Branching ratio of the ^{26}Mg$(e,e'\alpha_0)^{22}$Ne reaction in the giant resonance region

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This work presents results from an $(e,e'\alpha_0)$ experiment in ^{26}Mg. The α_0 decay branch of the GDR exhibits a small strength, as compared with the statistical expectation, and a large transition radius. Those characteristics suggest that only a fraction of the nuclear charge (close to the surface) participates in the process that leads to the α decay to the ground state of ^{22}Ne.
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In a recent paper [1], we reported on the $E0$, $E1$, and $E2$ multipole components of the ^{26}Mg$(e,e'\alpha_0)$ cross section, obtained in a model-independent analysis. The integrated strength of those cross sections exhaust very small fractions of the corresponding energy-weighted sum rules (EWSR): 0.5, 3, and 1% for $E1$, $E2$, and $E0$, respectively. This work presents a distorted-wave Born approximation (DWBA) analysis of the $E1$ component of the $(e,e'\alpha_0)$ and (e,e') reactions and a comparison of the measured branching ratios with Hauser-Feshbach statistical model calculations, offering a possible explanation for the small strengths associated with the α_0 decay of ^{26}Mg.

The $E1$ form factor is given by

$$F_{E1}^2(q)=\frac{\int_{14\ \mathrm{MeV}}^{22\ \mathrm{MeV}}\sigma_{E1}(E_x)dE_x}{\sigma_M},\qquad(1)$$

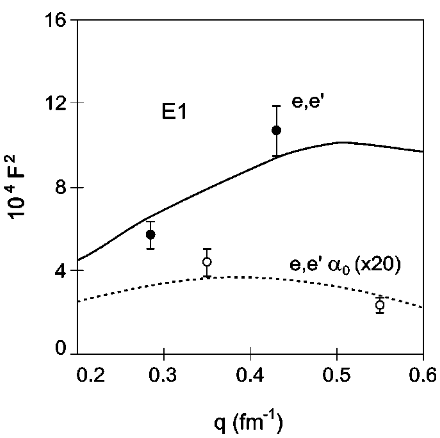

FIG. 1. $E1$ form factors for (e,e') (full circles) and $(e,e'\alpha_0)$ (open circles) reactions. DWBA calculations using the GT model for the charge distribution are shown for $c_h=c_0$ (full curve) and $c_h=1.4c_0$ (dotted curve). See text for explanations.

where $\sigma_{E1}(E_x)$ is the $E1$ cross section for an excitation energy E_x and σ_M is the Mott cross section. The integration is done over the interval 14–22 MeV, where essentially all the $E1$ strength of the α_0 channel is located [1]. Figure 1 shows the $E1$ form factors, versus the momentum transferred, q, for the $(e,e'\alpha_0)$ reaction (present work, open circles, data obtained at the MAMI-A2 microtron [2]) and for the (e,e') reaction (Ref. [3], full circles). The lines represent results of calculations using the distorted wave Born approximation formalism[4] and the Goldhaber-Teller (GT) model for the transition-charge density distribution

$$\rho_L^{\mathrm{tr}}(r)=C^{\mathrm{GT}}r^{L-1}\frac{d\rho_0(r)}{dr},\qquad(2)$$

where $\rho_0(r)$ is the ground-state charge density distribution. The GT model was chosen because it describes the full set of experimental data better than other models. The ground-state charge density distribution is represented by a two-parameter Fermi function

$$\rho_0(r)=\rho_0\{1+\exp[(r-c_0)/z]\}^{-1},\qquad(3)$$

with experimental values of parameters: $c_0=3.06$ fm and $z=0.52$ fm [5]. These values were used for the calculation of the GT transition-charge density distribution to describe the (e,e') data. For an adequate description of the $(e,e'\alpha_0)$

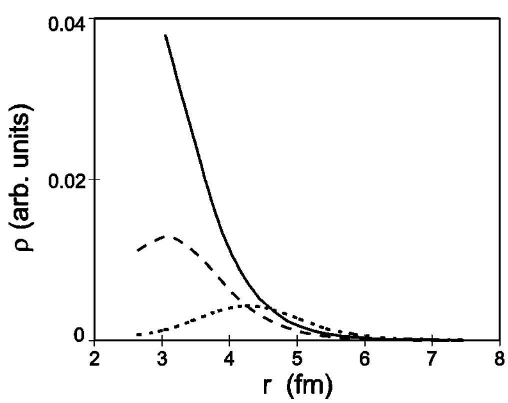

FIG. 2. Charge density distributions: for the ground state (full curve), for $\rho_1^{\mathrm{tr}}(r)$ corresponding to $c_h=c_0$ (dashed curve), and for $\rho_1^{\mathrm{tr}}(r)$ corresponding to $c_h=1.4c_0$ (dotted curve).

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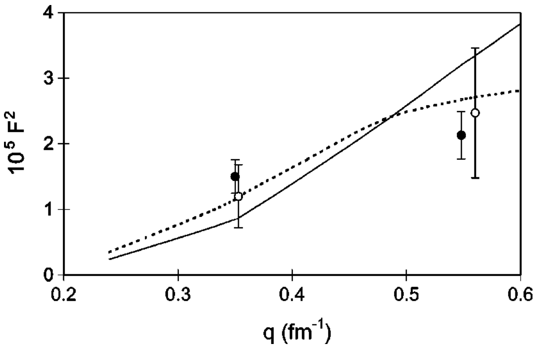

FIG. 3. Form factors for the $(e,e'\alpha_0)$ reaction: $E0$ (open circles) and $E2$ (full circles). The full curve represents a DWBA calculation using the GT model for the charge distribution and $c_h = c_0$. Dotted curve: the same for $c_h = 1.4c_0$.

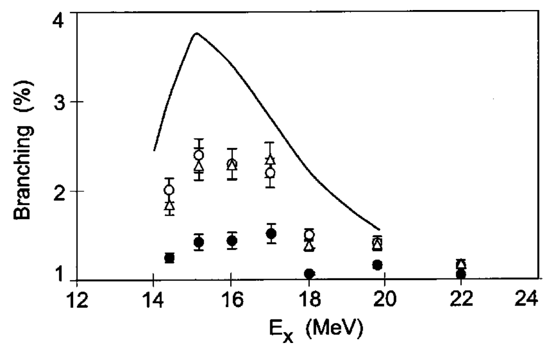

FIG. 4. Branching ratios for the $(e,e'\alpha_0)$ reaction. The full curve represents a purely statistical decay. The experimental branching ratios, obtained as the ratio of the form factors for the $(e,e'\alpha_0)$ and (e,e') reactions are shown for $q=0.35$ fm^{-1} (open circles) and 0.54 fm^{-1} (full circles). The branching ratios obtained from the extrapolated form factors (see text) are shown by the triangles.

data, the transition-charge density distribution was calculated using a hypothetical ground-state charge distribution given by $c_h = 1.4c_0$ and $z = 0.52$ fm. These calculations were also normalized to the experimental data by adjusting the resonance strength.

It is interesting to notice the different q dependence of the form factors for (e,e') and $(e,e'\alpha_0)$ reactions. The (e,e') form factor increases with q in the measured range (0.35–0.55 fm^{-1}), while the $(e,e'\alpha_0)$ form factor decreases in this same range. The different character of the q dependence of the form factors can be explained, in the framework of the GT model, as a result of a difference in the radial dependence of the transition-charge density [4]. Figure 2 shows the charge density distributions for the ground state of ^{26}Mg (solid curve); for $\rho_1^{tr}(r)$ calculated both with $c_h = c_0$ (dashed curve) and with $c_h = 1.4c_0$ (dotted curve). $\rho_1^{tr}(r)$ was normalized [4] according to $\int_0^\infty \rho_1^{tr}(r) r^3 dr = 1$. A large transition radius in the case of the $(e,e'\alpha_0)$ reaction means that only a superficial fraction of the charge participates in the process. Data for $E2$ and $E0$ resonances (Fig. 3) are not so sensitive to the choice of c_h, since for these multipolarities both values of c_h give the same q dependence for the form factor. Nevertheless, DWBA calculations for $c_h = 1.4c_0$ describe the experimental data somewhat better.

We also calculated the α_0 branching ratio assuming the decay to be completely statistical, independent of structure effects, for all kinds of emitted particles. The calculation [6] was accomplished in the Hauser-Feshbach approach [7], assuming complete separation between the channels:

$$P_i = \frac{\sigma_i(E_\gamma)}{\sigma_{\text{abs}}(E_\gamma)} = \frac{\sum_{m_s l} T_i^{m_s l}(E_\gamma - Q_i)}{\sum_k \sum_{m_s l} T_k^{m_s l}(E_\gamma - Q_k)}, \tag{4}$$

where $\sigma_i(E_\gamma)$ is the partial cross section for the ith decay channel, $\sigma_{\text{abs}}(E_\gamma)$ is the absorption cross section, $T_i^{m_s l}(E_\gamma - Q_i)$ is the transmission coefficient for the ith channel, m_s and l are the spin and angular momentum of the emitted particle, and Q_i is the energy of the reaction threshold. To calculate the transmission coefficients we used optical model parameters from Ref. [8] and the available experimental data for the energy levels of the residual nuclei. The results of such calculations are shown in Fig. 4 by the solid curve. Experimental data for the branching ratio were obtained as the ratio of the form factors for the $(e,e'\alpha_0)$ and (e,e') reactions. This was done for the energy bins associated with the structures that appear in the energy spectra. These ratios are shown in Fig. 4, for $q=0.35$ fm^{-1} (open circles) and 0.54 fm^{-1} (full circles). The experimental values for the branching ratio are different for $q=0.35$ and 0.54 fm^{-1} and both sets of data are significantly below the statistical calculation. These facts build up a pattern which is incompatible with the statistical decay of a nuclear level, since in this case the branching ratio should be independent of the momentum transferred. But supposing that in the $(e,e'\alpha_0)$ reaction only a superficial part of $\rho_1^{tr}(r)$ participates in the process (corresponding to $c_h = 1.4c_0$), we can extrapolate, in the framework of the GT model, the $(e,e'\alpha_0)$ form factors to the photon point. The values of the branching ratios corresponding to the extrapolated form factors are the same for $q = 0.35$ and 0.54 fm^{-1}. The averaged values of the branching ratio (triangles), obtained from the form factors extrapolated to the photon point [using $c_h = c_0$ for the (e,e') reaction and $c_h = 1.4c_0$ for the $(e,e'\alpha_0)$ reaction] are also below the statistical predictions.

The q dependence of the $E1$, $E2$, and $E0$ form factors of the reaction ^{26}Mg$(e,e'\alpha_0)^{22}$Ne correspond to transition-charge densities concentrated on the surface of the nucleus. The measured α_0 branching ratio for $E1$ transitions is less than the statistically expected value, indicating a nonstatistical mechanism of the α_0 decay.

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