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LETTER TO THE EDITOR

Alpha capture to the giant dipole resonance

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Abstract. Cross sections for α capture to the giant dipole resonances of 1d2s and 1f2p shell nuclei are shown to be in agreement with Hauser–Feshbach calculations. Isospin mixing in ^{28}Si, ^{32}S and ^{40}Ca is discussed. It is shown that α caputure data do not provide a conclusive test for the proposed isosplitting of the ^{60}Ni and ^{42}Ca giant dipole resonances.

The study of α capture reactions has not become as important a method of investigating the giant dipole resonance as was first hoped (Meyer-Shutzmeister *et al* 1968, Watson *et al* 1973, Branford *et al* 1973). A reason for this is that (α, γ) excitation functions do not exhibit a giant dipole resonance (GDR) shape, which could be due to α capture exciting other states. To obtain more information on this problem, we have carried out a systematic study of α capture on 1d2s and 1f2p shell nuclei.

Excitation functions at 90° to the beam direction and angular distributions were measured for the (α, γ_0) reaction using targets of ^{38}Ar, ^{40}Ar, ^{48}Ti and ^{56}Fe. The experimental details are described by Watson *et al* (1973) and Foote *et al* (1974a, b). The angular distribution measurements showed that the reaction proceeds almost entirely through 1^- states. The measured excitation functions were smoothed sufficiently to remove the fine structure and converted to those for the inverse reaction using the principle of detailed balance. These results are shown in figure 1 together with other (α, γ_0) data.

We observed from these data that the maximum cross sections occur at α energies close to the Coulomb barrier height and have magnitudes approximately inversely proportional to the number of open channels. These results, taken together with other supporting evidence (Meyer-Shutzmeister *et al* 1968, Watson *et al* 1973, Kellar and McConnell 1972, Meneghetti and Vitale 1965), strongly suggest that the (γ, α_0) reaction proceeds through the compound nucelus in a statistical manner. In view of this, we have calculated (γ, α_0) cross sections for these reactions using the theory of Hauser and Feshbach (1952). The cross section can be expressed as

$$\sigma(\gamma, \alpha_0) = \sigma_{\mathrm{CN}} \frac{T_{\alpha_0}}{\Sigma_i T_i} \qquad (1)$$

where σ_{CN} is the total absorption cross section for dipole radiation, T_i are transmission coefficients, and the summation is taken over all decay channels. The sum of T_i for low excitation in the residual nuclei was calculated using the energies and J^π of known isolated levels, while at high excitation energies, the level densities given by Gilbert and

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Cameron (1965) were used. The σ_{CN} used for ^{28}Si, ^{30}Si, ^{40}Ca, ^{42}Ca and ^{44}Ca were the total photonuclear absorption cross sections for natural Si and Ca measured by Bezic *et al* (1968). For ^{52}Cr and ^{60}Ni, approximate σ_{CN} were obtained by adding together (γ, n) and (γ, p) photonuclear cross sections of Berman (1973), and Ishkhanov *et al*

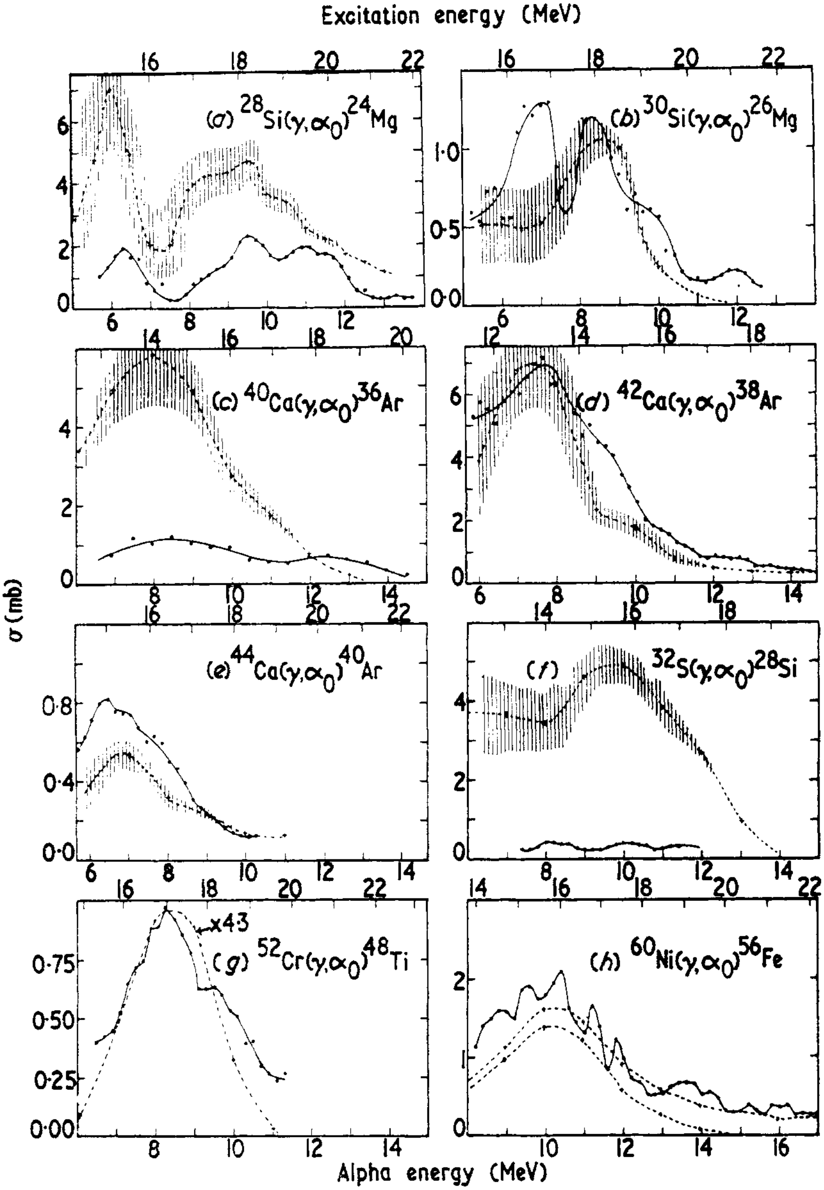

Figure 1. Excitation functions for the (γ, α_0) reaction obtained from α capture data using the principle of detailed balance. The data shown in (*a*) and (*f*) are from Meyer-Shutzmeister *et al* (1968). Those in (*b*) are from Watson *et al* (1973). The relative experimental errors are approximately ± 10%. The absolute errors are ± 25%. The broken curves are the results of calculations (see text). The vertical lines indicate the relative errors due to uncertainties in the total photonuclear cross sections where they are greater than ± 10%. The crosses indicate the energies at which transmission coefficients were calculated.

(1970). The (γ, n) and (γ, p) cross sections of Antropov *et al* (1967) and Shoda *et al* (1962) were used for ^{32}S. The transmission coefficients for p, n and α channels were calculated using the optical model parameters of Perey (1963), Wilmore and Hodgson (1964), and Bock *et al* (1967), respectively. The calculated (γ, α_0) cross sections are compared to the experimental data in figure 1.

Figure 1 shows that in all cases the excitation energy of the calculated peak in the (γ, α_0) cross section is in good agreement with experiment. For $N \neq Z$ nuclei, in which excitation of the GDR is isospin allowed, the absolute magnitudes and shapes of the excitation functions are in reasonable agreement with experiment. The exception to this is ^{52}Cr (γ, α_0) for which it was necessary to multiply the calculated cross section by a factor of 4·3 to give agreement with experiment. This reaction differs from the others in that the number of open channels is very much higher. This reduces the statistical contribution to the cross section making the effect of the non-statistical cross section more important (discussed later). In addition, the statistical contribution to the peak cross section depends heavily on the accuracy of the level density formula; for all the other data shown in figure 1, the calculated peak cross sections are determined using known isolated levels. For $N = Z$ nuclei, the calculated (γ, α_0) strength is larger than the observed strength as expected since α capture to the GDR of $T = 0$ nuclei is isospin forbidden. In view of these results and the other supporting evidence presented here, we conclude that α capture most probably excites the GDR. This is assumed in the following.

It is observed that the ratio of the calculated to experimental cross sections for the $N = Z$ nuclei increase with excitation energy. Since α capture to the $T = 1$ GDR of a self-conjugate nucleus most probably takes place through a $T = 0$ component, these results imply that the amplitude α of the $T = 0$ isospin impurity, increases with excitation energy up to $E_x \simeq 20$ MeV. At higher energies, it has been suggested by Watson *et al* (1973) that α decreases with increasing E_x. We conclude, therefore, that the data presented here give further support to the idea suggested by Wilkinson (1956) that α increases initially with respect to E_x due to Γ/D increasing and then decreases when Γ becomes much larger than the Coulomb matrix elements.

Assuming that $\sigma(\gamma, \alpha_0)$ is proportional to α^2, we calculated average values of α for the energy ranges considered here. The results are $\bar{\alpha}(^{28}\text{Si}) = 0{\cdot}6 \pm 0{\cdot}3$, $\bar{\alpha}(^{32}\text{S}) = 0{\cdot}3 \pm 0{\cdot}15$ and $\bar{\alpha}(^{40}\text{Ca}) = 0{\cdot}5 \pm 0{\cdot}2$. Previously, Wu *et al* (1970) determined the degree of isospin mixing for these nuclei in the GDR region from the ratio $\bar{\sigma}(\gamma, \text{p}_0)/\bar{\sigma}(\gamma, \text{n}_0)$. Using the expression deduced by Barker and Mann (1957) they obtained $\bar{\alpha}(^{28}\text{Si}) = 0{\cdot}15 \pm 0{\cdot}06$, $\bar{\alpha}(^{32}\text{S}) = 0{\cdot}00 \pm 0{\cdot}05$ and $\bar{\alpha}(^{40}\text{Ca}) = 0{\cdot}20 \pm 0{\cdot}02$ whereas we obtained $\bar{\alpha} \simeq 1$ in the regions of the (γ, n_0) and (γ, p_0) data. These differences could be due to the following: (i) the formula given by Barker and Mann (1957), which was derived for the particular case of two isolated levels, is not valid in the region of the GDR where there are many strongly interfering levels; (ii) the Γ_{α_0}/Γ are larger for 4n nuclei than given by statistical theory; (iii) neither analysis takes ground state isospin impurities into account.

Figure 1 shows that, at the highest energies, the calculated cross sections are smaller than those observed. A possible explanation is that decay to the very large number of complicated highly excited states in the residual nuclei is inhibited due to small overlap of the initial and final state wavefunctions. Alternatively this may be due to a small non-statistical contribution to the cross section (Meneghetti and Vitale 1965) for which Γ_{α_0}/Γ is approximately constant in a similar manner to $\Gamma_{\text{p}_0}/\Gamma$ for p capture (eg Watson *et al* 1973). Assuming this, the non-statistical cross section was estimated to be about

0·4 mb at the GDR excitation energy. The effect of including this component is shown in figure 1(*h*).

It has recently been suggested that the study of α capture reactions on $N \neq Z$ nuclei should be a sensitive method of investigating isospin splitting of the GDR since only the $T_<$ component should be excited (B M Spicer 1972, private communication, Branford *et al* 1973, Paul 1973, Hanna 1973 and Segel 1973). Isospin splitting of the GDR of ^{42}Ca and ^{60}Ni has been investigated using the (p, γ) reaction by Diener *et al* (1971, 1973). It was concluded that the $T_<$ GDR have widths of about 3·5 MeV and occur at $E_x = 18{\cdot}0$ MeV in ^{42}Ca and $E_x = 16{\cdot}6$ MeV in ^{60}Ni. Our results are consistent with these assignments but are very insensitive to changes in both the position and width of the $T_<$ GDR. We conclude, therefore, that the α capture reaction does not provide a conclusive test for isosplitting of the GDR.

In summary, we conclude: (i) the (γ, α_0) data is well described using the assumption that α capture excites the GDR; (ii) the (γ, α_0) cross section is given by the total γ absorption cross section multiplied by a statistical function and therefore the excitation function does not have the GDR shape; (iii) valuable information has been obtained on isospin mixing; and (iv) the study of α capture reactions is not suited to investigations of isospin splitting.

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