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ABSTRACT

The sought, but previously unobserved, isospin-forbidden particle-decay modes of a T=2 state in a T_z=0 nucleus have been determined by particle-particle coincidence techniques. Proton decays (ΔT=1 or 2) and strong evidence for α-particle decays (ΔT=2) from the ^{24}Mg, T=2 state were observed and show $\Sigma\Gamma_{particle} \gg \Gamma_{\gamma}$.

Even though the locations (and very large upper limits on the widths) of many 0+, T=2 states in $T_z=0$ nuclei are known,[1,2] no further information on their properties is available. Since in general no T=2 particle-decay channels are open for these T=2 states, they are expected to be relatively sharp. Their isospin-forbidden particle decays are of particular interest since they provide a sensitive measure of the isospin impurity admixed into these states by charge dependent forces (Coulomb plus nuclear). Although attempts to determine the particle-decay properties and total widths of these states through their observation as "twice T-forbidden" compound nucleus resonances in proton scattering have been made—a technique successfully applied to T=3/2 states[3,4]—solely negative results were obtained.[3,5,6]

In order to be certain that a typical T=2 state does indeed possess a total particle width comparable to its gamma width ($\Sigma\Gamma_{particle} \gtrsim \Gamma_{\gamma}$), and to sufficiently establish its decay properties to ascertain whether its exploration by compound resonance techniques is feasible, the isospin-forbidden particle decay of the ^{24}Mg, 0+, T=2 state populated in the isospin-allowed ^{26}Mg(p,t)^{24}Mg reaction has been investigated. This particular T=2 state was chosen since previous searches for it in resonance experiments were unsuccessful[3,6] and since its low proton-decay energy makes it accessible to standard electrostatic accelerators.

Figure 1a shows all the probable[7] decay modes open to the ^{24}Mg T=2 state. Utilizing the 42.1 MeV proton beam of the Berkeley 88-inch cyclotron, we have measured coincidences between tritons forming this state at 15.43±0.07 MeV excitation and decay protons [E_{max}(lab) = 3.9 MeV] or α-particles [E_{max}(lab) = 6.1 MeV] leading to the ^{23}Na or ^{20}Ne levels indicated by heavy lines in the figure. Figure

1b presents the layout of the three, three-counter telescopes which were employed; E-reject detectors were used to reduce background. Tritons leading to the T=2 state were identified[8] in system 1 placed at the L=0 peak angle of 22.4 deg lab. Fast and slow coincidences were required between tritons and A) identified protons in system 2 or 3 or identified α-particles in system 2 (solid angles of 3.5×10^{-3}sr) or B) particles stopping in the ΔE detector of system 3 (solid angle of 8.0×10^{-3}sr). Because of the small solid angles of systems 2 and 3 arising from the need for particle identification, the low cross section for tritons populating the T=2 state ($d\sigma/d\Omega \approx 100$ μb/sr), and a counting rate limitation of 30,000 cps in the system 1 E-detector, an average of only two coincidence events per hour in both systems from the decay of this state was obtainable. Forty hours of coincidence data were recorded in four 512 × 512 arrays on magnetic tape utilizing an on-line PDP-5 computer while the cumulative triton singles data were stored in a 1024 channel pulse-height analyzer. The spin-zero property of the T=2 state ($\Gamma \leq 35$ kev[9]) guaranteed an isotropic decay with respect to the ^{24}Mg c.m. system—thus detailed angular correlation measurements were not required to extract decay widths.

Data from several coincidence arrays are presented in Fig. 2. Part 2a shows the triton coincidences with particles stopping in the ΔE detector of system 3; coincident particles which lost more than 1.8 MeV in this detector were required by kinematics to be α-particles. Alpha decays leading to the ^{20}Ne ground and first excited states lie inside the two bands on the figure. These bands are established from the curve given by 3-body kinematics adjusted for finite counter geometry, energy losses in the target and electronic resolution. (Events corresponding to energy losses of less than 1.8 MeV in the ΔE detector are probably due to triton-proton coincidences.) Figure 2b shows the array arising from triton coincidences with identified protons in system 3. The bands encompass decays to the ground and first excited states of ^{23}Na.

A triton singles spectrum is shown at the top of Fig. 2c; the resolution (FWHM) of the T=2 peak is about 180 keV. Below this spectrum are displayed projections of bands from three of the coincidence arrays onto the triton axis. The ^{23}Na ground and 0.44 MeV state projections contain data from systems 2 and 3; data for the other ^{23}Na levels come only from system 2. The ^{20}Ne + α data are obtained from system 3.[10]

Counts attributed to the decay of the T=2 state were obtained by summing the projected spectra over the appropriate triton energies and subtracting A) the chance background and B) the "real" continuum background. The continuum was assumed smooth, and was calculated by interpolating the projected count level averaged over 15 channels on both sides of the T=2 peak. Fractional decay widths for each observable decay mode were obtained by comparing its net coincidence counts to the number predicted from the triton singles data after transforming[11] the isotropic decay of the T=2 state in the ^{24}Mg c.m. system to the laboratory, assuming 100 per cent decay via that particular mode.

The sum of all fractional widths for decay to the six lowest ^{23}Na levels and the lowest two levels of ^{20}Ne is $1.3_0 \pm 0.2_0$. This sum should be ≤ 1.0; although the discrepancy is outside one standard deviation, it is considered to be statistical. There is, of course, no way to be certain that a small state does not lie underneath the T=2 state[12] and, perhaps, decay anisotropically. Further, from the nature of the projected data in Fig. 2c, such a state would more probably α-decay. However, since the major peaks in the projected spectra associated with the T=2 decays center precisely about the relevant triton energy and since the triton singles peak shape coupled with an absolute comparison of the $^{26}Mg(p,t)^{24}Mg(T=2)$ with the $^{26}Mg(p,^{3}He)^{24}Na(T=2)$ angular distribution data[13] implies < 10 per cent "contamination", we consider a significant contribution from such a small state to be improbable. In any event, no such problem could affect the conclusion that the major decay mode of the ^{24}Mg T=2 state is via proton decay to the ^{23}Na g.s. Figure 1a presents the observed data on the decay of the T=2 state.

Since the sum of the observed ^{24}Mg T=2 fractional particle-decay widths is equal to $1.3_0 \pm 0.2_0$, the isospin-allowed gamma width must be relatively quite small. After correcting for penetrabilities,[14] the dimensionless α-particle reduced width for decay to the ^{20}Ne 1.63 MeV state, requiring $\Delta T=2$, is about half the proton + ^{23}Na g.s. width ($\Delta T=1$ or 2). Alpha-particle widths are expected to be particularly interesting from the point of view of isospin mixing because in first order only the iso-tensor part of the charge dependent perturbation can mix T=0 amplitude into the T=2 states of $T_z=0$ nuclei (compare Ref. 15). By contrast, isospin-forbidden decays of T=3/2 states may result from both the iso-vector and the iso-tensor part of the charge dependent interaction.

The present experiment does not yield information on the absolute width of this ^{24}Mg T=2 state; further, some uncertainty in the relative widths results from the continuum underneath the state. However, since the proton + ^{23}Na g.s. width is approximately 60 per cent of the total width, it should in fact be possible for compound resonance experiments to provide more detailed data on the properties of this T=2 state.[16]

We wish to acknowledge several valuable discussions with Professor Gerald T. Garvey.

FOOTNOTES AND REFERENCES

*Work performed under the auspices of the U. S. Atomic Energy Commission.

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7. The only other open decay mode, $^{12}C + {}^{12}C$ + 1.5 MeV, would be strongly inhibited by the Coulomb barrier. The ^{23}Na level scheme is taken from A. R. Poletti and D. F. H. Start, Phys. Rev. 147, 800 (1966) and references therein; the ^{20}Ne data come from T. Lauritsen and F. Ajzenberg-Selove, in Nuclear Data Sheets-1962, compiled by K. Way, et al., NRC 61-5, 6.
8. F. S. Goulding, D. A. Landis, J. Cerny, and R. H. Pehl, Nucl. Instr. and Methods 31, 1(1964).
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10. Only α-particles corresponding to transitions to the ^{20}Ne g.s. were cleanly observed in system 2 due to the ΔE counter thickness. The fewer coincidence counts resulting from the smaller solid angle of this system were in agreement with the data from system 3, but were not incorporated.

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12. It is of some interest to note that the ^{22}Ne(^{3}He,n)^{24}Mg reaction near this excitation populates only the T=2 state at 15.43 MeV and an additional level at 15.54 MeV (unobserved in these results) with a FWHM of about 380 keV (Ref. 9).

13. J. Cerny and G. T. Garvey, unpublished data.

14. W. T. Sharp, H. E. Gove, and E. B. Paul, A.E.C.L. Report 268, Chalk River, Ontario, 1955.

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16. Although angular momentum statistical factors significantly aid the observation of a T=3/2 state in a $|T_z|$=1/2 nucleus compared to the lowest T=2 state in a T_z=0 nucleus, it is interesting to note that, in general, resonance studies of the latter require lower proton energies which may encourage their investigation.

FIGURE CAPTIONS

Fig. 1. (a) Level diagram showing the ^{24}Mg, 15.43 MeV, 0+, T=2 state and its possible particle-decay modes. Observed transitions are indicated with arrows, along with their percentage branching ratios. (b) Schematic representation of the experimental setup showing the arrangement of the three telescopes and target with respect to the incident beam. Thicknesses of the phosphorous-diffused or lithium-drifted silicon detectors are indicated.

Fig. 2. (a) A two-dimensional spectrum of individual events of tritons from system 1 in coincidence with particles stopping in the ΔE detector of system 3. (b) A two-dimensional spectrum of individual events of tritons from system 1 in coincidence with protons from system 3. The pronounced peak corresponds to decays from the ^{24}Mg T=2 state to the ^{23}Na g.s. (c) The upper spectrum presents the triton singles data. The lower spectra are projections of the bands in the coincidence data onto the triton axis; the arrows in these spectra indicate the energy cutoffs required by kinematics.

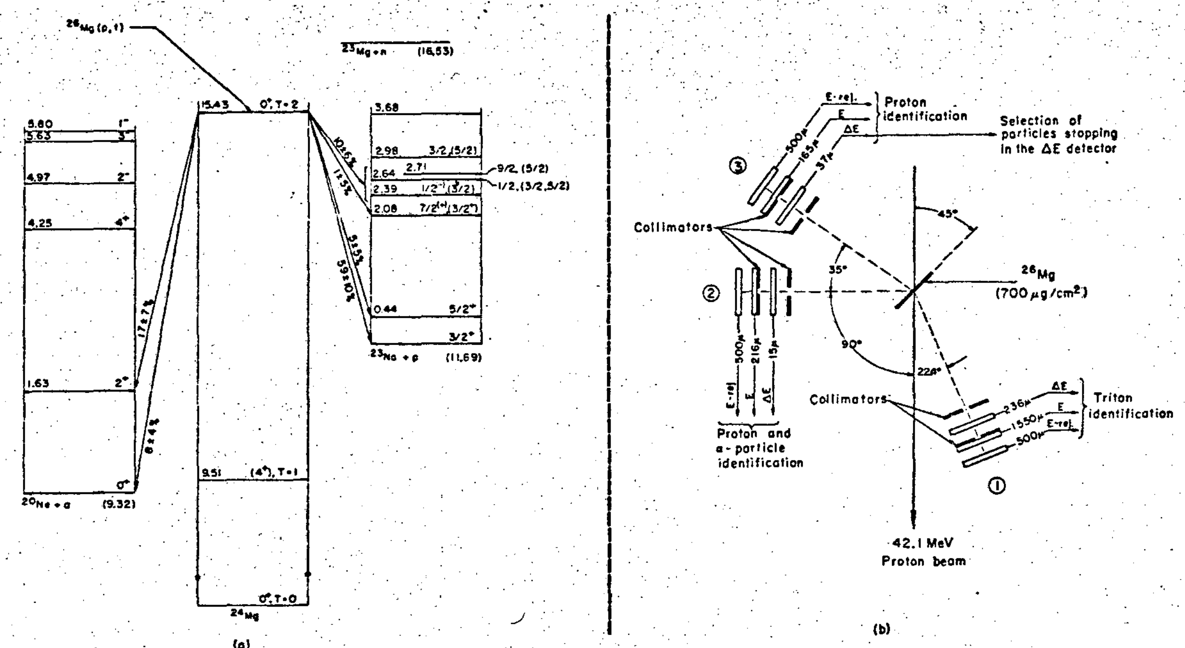

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Fig. 1

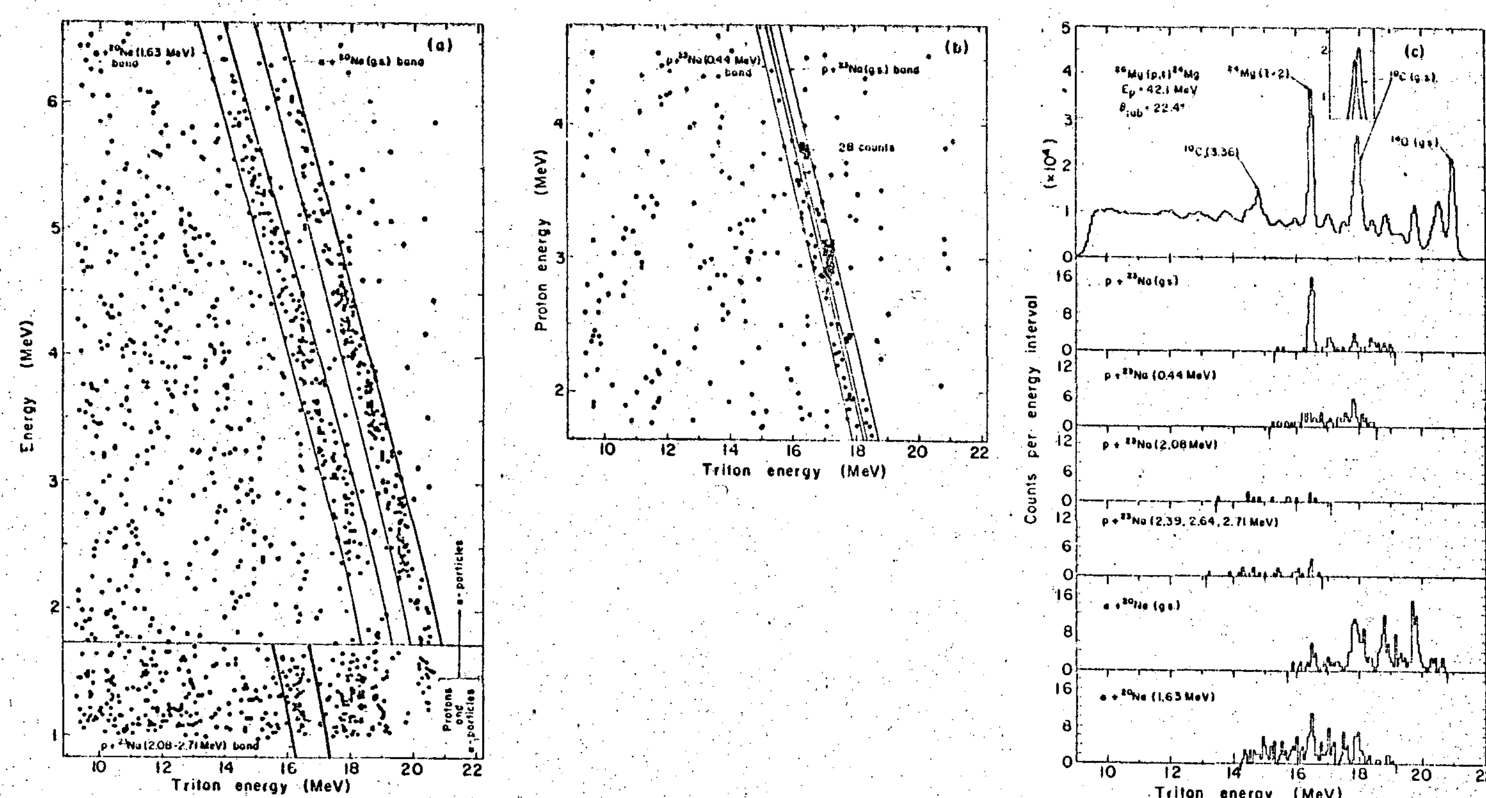

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Fig. 2