OBSERVATION OF $T=2$ LEVEL IN ^{24}Mg AS A COMPOUND-NUCLEUS RESONANCE*

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The lowest $T=2$ level in the self-conjugate nucleus ^{24}Mg has been observed as a sharp resonance in the once-T-forbidden capture reaction $^{23}\mathrm{Na}(p,\gamma)^{24}\mathrm{Mg}_{T=1}{}^*$ and in the twice-T-forbidden elastic scattering $^{23}\mathrm{Na}(p,p_0)^{23}\mathrm{Na}$. The assignment of $J=0$ to this level at $E_x=15.436\pm0.005$ is confirmed by γ-γ correlation measurements.

Several $T=2$ levels in self-conjugate nuclei have been observed as final states in nuclear reactions.[1-4] However, attempts to observe these levels as compound nucleus resonances have not been successful.[5] This Letter reports such an observation of the lowest $T=2$ level in ^{24}Mg, which had been observed[1,3] as a final state in the isospin-allowed reactions $^{26}\mathrm{Mg}(p,t)^{24}\mathrm{Mg}$ and $^{22}\mathrm{Ne}(^3\mathrm{He},n)^{24}\mathrm{Mg}$ but had not been found[5] in the twice-T-forbidden scattering process $^{23}\mathrm{Na}(p,p)^{23}\mathrm{Na}$. The level has now been located and studied by means of the once-T-forbidden capture reaction $^{23}\mathrm{Na}(p,\gamma)^{24}\mathrm{Mg}_{T=1}{}^*$ which leads to a cascade in isospin $T=2\to1\to0$, since the $T=1$ level gamma decays to lower levels. Actually, the observed capture is to a pair of 1^+, $T=1$ levels at 10.03 and 10.80 MeV for which all particle channels are closed (the α_0 channel is energetically open but closed by conservation of spin and parity). Following the location of the $T=2$ level, its particle decay modes were sought in the reactions $^{23}\mathrm{Na}(p, p_0p_1\cdots)^{23}\mathrm{Na}$ and $^{23}\mathrm{Na}(p,\alpha_0\alpha_1\cdots)^{20}\mathrm{Ne}$.

Thin ^{23}Na targets evaporated onto tantalum backings were bombarded with protons from the Stanford High Voltage Engineering Corporation Model FN tandem accelerator. The emitted gamma rays were observed with a 10-in. $\times$10-in. NaI detector encased in an anticoincidence plastic shield and employing pulse-pileup rejection.[6] At $E_p=3.906\pm0.003$ MeV[7] a sharp resonance was observed for a group of four gamma rays with energies of 10.80 ± 0.10, 10.03 ± 0.06, 9.5 ± 0.2, and 8.66 ± 0.10 MeV [see Fig. 1(a)]. Assigning the 10.80- and 10.03-MeV gamma rays as ground-state transitions from 1^+, $T=1$ states and the 9.5- and 8.66-MeV gamma rays as branches to the first excited state in ^{24}Mg, we identify the resonance as the lowest 0^+, $T=2$ state at $E_x=15.436\pm0.005$ MeV.[7] This value agrees with the values of 15.441 ± 0.015 MeV[3] and 15.43 ± 0.07 MeV.[4] The 1^+, $T=1$ states are presumably those observed[8] in $^{23}\mathrm{Na}(d,n)^{24}\mathrm{Mg}$, and they agree well with analog states in ^{24}Na. In fact, the two 0^+, $T=2$ to 1^+, $T=1$ transitions in ^{24}Mg are the gamma analogs of the two observed beta transitions from $^{24}\mathrm{Ne}(0^+, T=2)$ to $^{24}\mathrm{Na}(1^+, T=1)$.

If the target used in Fig. 1 is thick compared with the resonance width, an approximate value of $\Gamma_\gamma\Gamma_p/\Gamma$ of 1.0 eV is obtained for capture to the 10.03 level. If $\Gamma_p\approx0.6\Gamma$ as indicated by McGrath, Cosper, and Cerny,[4] then $\Gamma_\gamma\approx1.7$ eV. The Weisskopf limit for $M1$ radiation is 3.3 eV. The initial slope in the yield curve indicates $\Gamma<2$ keV.

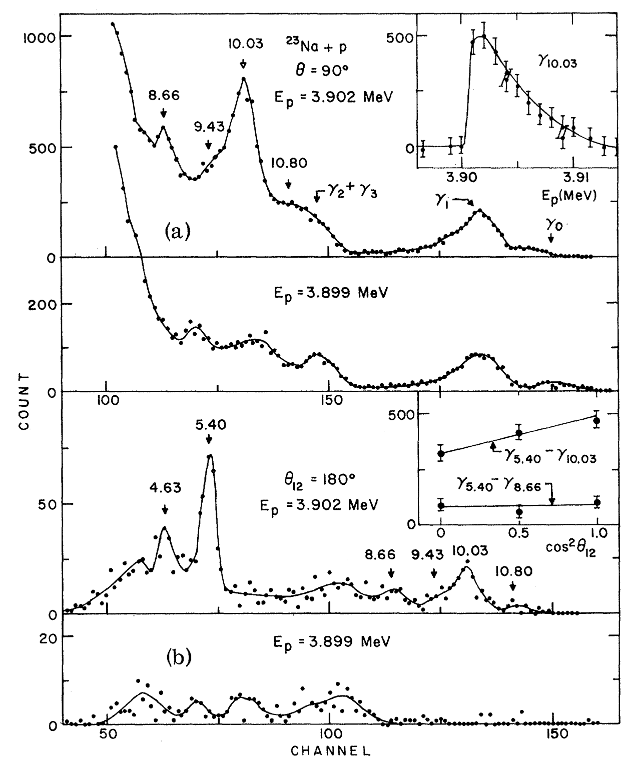

FIG. 1. (a) Top: Spectra of gamma rays obtained on and off the 0^+, $T=2$ resonance of ^{24}Mg. The insert shows the yield curve of the 10.03-MeV gamma ray obtained with a target 4 keV thick. (b) Bottom: Spectra of coincident gamma rays obtained on and off resonance. The 10-in. detector was gated with 4- to 6-MeV pulses from a 3-in. detector. The insert shows the angular correlations for the 5.40- to 10.03-MeV and 5.40- to 8.66-MeV cascades.

The primary capture gamma rays were revealed in coincidence spectra obtained by gating the 10-in.×10-in. detector with 4- to 6-MeV pulses from a 3-in.×3-in. NaI detector [see Fig. 1(b)]. In addition to a 10.03-MeV peak, the coincident 5.40-MeV gamma ray also appears in the spectrum, since the window in the 3-in.×3-in. detector records Compton pulses of the 10.03-MeV gamma ray. There is also evidence for the 4.63- to 10.80-MeV cascade, as well as for the branches to the first excited state.

The γ-γ correlation functions for the cascades through the 10.03-MeV level were measured as shown in the insert in Fig. 1(b). Theoretical angular correlations of $1+\cos^2\theta$ for a 0-1-0 cascade and $1+(1/13)\cos^2\theta$ for a 0-1-2 cascade (second gamma ray dipole) are expected. The correlation for the cascade to the ground state was determined by observing the angular dependence of the coincident yield of the 5.40-MeV gamma ray. This measurement contains a contribution from the cascade to the first excited state, since the window in the 3-in.×3-in. detector also records Compton pulses of the 8.66-MeV gamma ray. The latter correlation was determined by observing the angular dependence of the coincident yield of the 8.66-MeV gamma ray. After making solid angle corrections and allowing for the mixed correlation, one obtains the theoretical correlations shown by the solid lines. All gamma rays following the decay of the 0^+ level should be isotropic relative to the proton beam. Within experimental error isotropy was observed for the 10.03- and 8.66-MeV gamma rays.

The particle reactions were observed in a 24-in. scattering chamber. Only in the elastic scattering at $\theta_L \approx 165°$ was the $T=2$ anomaly observed. The curve in Fig. 2 is the average of four runs. To establish that the proton anomaly occurs at the same energy as the gamma resonance, the data shown in the insert were obtained. Immediately after locating the dip in the proton yield, the accelerator beam was switched, without adjustment, to the gamma-ray station and the gamma-ray resonance was obtained. The strength of the proton anomaly indicates that Γ_p constitutes a major portion of Γ_{tot}, in agreement with the results of McGrath, Cosper, and Cerny.[4] Although no anomalies were observed for the particles α_0, α_1, and p_1, at the angles used in the present work, the indicated upper limits on the widths are probably consistent with the earlier observations.[4]

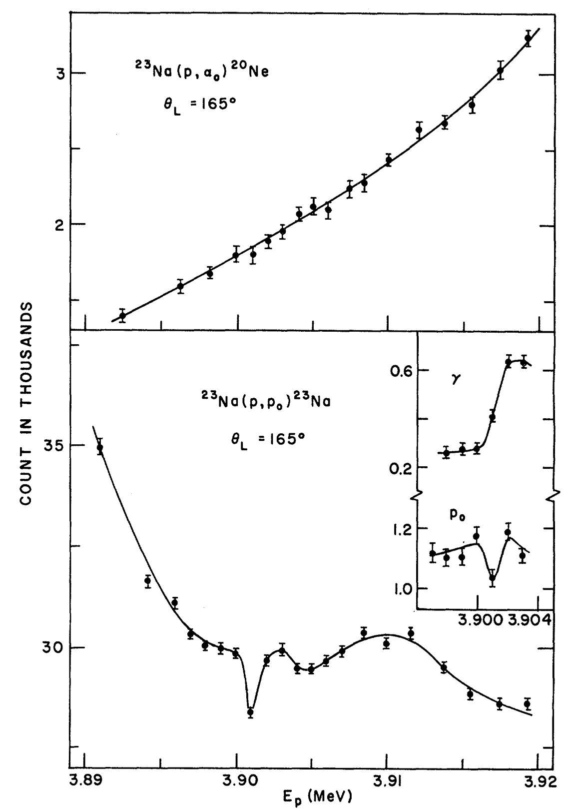

FIG. 2. Yield curves of particles from the reactions ^{23}Na$(p,p_0)^{23}$Na and ^{23}Na$(p,\alpha_0)^{20}$Ne in the vicinity of the $T=2$ resonance of ^{24}Mg. The insert shows a comparison of the (p,γ) and (p,p_0) reactions obtained under similar conditions.

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EXCITATION-FUNCTION STRUCTURE IN $O^{16}+O^{16}$ SCATTERING*

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In recent years excitation functions and angular distributions for heavy-ion–induced reactions and scattering have been studied extensively at low and medium incident energies. The observation of resonances, correlated in energy, in all open channels of the $C^{12}+C^{12}$ system in the region of the Coulomb barrier led to the discovery and study[1,2] of nuclear molecular states. Structure at higher energies in the excitation curve for both elastic scattering and alpha-particle emission from this system was shown to exhibit no cross correlations and was successfully explained[3,4] as reflecting fluctuation phenomena.

A particularly interesting result of the early experiments[5,6] was the total lack of apparent structure in the $O^{16}+O^{16}$ elastic-scattering excitation functions in the same energy range. In this Letter we wish to report on extensions of the $O^{16}+O^{16}$ measurements to higher bombarding energies. In striking contrast to the earlier work we find very pronounced and regular structure in the excitation functions; we suggest that this structure may provide interesting insight into the mechanisms of heavy-ion interactions.

The experiments involved bombardment of self-supporting SiO targets with O^{16} ion beams in the energy range from 35 to 80 MeV from Yale's High Voltage Engineering Corporation Model MP tandem accelerator. Measurement of elastic scattering uncontaminated by inelastic processes was assured through requirement of kinematic coincidence between scattered and recoil O^{16} ions; a detector array allowed simultaneous coincidence measurements at five variable angles. Angles subtended by the detectors were ±0.5° and the angle setting precision was better than 0.1°. Absolute cross sections were determined by comparison with Mott-scattering predictions at 20 MeV and are quoted with an accuracy of ±20 %.

Excitation functions measured at 50°, 60°, 70°, 80°, and 90° in the center-of-mass frame are shown in Fig. 1. It should be noted that for pure Mott scattering the 90° yield function is smooth. Several angular distributions mea-

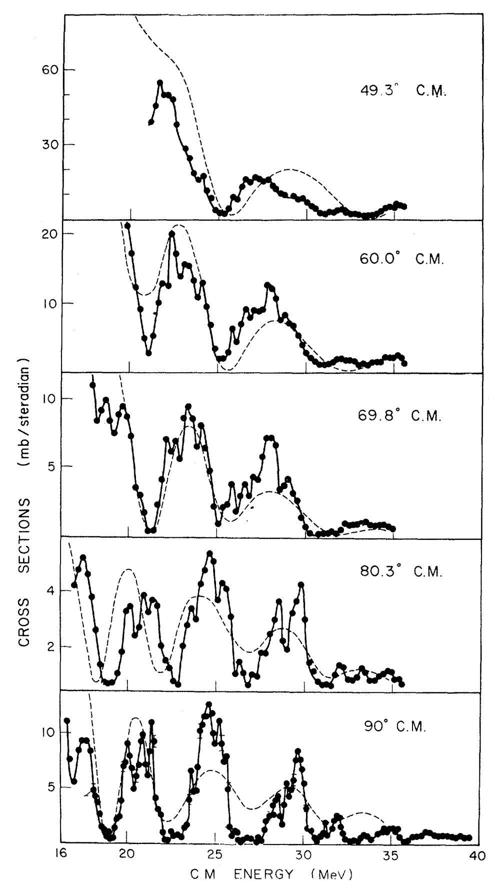

FIG. 1. $O^{16}+O^{16}$ elastic-scattering excitation functions measured at five different angles. The dashed curves represent the theoretically predicted excitation functions calculated with the potential listed in Table I. The excitation functions at 50° to 80° were measured with an effective energy resolution reflecting target thickness of 400 keV. The energy resolution for the 90° excitation function was 125 keV.