Search for the Electroproduction of the $N'(1470)$ Resonance from Deuterium*

J. L. ALBERI, J. A. APPEL,† R. J. BUDNITZ,‡ J. CHEN, J. R. DUNNING, JR., M. GOITEIN,§ K. HANSON, D. C. IMRIE,|| C. A. MISTRETTA,** AND RICHARD WILSON
Harvard University, Cambridge, Massachusetts 01451

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The energy spectrum of electrons inelastically scattered at 20° lab from deuterium has been measured for an incident electron energy of 1578 MeV. The virtual photon cross section has two peaks at mass values corresponding to the $\Delta(1236)$ and $N'(1525)$ resonances. No peak was observed in the mass region of the $N'(1470)$ Roper resonance. The upper limit for the contribution of the Roper resonance to the virtual photon cross section is estimated to be 120 μb.

I. INTRODUCTION

A RESONANCE with the same quantum numbers as the nucleon, $(I,J^P)=(\frac{1}{2},\frac{1}{2}^+)$, and a mass of approximately 1470 MeV, has been predicted in pion-nucleon phase-shift analyses by Roper *et al.*[1] and by others.[2,3] A peak at the appropriate mass value has been observed in small-angle p-p and π-p inelastic scattering at several energies.[4–8] The total photon-proton cross section does not exhibit an obvious bump in the vicinity of 1470 MeV; the presence of the resonance must be inferred from a complicated analysis of the photoproduction angular distribution. Two recent analyses have predicted small Roper resonance contributions.[9,10] Similarly, no obvious peak has been observed at the appropriate mass value in the energy spectrum of electrons scattered inelastically from protons at four-momentum transfers between 0.1 and 4 $(\mathrm{BeV}/c)^2$.[11–13] One model (relativistic N/D model[14]) for the electroproduction of this resonance suggests a large excitation at high four-momentum transfers; other models suggest small effects.[14]

The above experiments have investigated scattering from protons. The aim of the experiment reported here was to determine whether the electroproduction of the Roper resonance from *neutrons* was sufficiently large to produce a clear peak in the energy spectrum of electrons inelastically scattered from deuterium at a four-momentum transfer near 0.1 $(\mathrm{BeV}/c)^2$. For comparison purposes, a limited amount of less precise data was obtained with the target filled with hydrogen.

The reaction was studied at a low four-momentum transfer since the hadron scattering experiments noted above have indicated that the $\Delta(1236)$ and $N'(1470)$ resonance cross sections decrease more rapidly with four-momentum transfer than those of the higher pion-nucleon resonances. The application of static threshold relations to the electroproduction of nucleon resonances[11] also indicates that the *relative* contribution of the Roper resonance may be larger at small four-momentum transfers.

Several alternative $SU(3)$ classifications of the Roper resonance have been suggested, but the existing evidence appears to favor the assignment of the resonance to the $\{\overline{10}\}$.[15] Lipkin[16] has observed that if the resonance is a member of the $\{\overline{10}\}$, then its photoproduction from a proton is forbidden by U-spin conservation, whereas photoproduction from a neutron is allowed, i.e.,

$$\begin{aligned} &\underset{U=\frac{1}{2}}{\gamma+p} \rightarrow \underset{U=\frac{3}{2}}{N^+(\tfrac{1}{2},\tfrac{1}{2}^+)}, \quad \text{(forbidden)} \\ &\underset{U=1}{\gamma+n} \rightarrow \underset{U=1}{N^0(\tfrac{1}{2},\tfrac{1}{2}^+)}, \quad \text{(allowed)}. \end{aligned} \tag{1}$$

Similarly, Lipkin noted that decay selection rules

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† Partially supported by a Danforth Foundation Graduate Fellowship.
‡ Presently at the Lawrence Radiation Laboratory, University of California, Berkeley, Calif.
§ Partially supported by a Frank Knox Memorial Fellowship and by an IBM Fellowship.
|| Permanent address: University College London, London, England.
** Presently at the University of Wisconsin, Madison, Wisc.

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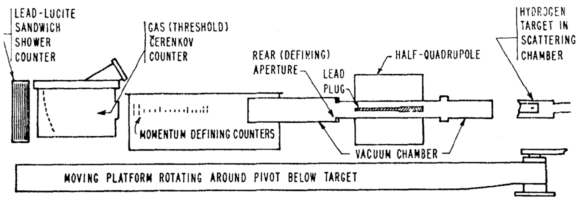

FIG. 1. Side view of electron spectrometer.

occur if the Roper resonance can be assigned to the $\{\overline{10}\}$. For example, a member of the $\{\overline{10}\}$ cannot decay into a member of the $\{10\}$ or the $\{8\}$, so that the decay of the Roper resonance into the $\Delta(1236)$ and a pion is forbidden. It has been observed that the inelastic decay of the $N'(1470)$ is not $\Delta(1236)+\pi$,[15] so that this part of Lipkin's prediction appears to be confirmed. Recently, Donnachie[15] has suggested, on the basis of fixed-t dispersion relations, that the photoproduction of the Roper resonance from neutrons is two orders of magnitude greater than that from protons, a result which tends to confirm Lipkin's assignment.

II. APPARATUS AND DATA REDUCTION

The apparatus, which is shown in Fig. 1, has been described in detail by Goitein[17] and by Budnitz *et al.*[18] Only the scattered electron was detected in this experiment. The apparatus comprised a half-quadrupole magnetic spectrometer at 20° to the incident beam, followed by a threshold gas Čerenkov counter and a lead-Lucite shower counter. The momentum resolution of the spectrometer was approximately 2.0% (full width at half-maximum). The electron solid angle was 0.8 msr. An external electron beam from the Cambridge electron accelerator, with an energy of 1578 MeV, was focussed to form a 2-mm-diam spot on a 5-cm-thick liquid deuterium (or hydrogen) target. The horizontal position of the electron beam after the target was monitored by a tuned rf cavity. A Faraday cup, whose stability was monitored by a secondary emission monitor, measured the incident beam flux.

The data have been corrected for the effects of counter efficiencies, target-produced background, and electron radiation. The method used to make the radiative correction has been described by Mistretta[19] and is similar to the procedure of Bjorken.[20] The data were normalized to a concurrent measurement of the elastic electro-proton cross section at the same incident energy and scattering angle. The over-all normalization error is estimated to be 5%.

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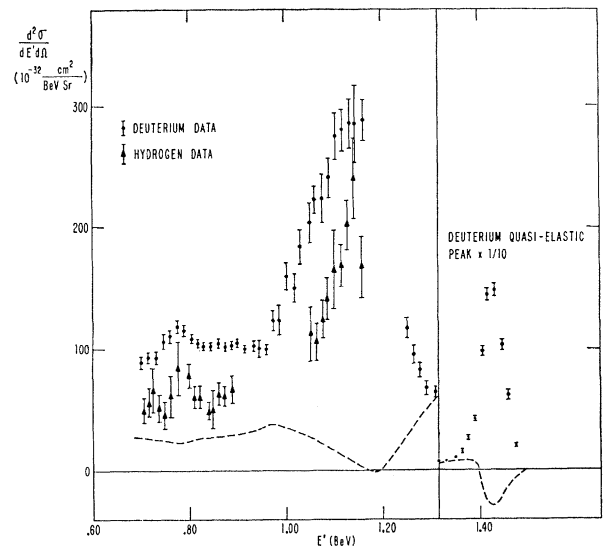

FIG. 2. Doubly differential inelastic scattering cross sections for hydrogen and deuterium at 19.98° lab, 1.578-MeV incident electron energy. The dashed line is the radiative correction applied to the deuterium data.

III. RESULTS AND DISCUSSION

Figure 2 shows the doubly differential cross sections $d^2\sigma/dE'd\Omega$ for hydrogen and deuterium as a function of the final electron energy. The dashed curve is the radiative correction applied to the deuterium data. In the deuterium measurements, peaks are observed for both $\Delta(1236)$ and $N'(1525)$ resonances at the appropriate final electron energy, while the less extensive hydrogen data indicate the presence of a peak at 1525 MeV. The $N'(1470)$ is not strongly excited from either hydrogen or deuterium. The deuterium-to-hydrogen cross-section ratio is approximately 1.7 over the region studied.

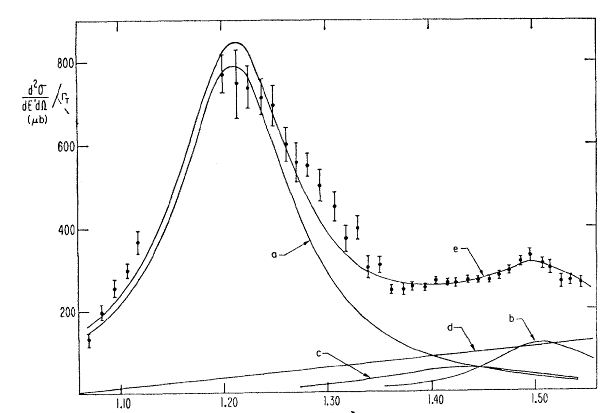

FIG. 3. $(d^2\sigma/dE'd\Omega)/\Gamma_T$ for deuterium as a function of isobar mass. Curve (e) is the best fit to the data using three nonrelativistic Breit-Wigner resonance curves plus a straight-line background. Curves (a)–(c) are the individual contributions of the $\Delta(1236)$, Roper, and $N'(1525)$ resonances, respectively; (d) is an estimate of the background.

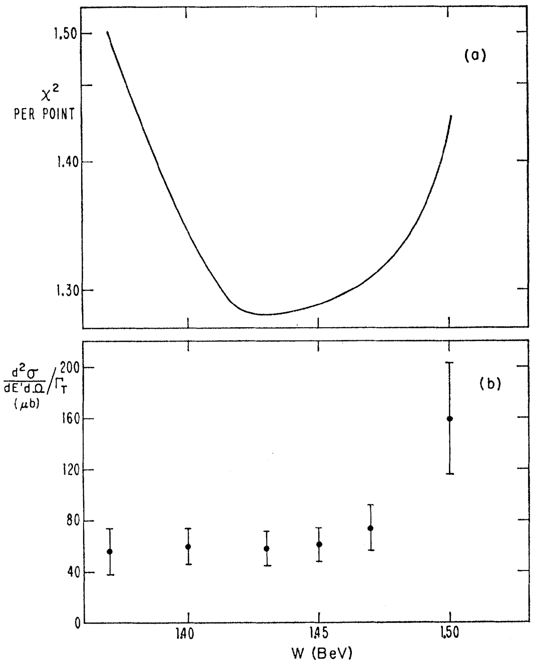

FIG. 4. (a) χ^2 of fit as a function of the assumed mass of the Roper resonance. (b) Peak value of fitted Roper resonance contribution as a function of assumed mass.

Following Hand,[21] the virtual photon cross section may be written as

$$\frac{d^2\sigma}{dE'd\Omega}\Big/\Gamma_T=\sigma_T+\epsilon\sigma_0,$$

where

$$\Gamma_T=\frac{\alpha}{4\pi^2}\frac{k}{q^2}\frac{E'}{E}\left[2+\frac{\cot^2(\frac{1}{2}\theta)}{(1+q_0^2/q^2)}\right] \tag{2}$$

and

$$\epsilon=[1+2(1+q_0^2|q^2)\tan^2(\tfrac{1}{2}\theta)]^{-1}.$$

E and E' are the incident and scattered electron energies, respectively, θ is the electron scattering angle, q^2 is the invariant square of the four-momentum transfer, and $q_0=(E-E')$. k is the equivalent photon energy, $(W^2-M^2)/2M$, where W is the pion-nucleon c.m. energy and M is the proton mass. σ_T and σ_0 are the transverse and longitudinal parts of the virtual photon cross section. Γ_T is the number of transverse virtual photons per unit energy and angle of the scattered electron, and ϵ is the transverse polarization of the virtual photon.

Figure 3 and Table I present the virtual photon cross section of deuterium as a function of W. The tail of the quasi-elastic peak has been subtracted from the five cross-section values with $W<1.12$ BeV. For the remainder of the data, its effect was negligible. To obtain an upper limit for the contribution of the Roper resonance, the deuterium data were fitted, using the sum of three nonrelativistic Breit-Wigner curves plus a straight-line background. The masses and widths of the $\Delta(1236)$ and $N'(1525)$ were constrained to known values. The Roper resonance was assumed to have a width of 210 MeV and several fits were attempted with the mass varying from 1370 to 1500 MeV, since the precise peak position expected in electroproduction is uncertain. The experimental deuterium quasi-elastic peak was folded into the Breit-Wigner shapes to approximate the broadening of the resonances due to the nucleon motion in the deuteron and the experimental energy resolution.

Curve (e) in Fig. 3 is the best fit; curves (a)–(c) are the contributions of the individual resonances and (d) is an estimate of the background. Figure 4(a) shows the χ^2 value of the fits and Fig. 4(b) the peak value of the Roper resonance contribution as a function of the mass assumed for the resonance. The errors shown in the figure are purely statistical. χ^2 has a broad minimum at the appropriate mass and there is a large region over which the fitted value of the Roper resonance contribution remains approximately constant at 60 μb. However, the dominant errors in the estimation of the

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TABLE I. $(d^2\sigma/dE'd\Omega)/\Gamma_T$ for deuterium. The tail of the quasi-elastic peak has been subtracted from the five cross-section values with $W<1.12$ BeV. The errors shown are relative only; there is an additional scale error of 5%

E' (BeV)	W (BeV)	$(d^2\sigma/dE'd\Omega)/\Gamma_T$ (μb)	Error (μb)
0.703	1.546	264	14
0.717	1.536	270	13
0.731	1.526	267	15
0.747	1.516	302	16
0.758	1.508	311	13
0.775	1.497	331	14
0.789	1.487	318	10
0.804	1.476	296	8.9
0.818	1.466	283	9.3
0.831	1.458	272	7.0
0.846	1.446	270	7.4
0.861	1.436	274	7.3
0.875	1.426	264	7.3
0.888	1.416	265	7.3
0.903	1.405	268	8.3
0.917	1.395	253	7.8
0.934	1.383	259	9.9
0.945	1.374	252	17
0.961	1.362	250	11
0.975	1.351	308	21
0.990	1.340	306	30
1.004	1.329	399	28
1.018	1.318	371	30
1.032	1.307	453	35
1.050	1.293	503	39
1.061	1.284	551	27
1.077	1.271	558	49
1.090	1.261	601	41
1.103	1.249	695	48
1.118	1.237	714	42
1.134	1.224	739	51
1.146	1.214	750	84
1.162	1.201	772	45
1.253	1.119	368	25
1.266	1.108	298	23
1.278	1.096	257	19
1.291	1.083	198	20
1.305	1.070	133	18

Roper resonance contribution are clearly not statistical, but are due to uncertainties in the detailed behavior of the tails of the other resonances and the background. We estimate that the uncertainty in these factors is of the same order as the fitted Roper resonance contribution. Therefore, our upper limit for the contribution of the Roper resonance to the virtual photon cross section of deuterium is 120 μb at $W=1430$ MeV, $q^2=0.16$ (BeV/c)^2, $\epsilon=0.80$. The photoproduction analysis of Ref. 9 predicts a Roper resonance contribution at $W=1350$ MeV of approximately 12% of the cross section at the $\Delta(1236)$ peak. Extrapolating this result to $W=1470$ MeV, assuming a Breit-Wigner shape for the Roper resonance, the predicted contribution at the resonance peak is approximately 50% larger than the experimental upper limit.

Although the hydrogen cross-section values measured in the present work are of limited precision, some useful comparisons can be made with previous data. Since the deuterium-to-hydrogen cross-section ratio is observed to be practically independent of W in this energy region, an estimate of the virtual photon cross section of hydrogen can be obtained by scaling the best fit to the deuterium data by the measured cross-section ratio.

At $W=1236$ MeV, this method predicts a virtual photon cross section of 520±41 μb for $q^2=0.22$ (BeV/c)^2, $\epsilon=0.9$. Lynch *et al.*[12] have obtained $\sigma_T=444\pm13$ μb, $\sigma_0=88\pm23$ μb at $q^2=0.2$ (BeV/c)^2, implying, from Eq. (1), a virtual photon cross section of 520±24 μb at $\epsilon=0.9$, in excellent agreement with the present estimate.

Similarly, at $W=1525$ MeV, the virtual photon cross section of hydrogen is estimated to be 184±20 μb. Figure 5 shows that this result is in good agreement with electroproduction results at higher four-momentum transfers.[11–13] For the purposes of this comparison, the nucleon isovector form factor $G_{MV}(q^2)$ has been approximated by the dipole fit relation[22]:

$$G_{MV}(0)|G_{MV}(q^2)=\{1+q^2/[0.71\ (\mathrm{BeV}/c)^2]\}^2. \quad (3)$$

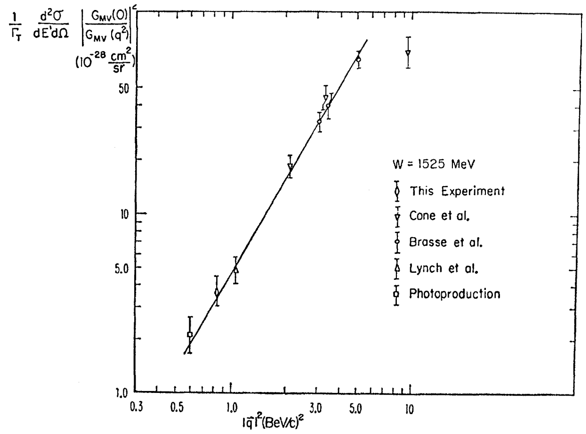

FIG. 5. $(1/\Gamma_T)(d^2\sigma/dE'd\Omega)[G_{MV}(0)/G_{MV}(q^2)]^2$ as a function of $|\mathbf{q}|^2$, the square of the three-momentum transfer to the isobar system, at $W=1525$ MeV.

The total photoproduction cross section shown in Fig. 5 is that obtained by Brasse *et al.*[13] from an analysis of bubble-chamber data.

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