Giant-Dipole-Resonance Region of ^{15}N Observed via ^{14}C$(p,p)^{14}$C Cross Section and Polarization Measurements*

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(Received 15 July 1974)

Cross sections and polarizations have been measured for ^{14}C$(p,p)^{14}$C scattering over the energy range corresponding to the giant-dipole-resonance region of ^{15}N. The results indicate a $J^\pi = \frac{3}{2}^+$ resonance of about $\Gamma = 4$ MeV near $Ep = 10$ MeV. This resonance appears to be the giant dipole resonance observed in (p,γ) measurements.

Recent measurements of the analyzing powers and cross sections of protons elastically scattered from ^{28}Si have suggested, on the basis of the energy dependence of the spin-orbit potential obtained from an optical-model analysis, that these data are sensitive to the existence of the giant dipole resonance (GDR) of ^{29}P.[1] In this Letter we will report our results of a study of the GDR of ^{15}N using the reaction ^{14}C$(p,p)^{14}$C. The intent of this work was to establish whether the correlation suggested in Ref. 1 could be more definitely established and, if so, what parameters could be extracted.

The experiment was performed by using the polarized-ion source at the Triangle Universities Nuclear Laboratory. Angular distributions were measured at 8 energies between $E_p = 7.5$ and 12.45 MeV. Data were taken in 10° steps from 50° to 160°. Eight detectors were used—four left and four right—and each run was made with the proton spin up and down. The beam polarization was determined to be 0.82 ± 0.02 by means of the quench-ratio technique.[2] The ^{14}C targets used for this work were made by cracking 70% ^{14}C-enriched acetylene on a 0.12-μm-thick nickel backing and were about 10 keV thick for 3.4 MeV protons. The cross sections were obtained by summing the polarization results as well as by measuring them independently with an unpolarized beam. At angles forward of 85°, where the elastic ^{12}C, ^{14}C, and ^{16}O peaks overlap, measurements of the ^{12}C and ^{16}O cross sections were used in extracting the ^{14}C data.

The cross section for the reaction ^{14}C$(p,p)^{14}$C was measured as a function of energy at two angles. The main component of the GDR as observed in ^{14}C$(p,\gamma_0)^{15}$N measurements occurs at about $E_p = 10.5$ MeV and is not distinct in these excitation functions. This result is not surprising since the γ-ray operator is very selective and so (p,γ) or (γ,p) measurements reveal only a special part of the wave function—presumably described to first order by the one-particle, one-hole (1p-1h) model (1p-2h in the case of ^{15}N). On the other hand the giant-resonance states certainly have proton decay widths and so should be contained in the (p,p) data. The question is can they be separated out?

We began our analysis of these data by performing an optical-model fit at each energy using the code JUPITOR.[3] A typical set of parameters (at, say, 8 MeV) were $V = 52.8$ MeV, $W_s = 2.35$ MeV, $V_{\text{s.o.}} = 7.56$ MeV, $a = 0.7$ fm, $r_0 = 1.75$ fm, $a_s = 0.7$ fm, and $r_s = 1.52$ fm. Note that we are using surface absorption (derivative Woods-Saxon form factor). Although the spin-orbit potential displayed some energy dependence, the results were difficult to interpret. Therefore, the results were converted into a set of complex phase shifts at each energy. These were then used in a phase-shift analysis of the data. The optical-model results at each energy were used as starting param-

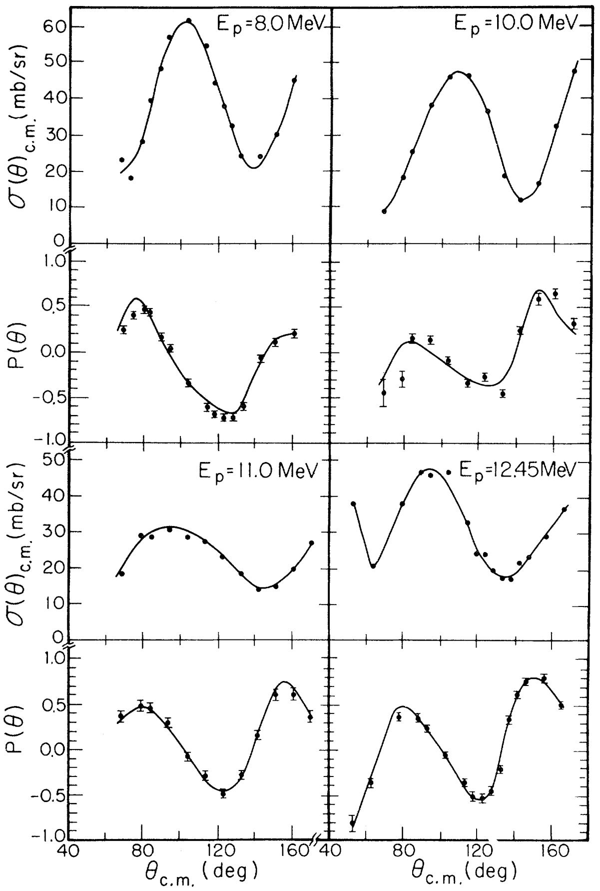

FIG. 1. Angular distributions of cross section and polarization for the reaction $^{14}C(p,p)^{14}C$ at 8.0, 10.0, 11.0, and 12.45 MeV. The fits shown were obtained from a complex–phase-shift analysis of the data. The error bars represent the statistical errors associated with the data points. The statistical error associated with the cross section data are less than 2%.

eters at all energies. Other initial sets of phases were also tried in order to determine if the set obtained was indeed the best fit (the lowest χ^2). Typical resulting fits are shown along with the data at the four energies of 8.0, 10.0, 11.0, and 12.45 MeV in Fig. 1.

The partial waves included in our analysis extended up through $f_{7/2}$. The complex phase shift is represented by the real part $\delta_l^\pm$ and the imaginary part $\eta_l^\pm$. It is convenient to present the imaginary part in terms of the damping parameter $\gamma_l^\pm = \exp(-2\eta_l^\pm)$. The quantities $\delta_l^\pm$ and $\gamma_l^\pm$ are shown as functions of energy in Fig. 2. The f-wave phase shifts were small and relatively constant as a function of energy and are not shown.

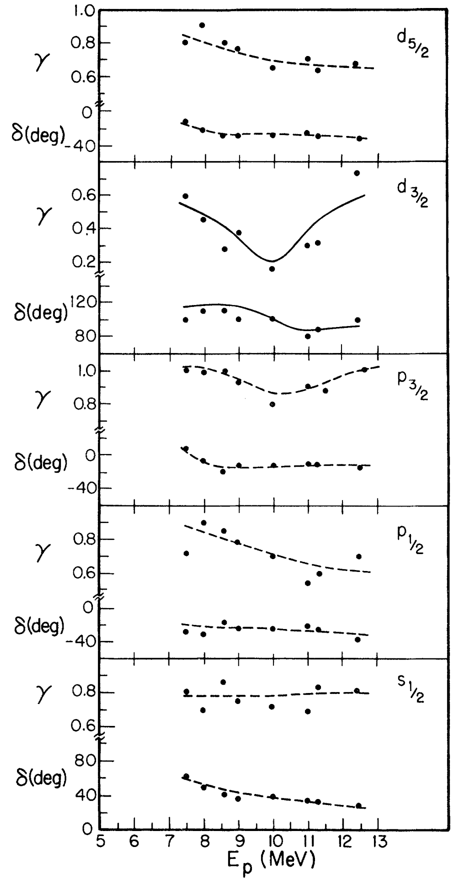

FIG. 2. Complex phase shifts as functions of energy resulting from fitting the cross section and polarization data. The dashed lines are smooth curves drawn to suggest the energy dependence. In the $d_{3/2}$ case the solid lines are fits generated as described in the text.

It is seen in Fig. 2 that the dominant energy dependence in these results occurs in the $d_{3/2}$ phase shift. This result is what we would expect if the GDR was to be seen since it is primarily $J^\pi = \frac{3}{2}^+$ and is centered around $E_p = 10.5$ MeV. In order to evaluate this result explicitly we next attempted to add resonances to a set of background phases. The cross sections and polarizations were calculated with a scattering matrix S, defined by

$$S_l^\pm = \exp[2i(\omega_l + \delta_l^\pm)]\{\exp(-2\eta_l^\pm) + \exp(2i\varphi_p)[i\Gamma_p(E_{\mathrm{res}} - E - \tfrac{1}{2}i\Gamma)]\},$$

where ω_l is the Coulomb phase shift; $\delta_l^\pm + i\eta_l^\pm$ is the off-resonance phase shift describing the elastic scattering for the lth partial wave with $J^\pi = l \pm \frac{1}{2}$; E_{res}, Γ, and Γ_p are, respectively, the energy, total

TABLE I. Parameters for the resonance calculation.

Partial wave	Background phase shifts[a] δ (deg)	γ
$s_{1/2}$	33.80	0.68
$p_{1/2}$	− 21.10	0.53
$p_{3/2}$	− 10.30	0.91
$d_{3/2}$	105.00	0.70
$d_{5/2}$	− 26.70	0.68
$f_{5/2}$	10.55	0.85
$f_{7/2}$	11.64	0.83

Resonance Parameters

J^π	Γ_p (MeV)	Γ (MeV)	E_{res}(lab) (MeV)	φ (deg)
$\frac{3}{2}^+$	1.0	4.0	10.0	0.0

[a] Phase shifts (other than $d_{3/2}$) were obtained from the 11-MeV data.

width, and partial elastic width of the resonance; and φ_p is the resonance mixing phase.[4] In addition to calculating the cross sections and polarizations, we calculated the net complex phase shift (described in terms of δ and γ) including the effects of the resonance. With a set of energy-independent background phases and a single $\frac{3}{2}^+$ resonance, we obtained the result shown in Fig. 2 as the solid lines. The parameters for this calculation are given in Table I. The other complex phase shifts were held constant over the energy region. Of course they could be given an energy dependence such as that suggested by the dashed lines in Fig. 2, but little would be gained. It is interesting to note that the $p_{3/2}$ partial wave shows some indication of resonance behavior. This could be the effect of a giant $E2$ resonance.

We see that the $d_{3/2}$ partial wave can be well accounted for by a single $\frac{3}{2}^+$ resonance at $E_p = 10.0 \pm 0.5$ MeV having a width of about 4 MeV and a partial width of 1 MeV. If the reduced width is calculated according to $\Gamma = 2P_l\gamma_l^2$, one finds it to be about one tenth of the single-particle limit. An additional important result of our analysis was the discovery that if many levels were introduced, following the structure of the (p,γ) data,[5,6] the present data could not be reproduced. We do observe that if one draws a smooth curve through the structured (p,γ) data (see Ref. 6) one obtains a resonance having a width of about 4 MeV centered near 10 MeV. Other effects[7] which could account for these results have been considered but were not able to give a consistent description of the data.

It is well known that the 1p-1h model is an inadequate description of the giant dipole resonance.[8] Such features as the intermediate structure, the angular distributions of certain partial cross sections, and the proton-neutron branching ratio are not accounted for. And, while the absorption cross section shows more structure than the theory, the angular distributions show less. The results of the present experiment and further studies of (p,p) cross sections and polarizations in this energy region should shed new light on the giant-resonance phenomenon. A detailed 2p-1h continuum calculation of these effects observed in this work is in progress and will be published in the near future.[9]

The authors gratefully acknowledge the indispensible contribution of Dr. T. B. Clegg who developed the Triangle Universities Nuclear Laboratory polarized-ion source.

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*Work partially supported by the U. S. Atomic Energy Commission.

†Work partially supported by Research Corporation.

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