Production of $N_{11}$ Resonance and Properties of the Neutral Vector Mesons

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Neutral vector mesons ($\omega$ and $\varphi$) are usually thought to be coupled to some conserved current, and are frequently discussed in connection with conservation of hypercharge and baryon number. The purpose of this article is to suggest that the study of the recently found $I=1/2$, $J=(1/2)^+$ resonance (hereafter denoted as $N_{11}$) may be quite suitable for an experimental check of the above mentioned property of the neutral vector mesons.

The existence of $N_{11}$ resonance is first suggested from the phase shift analysis of $\pi N$ scattering, from which the quantum number of $N_{11}$ is determined to be $(I,J)^p=(1/2, 1/2)^+$.

Among various experiments, the existence of $N_{11}$ is most clearly observed in the reaction $K^-p\rightarrow K^-n\varphi$, $K^-p\rightarrow K^-p\pi^0$, $K^-p\rightarrow K^-p\pi^0$, where $P_s=(p_1+p_2)^+$, $Q_s=(p_2-p_1)^+$. If neutral vector bosons are coupled to conserved currents, only a definite linear combination of the first two couplings is permissible, namely, $\bar{N}_{11}(p_2)\sigma_s p_s N(p_1)V_s$. These coupling forms give simple amplitudes for the reaction $V_s(Q)+N(S_j)\rightarrow N_{11}+N(S_j)+\pi(q)$. These amplitudes are tabulated in Table I. In practice we observe this process as virtual one, and the quantities in the Table should be estimated in the rest frame of the produced $N_{11}$.

In the case of $KN$ collision (Fig. 1),

$$K(k_i)+N(s_i)\rightarrow K(k_f)+N_{11}$$

$\rightarrow K(k_f)+N(S_j)+\pi(q), \quad (1)$

$Q_s=(k_f-k_i), \quad \epsilon_0, Q_s(k_f+k_i)\epsilon_0$, so that the coupling $\bar{N}_{11}Q_s N_{11}$ gives no contribution. For the processes suitable for the study of nature of neutral vector bosons, this coupling gives no contribution, in general. We have dropped, therefore, this $\bar{N}_{11}Q_s N_{11}$ coupling as well as the terms proportional to dominance of such one particle exchange is, however, already verified in the $\rho$-exchange model for the reaction of the type $KN\rightarrow KN_{11}^s$, where $N_{11}^s$ is the 1238 Mev $\pi N$ resonance.\(^{4,5}\)

Now we suggest that from the analysis of the pion decay distribution of excited $N_{11}$, we can infer the coupling form of neutral vector mesons. Generally, there are three independent type of $\bar{N}_{11}N_{11}N_{11}N_{11}$ coupling, where $V_s$ stands for the neutral vector boson. These are $\bar{N}_{11}(p_2)\gamma_s N(p_1)V_s$, $\bar{N}_{11}(p_2)p_s N(p_1)V_s$ and $\bar{N}_{11}(p_2)Q_s N(p_1)V_s$, where $P_s=(p_1+p_2)^+$, $Q_s=(p_2-p_1)^+$. Neutral vector bosons are coupled to conserved currents, only a definite linear combination of the first two couplings is permissible, namely, $\bar{N}_{11}(p_2)\sigma_s p_s N(p_1)V_s$. These coupling forms give simple amplitudes for the reaction $V_s(Q)+N(S_j)\rightarrow N_{11}+N(S_j)+\pi(q)$. These amplitudes are tabulated in Table I. In practice we observe this process as virtual one, and the quantities in the Table should be estimated in the rest frame of the produced $N_{11}$.

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Table I. The decay amplitudes of $N_{11}$ for various coupling forms. $M$ and $m$ are masses of $N_{11}$ and $N$, respectively. $E_{k,f}$ is the energy of nucleon. The metric adopted is $Q^2=Q_0^2-Q^2$.

<table>
<thead>
<tr>
<th>coup. form</th>
<th>amplitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M(\pm m)\bar{N}<em>{11}(p_2)N</em>{11}N_{11}$</td>
<td>$-(M+m)\epsilon_0 [((E_i+m)(E_f+m)]^{-1/2}(\epsilon \cdot q)(\epsilon \cdot [Q \times \epsilon]) + \epsilon_0 (M+m) i(\epsilon \cdot q)]$</td>
</tr>
<tr>
<td>$\bar{N}<em>{11}P_s N</em>{11}N_{11}$</td>
<td>$-(2M/m)(E_i+m)^{-1/2}(E_f+m)^{-1/2}(\epsilon \cdot q)\epsilon_0$</td>
</tr>
<tr>
<td>$\bar{N}<em>{11}\sigma_s Q_s N</em>{11}N_{11}$</td>
<td>$m^{-1}[(E_i+m)(E_f+m)]^{-1/2}(M+m)(\epsilon \cdot q)(\epsilon \cdot [Q \times \epsilon] + \epsilon_0 Q^2 i(\epsilon \cdot q)]$</td>
</tr>
</tbody>
</table>
to $Q,e_e$ from the Table. Reaction (1) is most suitable for our purpose, since one $ps$-boson exchange is forbidden.

![Diagram](image)

### Fig. 1.

It is interesting to ask whether both $\omega$ and $\varphi$ are coupled to $N_{11}N$ vertex. In the $SU(6)$ 35-dimensional representation for $ps$- and vector-boson, the smallness of $N_{11}N\rho$ coupling would lead to the smallness of $N_{11}N\omega$ coupling, which is consistent with the indication that this $N_{11}$ is rather strongly coupled to $\eta N$ channel. The question may be solved by studying the electro-production of $N_{11}$: $e+N\rightarrow e+N+\pi$ (or $\eta$). This experiment will supply us with information about the $Q^2$ dependence of the coupling $g(Q^2)N_{11}$. By assuming a suitable pole approximation for $g(Q^2)$, we can decide the masses of intermediate bosons. Such procedure has been applied to electromagnetic form factor of nucleon successfully. The cross section for process $e+N\rightarrow e+N_{11}$ is given by

$$
\frac{d\sigma}{dQ} = - \left[ e^2 g^2 / 8(4\pi)^2 \right] \cdot [E^2 m^2 \\
\times \{1 + (2E/m)\sin^2(\theta/2)\} \sin^2(\theta/2)]^{-1} \\
\times [Q^2 (M+m)^2 - (M^2-m^2)^2 \\
\quad + 2Q^2 m^2 \cot^2(\theta/2)]
$$

(2)

in laboratory system. In the above, $E$ is the energy of incident electron, and $\theta$ is the scattering angle of final electron. Since the process is essentially a two-body pro-

1) See, for example, J. J. Sakurai, in *Theoretical Physics*, IAEA, 1963.