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LAWRENCE RADIATION LABORATORY

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ISOSPIN-FORBIDDEN DECAY PROPERTIES OF THE LOWEST T = 2 STATES OF
^{20}Ne, ^{24}Mg, ^{28}Si, ^{32}S, AND ^{40}Ca†

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ABSTRACT

The lowest T = 2 states of ^{20}Ne, ^{24}Mg, ^{28}Si, ^{32}S, and ^{40}Ca have been

formed using the (p,t) reaction. The isospin-forbidden proton ($\Delta T = 1$ or 2)

and alpha particle ($\Delta T = 2$) decay modes of these states have been determined

by counting triton-proton and triton-alpha coincidence events. The major decay

modes of the states are: ^{20}Ne$(\alpha_1 + \alpha_2, \alpha_3 + \alpha_4)$; ^{24}Mg$(p_0)$; ^{28}Si$(\alpha_0)$; ^{32}S$(p_0)$;

^{40}Ca(α_0). Simple Coulomb calculations were performed for ^{40}Ca; these assumed

pure shell-model configurations and considered isospin mixing in only the

(1d,1f) shells. They did not predict the relatively large $\Delta T = 2$ isospin

impurities necessary to explain the observed alpha-particle decay.

INTRODUCTION

It is well known that isobaric analog states in light and heavy nuclides can be characterized to a good approximation by a single isospin quantum number since the nuclear force is nearly charge-independent. The magnitudes of $\Delta T = 1$ impurities introduced by the Coulomb potential in low-lying states of several $T = 0$ light nuclides have been calculated by MacDonald[1] and found to be small. From experimental data on isospin-forbidden gamma and particle transitions, Wilkinson[2] observed that the impurities were in substantial agreement with these theoretical estimates. Blin-Stoyle[3] has summarized analyses of both beta-decay rates and masses of the mass-14 $T = 1$ states in terms of the Coulomb potential plus a generalized charge-dependent nuclear force. He concludes that "none of the data are inconsistent with a nuclear charge-dependent force of the order of a percent or so." One hopes that studies of "isospin-forbidden" processes may provide information about the form of nuclear charge-dependent interactions in nuclei, or at least, about the wave functions admixed by these interactions.

In this paper, experimental data on the isospin-forbidden particle decay of five $T = 2$ analog states in self-conjugate $T_z = (N-Z)/2 = 0$ nuclides are presented. The $T = 2$ states are analogs of the ground state of the (Z-2, N+2) nuclides with spin-parity 0^+ and are readily formed in two-nucleon transfer reactions on $T = 1$ target nuclides. Several of these states also have been observed[4,5,6] as isospin-forbidden compound nucleus resonances having total widths less than 2.5 keV, the small widths presumably reflecting a relatively high degree of isospin purity since none of the states have any isospin-allowed particle decay modes. A comprehensive review of experimental data on analog states, containing literature references on $T = 2$ states, has been given recently.[7]

The decay schemes of the lowest $T = 2$ states in ^{20}Ne, ^{24}Mg, ^{28}Si, ^{32}S, and ^{40}Ca were determined by counting tritons coincident with protons or alpha particles resulting from reactions of the form:

$$[(Z, N+2)T = 1, T_z = 1] + p \longrightarrow [(Z,N)2,0] + t$$
$$ \longrightarrow [(Z-1),N)1/2,1/2] + p$$
$$ \longrightarrow [(Z-2,N-2)0,0] + \alpha$$

Each of the $T = 2$ states is unbound to several proton ($\Delta T = 1$ or 2) and alpha particle ($\Delta T = 2$) decay channels. The decay energies for protons range from 3.12 MeV to 3.89 MeV and for alpha particles from 4.94 MeV to 12.00 MeV. The branching ratios are indicative of the relative effectiveness of the isovector ($\Delta T = 1$) compared to the isotensor ($\Delta T = 2$) charge-dependent interactions in admixing into the analog states (or final states) those configurations that are compatible with the observed decay.

Early attempts to observe $T = 2$ states as isospin-forbidden elastic scattering resonances were not successful.[8] Consequently, the initial experiment of the kind reported here was undertaken in order to ascertain that the isospin-forbidden particle-decay widths were indeed larger than the isospin-allowed gamma-decay widths as has been found for the $T = 3/2$ states.[9] Our preliminary results on the decay of the $T = 2$ states in ^{24}Mg and ^{28}Si have already appeared.[10] Recently, the Stanford group[5,6] has located $T = 2$ states in both particle-gamma and particle-particle resonance reactions. Comparisons of these data with those given here show qualitative agreement.

EXPERIMENTAL PROCEDURE

The data were obtained using proton beams from the Berkeley 88-inch cyclotron. The beam energy was adjusted from 42 MeV to 46 MeV, depending on the Q-values for formation of the T = 2 states, in order that outgoing tritons in the forward direction had energies of approximately 20 MeV. Previous work had indicated that the (p,t) cross sections are maximized around this energy.[11]

Self-supporting targets of ^{26}Mg (99.2% enriched), ^{30}Si (89%), Cd^{34}S (37.2%), and ^{42}Ca (94.4%) were used. The ^{26}Mg target was about 1 mg/cm^2 thick, and the others were between 400 and 500 μg/cm^2 thick. The ^{20}Ne data were collected using a ^{22}Ne gas target and the experimental arrangement will be discussed separately. Outgoing tritons were detected in a counter telescope positioned at +22 degrees with respect to the beam direction; this angle is at the second maximum of the L = 0 angular distributions to the analog states. The (p,t) cross sections at this angle are only about 80 to 100 μb/sr; therefore, two "decay" counter telescopes were operated in parallel in order to increase the data acquisition rate. These two telescopes were fixed at -90 degrees and -125 degrees. All three telescopes consisted of ΔE, E, and E-reject silicon-semiconductor detectors (the last being used to reject particles that passed through the E detector). Each of the "decay" telescopes consisted of 50μ ΔE, 280μ E, and 500μ E-reject detectors. Decay alpha particles from the analog states could not penetrate the ΔE detectors, but could be identified unambiguously from the reaction kinematics. A schematic representation of the experimental apparatus is shown in Fig. 1.

Signals from each detector were amplified and passed on to Goulding-Landis particle identifiers. Triton singles energy spectra were accumulated

in the memory core of an on-line PDP-5 computer using a multiplexer and analog-
to-digital converter. If pulses occurred in either of the decay ΔE detectors
in fast coincidence ($2\tau \sim 50$ ns) with a pulse in the triton ΔE detector, then
the appropriate telescope signals were fed to the particle identifiers. Pro-
vided the event involved a triton in the triton telescope and either a proton
or a particle stopping in the ΔE detector of either decay telescope, total
energy signals together with the necessary logic signals were passed on to the
computer and the data were stored on magnetic tape for later analysis. These
data were finally displayed and plotted as 512×512 channel two-dimensional
energy spectra together with the 512 channel triton singles data.

Apertures placed in front of the detectors served to define the accept-
ance solid angles; additional apertures and magnets placed in front of the
defining apertures helped to reduce the electron noise background. The triton
telescope subtended 9.2×10^{-4} sr. The ΔE detectors of the decay telescopes
subtended about 1.5×10^{-2} sr and the E detectors subtended about 1.2×10^{-2} sr.
These relatively large solid angles, necessary to insure reasonable data
accumulation rates, were obtained by using detectors about 1.2 cm in diameter
as well as 1 cm defining apertures. Since the calculated branching ratios
depend on the solid angles of the decay telescopes, and "dead" regions near
the edge of the depleted volumes of the detectors might have reduced the
effective solid angles, compared to those found from geometrical measurements,
two methods were employed to measure these angles by actual particle counting.
First the ΔE solid angles were determined to $\pm5\%$ by mounting a ^{212}Pb alpha-
particle source in the target plane (masked by an aperture the size of typical
proton beam spots) and comparing the ΔE counting rates to those of a detector

placed behind a much smaller aperture of known solid angle. The E solid angles were found to ±15% using data from the $^{19}F(p,t)^{17}F$ (3.10 MeV) → p + ^{16}O reaction. The ^{17}F 3.10 MeV state with spin 1/2 decays 100 percent by isotropic proton emission (in the ^{17}F recoil coordinate system) to the ^{16}O ground state. A 36 MeV proton beam and a CaF_2 target were used to obtain the triton-proton decay coincidence data. These data were then analyzed in the manner described below, to yield the E detector solid angles.

A single decay telescope consisting of a 37μ ΔE and 275μ E detector was used in the ^{20}Ne experiment. The 6.4 cm diam cylindrical ^{22}Ne (91.3%) gas target was covered with 25μ Havar foil; a tube at -90 degrees projected into the target volume so that a 6.4μ Mylar foil window could be mounted 1.25 cm from the reaction volume. The reaction volume was defined by two apertures placed in front of the triton telescope positioned at +22.8 degrees. The decay telescope at -90 degrees viewed the entire reaction volume through the Mylar window; this thin window allowed relatively low energy decay products to escape the target with only minor energy losses or straggling. The decay telescope geometry guaranteed equally efficient detection of decay particles which originated anywhere in the reaction volume. The solid angle of the decay telescope was defined by a single aperture in front of the ΔE detector and was calculated from the geometry to be 6.0×10^{-3} sr (±20%).

DATA ANALYSIS

Coincidence data from the ^{42}Ca(p,t)^{40}Ca reactions are exhibited as

two-dimensional energy spectra in Figs. 2 and 3 and are typical. The kinematics

of reactions with three-particle final states are completely specified if the

momenta of two of the particles are measured. Thus, the data are expected to

lie along bands determined by the kinematics and experimental resolution. The

diagonal lines shown in the figures were calculated from the kinematics and

many events cluster along the ^{39}K (g.s.) + p and ^{36}Ar (g.s.) + α lines.

Typically, the overall triton resolution was 130 keV and the proton resolution

was about 100 keV. The overall alpha particle (ΔE) resolution was primarily

determined by energy losses in the target. The events in the figures corre-

sponding to 24.8 MeV tritons are accidentals associated with the high yield

^{16}O(p,t)^{14}O contaminant reaction; the number of these events was used as a

measure of the chance-coincidence rate.

Data along the kinematic lines were added from both decay telescopes

and projected onto the triton energy axis in order to find the decay properties

of the T = 2 states. Figure 4 shows these projections of the ^{40}Ca data along

with the triton singles energy spectrum. The triton spectrum cuts off at about

26 MeV because of the relatively thin triton telescope detectors which were

employed in order to lower the chance coincidence rates. The largest peak in

the singles spectrum, excepting contaminants, corresponds to the ^{40}Ca T = 2

state at 11.978±0.025 MeV. The ^{36}Ar (g.s.) + α projection exhibits a prominent

peak at the same triton energy, indicating the principal decay mode   of this

T = 2 state.

The net number of events associated with the various T = 2 decay modes was found by summing the projected spectra over the triton energy interval containing the T = 2 triton peak as determined from the singles spectrum, and subtracting: 1) the "real" three-particle continuum background; and 2) the "chance" background. The former was assumed to vary linearly over the T = 2 interval and, hence, was estimated by interpolating the background height on either side of this interval. The chance background was calculated from the known singles counting rates together with the known singles spectrum shapes. This method for calculating the number of chance events occurring in any region of the two-dimensional arrays was always tested by comparing its results to the observed numbers of events occurring in portions of the arrays where only chance events could contribute (for example, the regions corresponding to 24.8 MeV tritons in Fig. 2). Both kinds of background subtractions were usually small compared to the total number of events observed for dominant transitions.

The branching ratios were calculated by comparing the net number of coincidence events in a given decay mode to the number predicted from the net number of triton singles counts, the decay telescope solid angles, and the Jacobian relating laboratory cross sections to those in the coordinate system at rest with respect to the recoiling T = 2 state. All the T = 2 states discussed here have spin-parity 0^+ and decay isotropically in this coordinate system.

RESULTS

Spectra of the projected coincidence data together with the triton

singles spectra for ^{20}Ne and ^{32}S are shown in Figs. 5 and 6 (similar figures

for ^{24}Mg and ^{28}Si appear in Ref. 10). The relatively poor quality ^{20}Ne data

is in part related to the geometry of the gas target experiment which resulted

in appreciably smaller real to chance counting rate ratios compared to the

solid target data. For both this reason, and the small solid angle of the

single decay telescope, relatively few data were obtained. Table I summarizes

the branching ratio results for all five T = 2 states. The standard deviations

tabulated for the individual decay modes in the table represent only counting

statistics. The deviations listed for the summed branching ratios also include

uncertainties in the decay telescope solid angles and an assumed 10% uncer-

tainty in the net number of triton singles counts contained in the T = 2 peaks

arising from the possible presence of small peaks in the continuum background.

The summed branching ratios (X100) clearly should be less than or

equal to 100%. It is apparent from the table that the sums are in fact close

to 100%. Although the experimental technique used in the present work does not

permit examination of all energetically-allowed decay modes because of experi-

mental cutoffs, in general barrier penetration effects make transitions to

high-lying states which could not have been detected relatively unimportant.

Column five in the table lists the branching ratios after normalization to

100%—it is not implied that gamma decays or unexamined particle decays do not

make small contributions to the total widths. For convenience, the decay

schemes also are presented in Figs. 7 through 11 where all the states of the

(Z-1,N) and (Z-2,N-2) residual nuclides lying below the T = 2 states are

illustrated. [12]

A necessary condition for events ascribed to the decay of the spin

zero T = 2 states is that branching ratios derived from each decay telescope

be the same, since the decay is presumably isotropic. The ratios of branching

ratios for all the major decay modes found from the -90 degree and -125 degree

telescopes are listed in Table II; they lie within one standard deviation of

unity and are thus consistent with this requirement.

DISCUSSION

The T = 2 states investigated in the present work are found to decay

both by isospin-forbidden proton and alpha-particle emission. Moreover,

excluding the T = 2 state in ^{20}Ne, these states have large branching ratios

for decay to the ground states of the residual nuclides. This second property

makes feasible the task of locating the states as compound nuclear resonances,

and all have now been located utilizing this technique except the one in ^{40}Ca.

The resonance data have generally provided precise determinations of the exci-

tation energies and total width upper limits, but have not been utilized to

yield information about the particle-decay branching ratios; this prohibits

quantitative comparisons with the results given here. [An exception is the

work[4,5] on ^{19}F + p which gives $\Gamma p_o/\Gamma$ = 6.2±0.4% and Γ = 2.1±0.5 keV for the

^{20}Ne, T = 2 state. From Table I, $\Gamma(p_o + p_1 + p_2)/\Gamma \sim$ 14±9%.] Both the ob-

servations[6] of the T = 2 states of ^{24}Mg, ^{28}Si, and ^{32}S as resonances in

^{23}Na + p, ^{24}Mg + α, and ^{31}P + p and the unsuccessful attempt[13] to observe the

^{28}Si state as an ^{27}Al + p resonance are in qualitative agreement with the

present results.

Before conclusions concerning the importance of various kinds of

isospin-admixtures can be made, barrier penetration factors should be

considered. Table III lists the Wigner-limit width calculated from graphs[14] of Coulomb wave functions. Since the widths for the two types of decay are comparable, the specific decay properties evidently are strongly influenced by the details of the admixed lower isospin configurations. The problem of interpretation is complicated because the data span the region from the $1d_{5/2}$, $2s_{1/2}$, shells, where deformations exist, to the $1d_{3/2}$, $1f_{7/2}$ shells where the spherical shell model has some validity. A modest attempt to estimate the kinds of impurities which would be introduced by the Coulomb potential was undertaken in ^{40}Ca in order to ascertain whether large $\Delta T = 2$ admixtures (which presumably account for the alpha particle decay) might be expected.

The simple mixing calculation assumed pure shell-model configurations and included isospin mixing in only the outer (unfilled) shells. The T = 2 state of ^{40}Ca was taken to have the structure $|(1d_{3/2})^{-2}_{01} (1f_{7/2})^2_{01}; 02\rangle$. Amplitudes of admixtures of several T' = 0 or T' = 1 states in this T = 2 state, and also of a T' = 2 state into the T = 0 ^{36}Ar ground state were calculated in first order perturbation theory. The ^{36}Ar ground state was assumed to have the structure $|(1d_{3/2})^4_{00}; 00\rangle$ and the alpha particle isospin impurity was ignored. The matrix elements of the Coulomb potential, $\langle\Psi(T)|V_c|\Psi(T')\rangle$, were calculated for these components using harmonic oscillator wave functions with a size parameter $\nu = m\omega/\hbar = 0.25$ fm^{-2}. The irreducible tensor components of V_c which have rank one and two have selection rules $\Delta T = 1$ and $\Delta T = 2,0$ respectively for self-conjugate nuclides. The T' states considered in ^{40}Ca included the 0 particle-0 hole ground state, the 4 particle-4 hole state[15] at 3.35 MeV, and the 2 particle-2 hole states having the same nuclear configurations assumed for the T = 2 state, but recoupled in isospin to zero or one. These last states

are the so-called anti-analog states and the Coulomb matrix elements were
expected to be relatively large. The locations of these states are not
established experimentally; however, in the ^{40}K energy level scheme,[12] the
lowest spin zero state appears to lie no lower than 2.3 MeV. Assuming that
this is the location of the $T = T_z = 1$, 2 particle-2 hole state, then its
analog in ^{40}Ca lies at about 10 MeV. Since the energy splitting between analog
and anti-analog states is thought to be proportional to $\vec{T}_1 \cdot \vec{T}_2$ (see Refs. 16
17), the (T = 0)2 particle-2 hole state is therefore expected to lie at about
9 MeV.

The calculated admixture coefficients $\alpha_{TT'} = \{\langle \Psi(T)|V_c|\Psi(T')\rangle/(E_{T'}-E_T)\}$
are tabulated in Table IV; note that the largest coefficient occurs for the
T' = 1 anti-analog state. Only a few T' states were considered and, of course,
many other states exist near the T = 2 state at 11.98 MeV. Nevertheless, within
the framework of this initial calculation it is perhaps reasonable to ignore
most of these other states since only a small fraction of these states will have
zero angular momentum and none are expected to have the structure required to produce
large Coulomb matrix elements. [The latter speculation is clearly true only
to the extent that the T = 2 state consists solely of the assumed 2 particle-
2 hole configuration.] The admixtures listed in the table do not appear to
be large enough to yield a $\Delta T = 2$ decay width of, say, 1 keV. It would be
useful to have accurate width measurements from resonance experiments; however,
it appears unlikely on the basis of known widths for similar analog states
that the type of mixing considered here would be able to account for it.

On the basis of the calculated admixtures, $\ell = 3$ proton emission to a
low-lying $J^\pi = 7/2^-$ state of ^{39}K resulting from the rather large $\Delta T = 1$,

2 particle-2 hole admixture might be expected rather than alpha particle decay.
Unfortunately, the small penetration factor for decay to the ^{39}K 2.82-MeV
state effectively precludes this mode of decay, preventing examination of the
importance of this admixture. Generalizing these speculations, i.e., that
mixing with the anti-analog states might influence the decay properties of
T = 2 states in the other nuclei that were examined, it turns out that in every
case either small penetration factors or small overlaps of initial and final
states (assuming/the T = 2 analog states in the lighter nuclides have struc-
                   for simplicity that
tures given by the axially symmetric Nilsson model) may hinder proton emission.
Thus, the absence of any proton decay to excited states in the (Z-1,N) residual
nuclides does not reflect upon the importance of such mixing. It is clear,
however, that neither the observed ground state proton decay of ^{24}Mg or ^{32}S nor
the alpha particle decay of the other T = 2 states can be adequately explained
by the methods used.

Many aspects of the isospin mixing problem have not been considered:
the states undoubtedly have more complicated structure than is considered here
and the calculational approach used is actually only appropriate for calculating
impurities in low-lying bound states, i.e., the "external" mixing arising from
the different neutron and proton wave functions in the exterior region is com-
pletely ignored.[18]

It is hoped that the experimental results presented here will stimulate
more extensive theoretical efforts to describe the isospin-forbidden decay
properties of these states. In particular, it will be interesting to learn
whether the Coulomb potential is capable of generating the ΔT = 2 admixtures
implied by the observed alpha particle decay of several of the states which
have been studied.

FOOTNOTES AND REFERENCES

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1. W. H. MacDonald, Nuclear Spectroscopy, Part B, ed. by F. Ajzenberg-Selove,
    (Academic Press, New York, 1960) p. 932.

2. D. H. Wilkinson, ibid, p. 852.

3. R. J. Blin-Stoyle, Selected Topics in Nuclear Spectroscopy, ed. by B. J.
    Verhaar, (North-Holland Publishing Co., Amsterdam, 1964) p. 213.

4. R. Bloch, R. E. Pixley, and P. Truöl, Phys. Letters 25B, 215 (1967).

5. H. M. Kuan, D. W. Heikkinen, K. A. Snover, F. Riess, and S. S. Hanna,
    Phys. Letters 25B, 217 (1967).

6. F. Riess, W. J. O'Connell, D. W. Heikkinen, H. M. Kuan, and S. S. Hanna,
    Phys. Rev. Letters 19, 367 (1967); K. A. Snover, D. W. Heikkinen, F. Riess,
    H. M. Kuan, and S. S. Hanna, Phys. Rev. Letters 22, 239 (1969); D. W.
    Heikkinen, H. M. Kuan, K. A. Snover, F. Riess, and S. S. Hanna, Bull. Am.
    Phys. Soc. 13, 884 (1968).

7. J. Cerny, Annual Reviews of Nuclear Science, Vol. 18, ed. by E. Segrè,
    (Annual Reviews Inc., Palo Alto, California, 1968) p. 27.

8. D. J. Bredin, O. Hansen, G. M. Temmer, and R. Van Bree, Isobaric Spin in
    Nuclear Physics, ed. by J. D. Fox and D. Robson, (Academic Press, Inc.,
    New York, 1966) p. 472. G. M. Temmer and R. Van Bree, International
    Nuclear Physics Conference, Gatlinburg, Tennessee, ed. by R. L. Becker,
    C. D. Goodman, P. H. Stelson, and A. Zucker, (Academic Press, Inc.,
    New York, 1967) p. 885.

9. G. M. Temmer, Proc. Int. Conf. on Nuclear Structure, Dubna, (International
    Atomic Energy Agency, Vienna, 1968) p. 249.

10. R. L. McGrath, S. W. Cosper, and J. Cerny, Phys. Rev. Letters $\underline{18}$, 243 (1967)

    R. L. McGrath, J. C. Hardy, and J. Cerny, Phys. Letters $\underline{27B}$, 443 (1968).

    Within experimental uncertainties, these preliminary data agree with the

    present results.

11. S. W. Cosper, H. Brunnader, J. Cerny, and R. L. McGrath, Phys. Letters

    $\underline{25B}$, 324 (1967).

12. T. Lauritsen and F. Ajzenberg-Selove, Nuclear Data Sheets, compiled by

    K. Way et al., (Printing and Publishing Office, National Academy of

    Sciences - National Research Council, Washington, D. C., 1962); P. M. Endt

    and C. Van der Leun, Nucl. Phys. $\underline{A105}$, 1 (1967). The ^{23}Na level scheme

    is taken from A. R. Poletti and D. F. H. Start, Phys. Rev. $\underline{147}$, 800 (1966),

    and references therein.

13. H. M. Kuan, F. Riess, K. A. Snover, D. W. Heikkinen, D. C. Healey, and

    S. S. Hanna, Bull. Am. Phys. Soc. $\underline{13}$, 884 (1968).

14. W. T. Sharp, H. E. Gove, and E. B. Paul, Atomic Energy of Canada Limited

    Report No. 268, 1955 (unpublished).

15. J. R. MacDonald, D. F. H. Start, R. Anderson, A. G. Robertson, and M. A.

    Grace, Nucl. Phys. $\underline{A108}$, 6 (1968); W. J. Gerace and A. M. Green, Nucl.

    Phys. $\underline{93}$, 110 (1967).

16. R. K. Bansal and J. B. French, Phys. Letters $\underline{11}$, 145 (1964).

17. L. Zamick, Phys. Letters $\underline{19}$, 580 (1965).

18. D. Robson, Annual Review of Nuclear Science, Vol. 16, ed. by E. Segrè,

    (Annual Reviews, Inc., Palo Alto, California, 1966) p. 119.

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Table I. Summary of T = 2 branching ratio data.

Mode	Net events	Branching[a] ratios (X100)	Summed[b] branching ratios	Normalized branching ratios
^{20}Ne $\rightarrow$ ^{16}O + α_o	-3 ± 2	-6 ± 5		~ 0
^{16}O + $(\alpha_1+\alpha_2)$	17 ± 6	35 ± 12		38
^{16}O + $(\alpha_3+\alpha_4)$	15 ± 6	29 ± 12		32
^{19}F + $(p_o+p_1+p_2)$	7 ± 4	14 ± 9		16
^{19}F + $(p_3+p_4+p_5)$	6 ± 4	13 ± 8		14
			85 ± 29	
^{24}Mg $\rightarrow$ ^{23}Na + p_o	108 ± 11	71 ± 7		74
^{23}Na + p_1	1 ± 6	1 ± 4		1
^{20}Ne + α_o	7 ± 6	3 ± 3		3
^{20}Ne + α_1	48 ± 10	22 ± 4		22
			97 ± 16	
^{28}Si $\rightarrow$ ^{24}Mg + α_o	93 ± 10	72 ± 8		81
^{24}Mg + α_1	11 ± 5	8 ± 4		9
^{27}Al + p_o	4 ± 7	4 ± 8		5
^{27}Al + (p_1+p_2)	4 ± 5	4 ± 5		5
			88 ± 16	
^{32}S $\rightarrow$ ^{31}P + p_o	32 ± 6	86 ± 17		75
^{28}Si + α_o	9 ± 4	18 ± 7		16
^{28}Si + α_1	6 ± 3	11 ± 5		9
			115 ± 24	

(continued)

Table I. Continued.

Mode	Net events	Branching[a] ratios (X100)	Summed[b] branching ratios	Normalized branching ratios
$^{40}Ca \rightarrow ^{36}Ar + \alpha_0$	125±12	116±11		100
$^{36}Ar + \alpha_1$	-2±2	-1±2		∿0
$^{39}K + p_0$	-2±7	-3±9		∿0
			112±19	

[a]Standard deviation includes only counting statistics.

[b]Standard deviation also includes uncertainties in the number of triton counts and in decay telescope solid angles as explained in the text.

Table II. Ratios of branching ratios derived from delay telescope
data at -90 degrees compared to telescope data at -125 degrees.

Decay mode	Ratio: $\dfrac{\text{Branching ratio } (-90°)}{\text{Branching ratio } (-125°)}$
$^{24}\text{Mg} \longrightarrow {}^{23}\text{Na} + p_o$	1.24 ± 0.28
$^{20}\text{Ne} + \alpha_1$	1.50 ± 0.59
$^{28}\text{Si} \longrightarrow {}^{24}\text{Mg} + \alpha_o$	1.08 ± 0.23
$^{32}\text{S} \longrightarrow {}^{31}\text{P} + p_o$	0.86 ± 0.35
$^{40}\text{Ca} \longrightarrow {}^{36}\text{Ar} + \alpha_o$	1.28 ± 0.26

Table III. Wigner-limit widths for particle decay of T = 2 states
where $\Gamma = 3 \cdot R/(F_\ell^2 + G_\ell^2) \cdot \hbar^2/MR$.

T = 2 state	Γp_o [a]	ℓp_o	$\Gamma \alpha_o$ [b]
^{20}Ne	7.25 MeV	s	7.85 MeV
^{24}Mg	1.41	d	3.11
^{28}Si	0.66	d	1.29
^{32}S	2.70	s	0.65
^{40}Ca	0.38	d	0.13

[a] $R = 1.5\ A^{1/3}$ fm.

[b] $R = (1.4\ A^{1/3} + 1.6)$ fm.

Table IV. Calculated isospin admixtures $\alpha_{TT'}$ in the ^{40}Ca
$T = 2$ state and ^{36}Ar ground state.

	Excitation	$\langle T=2 \vert V_c \vert T' \rangle$	$\alpha_{TT'}$
^{40}Ca			
$\vert (1d_{3/2})^{-2} (1f_{7/2})^2 \ J=0, T=2 \rangle$			
$\longrightarrow \vert (1d_{3/2})^8 \ T'=0 \rangle$	0.0 MeV	16 MeV	1.3×10^{-3}
$\longrightarrow \vert (1d_{3/2})^{-4} (1f_{7/2})^4 \ T'=0 \rangle$	3.35	13	1.5×10^{-3}
$\longrightarrow \vert (1d_{3/2})^{-2} (1f_{7/2})^2 \ T'=0 \rangle$	~9	22	7.3×10^{-3}
$\longrightarrow \vert (1d_{3/2})^{-2} (1f_{7/2})^2 \ T'=1 \rangle$	~10	420	2.1×10^{-1}
^{36}Ar			
$\vert (1d_{3/2})^4 \ J=0, T=0 \rangle$			
$\longrightarrow \vert (1d_{3/2})^4 \ T'=2 \rangle$	10.86	150	1.4×10^{-2}

The size parameter is $\nu = 0.25 \ \mathrm{fm}^{-2}$.

FIGURE CAPTIONS

Fig. 1.   A schematic diagram of the experimental apparatus. Telescope #1

detected tritons, and "decay" telescopes #2 and #3 detected either protons

or particles stopping in the ΔE detectors (alpha particles). If one of

these events arrived in coincidence with a triton, the appropriate linear

and logic signals were passed on to the multiplexer—A.D.C. and to the

computer. [The electronics for telescope #2 are similar to #3 and are

not shown.]

Fig. 2.   A two-dimensional energy spectrum of triton-proton coincidence events

from the $^{42}Ca(p,t)^{40}Ca \rightarrow p + ^{39}K$ reaction. The diagonal lines labeled by

the residual states of ^{39}K were calculated from the kinematics.

Fig. 3.   A two-dimensional energy spectrum of events consisting of tritons in

coincidence with particles which stopped in the ΔE detector of telescope

#3. From the ΔE energy losses, these particles are known to be alpha

particles and, consequently, the data correspond to the $^{42}Ca(p,t)^{40}Ca \rightarrow$

$\alpha + ^{36}Ar$ reaction. As in Fig. 2, the diagonal lines were calculated from

the kinematics. The cluster of events along the ^{36}Ar ground state line

at 22.4 MeV triton energy is associated with the decay of the 0^+ T = 2

state located at 11.98 MeV in ^{40}Ca.

Fig. 4.   The top spectrum shows the triton singles data containing the ^{40}Ca

T = 2 state. The lower-lying excited states are not observed because of

the relatively thin detectors used in the triton telescope. The lower

spectra are summed projections from both decay telescopes of events lying

along kinematic bands in the coincidence data onto the triton energy axis;

the arrows in these spectra mark the energy cutoffs determined by kine-
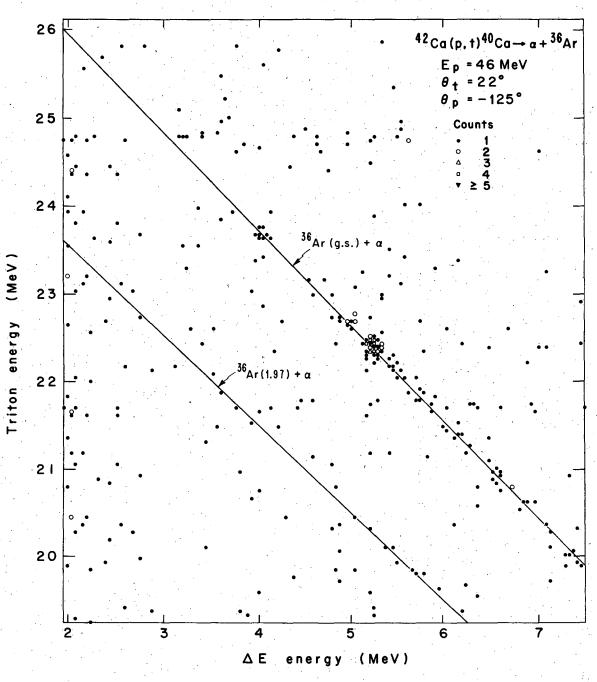
matics and detector thicknesses.

Fig. 5. The top spectrum shows some of the triton singles data from the ^{22}Ne(p,t)^{20}Ne reaction; the projected coincidence data are shown in the lower spectra. The events in the interval between the arrows drawn on either side of the T = 2 state peak were summed to obtain the branching ratios.

Fig. 6. Triton singles data containing the 0^+ T = 2 state in ^{32}S, together with the summed projections of the coincidence data (see Fig. 4 caption).

Fig. 7. Decay scheme showing energetically-allowed particle-decay models of the 16.73 MeV T = 2 state of ^{20}Ne. The level data are taken from the literature. The normalized branching ratios determined in this work are given alongside the arrows.

Fig. 8. Decay scheme for the 15.43 MeV T = 2 state of ^{24}Mg. (See Fig. 7 caption).

Fig. 9. Decay scheme for the 15.21 MeV T = 2 state of ^{28}Si. (See Fig. 7 caption).

Fig. 10. Decay scheme for the 11.98 MeV T = 2 state of ^{32}S. (See Fig. 7 caption).

Fig. 11. Decay scheme for the 11.98 MeV T = 2 state of ^{40}Ca. (See Fig. 7 caption).

Fig. 1

E-rej AMP

Particle identifier

Linear gate

E protons

Anti

E AMP

c/o

Proton slow coinc.

ΔE AMP

c/o

Linear gate

ΔE'

Mixer

Fast coinc. $\tau \sim 50$ns

Anti from $E_{c/o}$

ΔE' slow coinc.

Routing

Mag. tape

Multi-plexer and ADC

Computer

Start gate

Tritons

CRT disp.

ΔE AMP

Particle identifier

Linear gate

E tritons

E AMP

Anti

E-rej AMP

35°

90°

22°

Proton beam

PA PA PA

③

②

①

XBL687-3282

-22-

UCRL-18940

$^{42}Ca(p,t)^{40}Ca \rightarrow p + {}^{39}K$

$Ep = 46$ MeV
$\theta_t = 22°$
$\theta_p = -125°$

Counts
• 1
∘ 2
△ 3

$^{39}K (2.53) + p$

$^{39}K (g.s.) + p$

Proton energy (MeV)

Triton energy (MeV)

Fig. 2

XBL 687-3278

Fig. 3

^{42}Ca(p,t)^{40}Ca

E$_p$ = 46 MeV

θ_{lab} = 22°

^{10}C 3.34 MeV
+^{14}O 6.59 MeV

^{10}C g.s.

11.978 MeV
T = 2

^{14}O g.s.
(×1/2)

^{39}K g.s. + p

^{36}Ar g.s. + α

^{36}Ar (1.97 MeV) + α

Counts

Triton energy (MeV)

XBL687-3279

Fig. 4

Fig. 5

XBL67II-5606

XBL688-3519

Fig. 6

Fig. 7

XBL67II-5636-A

Fig. 8

UCRL-18940

XBL686-3074

Fig. 9

XBL688-3518

Fig. 10

UCRL-18940

Fig. 11

XBL 687-3280