Remarks on the Neutrino Oscillation.

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Recently there has been controversy about the neutrino oscillation. Reines, et al. (1) have interpreted their data as evidence for neutrino oscillation, while Bohm et al. (2) have found no such evidence from their \( \bar{\nu}_e + p \) reaction data. The neutrino oscillation model seems to be the only choice presently available to understand the reactor neutrino data (1-3). On the other hand, the accumulating experimental evidence (3-4) in the analysis of oscillation parameters in reactor and high-energy neutrino-induced charged-current reactions seems to indicate that there is no neutrino oscillations within acceptable limits. This raises the question of how to interpret Irvine group's (1) data. It is one of the objectives of this letter to show that the Irvine group's data are not due to neutrino oscillation. Instead, they are to be attributed to the possible presence of extra channels in neutrino-induced reactions. We propose that the basic inverse beta decay \( \bar{\nu}_e \rightarrow e^+ n \) under consideration is accompanied by other neutrino-induced phion (\( \phi \)) production channels, such as \( \bar{\nu}_e \rightarrow e^+ \phi p \). The weak production of phion, a low-mass pseudoscalar meson is allowed energetically for the given reactor neutrino energy range (up to 10 MeV), since the mass of the phion is 1 MeV. In this letter we assume the existence of phion. A more detailed description of phion, its application and possible method of detection have been discussed elsewhere (4).

The Irvine group observed the reactor antineutrino-induced reactions on deuteron. The known reactions are the charged-current branch (ccd): \( 5d \rightarrow e^+ nn \), and the neutral-current branch (ncd): \( 5d \rightarrow \bar{\nu}pn \). In the experiment, two coincident neutrons are taken as the signature of the ccd and a single neutron as that for the ncd. Then the experimental ratio of two-neutron rate to one-neutron rate is measured to be, \( r_{\text{exp}} = \frac{3}{5} \).

References:

= 0.167 ± 0.093. On the other hand, the theoretical ratio, \( r_{\text{theor}} = \frac{\sigma(\text{ccd})}{\sigma(\text{ncd})} \), is calculated to be 0.42 for the calculated spectrum of Davis et al. (DVMS) \(^6\) and 0.44 for that of Avignone and Greenwood (AG) \(^7\). Thus the ratio of ratios, \( R \), defined as

\[
R = \frac{\frac{\sigma(\text{ccd})}{\sigma(\text{ncd})}_{\text{exp}}}{\frac{\sigma(\text{ccd})}{\sigma(\text{ncd})}_{\text{theor}}} = \frac{r_{\text{exp}}}{r_{\text{theor}}}
\]

comes out to be 0.40 ± 0.22 for the DVMS spectrum and 0.38 ± 0.21 for the AG spectrum. This clear deviation of \( R \) from the expected value of unity, regardless of the spectrum is interpreted by the Irvine group as an evidence for neutrino coalescence.

### Table I \(^2\) - Summary of results for the ratio \( \sigma_{\text{exp}} / \sigma_{\text{theor}} \).

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>Reaction</th>
<th>Neutrino Threshold (MeV)</th>
<th>AG Spectrum</th>
<th>DVMS Spectrum</th>
<th>Measured Neutrino spectrum</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.2</td>
<td>ncd</td>
<td>2.2</td>
<td>0.83 ± 0.13</td>
<td>1.1 ± 0.16</td>
<td>1.3 ± 0.22</td>
</tr>
<tr>
<td>11.2</td>
<td>ccd</td>
<td>4.0</td>
<td>0.32 ± 0.14</td>
<td>0.44 ± 0.19</td>
<td>0.61 ± 0.29</td>
</tr>
<tr>
<td>11.2</td>
<td>ccp</td>
<td>4.0</td>
<td>0.68 ± 0.12</td>
<td>0.88 ± 0.15</td>
<td>= 1.0</td>
</tr>
<tr>
<td>11.2</td>
<td>ccp</td>
<td>6.0</td>
<td>0.42 ± 0.09</td>
<td>0.58 ± 0.12</td>
<td>= 1.0</td>
</tr>
<tr>
<td>6</td>
<td>ccp</td>
<td>1.8</td>
<td>0.65 ± 0.09</td>
<td>0.84 ± 0.12</td>
<td>--</td>
</tr>
<tr>
<td>6</td>
<td>ccp</td>
<td>4.0</td>
<td>0.81 ± 0.11</td>
<td>1.02 ± 0.15</td>
<td>1.19 ± 0.27</td>
</tr>
</tbody>
</table>

\(^2\) This table is the same as table II in ref. \(^1\).

One of the objections to this interpretation is that the Irvine data (table I) seem to fail the crucial test of neutrino oscillation, as pointed out by Feynman and Vogel \(^8\), that the same reaction measured at the same energy should give different results at different distances. Table I shows that for the ccp reaction at 4.0 MeV neutrino detection threshold, the values for the ratio \( \sigma_{\text{exp}} / \sigma_{\text{theor}} \) for the DVMS spectrum are 0.88 ± 0.15 at 11.2 m and 1.02 ± 0.15 at 6 m, the same within errors. These values lead to a conclusion of no oscillation. The corresponding values for the AG spectrum lead to the same conclusion of no oscillation.

Perhaps the most serious objection \(^9\) to deducing neutrino oscillation from the data of table I is the following: Another ratio of ratios, \( R' \), can be defined as the ratio of \( \frac{\sigma(\text{ccd})_{\text{exp}}}{\sigma(\text{ccd})_{\text{theor}}} \) to \( \frac{\sigma(\text{ccd})_{\text{exp}}}{\sigma(\text{ccd})_{\text{theor}}} \), or equivalently,

\[
R' = \frac{\frac{\sigma(\text{ccd})}{\sigma(\text{ccd})}_{\text{exp}}}{\frac{\sigma(\text{ccd})}{\sigma(\text{ccd})}_{\text{theor}}} = \frac{r_{\text{exp}}'}{r_{\text{theor}}'}.
\]

\(^4\) Feynman and Vogel, see ref. \(^3\) above. This objection was pointed out to us by Dr. F. Reines in a private conversation as a "puzzle" that the measured cross-section \( \sigma(\text{ccd}) \) was too low by 1.6 standard deviations (at that time).