TEST OF SU(6) PREDICTIONS IN WEAK N^* PRODUCTION*

C. H. Albright and L. S. Liu
Northwestern University, Evanston, Illinois
(Received 26 January 1965)

Recently Wigner's supermultiplet theory[1] in nuclear physics has been extended independently by several authors[2] to the domain of elementary particle physics. The new group in question, SU(6), contains $SU(2)\otimes SU(3)$ as a subgroup and hence can be used to describe interactions which are both spin and unitary-spin independent in the symmetry limit. A consequence of this scheme is that the pseudoscalar meson octet and vector meson nonet can be conveniently assigned to the adjoint representation, $\underline{35}$, while the baryon $J^P=\frac{1}{2}^+$ octet and $\frac{3}{2}^+$ decuplet are identified as members of the $\underline{56}$. Predictions based on this symmetry scheme in the past have taken the form of mass sum rules[3] and magnetic-moment relations[4] which are in qualitative (and in some cases remarkable) agreement with experiment.

In the framework of SU(6), Bég and Pais[5] have constructed the following interaction:

$$3B_{\alpha\beta\gamma}^{\dagger}(p_2)B^{\alpha\beta\delta}(p_1)C_{\delta}^{\gamma}(q), \tag{1}$$

where

$$C_{\delta}^{\gamma}(q)=\frac{G_V}{\sqrt{2}}[\delta_i^{\,j}(L_0)_A^{\,B}-i\mu_W(\vec{\sigma}\cdot\vec{q}\times\vec{L}_A^{\,B})_i^{\,j}] + \frac{3}{5}\frac{G_A}{\sqrt{2}}(\vec{\sigma}\cdot\vec{L}_A^{\,B})_i^{\,j}, \tag{2}$$

to describe in the nonrelativistic limit the general semileptonic process,

$$\nu_l+B(1)\rightarrow B(2)+l, \tag{3}$$

where B refers to a member of the $\underline{56}$ and the remaining symbols are defined in reference 5. [Note that a misprint in the sign of the μ_W term has been corrected.[6]] Two important examples of (3), the elastic process

$$\nu_{\mu}+n\rightarrow p+\mu^-, \tag{4}$$

and the inelastic process

$$\nu_{\mu}+n\rightarrow N^{*+}+\mu^-, \tag{5}$$

are related[7] through Eqs. (1) and (2). In this note, we wish to test this relationship in detail.

A phenomenological analysis of Reaction (5) has been given by the present authors in a recent Letter.[8] The most general matrix element, $\mathfrak{M}$, for this process involves eight form factors, $F_i^{V,A}(t)$, with $i=1,2,3,4$, which are functions of the invariant momentum transfer squared, $t=-q^2=-(p_2-p_1)^2$. In order to make the necessary identification of our work with that of Bég and Pais, the nonrelativistic limit of Eq. (1) of reference 8 must be compared with the $n\rightarrow N^{*+}$ term in Eqs. (1) and (2) above. We find the following relations:

$$F_1^{V}(0)-2F_2^{V}(0)=\frac{4\sqrt{2}}{5}\left(\frac{3}{2}\right)^{1/2}\frac{\mu(p)-\mu(n)}{(e/2M)}=6.5, \tag{6}$$

$$F_1^{A}(0)=-\frac{2\sqrt{2}}{5}\left(\frac{3}{2}\right)^{1/2}\left(\frac{G_A}{G_V}\right)=-0.83. \tag{7}$$

Note that the direct axial-vector form factor, F_1^A, is determined uniquely both in magnitude and sign relative to F_1^V by the SU(6) theory of Bég and Pais.

In order to determine the two vector form factors individually, we invoke the conserved-vector-current (CVC) hypothesis and derive the linear relation

$$M_1^{\,2}F_1^{V}(0)+M_1(M_1+M_2)F_2^{V}(0) +(M_2^{\,2}-M_1^{\,2})F_3^{V}(0)=0; \tag{8}$$

cf. Eq. (4) of reference 8. The N^* photoproduction analysis by Gourdin and Salin[9] indicates that $F_3^V(0)/F_2^V(0)\simeq 0$. From Eqs. (6) and (8) we then deduce that

$$F_1^{V}(0)=3.5,\quad F_2^{V}(0)=-1.5. \tag{9}$$

This is in agreement with the numbers derived from the earlier work of Bég, Lee, and Pais[10] in which they postulated an effective electromagnetic vertex for the baryons in the SU(6) scheme.[11]

Concerning the effect of the remaining form factors, we now cite the following arguments.[8] The terms in $|\mathfrak{M}|^2$ involving F_3^V and F_3^A are at least "doubly" induced and are expected to give very small contributions to the production cross section. On the other hand, the in-

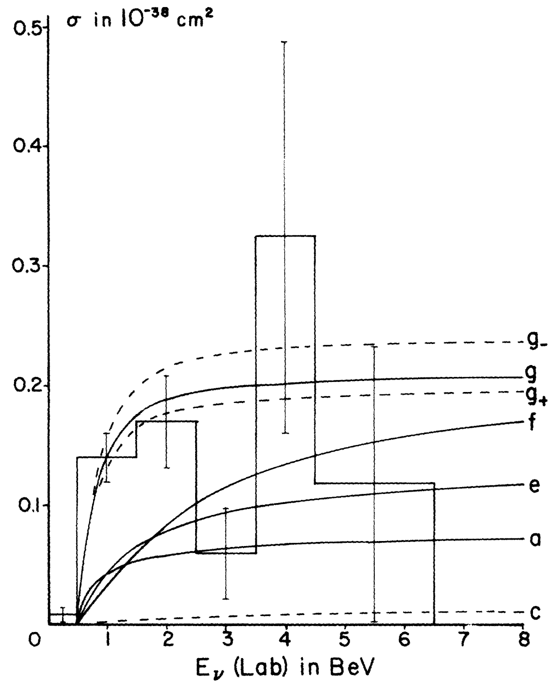

FIG. 1. Total cross section for the inelastic process $\nu_\mu + n \rightarrow N^{*+} + \mu^-$.

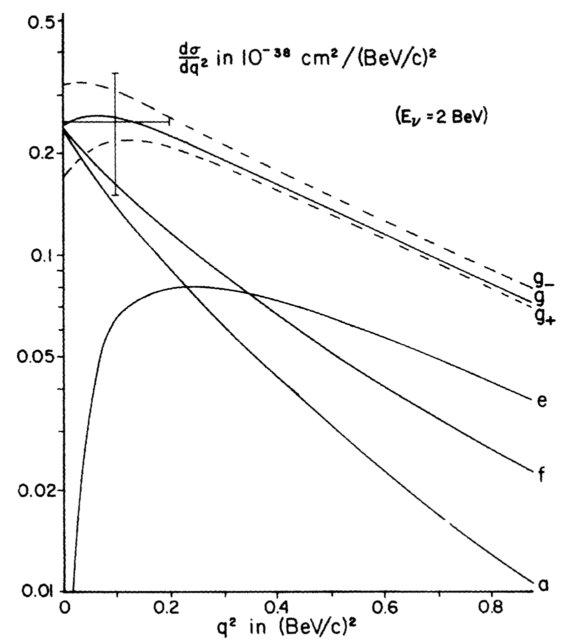

FIG. 2. Invariant differential cross section for the inelastic process $\nu_\mu + n \rightarrow N^{*+} + \mu^-$.

duced F_4^V and F_4^A terms are proportional to the lepton mass and hence also small. Thus we can safely drop these contributions in the numerical analysis.

Only the effect of F_2^A remains uncertain. Static theory leads one to believe that this form factor is small.[12] The hypothesis of a partially conserved axial-vector current at best relates F_1^A, F_2^A, and F_3^A at zero momentum transfer, but lack of information about F_3^A precludes determination of F_2^A. To exhibit the possible effect of F_2^A, we have included the range $-0.5|F_1^A| \leq F_2^A \leq 0.5|F_1^A|$.

Our numerical results for Reaction (5) are summarized in Figs. 1 and 2. The curves are labeled according to the convention of our previous Letter and show the various contributions. We adopt a Hofstadter-type q^2 dependence for the N-N^* transition form factors, i.e.,

$$F_i^{V,A}(-q^2) = F_i^{V,A}(0)/(1+q^2/b)^2, \qquad (10)$$

and set $b = 37.4 m_\pi^2$ as fitted in the elastic case.[13] The particular cases are listed in Table I. Case g refers to the unique prediction[5,10] of CVC and SU(6) with F_3^V and F_2^A omitted. The theoretical uncertainty in F_2^A considered above results in a band bounded by the two dashed curves of cases g_- and g_+. Case f is the analog of case g and refers to the antineutrino process $\bar{\nu}_\mu + p \rightarrow N^{*0} + \mu^+$. The experimental histogram and error bars are taken from the CERN heavy-liquid bubble chamber results of Block et al.[14] Since they report on weak N^* production per nucleon, we have scaled their results to the N^{*+} process by dividing by 2.

With the experimental uncertainties duly considered, the predictions of CVC and SU(6) appear rather striking. This is especially so since no attempt was made to achieve a best fit with the cutoff parameters $b_i^{V,A}$ adjusted for each form factor. The unique SU(6) prediction of the magnitude of the direct axial-vector form factor, i.e., $|F_1^A|/(G_A/G_V) \simeq 0.70$, is very compatible with the experimental information on the differential cross section at zero momentum transfer which is determined principally by this form factor. On the other hand, the vector form factors are weighted rather heavily according to Eq. (9). This is certainly a nontrivial mixture of F_1^A, F_1^V, and F_2^V which, however, results in a very reasonable total cross section. One sees that a nonvanishing F_2^A manifests itself mainly through its interference with the other three form factors.

With more data, the predictions will obviously be subject to a more stringent test. More accurate information on $d\sigma/dq^2$ would be desirable, but of course the theory of SU(6) becomes less reliable as q^2 departs from 0. The predictions for the antineutrino process[15] as given in case f serve as another crucial test for the theory, especially since the expected V-A interference term is so large.

We are grateful to Professor M. A. B. Bég and Professor A. Pais for sending us a preprint of their work prior to publication and for their interest in our work. We wish to thank Professor M. M. Block for many enlightening discussions concerning various aspects and results of the CERN neutrino experiments. We also wish to acknowledge a useful conversation pertaining to SU(6) with Professor J. J. Brehm and Professor R. H. Capps.

---

*Work supported in part by the National Science Foundation.

[1]E. Wigner, Phys. Rev. 51, 106 (1937).

[2]F. Gürsey and L. A. Radicati, Phys. Rev. Letters 13, 173 (1964); A. Pais, Phys. Rev. Letters 13, 175 (1964); B. Sakita, Phys. Rev. 136, B1756 (1964).

[3]T. K. Kuo and T. Yao, Phys. Rev. Letters 13, 415 (1964); M. A. B. Bég and V. Singh, Phys. Rev. Letters 13, 418, 509 (1964); F. J. Dyson and N.-h. Xuong, Phys. Rev. Letters 13, 815 (1964).

[4]M. A. B. Bég, B. W. Lee, and A. Pais, Phys. Rev. Letters 13, 514 (1964); B. Sakita, Phys. Rev. Letters 13, 643 (1964).

[5]M. A. B. Bég and A. Pais, Phys. Rev. Letters 14, 51 (1965).

[6]The authors of reference 5 have confirmed this correction (private communication).

[7]The relationship of these two processes in the limit of SU(6) symmetry has also been noted by R. P. Feynman, M. Gell-Mann, and G. Zweig, Phys. Rev. Letters 13, 678 (1964).

[8]C. H. Albright and L. S. Liu, Phys. Rev. Letters 13, 673 (1964). We use the same notations given in this Letter. A more detailed paper is in preparation.

[9]M. Gourdin and Ph. Salin, Nuovo Cimento 27, 193, 309 (1963).

[10]See Bég, Lee, and Pais, reference 4.

[11]These values for the vector form factors were previously deduced in reference 8.

[12]J. S. Bell and S. M. Berman, Nuovo Cimento 25, 404 (1962).

[13]See, e.g., R. Hofstadter, F. Bumiller, and M. R. Yearian, Rev. Mod. Phys. 30, 482 (1958).

[14]M. M. Block, H. Burmeister, D. C. Cundy, B. Eiben, C. Franzinetti, J. Keren, R. Møllerud, G. Myatt, M. Nikolic, A. Orkin-Lecourtois, M. Paty, D. H. Perkins, C. A. Ramm, K. Schultze, H. Sletten, K. Soop, R. Stump, W. Venus, and H. Yoshiki, Phys. Letters 12, 281 (1964).

[15]We understand that the CERN group is planning to begin an antineutrino run in April.

BARYON SPECTROSCOPY BY INELASTIC ELECTRON-PROTON SCATTERING*

A. A. Cone, K. W. Chen,† J. R. Dunning, Jr.,‡
C. Hartwig,§ N. F. Ramsey, J. K. Walker, and Richard Wilson
Department of Physics, Harvard University, Cambridge, Massachusetts
(Received 25 November 1964; revised manuscript received 5 February 1965)

We have measured the cross section for inelastic electron-proton scattering by detecting the scattered electrons. The apparatus has been briefly described in an earlier Letter.[1] In these measurements, an extensive set of data was taken at a laboratory scattering angle of 31°, and a lesser set at 90°. For the data at 31°, the incident energy of the electrons was fixed at one of three values corresponding to elastically scattered electrons of four-momentum transfers of 30, 45, and 100 inverse Fermis squared [11.7, 1.75, and 3.89 $(\mathrm{BeV}/c)^2$]. At each of these three values, the energy acceptance of the electron spectrometer was moved from the energy of the elastic electrons down to roughly half of this value, and we measured the energy spectrum of the scattered electrons in bins of a width of about 1.5% of the energy in the center of the bin. Peaks are observed in these spectra corresponding to resonant levels in the proton.

For comparison with photoproduction, we define a "gamma" energy K,

$$K = q_0 - \frac{q^2}{2M} = \frac{M^{*2} - M^2}{2M},$$

where M is the proton mass, M^* the rest mass of the excited resonance, and q is the four-momentum transfer.

It has been shown[2] that the cross section for inelastic electron-proton scattering (one-pho-