Title
STUDY OF BETA-DELAYED TWO-PROTON EMISSION IN 22Al AND 26P AND SEARCH FOR NEW EMITTERS

Author
Cable, M.D.

Publication Date
1984-04-01

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

Presented at the 5th Nordic Meeting on Nuclear Physics, Jyvaskyla, Finland, March 12-16, 1984

STUDY OF BETA-DELAYED TWO-PROTON EMISSION IN ^{22}Al AND ^{26}P AND SEARCH FOR NEW EMITTERS

M.D. Cable, J. Honkanen, E.C. Schloemer, M. Ahmed, J.E. Reiff, Z.Y. Zhou, and J. Cerny

April 1984

NUCLEAR SCIENCE DIVISION

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

LBL-17720

Study of Beta-Delayed Two-Proton Emission in ^{22}Al and ^{26}P and Search for New Emitters*

M. D. Cable, J. Honkanen[+], E. C. Schloemer, M. Ahmed,
J. E. Reiff, Z. Y. Zhou[++] and Joseph Cerny

Department of Chemistry
and
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720, U.S.A.

April 1984

*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.

LBL-17720

Study of Beta-Delayed Two-Proton Emission in ^{22}Al and ^{26}P and Search for New Emitters*

M. D. Cable, J. Honkanen+, E. C. Schloemer, M. Ahmed, J. E. Reiff, Z. Y. Zhou++ and Joseph Cerny

Department of Chemistry and Lawrence Berkeley Laboratory
University of California, Berkeley, California 94720, U.S.A.

April 1984

As predicted by Gol'danskii (see reference 1 and references therein), nuclei far from stability may decay via the unusual manner of ^{2}He (or 'diproton') emission. The diproton corresponds to a coupling of two protons in a virtual $^{1}S_{0}$ state which subsequently decays to two unbound protons. This ^{2}He nucleus has been calculated[1] to have an increased probability of barrier penetration relative to the independent emission of two protons. When the energetics permit ^{2}He emission, two competing modes of two-proton emission are also frequently allowed. These are a sequential proton decay through an intermediate state and the simultaneous emission of two uncoupled protons.

^{22}Al was suggested by Gol'danskii[2] in 1980 to be a prime candidate for beta-delayed two-proton emission. As indicated in Figure 1, the ^{22}Mg analog state of the ^{22}Al ground state is populated by superallowed beta decay. This state is open to single proton and two proton (or ^{2}He) emission. Following the observation of ^{22}Al as a beta-delayed single-proton emitter[3], experiments were designed to measure coincident protons emitted with a relative angle, η, ranging from about 0^{o} to 70^{o}.

^{22}Al ($t_{1/2}$ = 70 ms) was produced with the $^{24}Mg(^{3}He,p4n)^{22}Al$ reaction at the Lawrence Berkeley Laboratory 88-Inch Cyclotron. The recoiling nuclei were transported to a separate detection chamber using a helium jet system. This system thermalized nuclear reaction products in 1.3 atm of helium and carried the activity to a low pressure (100 millitorr) detection chamber via a 70 cm (1.3 mm i.d.) capillary. Transport times have been estimated to be approximately 50 ms. Protons were identified using a split-element solid state telescope with a coincidence requirement of typically 10 ns. The beta-delayed two-proton emission from ^{22}Al was subsequently observed[4]. Figure 2 provides a summary of the available two-proton data obtained at small relative angles in the initial and subsequent experiments. The labels x and g indicate the final state as the ^{20}Ne 2_1^+ or ground state, respectively. The individual proton decays which result in these final states are labeled by primed and unprimed pairs (e.g., the peaks x1 and x1' sum to the energy of the decay to the ^{20}Ne first excited state). Although the peak structure in the individual proton spectra is strongly suggestive of a sequential decay scheme, other mechanisms cannot be entirely excluded.

More recent work has been directed at establishing the 2p decay mechanism(s). Assuming ^{2}He breakup energies of about 500 keV, as estimated from reaction studies[5], ^{2}He decay should leave the constituent protons closely correlated in angle. For ^{2}He decays leading to the first excited state of ^{20}Ne, a breakup energy of 500 keV implies a maximum relative angle of ~40^{0}. In comparision, a sequential decay would emit protons over the complete angular range with an angular correlation appropriate to the intermediate state spin. For decays resulting in the ^{20}Ne first excited state and assuming intermediate state spins from 1/2 to 7/2, the angular correlation variations have been estimated to be no more than 10-20%. Therefore a large angle geometry would not be able to observe a ^{2}He component of the decay but would remain sensitive to the other modes. A detection system was constructed (Figure 3) using two independent three-element telescopes with a mean relative angle of 120^{o} ($70^{o} \leq \eta \leq 170^{o}$.) Using the same transport system as described earlier, proton-proton coincidences were identified as illustrated in the composite data of several experiments given in Figure 4. The detection of 2p coincidences at large angles indicates that the decay does not proceed exclusively through ^{2}He emission.

The overall behavior of the data at these two angles suggests that the sequential mode is the dominant decay mechanism. The two-proton sum energy for the ^{22}Al x and g groups at large angles shows upward shifts of 220 and 300 keV, respectively, from the small angle measurements. These shifts are consistent with the predicted kinematic shift from a sequential decay scheme. In addition to the sum energy shift, in sequential decay the change in η will be reflected only in the energy of the second proton decay. The individual proton spectra for the ^{22}Al g group show the shift clearly in the peaks labeled g1' and g2. As indicated in Table I, these data characterize a possible decay sequence via intermediate states[6] at $E_x(^{21}Na) = 4.29$ and ~ 5.8 MeV. Although individual peak identification is not possible at the large angle for the ^{22}Al x decay branches, penetrability calculations suggest that the first proton is more likely to have the larger decay energy of each proton pair. Under this assumption and based on the small angle measurements, a tentative decay scheme is presented in Figure 5 using known states[6] of ^{21}Na.

Beta-delayed two-proton decay has also been observed[7] from the isotope ^{26}P; however, in this case ^{2}He emission from the analog state to the two-proton daughter ground state is spin-parity forbidden ($3^+ \nrightarrow 0^+$.) Small angle measurements utilizing the first detector arrangement have revealed two discrete peaks in the individual proton spectrum, at 1.21 and 3.69 MeV, again suggestive of a sequential proton decay. Large angle data show the same peaks (Figure 6) with a kinematic shift for the lower energy peak identifying it as the second transition of the two-proton sequential decay. These data for ^{26}P define a decay scheme as indicated in Figure 7 which could proceed through a known intermediate state of ^{25}Al (see Table I). Both ^{22}Al and ^{26}P appear to decay predominantly through sequential emission of two protons; however some uncertainties remain in developing a complete explanation of the ^{22}Al decay data.

Our most recent work has been directed at searching for additional beta-delayed two-proton emitters. The two-proton coincidence requirement provides a powerful and convenient technique for the removal of background activities in characterizing the decay of nuclei far from stability. Table II is a compilation of the most recent series of experiments. (The isotopes in Table II are either expected to be particle stable or unbound by < 1 MeV.) No new emitters have been observed. Upper limits for the production cross section were derived from observed counting rates in telescopes suited for the detection of protons with energies from 1.0 to 4.5 MeV. However, the heavier candidates in general have smaller available two-proton decay energy from the analog state. For example the ^{46}Mn beta decay daughter has at most 2.4 MeV of 2p decay energy available and a small asymmetry in the splitting of this between the two protons would result in one proton being below our detection threshold. A system is being developed with detector telescopes sensitive to lower proton energies and this will be used in future studies of beta-delayed two proton-emitters.

*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.

+Present address: Dept. of Physics, University of Jyvaskyla, Finland.

++Present address: Dept. of Physics, Nanjing University, China.

References

1. V.I. Gol'danskii, Usp. Fiz. Nauk. 87, 255 (1965); Sov. Phys. Uspekhi 8, 770 (1966).
2. V.I. Gol'danskii, Pis'ma Zh. Eksp. Teor. Fiz. 32, 572 (1980); JETP Lett. 32, 554 (1980).
3. M. D. Cable, J. Honkanen, R.F. Parry, H. M. Thierens, J. M. Wouters, Z. Y. Zhou, and J. Cerny, Phys. Rev. C26, 1778 (1982).
4. M. D. Cable, J. Honkanen, R. F. Parry, S. H. Zhou, Z. Y. Zhou and J. Cerny, Phys. Rev. Lett. 50, 404 (1983).
5. T. V. Congedo, I. S. Lee-Fan and B. L. Cohen, Phys. Rev. C22, 985 (1980).
6. P. M. Endt and C. van der Leun, Nucl. Phys. A310, 1 (1978).
7. J. Honkanen, M. D. Cable, R. F. Parry, S. H. Zhou, Z. Y. Zhou and J. Cerny, Phys. Lett. 133B, 146 (1983).

TABLE I. Calculated proton-daughter state mass excesses and excitations.

	Assumed p_1 group	Mass** Excess	E_x	Known*** State	
^{22}Al	(x1' / x1)*	3.99(2)	6.18(2)	6.170(30)	$(1/2\text{-}7/2)^+$
		4.39(2)	6.58(2)	---------	
^{22}Al	(x2' / x2)*	3.76(2)	5.95(2)	5.979(15)	$(1/2\text{-}7/2)^+$
		4.62(2)	6.81(2)	---------	
^{22}Al	(x3' / x3)*	3.59(2)	5.78(2)	5.770(20)	$(1/2\text{-}7/2)^+$
		4.81(2)	7.00(2)	7.060(30)	
^{22}Al	g1	3.62(3)	5.81(3)	5.770(20)	$(1/2\text{-}7/2)^+$
				5.815	$7/2^-$
^{22}Al	g2'	2.11(3)	4.30(3)	4.294(3)	$5/2^+$
^{26}P	g1'	-5.20(2)	3.72(2)	3.6957(5)	$(7/2^-)$

*Ordering is uncertain. Underlined group is the more probable candidate.
**Calculated using small angle values.
***Known states from Ref. 6 that are close enough in energy to be possible intermediate states.

Table II. Upper Limits for Production Cross-Sections

Beam Energy (MeV)	Beam	Target	Reaction	β-2p Branch (%)	Available p Energy† (MeV)	Available 2p Energy† (MeV)	Upper Limit for Production Cross Section (nb)
110	^{3}He	Mg	$^{24}Mg(^{3}He,p4n)^{22}Al$	1.5	8.2	5.6	100*
110	^{3}He	Si	$^{28}Si(^{3}He,p4n)^{26}P$	1.0	7.3	4.9	100*
110	^{3}He	Cd	$^{32}S(^{3}He,p4n)^{30}Cl$	2.5	8.4	5.6	40
110	^{3}He	Ca	$^{40}Ca(^{3}He,\alpha 4n)^{35}Ca$	4.7	8.8	4.2	3
93	^{6}Li	Ca	$^{40}Ca(^{6}Li,4n)^{42}V$	3.4	6.1	4.9	100
160	^{14}N	Ca	$^{40}Ca(^{14}N,2\alpha 4n)^{42}V$	3.4	6.1	4.9	40
160	^{14}N	Ca	$^{40}Ca(^{14}N,\alpha p6n)^{43}Cr$	7.3	7.7	4.0	20
160	^{14}N	Ca	$^{40}Ca(^{14}N,\alpha 4n)^{46}Mn$	6.6	4.1	2.4	20
126	^{10}B	Ca	$^{40}Ca(^{10}B,\alpha 4n)^{42}V$	3.4	6.1	4.9	20
126	^{10}B	Ca	$^{40}Ca(^{10}B,p6n)^{43}Cr$	7.3	7.7	4.0	10
126	^{10}B	Ca	$^{40}Ca(^{10}B,4n)^{46}Mn$	6.6	4.1	2.4	10

*This is an observed value for the production cross-section.
†These values have been estimated for the decay from the analog state.

Figure Captions

Fig. 1. Proposed partial decay scheme of ^{22}Al.

Fig. 2. Small angle ^{22}Al two-proton coincidence data. Part a) illustrates the summed two-proton energy peaks leading to the ^{20}Ne 2^+ , and ground state. The individual proton spectra for these two final states are shown in b) and c), respectively. Constituent protons of the two-proton sum peaks are indicated by primed and unprimed pairs.

Fig. 3. Schematic diagram of the large angle detector system.

Fig. 4. Large angle ^{22}Al two-proton coincidence data. The summed energy spectrum in part a) displays the kinematic shifts described in the text. The peak broadening relative to the narrow angle data is a reflection of the larger range of η for this measurement. The individual proton peaks leading to the ^{20}Ne ground state in Fig. 2c) are easily identified in Fig. 4c) although such a clear correspondence cannot be made between Fig. 2b) and 4b).

Fig. 5. Proposed new partial decay scheme for ^{22}Al. Intermediate states have been suggested using the small angle measurement for decays leading to the ^{20}Ne first excited state. Two-proton emission leading to the ground state has been determined from both large and small angle data.

Fig. 6. Large angle ^{26}P two-proton coincidence data. Beta-delayed two-proton decay from both ^{26}P and ^{22}Al are produced in this bombardment as illustrated in part a). The individual proton spectrum leading to the ^{24}Mg ground state is shown in b).

Fig. 7. Proposed new partial decay scheme for ^{26}P. The intermediate state of the two-proton emission was determined using both large and small angle data.

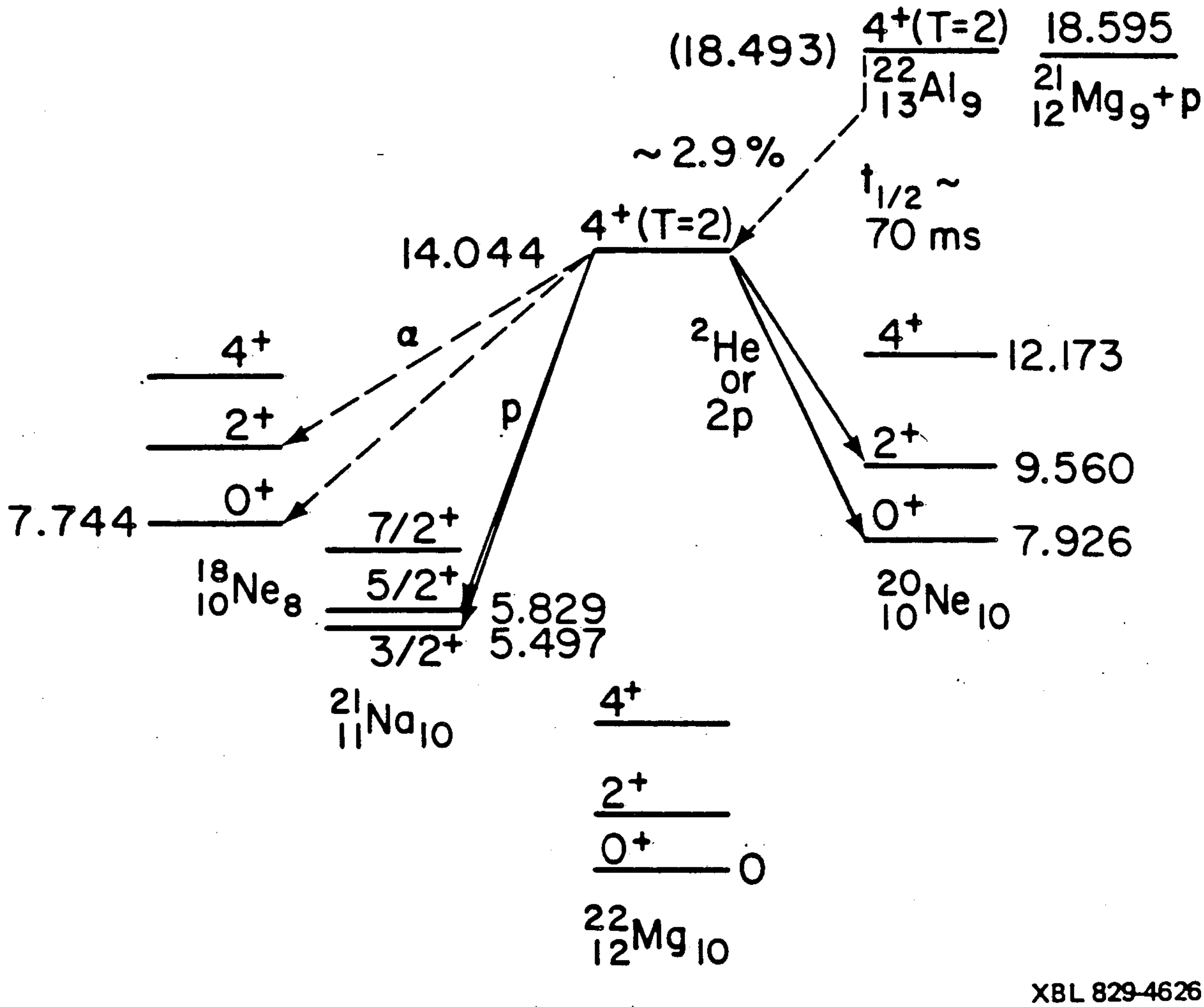

(18.493)
4⁺(T=2)
$^{22}_{13}Al_9$
18.595
$^{21}_{12}Mg_9+p$
~2.9%
$t_{1/2}$ ~ 70 ms
14.044
4⁺(T=2)
α
p
^2He or 2p
4⁺
2⁺
0⁺
7.744
$^{18}_{10}Ne_8$
7/2⁺
5/2⁺
3/2⁺
5.829
5.497
$^{21}_{11}Na_{10}$
4⁺
12.173
2⁺
9.560
0⁺
7.926
$^{20}_{10}Ne_{10}$
4⁺
2⁺
0⁺
0
$^{22}_{12}Mg_{10}$
XBL 829-4626

Fig. 1

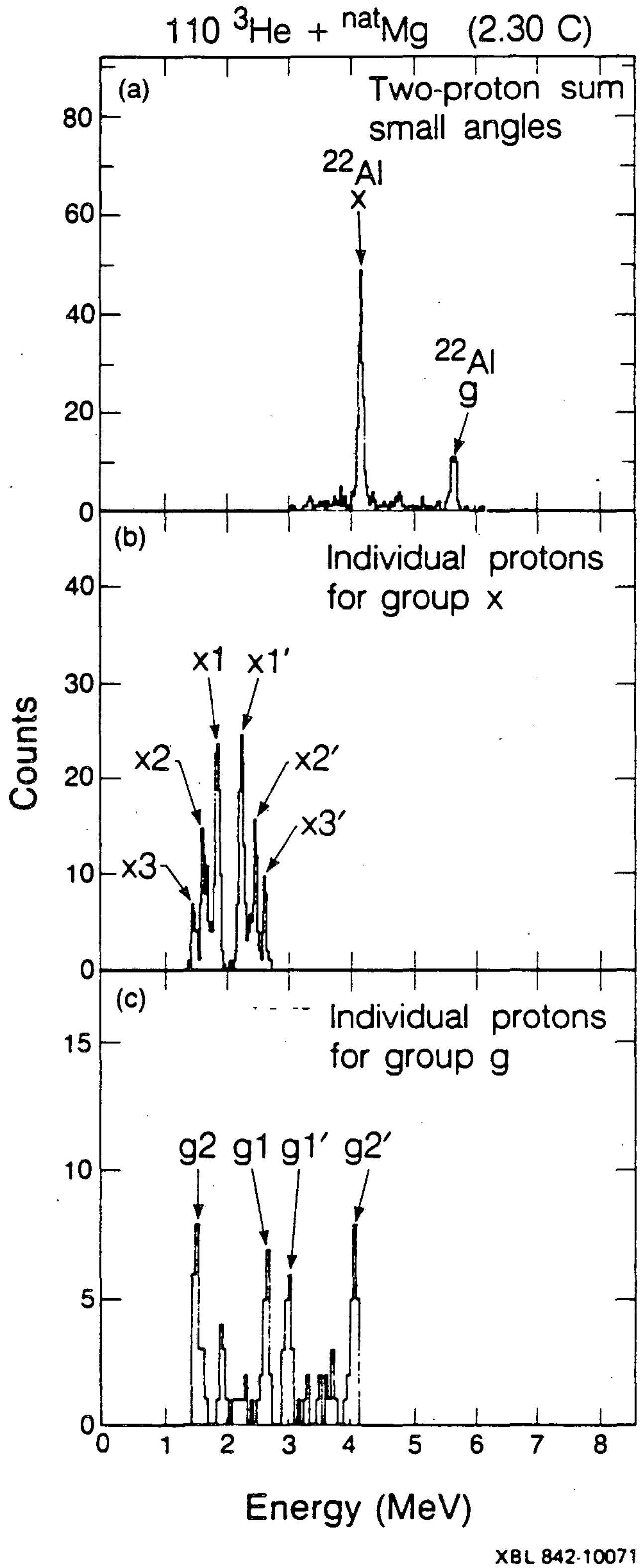
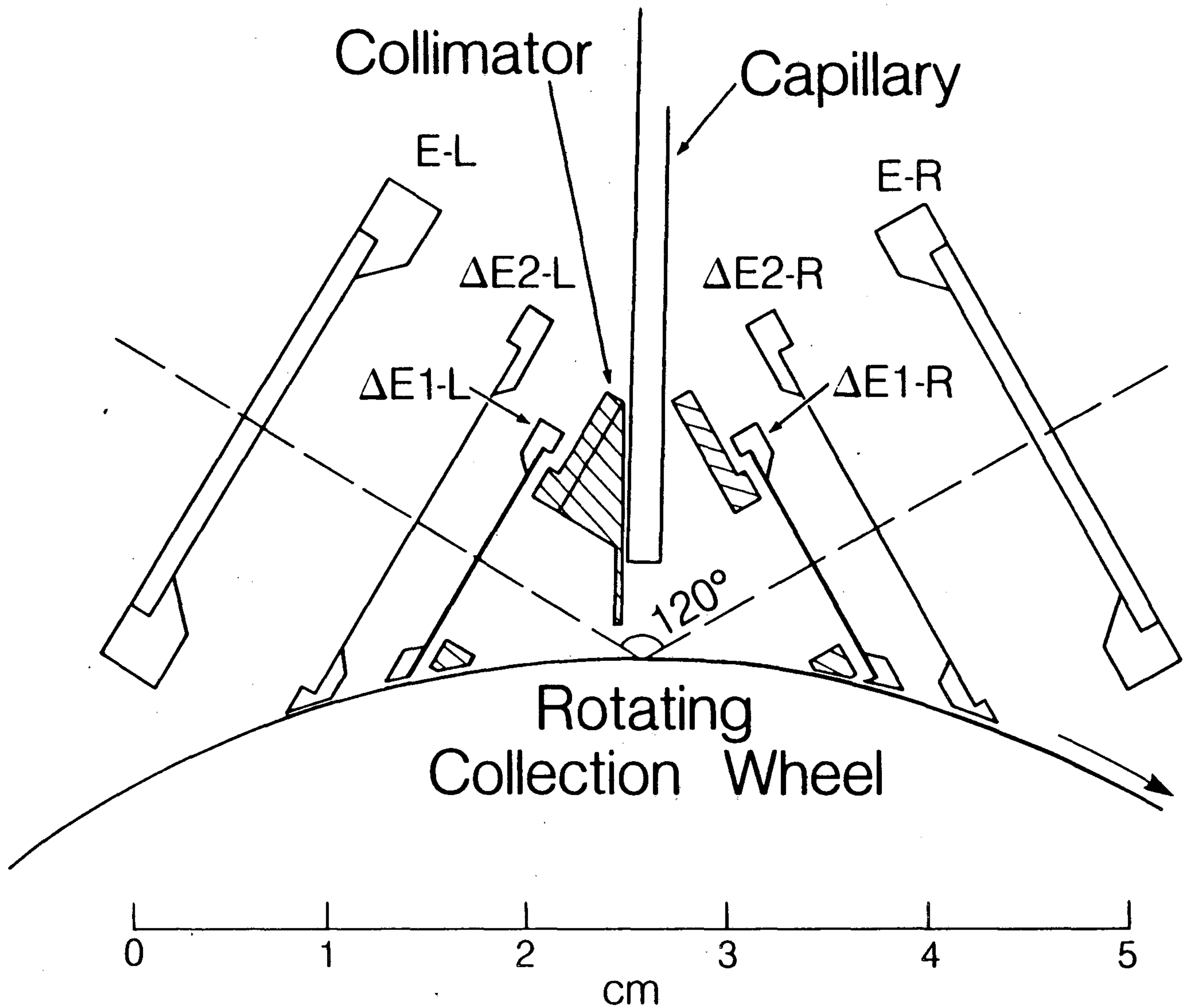

110 ^{3}He + ^{nat}Mg (2.30 C)
(a)
Two-proton sum
small angles
^{22}Al
x
^{22}Al
g
(b)
Individual protons
for group x
x1
x1′
x2
x2′
x3
x3′
(c)
Individual protons
for group g
g2 g1 g1′ g2′
Counts
Energy (MeV)
XBL 842-10071

Fig. 2



XBL 8311-6823

Fig. 3

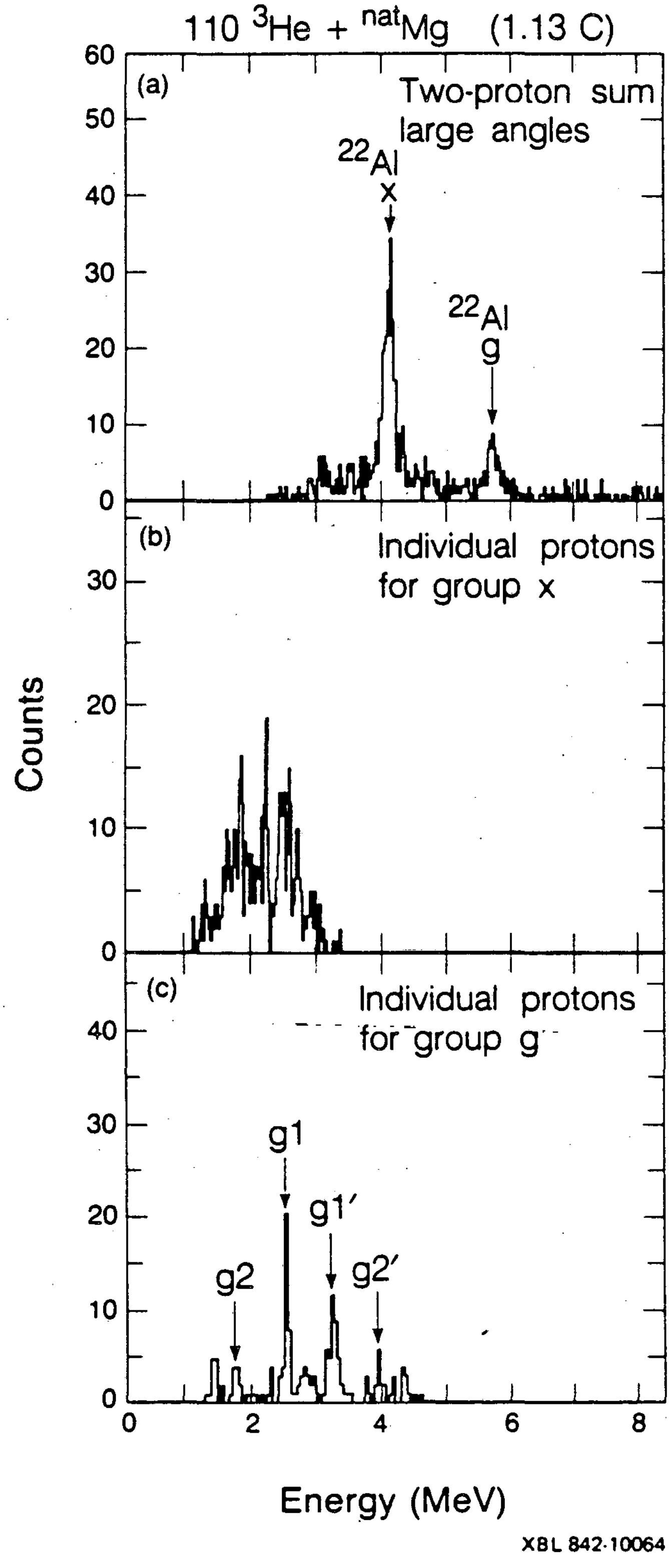
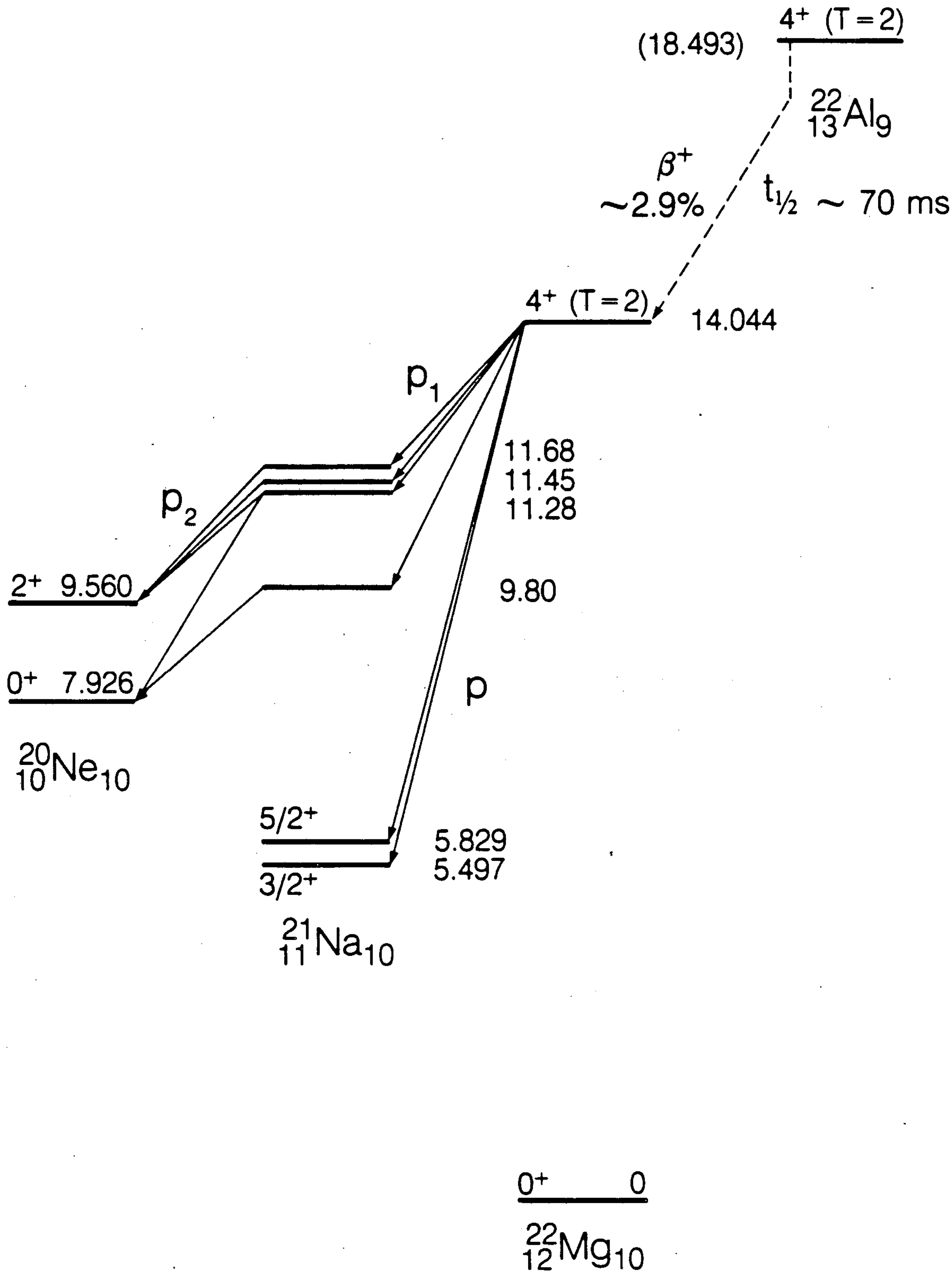

110 ^{3}He + ^{nat}Mg (1.13 C)
(a)
Two-proton sum
large angles
^{22}Al
x
^{22}Al
g
(b)
Individual protons
for group x
(c)
Individual protons
for group g
g1
g1′
g2
g2′
Counts
Energy (MeV)
0
10
20
30
40
50
60
0
2
4
6
8
XBL 842-10064

Fig. 4



4+ (T=2)
(18.493)
$^{22}_{13}Al_9$
β^+
~2.9%
$t_{1/2}$ ~ 70 ms
4+ (T=2)
14.044
p1
11.68
11.45
11.28
p2
2+ 9.560
9.80
0+ 7.926
p
$^{20}_{10}Ne_{10}$
5/2+
5.829
5.497
3/2+
$^{21}_{11}Na_{10}$
0+ 0
$^{22}_{12}Mg_{10}$
XBL 842-9422

Fig. 5

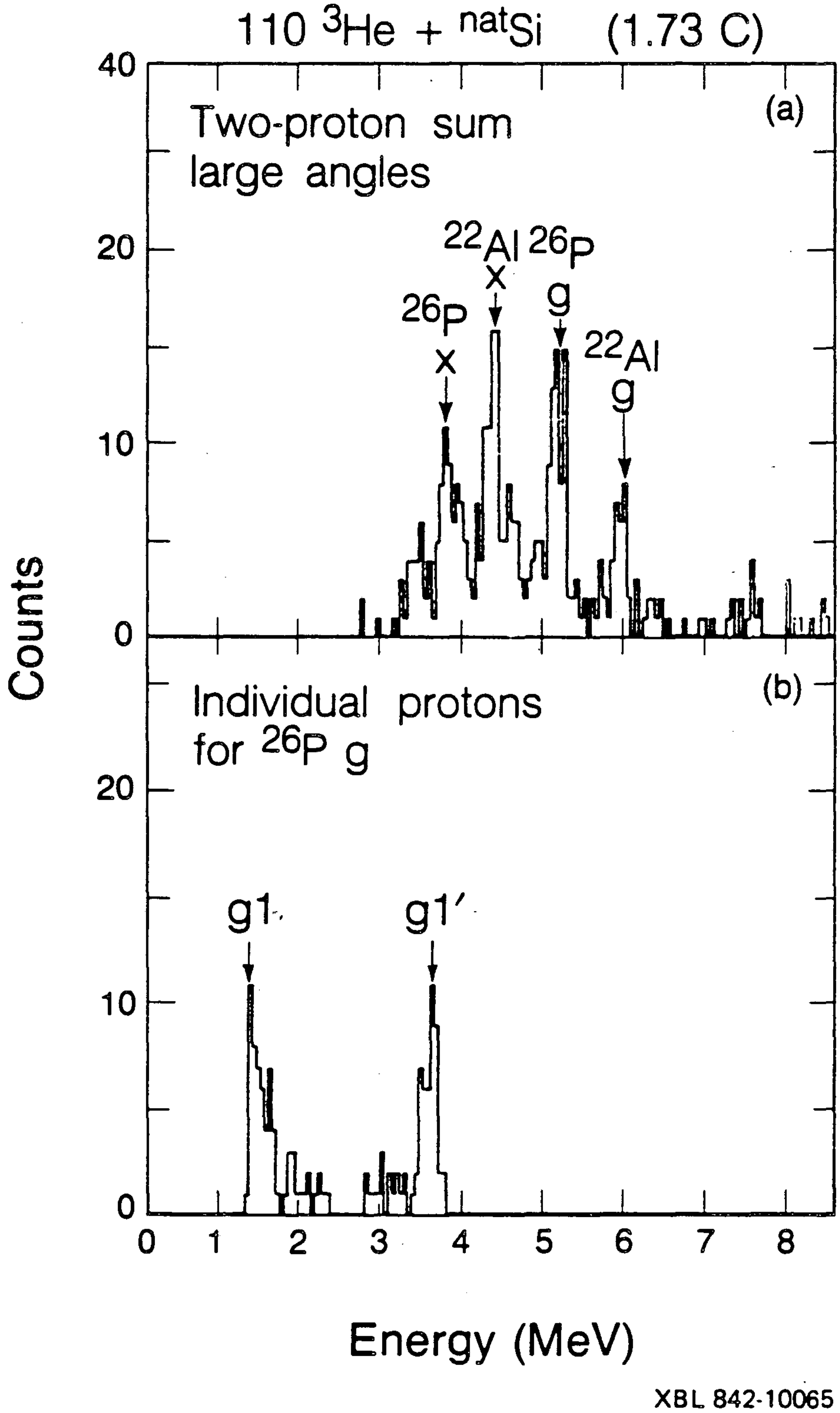
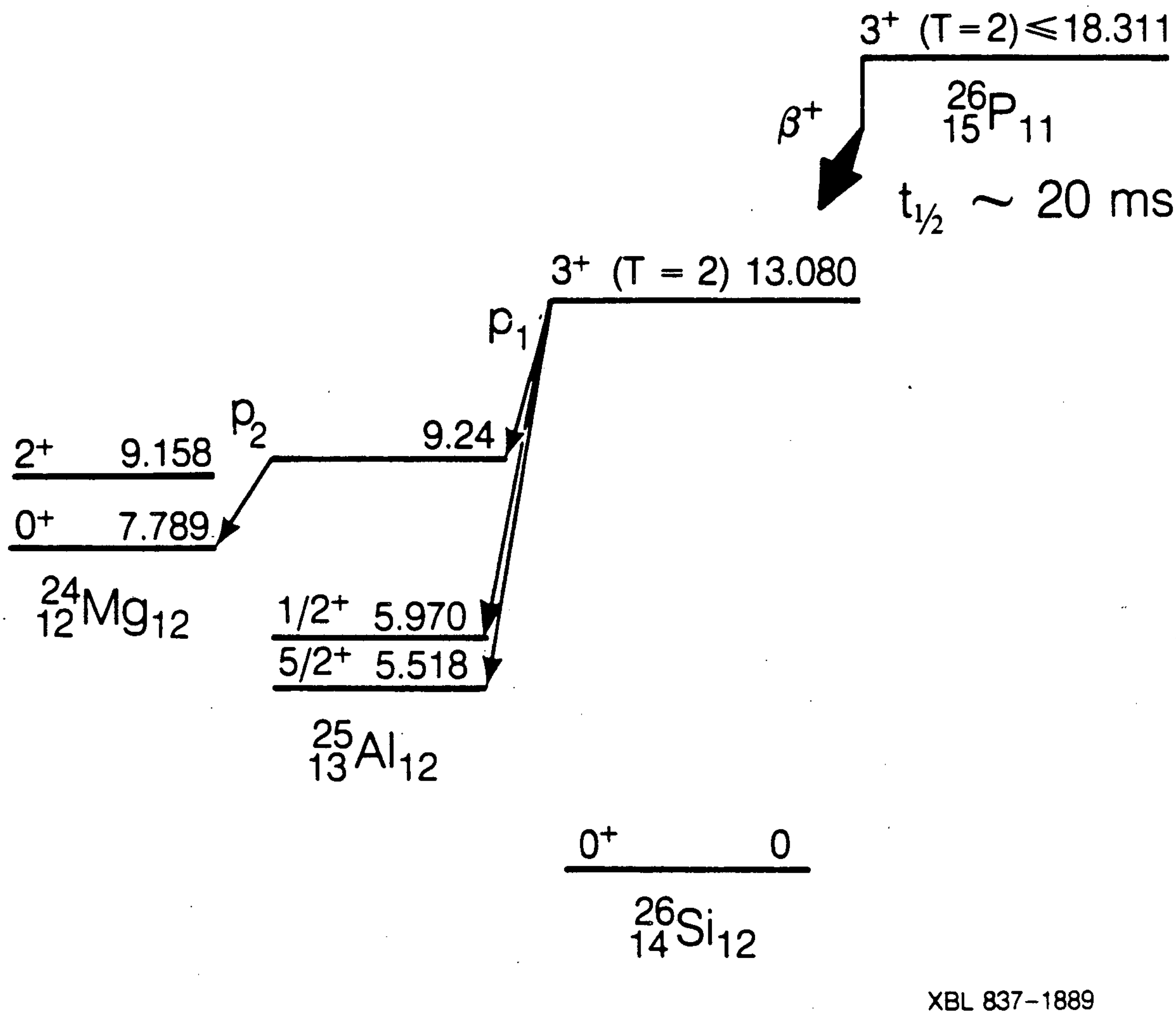

110 ^{3}He + ^{nat}Si (1.73 C)
40
20
10
0
Two-proton sum
large angles
(a)
^{22}Al
x
^{26}P
g
^{26}P
x
^{22}Al
g
Counts
Individual protons
for ^{26}P g
(b)
g1
g1′
0
1
2
3
4
5
6
7
8
Energy (MeV)
XBL 842-10065

Fig. 6



3+ (T=2)≤18.311
β+
26 15 P 11
t½ ~ 20 ms
3+ (T = 2) 13.080
p1
p2
9.24
2+ 9.158
0+ 7.789
24 12 Mg 12
1/2+ 5.970
5/2+ 5.518
25 13 Al 12
0+ 0
26 14 Si 12
XBL 837-1889

Fig. 7

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