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ON THE EXCITATION OF ISOSCALAR DIPOLE STRENGTH IN THE GIANT RESONANCE REGION BY INELASTIC ELECTRON AND HADRON SCATTERING

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The possible excitation of isoscalar dipole strength in the region of the giant resonances is investigated. The presence of 20% of the isoscalar dipole energy-weighted sum rule (EWSR) in the region of the giant quadrupole resonance (GQR) would have an appreciable cross section as compared to the total cross section attributed to GQR excitation, and would readily account for the forward–backward asymmetries observed in α_0-decay of the GQR in light nuclei.

One of the outstanding features of the decay of the giant quadrupole resonance (GQR) in light nuclei studied by inelastic α-scattering is the forward–backward asymmetry observed [1] in the α_0-decay channel. According to Bohr's theorem [2] for the decay of an isolated resonance, the decay pattern for such a resonance should have a forward–backward symmetry with respect to the recoil axis. However, the GQR exists in a region of the nuclear continuum where resonances of other multipolarities as well as knockout and multi-step processes could contribute. Interference of the GQR with resonances of opposite parity or possibly with quasi-elastic scattering into the region of the GQR [3] could explain the forward–backward asymmetry in the angular correlation pattern of the decay of the GQR. For instance, in an attempt to explain this forward–backward asymmetry Knöpfle et al. [1] assumed a cross section admixture of $\lesssim 10\%$ of E3 strength in the GQR region. Similarly, an admixture of E1 strength in this region would explain this forward–backward asymmetry. However, while the isovector giant dipole resonance (GDR) is rather strongly excited in inelastic electron scattering, it is known [4] to be weakly excited in inelastic α-scattering.

Another possibility which has been overlooked until recently and which could possibly explain such an asymmetry effect is the excitation of isoscalar giant dipole strength and its interference with the GQR. In this letter we would like to consider the possibility of exciting isoscalar dipole strength in electron and hadron scattering. Calculations are performed for $^{16}O(\alpha, \alpha')$ to serve as an example but similar calculations could be performed for other projectiles exciting these isoscalar dipole transitions.

In the long-wavelength limit, the electric dipole transition operator is given by

$$\sum e_i r_i = \tfrac{1}{2} e \sum r_i + \tfrac{1}{2} e \sum \tau_{3i} r_i \, .$$

The isoscalar part is proportional to the center of mass (c.m.) coordinate operator and thus cannot induce any intrinsic excitations in the nucleus. The isovector part, on the other hand, can induce excitations with $\Delta T = 0, \pm 1$. In self-conjugate nuclei ($T_3 = 0$), $\Delta T = 0$ electric dipole excitations are forbidden and their decay can only proceed via isospin admixtures to the ground state or the $1^-, T = 0$ states.

In recent years, isospin-forbidden $1^-, T = 0$ transitions have been observed to be excited strongly in inelastic electron [5,6] and hadron [7,8] scattering. This could be understood [7,9] because of the difference between the electric dipole operator and the operator responsible for 1^- excitations in inelastic electron and hadron scattering. In inelastic hadron scattering in the plane wave Born approximation (PWBA) assuming [10] a δ-interaction for the projectile–nucleon interaction and also in inelastic electron scattering, the inelastic dipole transition operator is given by:

$$D(q) = \sum_i j_1(qr_i)\, Y_1^0(\hat{r}_i)\,,$$

where q is the momentum transfer. While the first term in the expansion of D in terms of powers of qr is proportional to the c.m. coordinate and does not contribute to the excitation of 1^- intrinsic states of the nucleus, the second term in the expansion, $\Sigma_i\, q^3 \times r_i^3 Y_1^0(\hat{r}_i)$, has nonvanishing matrix elements of the type

$$\langle 0 | \sum_i q^3 r_i^3 Y_1^0(\hat{r}_i) \,|\, 1^-, T = 0\rangle\,.$$

For ^{16}O, calculations assuming a microscopic form factor where the c.m. motion was removed, were successful in describing the differential cross sections for the excitation of the 1^-, $T = 0$ state at $E_x = 7.12$ MeV in ^{16}O in inelastic electron [6] and hadron [7] scattering.

The excitation of these isoscalar dipole states in inelastic electron scattering has been investigated by Deal [9]. He considered the build-up of an isoscalar giant dipole resonance with respect to the isoscalar dipole operator $D = \Sigma_i\, r_i^3 Y_1^0(\hat{r}_i)$. An isoscalar dipole sum rule with center-of-mass correction terms was obtained, only a few percent of which was found [9] to be exhausted by the lowest 1^-, $T = 0$ states in ^{12}C, ^{16}O and ^{40}Ca. More than 90% of this isoscalar dipole strength which consists of 1p–1h, $1\hbar\omega$ and $3\hbar\omega$ excitations is then expected at higher excitation energies.

In fig. 1, the cross sections for the excitation of the 1^-, 7.12 MeV state in ^{16}O in the ^{16}O$(\alpha, \alpha')^{16}$O reaction at $E_\alpha = 75$ MeV [12] and $E_\alpha = 104$ MeV [11] are shown. The cross section for the 1^- state at $E_x = 12.44$ MeV taken at $E_\alpha = 75$ MeV is also shown. The data for this state taken at $E_\alpha = 104$ MeV were not good enough [11] to warrant further analysis. At $E_\alpha = 155$

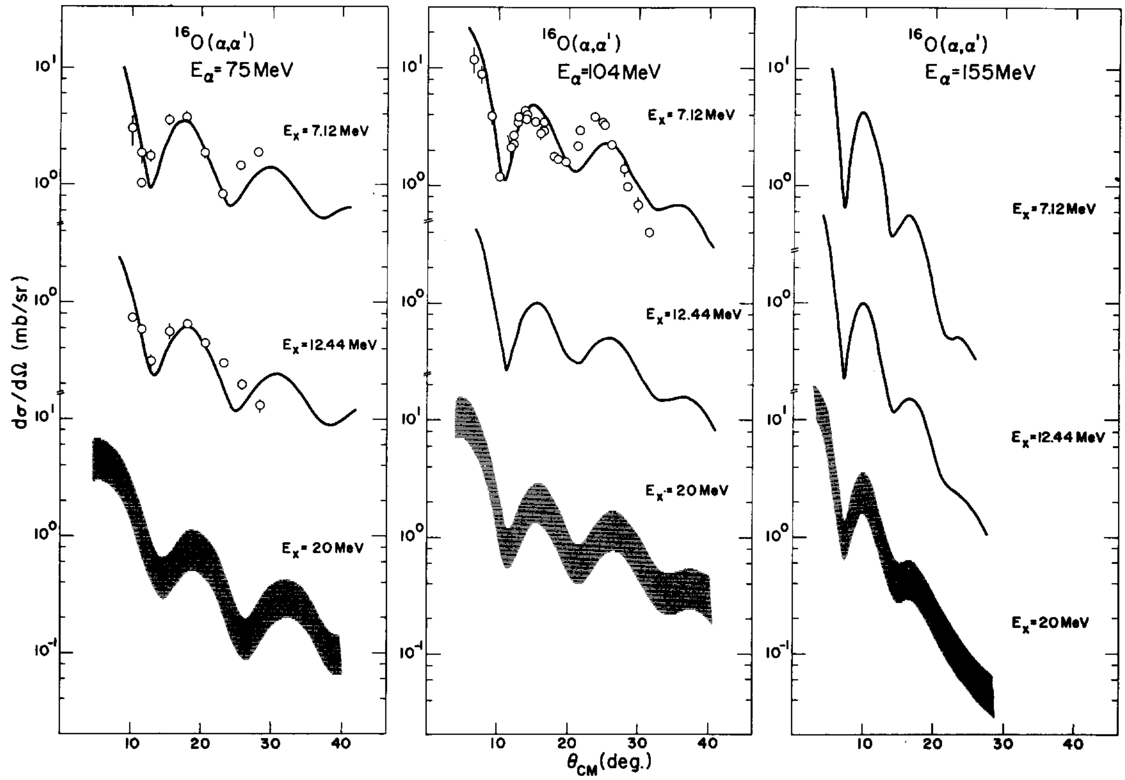

Fig. 1. The experimental differential cross sections of the 1^-, $T = 0$ states at $E_x = 7.12$ MeV and 12.44 MeV in ^{16}O taken at $E_\alpha = 75$ MeV and 104 MeV are obtained from refs. [11] and [12]. The curves are results of DWBA calculations with a collective isoscalar dipole form factor as described in the text. For the same state they are obtained with the same deformation parameter β at the various bombarding energies. If instead, the deformation length is assumed constant then the predicted cross sections at $E_\alpha = 155$ MeV should be increased by a factor $(1.46/1.16)^2 \approx 1.58$.

MeV [13] these states were not resolved from other strongly excited neighbouring states. The curves are results of DWBA calculations as will be described below.

The complex collective macroscopic transition potential for isoscalar dipole excitation is assumed to be derived from the optical potential in the same way the transition density for these isoscalar dipole transitions is obtained from the ground-state density. Such a transition density for isoscalar dipole excitations that exhaust the sum rule strength has been obtained by Deal [9] with c.m. correction terms included and is given by:

$$\rho_{\mathrm{tr}}(r) \sim \left[3r^2 \frac{\mathrm{d}}{\mathrm{d}r} + 10r + \tfrac{5}{3}\langle r^2 \rangle \frac{\mathrm{d}}{\mathrm{d}r} + \epsilon\left(r\frac{\mathrm{d}^2}{\mathrm{d}r^2} + 4\frac{\mathrm{d}}{\mathrm{d}r} \right) \right] \rho_0(r) ,$$

where $\langle r^2 \rangle$ is the mean square radius of the nucleus and ϵ is a small number given by:

$$\epsilon = (4/E_\mathrm{Q} + 5/E_\mathrm{M})\,\hbar^2/3mA ,$$

where E_Q and E_M are the quadrupole and monopole giant resonance energies, respectively. The overall result is insensitive to the choice of these energies since the term involving them is small. In the following calculations E_Q and E_M were taken to be $63A^{-1/3}$ and $80 \times A$ MeV, respectively, while $\langle r^2 \rangle$ was taken for a uniform mass density $[\langle r^2 \rangle = \frac{3}{5}R^2]$ with $R = 3.42$ fm.

DWBA calculations were performed with the program DWUCK [14]. The optical potential used in the calculation for $E_\alpha = 75$ MeV and $E_\alpha = 104$ MeV is labelled by pot. I in table 1 [11]. Pot. II was used for the calculations performed for $E_\alpha = 155$ MeV [13]. The predicted angular distributions for the 1^- transitions in ^{16}O are shown in fig. 1. At $E_\alpha = 75$ MeV and $E_\alpha = 104$ MeV, where experimental differential cross sections are available, the theoretical cross sections are seen to fit the data very well, except perhaps at backward angles where they underestimate the experimental cross section slightly. The parameter β, where $\beta^2 = \mathrm{d}\sigma_\mathrm{exp}/\mathrm{d}\sigma_\mathrm{DWUCK}$, obtained for the 7.12 MeV transition at $E_\alpha = 75$ MeV and 104 MeV is the same. The curve predicted for the 1^-, 7.12 MeV transition at $E_\alpha = 155$ MeV has been obtained with the same β and is found to constitute at forward angles a large fraction of the cross section of the unresolved 6.92 MeV and 7.12 MeV transitions at $E_\alpha = 155$ MeV [13].

The predicted DWBA curve with the above form factor is also found to fit the data of the 1^-, 12.44 MeV transition at $E_\alpha = 75$ MeV rather nicely. The parameter β obtained at this energy has been used to obtain the DWBA curves for this transition at $E_\alpha = 104$ MeV and $E_\alpha = 155$ MeV.

A model independent upper and lower limit for the fraction, f, of the isoscalar dipole EWSR exhausted by the 1^-, 7.12 MeV state in ^{16}O has been obtained by Deal [9] to be $3.7\% \leqslant f \leqslant 8\%$. The shaded areas in fig. 1, for all α bombarding energies indicate upper and lower limits for the excitation of a hypothetical 1^- state at $E_\mathrm{x} = 20$ MeV exhausting 20% of the isoscalar dipole EWSR as predicted by DWBA calculations. The deformation parameters β of the $E_\mathrm{x} = 20$ MeV state were normalized to that of the 7.12 MeV state to give the upper and lower bounds for the fraction of the EWSR exhausted by this state. It is evident that the predicted differential cross section for such a state is rather substantial. It constitutes on the average around 10% of the experimental cross section attributed [11, 13] to the excitation of the GQR.

It is clear that if such a strength (20% of the isoscalar dipole EWSR) is concentrated in one single sharp state (Γ_FWHM of the order of 0.5 MeV) it would have been experimentally observed. However, if this strength is widely distributed it would hardly be observed in a singles inelastic α-scattering experiment.

Table 1
Optical potentials of Woods–Saxon form used in the DWBA calculations.

	V (MeV)	r_R (fm)	a_R (fm)	W (MeV)	r_I (fm)	a_I (fm)	r_c (fm)
pot. I [a)]	89	1.46	0.69	14.4	1.92	0.40	1.3
pot. II [b)]	109.7	1.16	0.82	14.7	1.80	0.77	1.3

[a)] Obtained from ref. [11]. [b)] Obtained from ref. [13].

Evidence for excitations of various multipolarities in the GR region has been observed (see e.g. ref. [11]) but it was not possible to pinpoint which multipolarities exactly contribute. It is quite possible that much of the variation observed [11] in the angular distribution of the GR structure in ^{16}O could be partly attributed to the excitation of this isoscalar dipole strength.

We have estimated [15] the forward–backward asymmetry resulting from 10% cross section admixture of isoscalar dipole strength into the dominant GQR. In this we assumed that the isoscalar dipole strength decays in the same proportions to the various decay channels as the GQR. Moreover, we performed the calculation in the PWBA limit which seems to give a good description of the m-state populations for these high bombarding energies. The ratio of the forward to backward peaks of the $L = 2$ angular correlation pattern resulting from this calculation is 1.61, which is of the order of the observed [1] experimental ratio.

To conclude, we have found that the excitation of isoscalar dipole strength could be rather substantial in inelastic hadron scattering. It could explain some of the recently observed variations in angular distributions observed [11] in high-resolution α-scattering experiments as well as the forward–backward asymmetry observed [1] in recent angular correlation measurements. Such excitations are possible and their effects should be considered in future work.

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