Evidence for $\Delta T = 1$ Magnetic Quadrupole Transitions in ^{24}Mg Excited by 180° Electron Scattering

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The data of an earlier paper presenting the results of 180° electron scattering from ^{24}Mg have been reexamined using more refined data-treatment techniques. Present results favor an assignment of 2^- for $T=1$ states at 12.91 and 13.37 MeV with estimates for radiation widths Γ_0 of 0.11 and 0.13 eV, respectively. Revised transition widths for the 1^+, $T=1$ states at 9.94 and 10.70 MeV are found to be 7.6 and 17.6 eV, respectively, in better agreement with results of other workers.

IN a paper[1] dealing primarily with $M1$ transitions in ^{24}Mg excited by 180° scattering of 39- and 56-MeV electrons, it was suggested that the structure in the 13-MeV region might arise from magnetic quadrupole transitions. This suggestion has been explored with a quantitative analysis of this structure made possible by improved data-treatment techniques. In the process, it was decided to reanalyze the $M1$ transitions in the 10-MeV region.

The results of our analysis are presented in Table I. Tentative assignments of 2^- are given to levels at 12.91 and 13.37 MeV along with corresponding estimates of the radiation widths Γ_0 and transition radii R_M. The small intensities of these peaks in the 39-MeV spectrum and the indefiniteness of the baselines for peaks at excitation energies greater than 12 MeV are reflected in the large uncertainties given for the values of Γ_0 and R_M. These results are based on the assumption that only magnetic multipole transitions are significantly excited by 180° scattering. However, occasionally $E1$ transitions can be excited at 180°, and their intensity behavior as a function of momentum transfer may be indistinguishable from that of $M2$ transitions. The revised values of Γ_0 and R_M for the 1^+, $T=1$ states at 9.94 and 10.70 MeV are also given in Table I.

The data are analyzed employing equations based on the first (plane-wave) Born approximation.[1,2] However, the measured cross sections are first multiplied by a correction factor which accounts for distorted-wave effects[3] before being used in the plane-wave equations. This is our first use of such a correction for $M2$ transitions. The correction for $M1$ transitions was not used in obtaining the values given in Ref. 1.

We point out the general similarity between the full 56-MeV spectra of ^{24}Mg (Fig. 1 of Ref. 1) and ^{28}Si (Fig. 1 of Ref. 4). In each case, there are strong $\Delta T=1$, $M1$ transitions in the general region of 10 to 12.5 MeV, what appear to be rather strong $M2$ transitions in the region from 12.5 to about 15 MeV, and about four roughly equally spaced peaks between 15 and 21 MeV. Recent evidence[4] supporting the presence of 2^- levels in ^{28}Si at 13.12 and 14.66 MeV is of interest since Hill[5] predicts the existence of 2^-, $T=1$, spin-isospin resonance states in this nucleus at 14.3 and 14.8 MeV. It therefore seems reasonable to suggest that a similar identification may be made in the present case with the 12.91- and 13.37-MeV states in ^{24}Mg.

Independent of ^{28}Si, an assignment of 2^-, $T=1$ for these ^{24}Mg states is consistent with an isospin selection rule for magnetic multipole transitions in self-conjugate nuclei first given by Warburton.[6] Krone *et al.*,[7] using the ^{23}Na$(p, \alpha\gamma)^{20}$Ne reaction, report 2^- states in ^{24}Mg at 12.85 and 12.97 MeV. Our peak at 12.91 MeV is undoubtedly the unresolved combination of these states. Their work does not extend high enough in energy to include the 13.37-MeV state.

The revised values of Γ_0 for the two strong $\Delta T=1$, $M1$ transitions given in Table I show better agreement with the photon scattering results of Kuehne *et al.*[8] and

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TABLE I. Values of differential cross sections, spin and parity, transition radii, and radiation widths for energy levels excited in ^{24}Mg. Transition radii and radiation widths have been corrected to the distorted-wave theory.

Level energy (MeV)	$(d\sigma/d\Omega)_{56}$ (10^{-34} cm²/sr)	$(d\sigma/d\Omega)_{39}$	J^π	R_M (fm)	Γ_0 (eV)
9.94±0.03	104±5	202±15	1^+	$2.94_{-0.20}^{+0.18}$	$7.6_{-1.4}^{+1.6}$
10.70±0.03	194±7	372±21	1^+	$2.94_{-0.15}^{+0.13}$	$17.6_{-3.0}^{+3.5}$
12.91±0.06	76±18	58±33	(2^-)	$3.9_{-3.9}^{+1.4}$	$0.11_{-0.08}^{+0.14}$
13.37±0.05	95±18	63±38	(2^-)	$3.5_{-3.5}^{+1.5}$	$0.13_{-0.08}^{+0.18}$

with the more recent results of Titze[9] who uses electron scattering at angles of 104° to 153°. In particular, all three values of Γ_0 for the 10.70-MeV level are in good agreement. Titze has analyzed the 9.94-MeV peak into two components at 9.97 and 9.85 MeV. The sum of the corresponding Γ_0's is in good agreement with the value of Kuehne *et al.* and in fair agreement with our somewhat larger value. With the new values of Γ_0 we obtain a revised value for the ground-state ls coupling matrix element,[8,10] $\langle\sum \mathbf{l}_i\cdot\mathbf{s}_i\rangle = 6.79$ [see Eq. (6) of Ref. 1], which is now in better agreement with the value of 6.04 calculated[8] from the Nilsson model (with $\eta=4$).

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Theoretical Study of 1^+ and 3^+ States in Even-*A* Nickel Isotopes

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Employing the effective matrix elements of Kuo and Brown, of Auerbach, and of Cohen *et al.*, the low-energy 1^+ and 3^+ levels in even-*A* nickel isotopes are studied within the framework of the modified Tamm-Dancoff approximation. Their properties and reduced transition rates are examined.

It is well known that both the shell-model as well as the quasiparticle-model calculations predict 1^+ and 3^+ states for even-*A* single-closed-shell nuclei, though very few measurements have been reported so far concerning these levels. The purpose of this paper is to make available the predictions of the quasiparticle model about these levels for even-*A* nickel isotopes. An interest in these levels has been expressed in a recent publication by Lombard.[1]

The calculations reported here are carried out within the framework of the modified Tamm-Dancoff approximation (MTDA) method[2,3] by assuming Ni^{56} as the core with the valence neutrons occupying the $1p_{3/2}$, $0f_{5/2}$, and $1p_{1/2}$ single-particle orbitals. The unperturbed single-particle energies for the orbitals $1p_{3/2}$, $0f_{5/2}$, and $1p_{1/2}$ are taken to be 0.0, 0.78, and 1.08 MeV, respectively, from the Ni^{57} spectrum. The single-particle orbital $0g_{9/2}$ lies rather high (about 5 MeV) and therefore, is not included. The unpublished two-body renormalized matrix elements of the Hamada-Johnston potential as calculated by Kuo and Brown[4] (KB), the phenomenologically determined two-body matrix elements of Cohen *et al.*[5] (EIC), as well as those derived by Auer-

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