RIKEN Accel. Prog. Rep. **42** (2009)

An explanation of the NuTeV anomaly†

W. Bentz,*1 T. Ito,*1 I. C. Cloët,*2 and A. W. Thomas*3

[NUCLEAR PARTON DISTRIBUTIONS, Flavor dependence, Neutrino deep inelastic scattering]

The Paschos-Wolfenstein (PW) ratio is defined by[1)]

$$R = \frac{\sigma_{NC}^{\nu A} - \sigma_{NC}^{\overline{\nu} A}}{\sigma_{CC}^{\nu A} - \sigma_{CC}^{\overline{\nu} A}} ,$$

where A represents the nuclear target, and NC (CC) indicates weak neutral current (charged current) interactions. This ratio was determined by the NuTeV collaboration in 2002[2)] by using an iron target, where the measured inclusive deep inelastic (anti-) neutrino cross sections are integrated over the Bjorken scaling variable (x_A) and the energy transfer (y). The ratio can be expressed in terms of nuclear valence quark distributions $q_{A-} = q_A - \overline{q}_A$ by

$$\begin{aligned} R &= \frac{g_v^u \langle x_A u_{A-}\rangle - g_v^d \langle x_A d_{A-}\rangle}{3\langle x_A d_{A-}\rangle - \langle x_A u_{A-}\rangle} \equiv R_0 + \delta R \\ R_0 &= \frac{1}{2} - \sin^2\Theta_W \\ \delta R &\simeq \left(1 - \frac{7}{3}\sin^2\Theta_W\right) \frac{\langle x_A u_{A-} - x_A d_{A-}\rangle}{\langle x_A u_{A-} + x_A d_{A-}\rangle} , \end{aligned}$$

where Θ_W is the Weinberg angle, and for the quark weak vector charges (g_v^q) we follow the conventions of Ref.[3)]. $\langle \ldots \rangle$ implies integration over x_A, therefore the quantities in angle brackets are the fractions of the target momentum carried by the valence u and d quarks. R_0 is the PW ratio for isospin symmetric matter, and is given solely in terms of the Weinberg angle.

If one can determine the correction term δR arising from the neutron excess, the PW ratio provides a unique way to measure the Weinberg angle. In the NuTeV analysis, this correction was determined by assuming that the target is composed of free nucleons. The result was[2)] $R - \delta_{\rm f} R = 0.2723$, which implies $\sin^2\Theta_W = 0.2277$. The deviation from the Standard Model value (world average[4)]) $\sin^2\Theta_W = 0.2227$ is a three-sigma discrepancy [a)], and was often considered as an indication of physics beyond the Standard Model.

In our previous work[5)], we used the quark-diquark description of the nucleon in the Nambu-Jona-Lasinio model combined with the mean field approximation for infinite nuclear matter, to evaluate the valence quark distributions in isospin asymmetric nuclear environment. In this approach, which successfully describes the EMC effect[6)], we found that the additional binding (symmetry energy) of u quarks in $N > Z$ matter leads to an enhancement of medium modifications of the u quark distributions, and as a result the EMC effect increases as Z/N decreases from 1 to 0.6. Here we use our in-medium quark distributions for the same neutron excess as in the NuTeV experiment (5.74%) to investigate the influence of these isovector medium modifications on the PW ratio.

We use the Standard Model value of $\sin^2\Theta_W$, and split the correction into three pieces: $\delta R = \delta_{\rm f} R + \delta_{\rm med} R + \delta_{\rm csb} R$. The naive ("free") and medium corrections are evaluated in our model, while the correction arising from charge symmetry breaking ($m_d > m_u$) is taken from Ref.[7)]. Our results for $R - \delta_f R = R_0 + \delta_{\rm med} R + \delta_{\rm csb} R$ are shown in Table 1 in comparison to the NuTeV result quoted above. The medium correction $\delta_{\rm med} R = -0.0032$ comes mainly from the vector-isovector nuclear mean field (ρ^0), and only a small part from the Fermi motion of the nucleons. The final theoretical value, including medium modifications and charge symmetry breaking, is 0.2724, which explains the NuTeV result of 0.2723. Our conclusion is that the NuTeV measurement provides strong evidence that the nucleon is modified by the nuclear medium, and should not be interpreted as an indication for physics beyond the Standard Model.

R_0	+ med	+ csb	NuTeV
0.2773	0.2741	0.2724	0.2723

Table 1. Results for the PW ratio after naive isoscalarity corrections.

References
1) E.A. Paschos and L. Wolfenstein, Phys. Rev. **D 7** (1973) 91.
2) G.P. Zeller *et al.*, Phys. Rev. Lett. **88** (2002) 091802.
3) C. Amsler et al., Phys. Lett. **B 667** (2008) 1.
4) D. Abbaneo *et al.*, arXiv:hep-ex/0112021.
5) W. Bentz, I.C. Cloët and A.W. Thomas, RIKEN Accel. Prog. Rep. **41** (2008) 66.
6) I.C. Cloët, W. Bentz and A.W. Thomas, Phys. Lett. **B 642** (2006) 210.
7) J.T. Londergan and A.W. Thomas, Phys. Lett. **B 558** (2003) 132.

† Condensed from an article by I.C. Cloët, W. Bentz, and A.W. Thomas, to be published.

*1 Department of Physics, Tokai University, Kanagawa, Japan
*2 Department of Physics, University of Washington, Seattle, WA, U.S.A.
*3 Jefferson Laboratories, Newport News, VA, U.S.A.

a) The result deduced by NuTeV is $\sin^2\Theta_W = 0.2277 \pm 0.0013(\text{stat.}) \pm 0.0009(\text{syst.})$, while the world average is $\sin^2\Theta_W = 0.2227 \pm 0.0004$.