Neutrino recoil force in electron-capture decay of polarized nuclei: measurement prospects and potential applications

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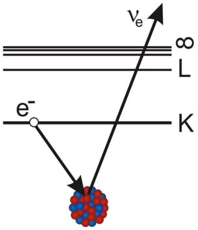
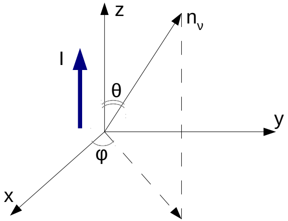
Recoil force in electron capture



Electron capture



Nuclear recoil energy is small $\Rightarrow$ all daughter atoms remain in the sample $\Rightarrow$ recoil force acts on the sample:

$$\mathbf{F}_{\text{recoil}} = -\langle \dot{\mathbf{P}}_\nu \rangle$$

Momentum carried away by neutrinos (per time unit) is

$$\dot{\mathbf{P}}_\nu = N \langle \dot{\mathbf{p}}_\nu \rangle$$

Average momentum carried by one neutrino (per time unit) is

$$\langle \dot{\mathbf{p}}_\nu \rangle = p_\nu \int d\Omega \cdot \mathbf{n}_\nu \cdot \frac{dw(\mathbf{n}_\nu)}{d\Omega}$$

$\Rightarrow$ if the angular distribution is anisotropic then $\mathbf{F}_{\text{recoil}} \neq 0$

For weak interactions

$$\frac{dw(\theta)}{d\Omega} \propto (1 + BP\cos\theta)$$

Motivation

Recoil force in EC was first discussed in papers:

- C. DeAngelis, L. M. Folan, V. I. Tsifrinovich, Phys. Rev. C, **86**, 034615. (2012).
- L. M. Folan, V. I. Tsifrinovich, Mod. Phys. Lett. A, **29**, 1430042 (2014).

Key points:

1. Estimates for recoil force
2. Force measurement with micromechanical devices
3. Applications: m_ν determination

Our work (see arXiv:1810.09896 for details)

1. Evaluation of recoil force for allowed transitions, m_ν is taken into account
2. Modified measurement scheme
3. More applications: NME's, $P_x\,(x = K, L, \dots)$, new physics, ...

Recoil force calculation

Neutrino angular distribution is given by

$$\frac{dw_{EC}(\theta)}{d\Omega} = \frac{w_{EC}}{4\pi}\left(1 + \eta BP\cos\theta\right), \qquad w_{EC} = \ln 2/T_{1/2}$$

Asymmetry reduction due to neutrino mass:

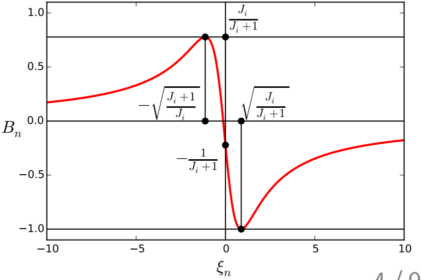
$$\eta = \frac{c\sum_x p_{\nu x}^2 |\psi_x(0)|^2}{\sum_x p_{\nu x} E_{\nu x} |\psi_x(0)|^2} \leq 1, \qquad \eta = 1 \text{ for } m_\nu = 0$$

Pure Gamow–Teller ($J_f = J_i \pm 1$)

$$B = \begin{cases} \frac{J_i}{J_i+1}, & J_f = J_i + 1, \\ -1, & J_f = J_i - 1. \end{cases}$$

Mixed Fermi & Gamow–Teller ($J_f = J_i$)

$$B = -\frac{1 + 2\sqrt{J_i(J_i+1)}\,\xi}{(J_i+1)(1+\xi^2)}, \ \xi = \frac{g_V M_F}{g_A M_{GT}}.$$



Recoil force calculation

Nuclear polarization:

$$P \simeq \frac{\beta(J_i + 1)}{3J_i}, \quad \beta = \frac{\mu B_0}{k_B T}(\ll 1)$$

Recoil force z-projection (for EC branching ratio I_{EC} and source activity α)

$$F_z = -\frac{N I_{EC} \ln 2 \, p_\nu \eta B P}{3 \, T_{1/2}} = -\frac{1}{3}\alpha I_{EC} p_\nu \eta B P$$

For massless neutrinos:

$$F_z = -\frac{N I_{EC} \ln 2 \, E_\nu B P}{3 \, c \, T_{1/2}} = -\frac{\alpha I_{EC} E_\nu B P}{3 \, c}$$

Typical values for our measurement scheme:
$B_0 = 10$ T, $T \sim 1$ K, $\beta \sim 10^{-3}$, $P \sim 0.1\%$
$I_{EC} \geq 0.98$, $\alpha \sim 1$ MBq

Recoil force measurement

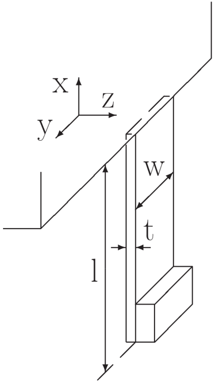
Idea by DeAngelis et al.

- Sample is attached to a cantilever
- Force is measured via $z = F/k$
- $F > 10^{-12}$ N

Problem: force is measurable only for optimistic experimental parameters

Our suggestion: use methods of magnetic resonance force microscopy

- Nuclear magnetic moments and recoil force oscillate with cantilever resonant frequency
- Sensitivity improves by $Q \leq 10^5$
- Smaller k
- $F > 10^{-19}$ N



$$F_{\min} = \frac{\sqrt{2kk_B T}}{Q}$$

Applications

- Neutrino mass:

$$\frac{F(m_\nu \neq 0)}{F(m_\nu = 0)} \simeq 1 - \left(\frac{m_\nu c^2}{Q_{EC}}\right)^2$$

- BSM physics: can probe unique contributions to ν emission asymmetry (Lorentz violation etc.)
- P_K, $P_L, \ldots$:

$$\begin{cases} P_K E_{\nu K} + P_L E_{\nu L} = E_\nu, \\ P_K + P_L = 1. \end{cases}$$

- Fermi & Gamow–Teller mixing ratio $\xi = \frac{g_V M_F}{g_A M_{GT}}$

Summary

- There is a recoil force caused by neutrino emission in EC
- Formula for the force is obtained for allowed nuclear transitions
- The force can be measured using methods of MRFM
- Information about neutrino and weak interactions can be probed

Thank you!