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EVIDENCE FOR A SINGLE DOMINANT STATE FOR THE $E1$ GIANT RESONANCE*

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The success of the particle-hole model[1-3] in explaining the gross properties of the giant-dipole resonance has stimulated some extensive calculations[4-7] which attempt to describe some of the more detailed properties of the giant resonance in closed-shell nuclei. These calculations have shown that ordinarily several particle-hole states are major contributors to a given giant-dipole resonance. While the calculated energies of these states are not all identical, they do tend to cluster in the desired region—a typical calculation gives several states within a region of a few MeV. As the calculations have been refined, so has the energy resolution of the experiments been improved. The improved experiments have indeed established structure within the giant resonance; in many cases there are several prominent peaks in a region of a few MeV. Thus, it has been natural to identify the observed structure with the various predicted particle-hole states,[8] especially since considerable leeway is possible in making such identifications since the calculations predict the positions of the states only within about 1 MeV. It is the purpose of this note to report that more detailed information makes such identification untenable.

In the program of studying the giant-dipole resonance through the (p,γ) reaction with protons from the ANL tandem van de Graaff, the nuclei C^{12}, Ne^{20}, and Si^{28} have been investigated. In each case the giant resonances involving transitions to the ground state (γ_0) and first excited state (γ_1) of the nucleus have been studied. The various experiments are discussed in detail elsewhere,[9-11] and the relevant results are summarized in Table I. The result that is most important to the present discussion is that throughout each giant resonance the gamma-ray angular distribution varies little with energy. Specifically, it is found that to within the experimental accuracy of about ± 0.1 the angular distribution coefficients usually remain close to their average values. Excursions in magnitude up to about 0.3 occasionally occur in a_2, the coefficient of P_2; and slow trends of up to about 0.03/MeV are sometimes present in a_1 and a_2. Spin and parity considerations alone would permit a_2 to vary from about +1 to −1 for pure $E1$ radiation, the exact limits depending on the quantum numbers involved in each giant resonance. (The odd terms in the angular distribution can be attributed[9,11] to interference with weak positive-parity radiation which contributes but incoherently to a_2.) Thus, the angular distributions appear to be much more nearly constant than might be expected from the complexity of the yield curves. A similar result has been obtained in other laboratories[12,13] for $N^{15}(p,\gamma_0)O^{16}$ and $P^{31}(p,\gamma_0)S^{32}$. This result implies that whatever the structure of a given giant resonance (and Table I shows that different giant resonances

Table I. Summary of experimental results on the (p,γ) giant resonance (references 9-11). The angular distributions that are quoted generally characterize the data to within 15 % throughout the giant-resonance region.

Nucleus	Type of observation	Energy interval and range	Result
C^{12}	90° yield curve	50-keV steps 4.0-14 MeV	Broad ($\Gamma \approx 1$ MeV) overlapping levels; no correlation between γ_0 and γ_1.
	Angular distribution[a]	50-keV steps 4.0-14 MeV	$W(\theta)_{\gamma_0} = 1+0.15P_1-0.6P_2$ $W(\theta)_{\gamma_1} = 1+0.15P_1$
Ne^{20}	90° yield curve	30-keV steps 4.3-9.1 MeV	Broad ($\Gamma \approx 400$ keV) levels usually well isolated, γ_0 and γ_1 well correlated.
	Angular distribution	100-keV steps 4.0-10.5 MeV	$W(\theta)_{\gamma_0} = 1+0.05P_1-0.7P_2$ $W(\theta)_{\gamma_1} = 1+0.05P_1+0.2P_2$
Si^{28}	90° yield curve	15-keV steps 4.0-12.5 MeV	Narrow ($\Gamma \approx 50$ keV) Ericson fluctuations, superimposed on intermediate structure; no correlation between γ_0 and γ_1.
	Angular distribution	15-keV steps 4.0-4.32 MeV 6.0-6.62 MeV 8.0-8.54 MeV 10.0-10.28 MeV 11.54-11.58 MeV	$W(\theta)_{\gamma_0} = 1+0.07P_1$ $W(\theta)_{\gamma_1} = 1+0.1P_1-0.45P_2-0.1P_3$

[a]The coefficients of P_1 are average values. They actually increase by about 0.03/MeV over the giant resonance.

can have very different structures), the initial proton configuration is the same for virtually all of the levels that make up a (p,γ) giant resonance; i.e., a given giant resonance is described by a single configuration which, in turn, may be a mixture of the particle-hole states.

This situation is here illustrated by the giant resonance built upon the ground state of Si^{28}. The yield curve for the reaction $Al^{27}(p,\gamma_0)Si^{28}$ (Fig. 1) exhibits a great deal of narrow structure which has been successfully analyzed as Ericson fluctuations arising from narrow overlapping levels.[11] The presence of these narrow levels is consistent with, but not predicted by, the particle-hole description which only purports to describe the broader structure (of intermediate width). Such structure, consisting of four rather well-defined groups, is observed in $Al^{27}(p,\gamma_0)Si^{28}$; very similar structure has been observed by Caldwell et al.[8] in the reaction $Si^{28}(\gamma,n)Si^{27}$. The gamma-ray angular distributions (Fig. 2) can be fitted to within about 15% by $W(\theta)=1+0.07\,P_1(\cos\theta)$ throughout the entire energy range and appear to be unaffected by either the narrow or the broader structure in the total yield—although some slow trend with energy is perhaps discernible.

Bolen and Eisenberg[7,14] have applied the particle-hole model to the γ_0 giant resonance in Si^{28}. Their results are shown in Table II. While the calculations predict the structure at least qualitatively, there is no agreement between the calculated and the observed angular distributions. The theory predicts widely varying angular distirbutions, in sharp contrast to the experimental observations. Similar conclusions can be drawn from other studies of (p,γ) angular distributions.[9,10]

The nuclei O^{16} and C^{12} have been justly regarded as triumphs of the particle-hole model. However, it may be that neither nucleus has yet provided a definitive test of the existence of individual particle-hole states. In O^{16} the $E1$ strength is concentrated in two states,[4,6] in good agreement with two prominent resonances observed[15] in the (p,γ_0) and inverse reactions. However, in these two states the $(1p_{1/2})^{-1}$ hole configurations are rather similar[4,6] so that the (p,γ_0) [or (γ,p_0) or (γ,n_0)] angular distributions might be invariant for this reason. In C^{12}, the

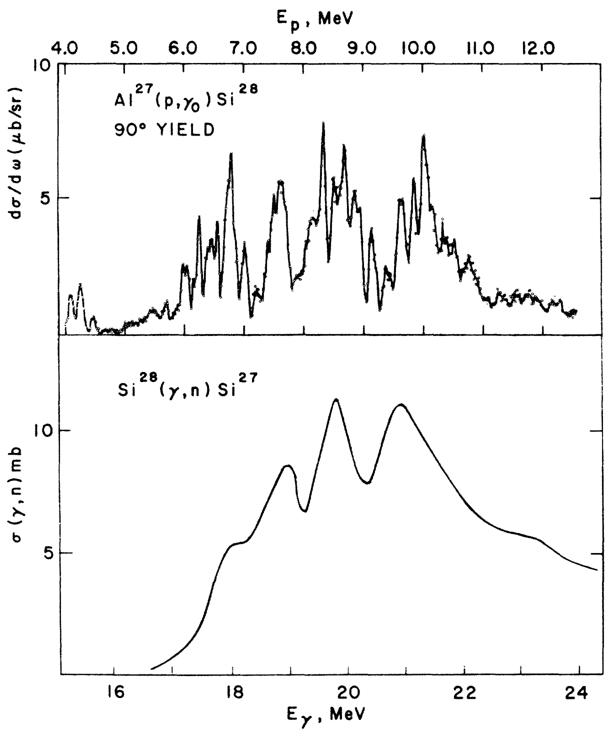

FIG. 1. Top curve: 90° yield of the ground-state gamma ray from the reactions $Al^{27}(p,\gamma)Si^{28}$. This yield curve was taken in 15-keV steps using a target about 10 keV thick. Bottom curve: yield of Si^{27} from the reaction $Si^{28}(\gamma,n)Si^{27}$ taken with a gamma-ray energy resolution of about 600 keV. The data are those of Caldwell et al. (reference 8). The two curves are plotted so as to be on the same gamma-ray energy scale.

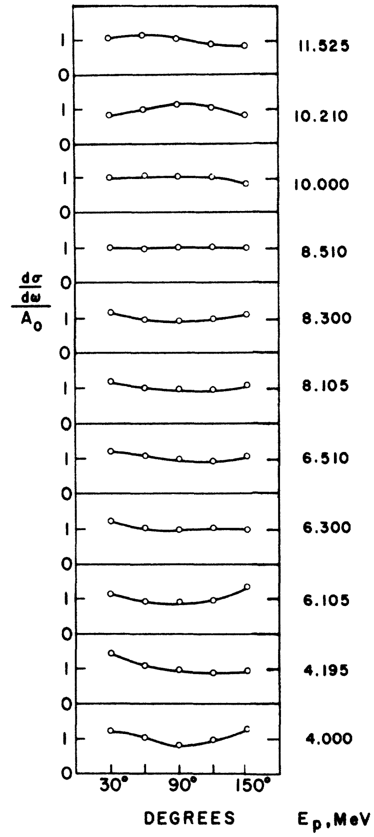

FIG. 2. Sample angular distributions of the ground state gamma ray from the reaction $Al^{27}(p,\gamma)Si^{28}$.

$E1$ strength is concentrated in the $(1p_{3/2})^{-1}1d_{5/2}$ configuration,[4,5] the contribution of the $(1p_{3/2})^{-1}$-$1d_{3/2}$ configuration being negligibly small. The observed angular distributions agree with this prediction.[9] Theory[4] and experiment[16] agree that the weak $(1p_{3/2})^{-1}2s_{1/2}$ configuration is well separated from the main giant resonance in C^{12}.

Thus it appears that the structure that is observed in the giant-dipole resonance is usually not due to the presence of separated particle-hole states. Instead, there emerges the picture of a single giant-resonance state or configuration that is spread out over many actual nuclear levels, even though the way in which this occurs varies greatly from nucleus to nucleus.

In order to account for the gross properties revealed by earlier evidence from (p,γ) reactions, Tanner[12] has discussed a model of a single direct-capture resonance interfering with weak compound-nucleus levels. However, it is difficult to reconcile this picture with the detailed data that are now available covering giant resonances in which intermediate structure is present (Si^{28}) or where strong, sometimes isolated, levels dominate (Ne^{20}).

Table II. Calculated[a] particle-hole states which compose the giant resonance in Si^{28}.

E_{expt}	Fractional dipole strength	Fractional (p,γ) strength[b]	Angular distribution[b]
13.7	2	1	$1-0.36P_2$
14.8	0	0	$1+0.39P_2$
16.1	14	24	$1-0.61P_2$
18.8	23	23	$1+0.26P_2$
19.9	11	25	$1+0.86P_2$
21.6	32	16	$1-0.77P_2$
25.8	18	11	$1+0.48P_2$

[a]References 7 and 14.
[b]Assuming Al^{27} to be $(1d_{5/2})^{-1}$.

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ELECTROMAGNETIC STRUCTURE OF THE NEUTRON AND PROTON*

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This Letter reports measurements of the form factors of the neutron in the range of four-momentum transfers 0.389 to 6.81 $(\mathrm{BeV}/c)^2$ [10 to 175 F^{-2}]. Our previously published measurements[1] on the proton form factors have been amended and extended.

We have measured the quasielastic scattering of electrons from a deuterium target and also the elastic scattering of electrons from a hydrogen target. Two methods were employed to separate the electron-neutron scattering cross section. In one method we have not demanded a coincidence between the scattered electron and the recoil proton, and in the other method a coincidence was required. In both of these methods, we use the impulse approximation in the form given by Durand[2] to analyze the results.

The momentum spectrum of scattered electrons is measured with an improved version of a previously described[1] quadrupole spectrometer.

All electrons within a momentum interval $\Delta p/p = 6.9\,\%$ are recorded. In addition, five counters, each with a momentum resolution of about 1.1%, were used to study the shape of the momentum distribution within the 6.9% interval of the scattered electrons. A correction was made for those electrons which were scattered quasielastically but were outside this momentum interval. The number of scattered electrons, after this correction was made, is proportional to $\sigma_{en} + \sigma_{ep}$. The number of electrons scattered elastically from the hydrogen target is proportional to σ_{ep}. The quantity $R = \sigma_{en}/\sigma_{ep}$ was then calculated.

At momentum transfers 0.389 to 1.17 $(\mathrm{BeV}/c)^2$ and at small angles of electron scattering (~31°), it was also possible to measure R by the second method. A high-energy recoil proton was detected by a three-counter telescope, the output of which was placed in fast coincidence with a pulse which signified that an electron had been detected within the 6.9% momentum interval. The solid angle subtended by the proton telescope was sufficiently large that no