Weak reactions with light nuclei

Nir Barnea, Sergey Vaintraub
The Hebrew University
Doron Gazit
INT, University of Washington

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Motivation

**PP** The energy production in the sun is dominated by the pp-chain $pp \rightarrow d + e^+ + \nu_e$. 

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q & = k - k' \\
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$k^\mu$ $P_0$$P_\mu$$P_f$
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$J_A$ The nuclear weak current.
Weak interaction with Nuclei

The weak Hamiltonian

\[ H_W = - \frac{G}{\sqrt{2}} \int d\mathbf{x} j_\mu(\mathbf{x}) J^\mu(\mathbf{x}) \]

The leptonic current

\[ \langle f | j_\mu(x) | i \rangle = l_\mu e^{-i q \cdot x} \]

The nuclear current

\[ J_0^\mu = (1 - 2 \sin^2 \theta_W) \tau_0 \frac{1}{2} J^V_\mu + \tau_0 \frac{1}{2} J^A_\mu - 2 \sin^2 \theta_W J^V_\mu J^\pm_\mu = \tau_\pm \frac{1}{2} J^V_\mu + \tau_\pm \frac{1}{2} J^A_\mu \]

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The Nuclear Current

- The currents are derived from EFT NLO Chiral Lagrangian and are accurate to $N^3$LO.

\[ J_{V,A}^{\mu} = J_{V,A}^{\mu}(1\text{-body}) + J_{V,A}^{\mu}(2\text{-body}) \]

Charge conservation. The vector current must fulfill

\[ \nabla \cdot J_V(x) = -i[H, J_{V,0}(x)] \]

The nuclear vector current contains convection and spin terms

\[ J(q) = J_c(q) + J_s(q) \]

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At low energy, the vector current MEC are implicitly included via the Siegert theorem.
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For low momentum transfer $qR \approx 7 \cdot 10^{-3} \omega A^{1/3} \ll 1$. The multipole expansion converge very fast.
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F = \frac{1}{\sqrt{4\pi}} \tau_{\pm}
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GT = -i g_A \sqrt{\frac{2}{3}} [\sigma \otimes Y_0(\hat{r})]^{(1)}_{\pm} \tau_{\pm}
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- The 2–body currents contribute mainly to the GT, $E_1^A$ multipole.

  $$C_0^A(q) = \frac{i}{\sqrt{4\pi}} \sigma \cdot \nabla$$

  $$L_0^A(q) = i g_A \frac{q}{3} [\sigma \otimes Y_1(\hat{r})]^{(0)}$$

  $$C_{1M}^V(q) = \frac{q}{3} Y_{1M}(\hat{r})$$

  $$E_{1M}^V(q) = -\sqrt{2} \frac{\omega}{q} C_{1M}^V(q)$$

  $$L_{1M}^V(q) = -\frac{\omega}{q} C_{1M}^V(q)$$

  $$M_{1M}^V(q) = -\frac{i}{\sqrt{6\pi}} \frac{q}{2 M_N} l_M$$

  $$M_{1M}^A(q) = -g_A \frac{q}{3} [\sigma \otimes Y_1(\hat{r})]_M^{(1)}$$

  $$E_{2M}^A(q) = i \sqrt{\frac{3}{5}} g_A \frac{q}{3} [\sigma \otimes Y_1(\hat{r})]_M^{(2)}$$

  $$L_{2M}^A(q) = \sqrt{\frac{2}{3}} E_{2M}^A(q)$$
The JISP16 NN Potential

The JISP16 reproduce the NN phase shifts in the range $0 - 300$ MeV.

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The β-decay half-life

\[ t_{1/2} = \frac{1}{f} \frac{\tau \log 2}{\langle F \rangle^2 + (F_A/F_V)^2 \langle GT \rangle^2} \]

\[ \langle GT \rangle \equiv \langle \psi_f \mid \sum_j \sigma_j \tau_j^+ \mid \psi_i \rangle \]

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Beta decay

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- 1-body currents underpredict the 3-body GT, and overpredict the 6-body GT.
Beta decay - 2-body current

The Gamow-Teller $^6\text{He} - ^6\text{Li}$ matrix element

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- HH calculations with EFT 2-body currents reconcile theory and experiment!
- The matrix-element is almost independent of the cutoff!
The 1-body current underpredict the $^3$H $\beta$-decay $\langle GT \rangle$. 

It overpredict the $^6$He $\beta$-decay $\langle GT \rangle$.

2-body currents derived from meson exchange model go in the wrong direction for $^6$He!

In contrast, EFT 2-body currents lead to reconciliation between theory and experiment.

The predicted $^6$He $\beta$-decay half-life is independent of the cutoff.
Conclusions

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Nir Barnea (HUJI)
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