workshop ed. by R. E. Chrien, BNL-50847, November, 1977, p. 57.
7. R. G. H. Robertson and B. H. Wildenthal, Phys. Rev. C8 (1973) 241.
8. R. G. Sextro, Ph.D. Thesis, University of California, Berkeley, CA. LBL-2360, 1973.
9. D. W. O. Rogers, N. Anyass-Weiss, S. P. Dolan, N. A. Jelley and T. K. Alexander, Can. J. Phys. 55 (1977) 206.
10. J. Honkanen, M. Kortelahti, J. Äystö, K. Eskola and A. Hautojärvi, to be published in Physics Scripta (1979); P. M. Endt and C. Van der Leun, Nucl. Phys. A214 (1973) 108.
11. A. H. Wapstra and K. Bos, At. Data Nucl. Data Tables 19 (1977) 175.
12. D. F. H. Start, N. A. Jelley, J. Burde, D. A. Hutcheon, W. L. Randolph, B. Y. Underwood, and R. E. Warner, Nucl. Phys. A206 (1973) 207.
13. F. Riess, W. J. O'Connell, D. W. Heikkinen, H. M. Kuan, and S. S. Hanna, Phys. Rev. Lett. 19 (1967) 367.

14. J. L. Osborne, E. G. Adelberger, and K. A. Snover, Nucl. Phys. A305 (1978) 144.
15. A. B. McDonald, E. D. Earle, W. McLatchie, H. B. Mak, D. J. Martin, and P. G. Ikossi, Nucl. Phys. A305 (1978) 151.

Table I. Properties of the A=24 isobaric quintet and coefficients of the IMME.

Nucleus	T_z	Mass Excess M [MeV]	E_x [MeV]	Reference
^{24}Si	-2	10.750(16)	0	IMME-prediction (quadratic)
^{24}Al	-1	5.903(9)	5.955(10)	This work
^{24}Mg	0	1.5016(16)	15.432(2)	[13],[14],[15]*
^{24}Na	1	-2.4473(12)	5.9702(9)	[12]
^{24}Ne	2	-5.949(10)	0	[11]

Predicted coefficients for the IMME: $M = a + bT_z + cT_z^2 + dT_z^3$

a	b	c	d	χ^2
1.5018 (15)	-4.1742 (37)	0.2250 (34)	-	0.13
1.5016 (16)	-4.1743 (37)	0.2263 (48)	-0.0009 (25)	-

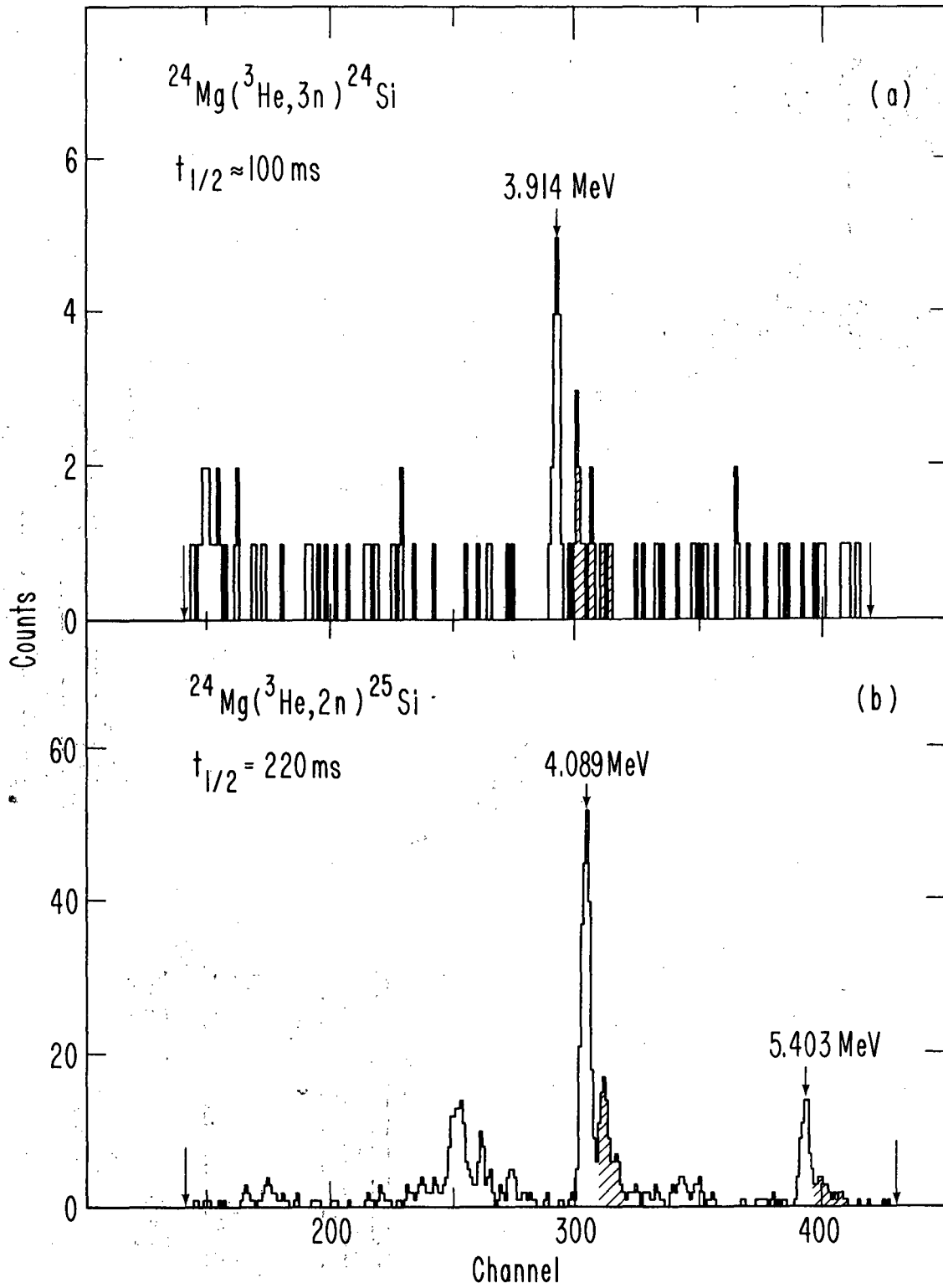
*The quoted value is the weighted mean of the results given in the references.

FIGURE CAPTIONS

Fig. 1. Spectra of beta-delayed protons from (a) ^{24}Si and (b) ^{25}Si .

Arrows at low and high energy indicate telescope cutoffs. Events in the shaded areas in both spectra are a pileup effect as discussed in the text.

Fig. 2. Proposed decay scheme for ^{24}Si . The $^{24}\text{Si} - ^{24}\text{Al}$ mass difference is taken from the quadratic IMME prediction.



XBL 7812-13343

Fig. 1

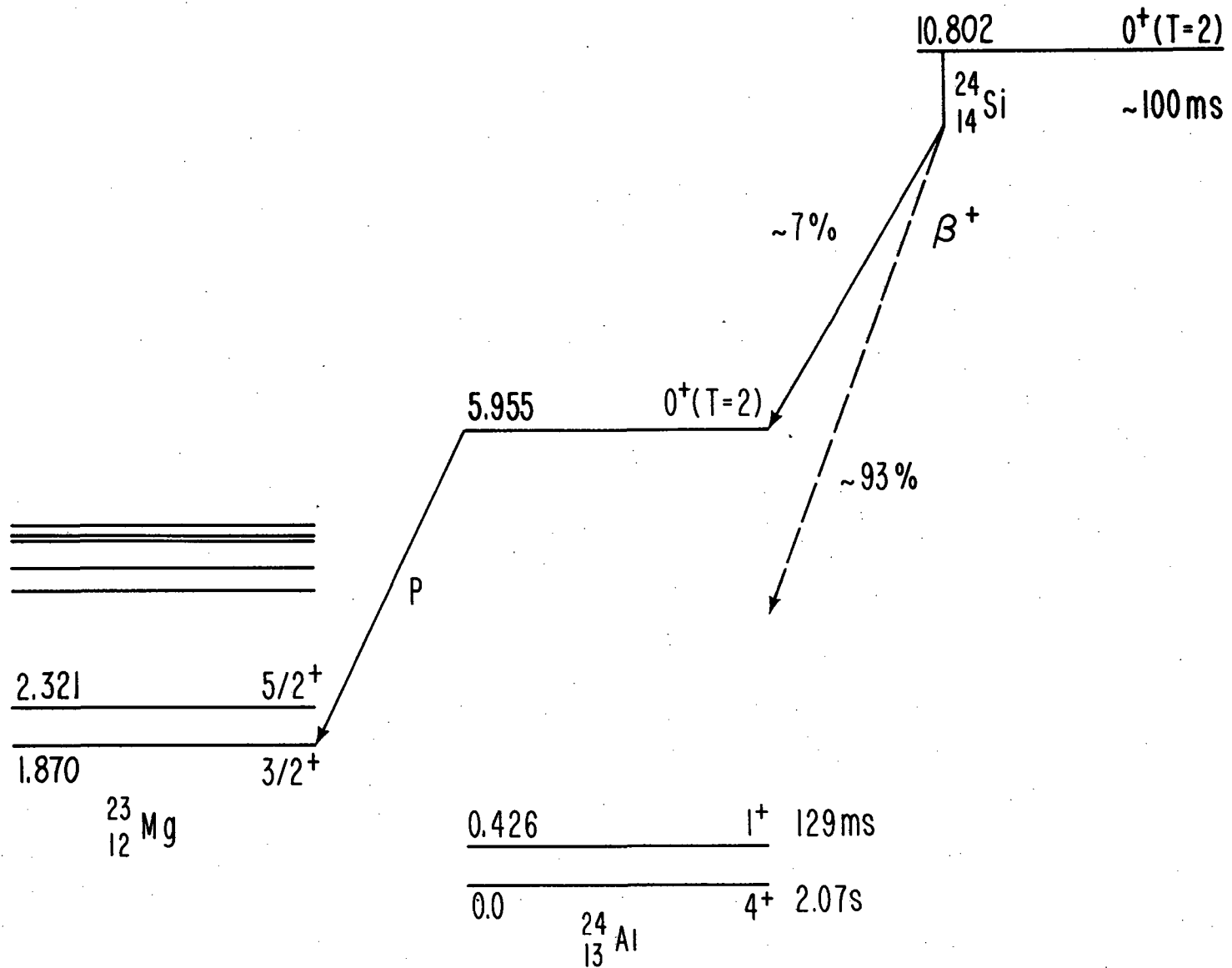


Fig. 2

XBL 7812-13344

This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720