Elastic and Inelastic Scattering of Protons by N^{14}†

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Differential cross sections for the elastic scattering of protons by N^{14} have been measured for proton energies between 1.0 and 4.1 Mev at center-of-mass scattering angles of 90.0° and 168.1°. Above 3.5 Mev the study was extended to four additional angles, 140.8°, 125.3°, 54.7°, and 39.2°, to provide information on a broad resonance near 3.9 Mev and a narrower resonance at 3.980 Mev. These two resonances also exhibit a measurable width for inelastic scattering to the first excited state of N^{14} at 2.31 Mev. All measurements were made with a differentially-pumped scattering chamber containing natural nitrogen gas. The probable error in the cross section is estimated at 3%; the energies of the incident protons were determined to ±3 kev. The data were analyzed to provide information on the resonance energies E_r and total widths Γ. Evidence was found for a previously unreported level with $E_r=2.535$ Mev, $\Gamma\cong1.8$ kev. From an investigation of the elastic and inelastic scattering data in the region of the level at 3.9 Mev it is concluded that the resonance is due to d-wave formation of a state of O^{15} having spin and parity $\frac{5}{2}^+$, with $E_r=3.878\pm0.008$ Mev, $\Gamma=85\pm8$ kev, $\Gamma_i=7$ kev.

I. INTRODUCTION

THE elastic scattering of protons by N^{14} has been studied prior to 1956 by several different investigators for proton energies ranging from 1.0 to 2.9 Mev.[1,2] Recently a rather comprehensive study was completed at Minnesota[3] in which differential cross sections were measured for five angles of scattering for protons with energy between 1.5 and 3.5 Mev.

A similar experiment was in progress at Duke[4] when the Minnesota results were first reported. Differential cross sections have been measured for proton energies between 1.5 and 4.1 Mev at the center-of-mass scattering angles of 167.8° and 90.0°. Above 3.5 Mev the study was extended to four additional angles to provide information on a broad resonance near 3.9 Mev,[5] about which little was known. In the region of overlap between the two studies, advantage has been taken of a precision electrostatic analyzer and thin gas targets to obtain a more accurate determination of proton energies and better energy resolution than was obtained in the Minnesota investigation. The data for 167.8° extend the cross section measurements to a larger scattering angle than has been studied previously. At this angle a rather comprehensive search for previously unreported resonance structure was made.

The cross sections for inelastic scattering to the 2.31-Mev level of N^{14} were also studied for incident proton energies above 3.0 Mev. Two resonances were observed at about 3.88 and 3.98 Mev. The existence of the corresponding levels in O^{15} has been reported recently from Oak Ridge[6] from a study of the gamma rays resulting from inelastic scattering.

The elastic and inelastic scattering cross sections have been analyzed to determine the resonance energies and total widths of the resonances observed in the cross section data. A recent report by Hagedorn *et al.*[7] presents a detailed analysis of the four resonances below 2.0 Mev, and contains also references to the results of earlier investigations. Duncan and Perry,[8] from a study of $N^{14}(p,\gamma)O^{15}$ have reported widths and resonance energies for the resonances observed in the capture cross section. However, for several of the higher-lying resonances observed in the elastic scattering cross sections, these parameters were either not known, or the values given involved relatively large uncertainties. In the present work it has been possible to determine these parameters, for most cases, with considerable accuracy.

II. EXPERIMENTAL PROCEDURE

A differentially-pumped scattering chamber containing natural nitrogen gas as the target was used for the measurement of the absolute differential cross sections. The angular spread and the size of the proton beam were defined by two 0.16-cm apertures located at a separation of 40 cm in the body of this tube. The number of protons incident upon the target volume during a given bonbardment was determined with a standard current integrator connected to a collector cup, which was isolated from the main chamber by a 0.5-μ nickel foil and kept at a vacuum of the order of 10^{-5} mm Hg by an oil diffusion pump. The detector was a thin (~0.03 mm) CsI crystal coupled to a 6292 photomultiplier. A precision slit system defined the effective target volume and also the acceptance solid angle of the detector. The chamber pressure was

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[1] G. W. Tautfest and S. Rubin, Phys. Rev. **103**, 196 (1956).
[2] Ferguson, Clark, Gove, and Sample, Preliminary Report PD-261, Atomic Energy of Canada Limited, Chalk River Project, 1956 (unpublished).
[3] Bolmgren, Freier, Likely, and Famularo, Bull. Am. Phys. Soc. Ser. II, **1**, 339 (1956) and Phys. Rev. **105**, 210 (1956).
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[5] Bashkin, Carlson, and Jacobs, Bull. Am. Phys. Soc. Ser. II, **1**, 212 (1956), and Douglas, Carlson, Bashkin, and Broude, Bull. Am. Phys. Soc. Ser. II, **3**, 198 (1958).
[6] Bair, Cohn, Kington, and Willard, Phys. Rev. **104**, 1595 (1956).
[7] Hagedorn, Mozer, Webb, Fowler, and Lauritsen, Phys. Rev. **105**, 219 (1956).
[8] D. B. Duncan and J. E. Perry, Phys. Rev. **82**, 809 (1951).

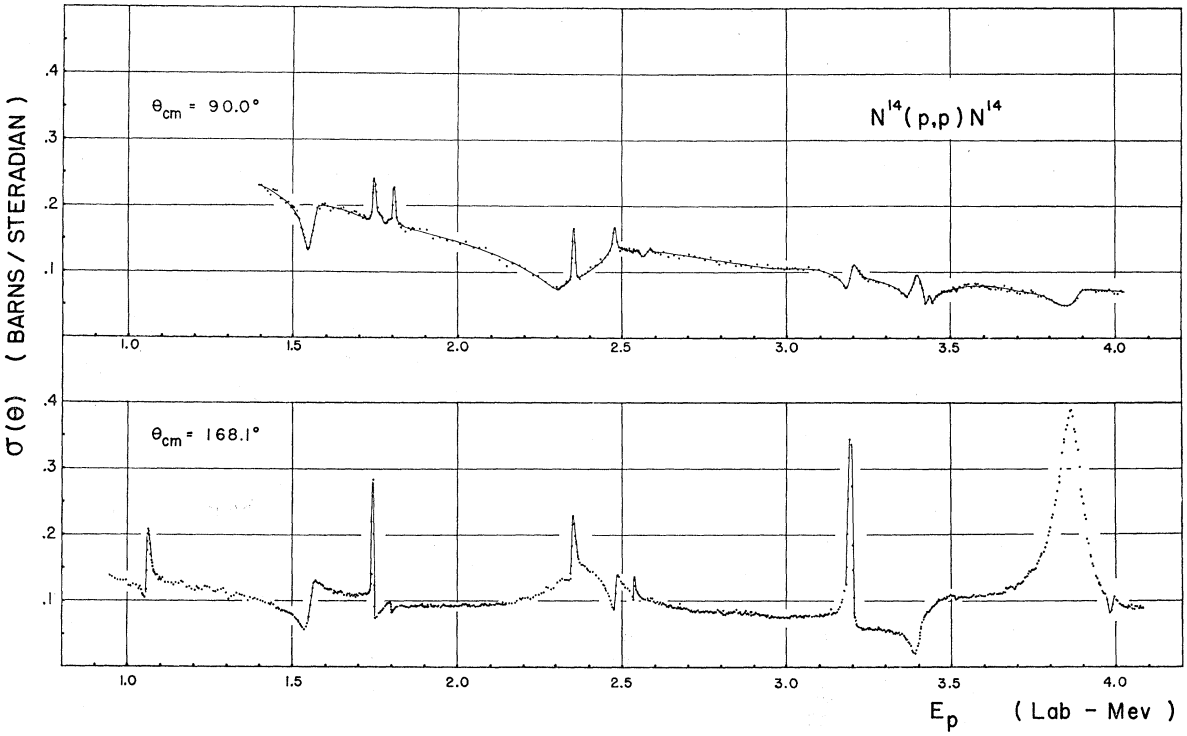

FIG. 1. Differential cross sections for the elastic scattering of protons from N^{14} as a function of incident proton energy for the scattering angles of 168.1° and 90.0°. Cross sections and angles are given in the center-of-mass system, proton energies in the laboratory system of coordinates.

regulated by a needle valve located in the nitrogen input line and was measured with an oil-filled U-tube manometer and two travelling microscopes. The determinations of the geometry of the chamber, the pressure of the target gas, and the elastic scattering counting rates were carried out to an accuracy calculated to yield values for the elastic cross sections with a maximum possible error of less than 3%, exclusive of counting statistics. The scattering angles were measured to within $\pm 0.05°$. The energy determination of the proton beam from the Van de Graaff accelerator was made with a cylindrical electrostatic analyzer, set for an energy resolution of 0.1%. The net spread in energy introduced by the finite thickness of the target and straggling effects due to the energy loss in the chamber gas was of the order of 1 kev for 2-Mev protons.

The target gas was ordinary tank nitrogen supplied by National Welders Supply. Mass spectroscopic analysis of a sample of this gas indicated a purity of better than 99.3% No contaminant, other than 0.37% N^{15}, was present in any amount greater than 0.1%.

The energy resolution of the CsI detector was of the order of 10% for 2–3 Mev protons. Examination of the pulse-height data showed the spectra to be quite clean in the region of the elastically scattered group; however, a slight background was present in the region of the inelastically scattered group. It was thought that this was due primarily to slit-edge scattering; the extreme thinness of the crystal rendered it almost insensitive to gamma rays. For measurement of the elastic scattering counting rates an integral discriminator was set just below the elastic group. For determination of the inelastic scattering counting rates, a ten-channel analyzer was set to scan the proton spectrum; appropriate background corrections were then made. The over-all probable errors involved in the determination of the absolute differential cross sections are 3% for the elastic cross sections and 7% for the inelastic cross sections.

Figure 1 shows the differential cross section for elastic scattering as a function of incident proton energy for two angles of scattering, 90.0° and 168.1° in the center-of-mass system. At the larger angle the region between 2.0 and 4.1 Mev was covered in steps of 4 kev or less in a systematic search for resonances. The absolute energy scale was calibrated by mounting a lithium target inside the chamber on a rotating arm in such a way that it could be positioned at the center of the chamber when desired. Measurement of the $Li^7(p,n)Be^7$ threshold at 1.882 Mev, first with no gas in the chamber and then with a typical operating pressure, served both to calibrate the electrostatic analyzer and to provide a direct measurement of the stopping power of the target gas. At other proton energies the stopping power of the gas was determined by observing the apparent shift of a resonance as the gas pressure was changed. The absolute energies over the range from 1.50 to 4.1 Mev are in error by no more than 3 kev at any point.

Some additional data obtained for the resonance structure above 3.5 Mev are shown in Fig. 2. The angles chosen are those for which the various Legendre polynomials vanish. Only the region above 3.6 Mev is shown in Fig. 2. For all but one of the angles the study was extended down to 3.3 Mev to tie in with the data of the Minnesota group.[3] The agreement in the region of overlap is within the quoted limits of error for the two sets of data.

Figure 3 shows the cross sections for elastic and inelastic scattering at 168.1° in the region of the broad resonance near 3.9 Mev. The angular distribution of the inelastically scattered protons, obtained at the peak of the inelastic resonance, is shown in Fig. 4. The data have been fitted with a distribution of the form

$$\sigma_i(\theta)=5.15(1-0.27\cos^2\theta) \text{ millibarns.}$$

The data extend forward only to $\theta=70°$; at smaller scattering angles the energy resolution of the detector was not high enough to separate the proton group corresponding to inelastic scattering from N^{14} from a rather weak group corresponding to elastic scattering from hydrogen, which was present in the target gas as a hydrocarbon contaminant. However, the pulse

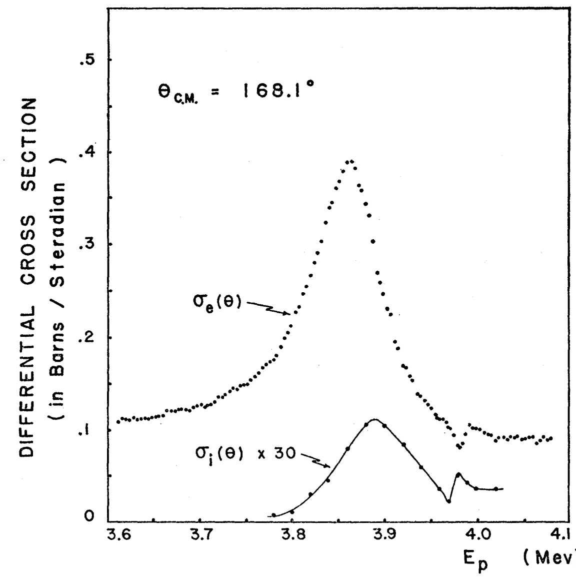

FIG. 3. Center-of-mass cross sections for $N^{14}(p,p)N^{14}$ and $N^{14}(p,p')N^{14*}$. The lower curve shows the differential cross sections (increased by a factor of 30) for inelastic scattering to the first excited state of N^{14} at 2.31 Mev. The elastic scattering cross sections in this region of proton energy are also shown to permit a comparison of the resonance structure observed in the two curves.

height spectra obtained with the ten-channel analyzer were examined carefully and appropriate background corrections were made, resulting in the cross sections and probable errors shown.

III. DISCUSSION OF RESULTS

The following analysis was carried out to provide information on the resonance energies E_r and the total widths Γ of the various resonance levels observed in the cross section data. Special consideration has been

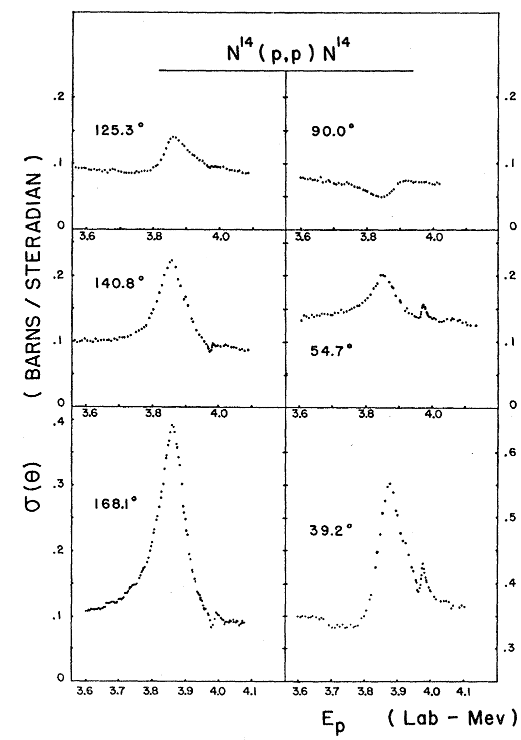

FIG. 2. Center-of-mass differential cross sections for $N^{14}(p,p)N^{14}$ for proton energies above 3.6 Mev. Shown here are the results of the cross section measurements for scattering angles of 140.8°, 125.3°, 54.7°, and 39.2°; the data for 168.1° and 90.0° are also shown.

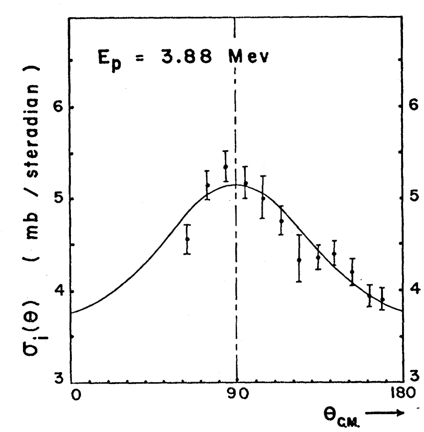

FIG. 4. Differential cross sections for inelastic scattering from N^{14} *versus* angle of scattering for $E_p=3.88$ Mev. Cross sections and angles are given in the center-of-mass system. The energy chosen for this study corresponds to the peak cross section observed in the inelastic cross section curve of Fig. 3. The angular dependence of the cross section has been fitted with the expression $\sigma_i(\theta)=5.15(1-0.27\cos^2\theta)$ millibarns.

TABLE I. Resonance parameters of excited states of O^{16}. Columns 1 and 2 give the resonance energies E_r and total widths Γ as obtained from the present analysis of $N^{14}(p,p)N^{14}$ and $N^{14}(p,p')N^{14*}$. Columns 3 and 4 present a summary of the values obtained from other sources.[a–d]

Present work		Summary from literature	
E_r (Mev)	Γ (kev)	E_r (Mev)	Γ (kev)
1.061±0.005	6±1.5	1.054±0.003	3±1[a]
1.550±0.005	35±5	1.544±0.006	34±4[a]
1.744±0.003	6±1.5	1.737±0.004	4±1[a]
1.804±0.003	8±3	1.799±0.005	4±1[a]
2.349±0.003	8.5±1.5	2.356±0.008	14±4[b]
2.38 ±0.05	260±70		
2.478±0.004	11±2	2.489±0.007	11±3[b]
2.535±0.003	1.8±0.5		
3.192±0.003	11±1.5	3.20 ±0.01	[c]
(~3.395)	(~50)		
(~3.440)			
3.878±0.008	85±0.05	3.910±0.008	90[d]
3.980±0.010	<30	4.000±0.008	25[d]

[a] See reference 7.
[b] See reference 8.
[c] See reference 3.
[d] See reference 6.

given to the analysis of the broad resonance near 3.9 Mev, for which it has been possible to determine also the angular momenta involved in the scattering process.

The general procedure of this analysis, which is essentially a "resonance phase-shift analysis" has been discussed previously.[9] It has been shown that in the region of a given resonance the dependence of the differential cross section upon the particular resonance phase shift may be written in the form

$$\sigma(E,\theta)=\lambda\!\!\!^{-2}\{A(E,\theta)+B(E,\theta)\sin^2[\beta+\xi(\theta)]\},\qquad(1)$$

where $\lambda\!\!\!^{-2}$ is the reduced proton wavelength, β is the resonance phase shift, and $\xi(\theta)$ is a constant phase shift. If the resonance is isolated, and not too broad, one may make the approximation that $A(E,\theta)$ and $B(E,\theta)$ are independent of energy, and the above expression may be fitted to the experimental data to yield the energy dependence of the quantity $\beta+\xi(\theta)$. Fitting this with the Breit-Wigner expression

$$\beta=\arctan\left(\frac{\Gamma_\lambda/2}{E_\lambda+\Delta_\lambda-E}\right)\cong\arctan\left(\frac{\Gamma/2}{E_r-E}\right)\qquad(2)$$

yields a set of best values for the resonance parameters E_r and Γ, and also for the constant ξ. For the narrow resonances the effects of ignoring the energy variation of Γ_λ and Δ_λ are small. However, for the broad levels (of the order of 100 kev or more) it was necessary to consider the effects of these variations, if only in an approximate manner.

If the resonance is *not* isolated, or if the resonance is quite broad, the procedure is essentially the same; however, the energy variations of $A(E,\theta)$ and $B(E,\theta)$ must then be taken into account. The energy variation of $A(E,\theta)$ is due primarily to the energy variation in the nonresonance contributions to the cross section, and may be determined approximately from the general behavior of the cross section in the region off-resonance. $B(E,\theta)$ is proportional to the square of the resonance scattering amplitude, which goes as Γ_e/Γ. If the resonance is relatively narrow, or if the reaction width is zero ($\Gamma_e=\Gamma$) this variation is expected to be negligible.

The results of this analysis are presented in Table I. A summary of the results of other investigations is also given for the purpose of comparison. In general, the agreement between the present assignments and earlier ones is good. With reference to the slight disagreement in total widths as obtained for the four lower resonances, it is pointed out that the results of the present investigation agree more closely with the earlier results published by Duncan and Perry.[8]

In the analysis of the various resonance data, it was necessary to give special consideration to those narrow resonances for which the experimental energy resolution was not sufficiently good to determine the true resonance shape. The *apparent* energy dependence of the resonance phase shift, as obtained from Eq. (1), is influenced most strongly in the region close to the resonance energy, to an extent determined by the relative magnitudes of the resonance width and the energy spread of the incident proton beam. The value of E_r may still be obtained with no difficulty. In attempting to obtain reasonable values for Γ, the following procedures were applied: (1) The energy dependence of the extracted phase shift β was fitted in the region where β varies only slowly with energy, and hence where the effects of the limited energy resolution are small.

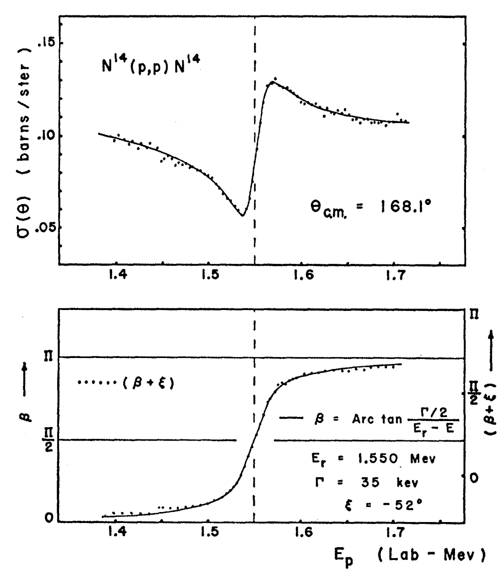

FIG. 5. Phase-shift analysis of 1.550-Mev resonance. Experimental cross sections are shown in the upper plot. The energy dependence of the resonance phase shift β is shown in the lower plot. The dots give the values of $(\beta+\xi)$ as extracted directly from the experimental data. The solid curve is the single-level dependence calculated for the resonance parameters given.

[9] W. Haeberli, Phys. Rev. 99, 640(A) (1955).

(2) The energy dependence of β was examined at resonance, taking into account directly the effects of the experimental resolution. Since the energy spread of the incident proton beam had been quite well determined this method could be applied with fairly high accuracy.

For the resonance having total widths of less than 10 kev both of the above procedures were applied in the determination of Γ; the results were found to agree quite well.

The resonances at 1.061, 1.550, 1.744, 1.804, and 3.192 Mev are reasonably well isolated, and the analysis involved no complications. The resonance at 1.550 Mev has been chosen as an illustration of the method. The results are shown in Fig. 5. The upper curve shows the experimental cross sections, the lower curve shows the values of $(\beta+\xi)$ extracted from these data by means of Eq. (1). These points have been fitted with the Breit-Wigner dependence for β given by Eq. (2) to yield a set of best values for the resonance energy E_r and the total width Γ. The results give $E_r=1.550$ Mev, $\Gamma=35$ kev, in very good agreement with the results reported by Hagedorn *et al.*[7]

For the resonances at 2.349 and 2.478 Mev the energy variation in $A(E,\theta)$ was estimated from the cross-section behavior in the region off-resonance; this variation was due primarily to the broad resonance at 2.38 Mev, and could be determined rather well. The variation in $B(E,\theta)$ was neglected, since the resonances are relatively narrow. The analysis outlined above was applied to the data for both 168.1° and 90.0°; a comparison of the results, which agree within the error limits given in Table I, would seem to indicate that this procedure is valid. The analysis of the resonance at 2.535 Mev was quite similar; however, in this case it was necessary to take into account the effects of the experimental resolution, which are rather severe. Since for this resonance the total width is of the same order as the energy spread of the incident proton beam, the uncertainties involved in correcting for this spread introduce relatively large uncertainties into the evaluation of Γ.

For the broad resonance at 2.38 Mev, values of E_r and Γ were obtained to yield a phase shift having the proper slope at resonance. The total width is related to this slope by $\Gamma=2(d\beta/dE)^{-1}$, evaluated at resonance. The reasons for this approach are evident from Eqs. (1) and (2). In the region far from resonance, the energy dependence of the phase shift β is influenced strongly by variations in both Γ_λ and Δ_λ; however, in the region close to E_r, the main variation in β is due to the variation in the proton energy E. Further, the errors introduced into the analysis by neglecting the energy variations in $A(E,\theta)$ and $B(E,\theta)$ are reduced under this treatment. Again, the results for 168.1° and 90.0° were compared to yield the values given in Table I. The existence of the corresponding level in O^{15} has been reported from other investigations. From considerations of the hard-sphere scattering phase shifts in this region of proton energy it has been suggested[10] that the anomalous behavior of the cross section is due to formation of a broad $J^\pi=\frac{1}{2}^+$ level at about 2.5 Mev. However, no accurate determinations of its width and resonance energy have been reported. The above analysis can be expected to yield a reasonably accurate determination of these parameters. Although the ultimate justification of these assignments rests with the complete phase-shift analysis in this region of proton energy, the knowledge of these parameters may prove useful in performing such an analysis. It should perhaps be pointed out that the above procedure, when applied to the analysis of broad resonances in $S^{32}(p,p)S^{32}$,[11] was found to give good agreement with the results of a more detailed phase shift analysis.

Investigation of the anomaly in the region of 3.4 Mev indicates that the observed variation involves two, or possibly more, resonance levels. Additional data obtained at the remaining angles of scattering support this conclusion. The energy variation of the extracted phase shifts show a single-level variation up to about 3.44 Mev, and then exhibits a break which appears at all angles. The curve can be fitted reasonably well at the lower energies assuming a level at $E_r=3.395$ Mev, with a width $\Gamma\cong 50$ kev. Evidence is also found for a somewhat narrower level with $E_r\cong 3.44$ Mev. These conclusions are quite tentative.

The analysis of the broad resonance in the region of 3.9 Mev was complicated by the fact that for this case the partial inelastic width is not zero, and varies rather strongly with energy. In attempting an analysis, one must therefore estimate the energy dependence of $B(E,\theta)$, which is given approximately by $B(E,\theta) =(\Gamma_e/\Gamma)^2B(\theta)$. For this case $\Gamma=\Gamma_e+\Gamma_i$, and it is apparent from Figs. 2 and 3 that Γ_i is considerably smaller than Γ_e; therefore, as a first approximation, the phase-shift analysis was carried out assuming that $\Gamma_e=\Gamma=$ constant. The results obtained for the six angles of scattering agree quite well, yielding $E_r=3.865$ Mev, $\Gamma=85$ kev. The variation between the values obtained for the different angles was about ± 7 kev for E_r and ± 5 kev for Γ. However, consideration of Eq. (1) suggests that the values for E_r obtained in this way are quite likely to be lower than the true values.

To complete the analysis, one must turn to the examination of the inelastic scattering data of Figs. 3 and 4. The observed anisotropy of the inelastic protons indicates that the resonance level of O^{15} has total angular momentum $J\geqslant\frac{3}{2}$ and the inelastically scattered proton has orbital angular momentum $l'\geqslant 1$. The expression for the total inelastic cross section is given by

$$\sigma_i=\pi\lambda\!\!\!^{-2}\frac{2J+1}{(2s+1)(2I+1)}\frac{\Gamma_e\Gamma_i}{(E_r-E)^2+(\Gamma/2)^2}, \qquad (3)$$

[10] A. J. Ferguson, Bull. Am. Phys. Soc. Ser. II 3, 26 (1958).
[11] J. W. Olness, Ph.D. thesis, Duke University (to be published).

TABLE II. Resonance parameters calculated for various possible assignments for 3.878-Mev resonance. Column 1 lists the various possible assignments of spin and parity for the level at $E_r=3.878$ Mev; columns 2 and 3 give the corresponding allowed values for the orbital angular momentum of the incident proton and the inelastically scattered proton, respectively. Column 4 gives the partial inelastic widths calculated from the data for these assignments. The maximum allowed widths, corresponding to a reduced inelastic width representing the full Wigner limit, are shown in column 5 for comparison.

J^π	l	l'	$(\Gamma_i)_{exp}$ (kev)	$(\Gamma_i)_W$ (kev)
$\frac{3}{2}-$	1,3	1	11	730
$\frac{5}{2}-$	1,3	3	7.1	3.6
$\frac{7}{2}-$	3,5	3	5.2	3.6
$\frac{3}{2}+$	0,2	2	11	80
$\frac{5}{2}+$	2,4	2	7.1	80
$\frac{7}{2}+$	2,4	4	5.2	<1

where $s=\frac{1}{2}$ is the spin of the proton, and $I=1$ is the spin of the target nucleus. The experimental value for the peak inelastic cross section was determined from the angular distribution measurements to be 58.8 ± 4.1 millibarns. (This figure is in good agreement with the total inelastic cross section calculated from the published data of the Oak Ridge group.[6]) With this value for σ_i, Eq. (3) was used to calculate the inelastic widths corresponding to the various possible assignments for J. The results are shown in Table II. Also shown, for each of the possible assignments of spin and parity, J^π are the allowed values for l and l', the orbital angular momentum of the incoming proton and the inelastically scattered proton, respectively. The maximum obtainable width, assuming a reduced inelastic width representing the full Wigner limit (given by $\gamma_W{}^2=3\hbar^2/2ma$), is also given. The value used for the nuclear radius was that given by $a=1.45\times10^{-13}(A^{\frac{1}{3}}+1)$ cm. With reference to Table II, the assignments involving $l'\geqslant3$ can be immediately ruled out, since the calculated partial widths exceed the Wigner limit by a factor of roughly 2 or more. One is thus left with the possible assignments $J^\pi=\frac{3}{2}^-$, $l'=1$; $J^\pi=\frac{3}{2}^+$, $l'=2$; or $J^\pi=\frac{5}{2}^+$, $l'=2$.

A reconsideration of the elastic scattering data of Fig. 2 results in the assignment of $\frac{5}{2}^+$ for the level of O^{15}. The possibilities for either a $\frac{3}{2}^-$ or a $\frac{3}{2}^+$ assignment can be ruled out on the basis of the observed scattering amplitude for 168.1°, which is considerably larger than one would obtain for a resonance with $J=\frac{3}{2}$. With respect to the $\frac{3}{2}^-$ assignment, which may involve only $l=1$ or 3, the observed variation of the resonance scattering amplitude with angle of scattering does not seem to agree with either pure p-wave formation, or pure f-wave formation, nor would an admixture of the two give the proper variation for most angles of scattering. Again, the amplitudes for s- and/or d-wave formation of a $\frac{3}{2}^+$ level are consistently smaller than those observed.

Conversely, the general angular dependence of the scattering amplitude obtained for pure d-wave formation of a $\frac{5}{2}^+$ state would seem to fit the data reasonably well. If one assumes further that the nonresonance contributions to the cross section in this region of proton energy are primarily p-wave and s-wave, the observed asymmetries are also in qualitative agreement with that expected for a d-wave resonance.

The analysis of the inelastic scattering data, taking into account the energy variation of Γ_i, yields the values $E_r=3.885\pm0.008$ Mev, $\Gamma=85\pm10$ kev, $\Gamma_i=7$ kev. For this assignment ($l'=2$) the calculated inelastic width varies in magnitude by a factor of two over the 200-kev interval near resonance; the energy dependence of the differential cross section exhibits an asymmetry which matches rather closely that of the experimental data. A reconsideration of the analysis of the elastic scattering data, taking into account the energy variation in Γ_i, results in the values $E_r=3.870\pm0.010$ Mev, $\Gamma=85\pm8$ kev. The overlap between the results of the analysis of the two sets of data is not large; however, it is expected that the analysis of the elastic scattering data yields a value for E_r too low, while the inelastic scattering analysis yields a value too high.

Not much can be said about the resonance at 3.980 Mev. The resonance appears only weakly in the elastic scattering curves. The inelastic cross section is so small that it was not considered feasible to attempt a detailed study of this resonance with the gas scattering chamber since one is limited by the capacity of the differential pumping system to relatively thin targets. However, upon correlating the results obtained here with those of the gamma-ray study,[6] it is concluded that the resonance most probably involves $J\geqslant\frac{3}{2}$, $l'\geqslant1$, and that $\Gamma_e<\Gamma_i$.

The inelastic scattering data lends additional support to the assignment of 0^+ for the spin and parity of the 2.31-Mev excited state of N^{14}. The angular distribution of the gamma rays at both the 3.878-Mev and 3.980-Mev resonances has been found to be isotropic.[6] Ignoring the possibility that this may be entirely accidental, the observation that the corresponding inelastic proton angular distribution is not isotropic rules out all possibilities other than $J=0$. It has been assumed throughout the above work that the 0^+ assignment is correct.

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