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Coulomb-Distortion Effects in Magnetic Multipole Electroexcitation*

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Computer calculations of Coulomb-distortion effects are presented for inelastic electron scattering inducing $M2$ transitions in light nuclei. The distortion effect is presented over $1 < Z < 20$, 40 MeV $< E_0 <$ 140 MeV, $10 < k < 19$ MeV, and for two large angles of scatter. The dependence of the calculation on the assumed nuclear transition current is displayed.

An addition is presented to our study of Coulomb-distortion effects for $M1$ transitions in nuclei induced by inelastic electron scattering.[1] Systematics of Coulomb distortion are presented here primarily for magnetic quadrupole ($M2$) transitions. The computations are made with the distorted-wave Born-approximation (DWBA) calculation of inelastic electron scattering developed by the Duke University group.[2]

Magnetic quadrupole transitions are under active exploration by several electron scattering groups. $M2$ transitions in even-even nuclei were first observed by inelastic electron scattering in ^{16}O at 19.08 MeV and in ^{12}C at 19.4 MeV.[3] These 2^-, $T=1$ states have been interpreted in the particle-hole model as components of the giant-dipole resonance resulting from spin-isospin-flip transitions. More recently, $M2$ transitions have been observed in ^{16}O at 12.53 and 12.97 MeV[4,5] and in ^{24}Mg at 12.91 and 13.37 MeV.[6] Further, the first 2^- resonance in ^4He appears to be visible in 180° electron scattering.[7]

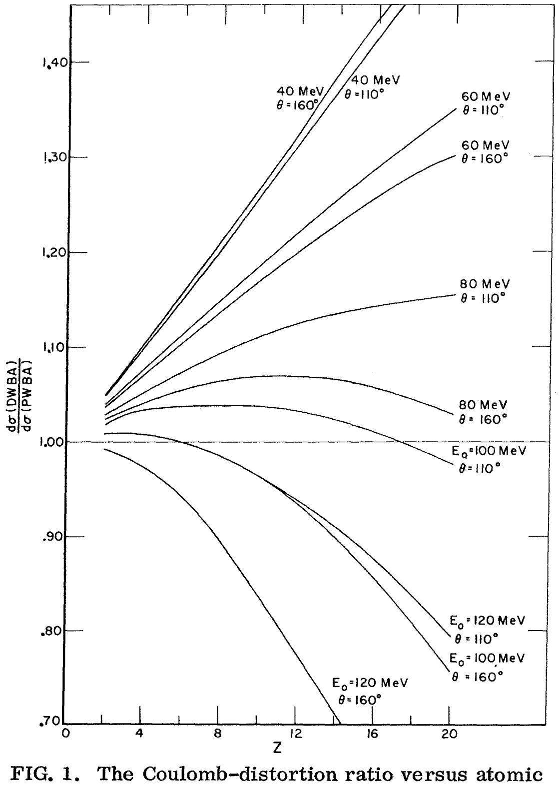

FIG. 1. The Coulomb-distortion ratio versus atomic number, incident electron energy, and angle is presented for electroexcitation of $M2$ transitions at 19 MeV.

The $M2$ cross sections increase as q^4 so that 2^- states are strongly excited in large-angle electron scattering at $E_0 \gtrsim 80$ MeV. Energy resolution of 80 keV at 100-MeV bombarding energy combined with the greatly improved ability in removing the radiation tail at large excitation energies presently make possible accurate determination of $M2$ form factors.[5] Therefore, it is important to improve on the plane-wave analysis of inelastic electron scattering cross sections.

Using the Duke program we have computed the Coulomb-distortion effects in $M2$ electroexcitation using a partial-wave analysis for the electron waves combined with a one-photon-exchange assumption for the nuclear excitation. The nuclear

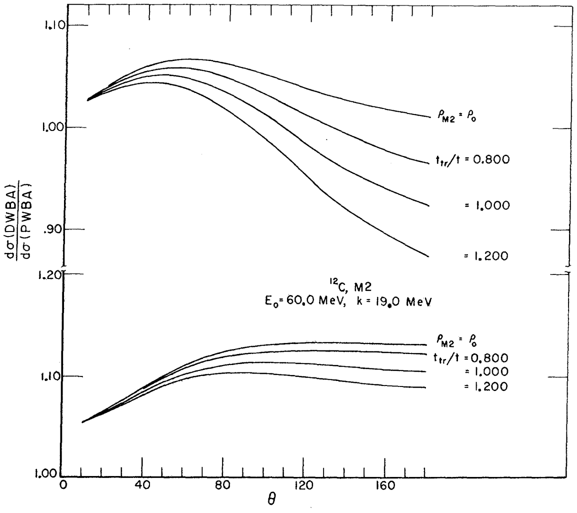

FIG. 2. The dependence of the DWBA calculation on the assumed nuclear model is given for electroexcitation of the 19-MeV $M2$ state in ^{12}C. The upper four curves are for $E_0 = 120$ MeV and the lower set for 60-MeV electrons. $\rho_{M2} = \rho_0$ and t_{tr}/t are explained in the text.

transition current was varied to check the model dependency of the computations. The relevant parameters have the following range:

electron energy	40 to 140 MeV,
atomic number	$_2$He to $_{20}$Ca,
excitation energy	13, 16, and 19 MeV for $M2$, 10 and 15 MeV for $M1$,
scattering angle	10 to 180°,
partial-wave number	10 to 15 waves,
nuclear model	incompressible and irrotational liquid drop using c and t from elastic electron scattering.

The distortion ratios for all combinations of these parameters are available in tabular form from the authors.

The results of the calculation are presented in the three figures where the ordinate is the distortion effect $d\sigma\,(\mathrm{DWBA})/d\sigma(\mathrm{PWBA})$. The denominator in the ratio is computed by the partial-wave analysis with $Z=0$. Figure 1 presents the $M2$ results at 19.0-MeV excitation. The distortion ratios are approximately the same at 13.0- and 16.0-MeV excitation. Two angles are displayed which approximate typical experimental conditions.

Figure 2 depicts the sensitivity of the Coulomb-distortion ratio on the model for the nuclear transition current in $M2$ electron scattering. The notation follows the earlier work,[1] where the transition current is $\vec{J}_N=\rho_2\vec{Y}^{M}_{L,L,1}{}^{*}$, where $\rho_2=r\,\partial\rho_0/\partial r$, and ρ_0 is the Fermi distribution. The constants in ρ_0 are from the ground-state charge distribution when $t_{\mathrm{tr}}/t=1.00$. The model is varied by changing the skin thickness, which makes the assumed surface current distribution more diffuse as t_{tr}/t increases from 0.8 to 1.2. A completely different model is shown in Fig. 2 for $\rho_2=\rho_0$, which spreads the assumed transition current uniformly over the nuclear volume. The 120-MeV computation for $_6$C is completely model dependent for large scattering angles; moreover, this model dependency becomes more pronounced for larger nuclei, e.g., $_{14}$Si. This sensitivity to the assumed nuclear model does not weaken the necessity of making Coulomb-distortion corrections, but rather it requires very accurate experiments to select the most consistent (best fit) model.[8,1]

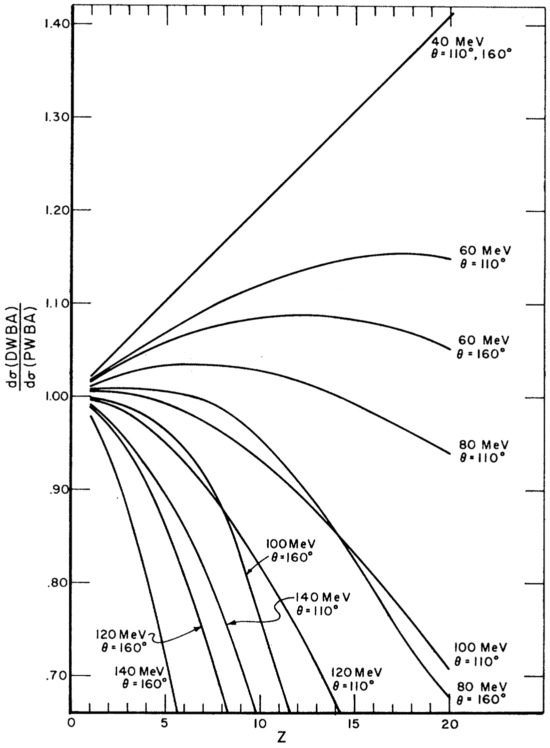

FIG. 3. The Coulomb-distortion ratio is plotted versus Z, E_0, and θ for $M1$ electroexcitation at 15 MeV.

The $M1$ distortion ratios are presented in Fig. 3 and represent an addendum to our earlier work. The nuclear transition current is parametrized as $(\partial\rho_0/\partial r)\vec{Y}^{M}_{111}{}^{*}$.

The computational errors as determined by the convergence of the last six partial waves are less than ±1% for the results presented here.

Finally the DWBA corrections have been applied to the 180° electron scattering measurements of $M2$ transitions at 12.91 and 13.37 MeV in $^{24}_{12}$Mg.[6] The radiative widths are reduced by approximately 40% from the plane-wave analysis, and the transition radii for these two states are reduced by ~8% compared with the values in the plane-wave analysis.

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Low-Energy Gamma Rays from Resonant Neutron Capture in $\mathrm{Tm}^{169\dagger}$

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Low-energy γ rays following slow-neutron capture in thulium have been used to check the angular-momentum assignments of the neutron resonances. A previous discrepancy in the spin of the 17.5-eV resonance has been resolved. The correlation between reaction widths noted in previous work has been recalculated and found to be substantially unchanged. An isomeric state at 183.2 keV has been investigated by measuring the delay in the low-energy transitions involving this state, and a half-life of 3.2 ± 0.3 μsec is obtained, in fair agreement with previous work.

1. INTRODUCTION

This brief note on some new experimental data on the $\mathrm{Tm}^{169}(n, \gamma)\mathrm{Tm}^{170}$ reaction is to be considered as an addendum to a paper by Lone *et al.*[1] In this paper, the emphasis was on the prompt high-energy γ rays from the resonance- and thermal-neutron capture in Tm^{169}. Additional data on the partial widths of the 151-eV resonance were reported by Chrien[2] at the Dubna Nuclear Structure Conference. In the present work, we have studied low-energy ($\leq$511-keV) γ rays from individual resonances in this nucleus. From these data, we have found it possible to (a) determine the spins of the neutron resonances and (b) find the half-life of an isomeric state at an excitation energy of 183.2 keV in Tm^{170}.

2. EXPERIMENTAL RESULTS

The data were obtained at the high-flux beam reactor fast chopper with a 37-c.c. Ge(Li) detector, a chopper speed of 10 000 rpm, and a flight path of 48.8 m. The Ge(Li) detector had a resolution of 3.8 keV at 511 keV. The thulium target was 3.8 ×3.8 in. with 179.4 g of $\mathrm{Tm_2O_3}$, and the total running time for the experiment was 31 h. The time-of-flight spectrum obtained is shown in Fig. 1, where the resonance energies are given in eV. We are able to resolve resonances up to an energy of 115.2 eV. Some recent work by de Barros *et al.*[3] has shown that the resonance at 94.0 eV is made up of two closely spaced resonances at 93.5 and 94.0 eV, and we are not able to resolve these. The straight lines under the resonances indicate the scan limits set on the time-of-flight to obtain the γ-ray spectra originating by neutron capture in these resonances. Such spectra obtained from the 14.4- and 34.8-eV resonances are shown in Fig. 2 and are typical of the γ-ray spectra obtained from these resonances. The analysis of these spectra to obtain the resonance spins is discussed in the next section.

3. DETERMINATION OF THE SPINS OF THE *s*-WAVE NEUTRON RESONANCES

These low-energy γ rays observed in resonance capture represent transitions between the different low-lying levels of the compound nucleus Tm^{170} and are the result of these states being populated by a large number of the high-energy primary transitions. Hence, these γ rays represent some sort of an average over contributions from many intermediate states and do not show the wide intensity fluctuations characteristic of primary transitions. In spite of such an averaging, one can expect the intensities of these low-energy γ rays to

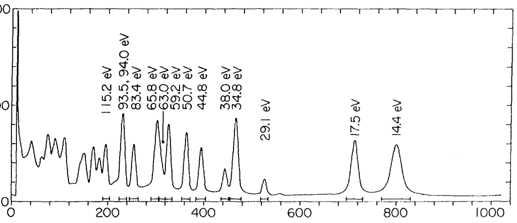

FIG. 1. Time-of-flight spectrum of thulium.