Polarized electron target as tool for testing time reversal symmetry violation and neutrino nature in leptonic weak interactions at low energies

Wiesław Sobków and Arkadiusz Blaut
Institute of Theoretical Physics, University of Wrocław

Introduction

- no difference between Dirac and Majorana neutrinos in Glashow-Salam-Weinberg model (GSW) [1] with V-A interaction (left-handed chirality) in relativistic limit
- no effects of time reversal symmetry violation (TRSv) in leptonic processes, e.g. neutrino-electron elastic scattering (NEES)
- single CP violating phase of CKM quark mixing matrix does not explain matter-antimatter asymmetry of universe (new TRSv phases are required)
- origin of parity violation is not clarified
- background problem in low energy neutrino experiments
- experimental results still leave space for non-standard complex S, T, P couplings of right chiral neutrinos
- new tools sensitive to interferences between V-A and S, T, P are needed to measure TRSv and distinguish between Dirac and Majorana neutrinos
- polarized electron target (PET) may shed some light on various open questions: precise measurement of background level in low energy solar neutrinos, TRSv, neutrino nature, neutrino magnetic moments, the flavor composition of (anti)neutrino beam, axions, spin-spin interaction in gravitation [2], [3], [4], [5], [6], [7], [8]

Assumptions

- detection process is elastic scattering of low energy neutrinos on polarized electrons of target: $v_e + e^- \rightarrow v_e + e^-$
- amplitude for Dirac neutrinos:
  \[
  M_{\nu e}^{(D)} = \frac{G_F}{\sqrt{2}} (\bar{\nu_e} \gamma^\mu (c_{\nu e} - c_{\nu e}^R) \bar{u}(p_e)(1 - \gamma_5) u_{\nu}))
  \]
  $c_{\nu e}, c_{\nu e}^R, c_{\nu e}^L$ are complex numbers and $c_{\nu e}^L = c_{\nu e}^R$
- amplitude for Majorana $\nu_e$ does not contain vector V and tensor T interactions
- incoming neutrino beam comes from unpolarized source and is linear superposition of left chiral with right chiral states
- due to superposition transversal components of neutrino spin polarization may appear
- model-independent considerations for flavor eigenstates in limit of vanishing neutrino mass.

Results

Fig. 2. Dependence of $d^2\sigma/d\omega d\Phi$ on $\phi$, for $\theta_e = \pi/2$, $E_e = 1$ MeV. $|\eta| = 0.2$ (dotted line), $|\eta| = 0.2$ (solid line)

- standard V-A interaction with only L chiral neutrinos
- left-right azimuthal asymmetry with asymmetry axis directed along $\Phi = \pi/2$

Fig. 3. $A_\Phi (\Phi = \pi/2)$ as a function of $G_F$ (dotted line) and $A_\Phi (\Phi = \pi/2)$ as a function of $G_F$ (solid line) for $\theta_e = \pi/2$

- possibility of TRSv for scenario with V-A, S, and T interactions: asymmetry axis location $\Phi_{\text{axis}}$ (upper plot in Fig. 4, dashed line) and value of asymmetry $A(\Phi_{\text{axis}})$ (lower plot in Fig. 4, dashed line) may change for Dirac neutrinos when $\theta_e = \pi/2$

Fig. 4. $A(\Phi) = 1 - \frac{\int d\Phi |A_{\theta_e}(\Phi)|^2}{\int d\Phi |A_{\theta_e}(0)|^2}$

- upper plot: dependence of $A(\Phi_{\text{axis}})$ on $\Delta\Phi_R$ for $\theta_e = \pi/2$ for the case of $V - A$ and $T R S v$ when $|\eta| = 0.2$ (dashed line)
  - lower plot: dependence of $A(\Phi_{\text{axis}})$ on $\Delta\Phi_R$ for $\theta_e = \pi/2$ for the case of $V - A$ and $T R S v$ when $|\eta| = 0.2$ (dashed line)

- upper plot for TRSv standard $V - A$ interaction (solid line): the combination of $V - A$ and $T R S v$ when $|\eta| = 0.2$ (dashed line)
  - lower plot for TRSv standard $V - A$ interaction (solid line): the combination of $V - A$ and $T R S v$ when $|\eta| = 0.2$ (dashed line)

Fig. 5. Dependence of $A(\Phi_{\text{axis}})$ on $\phi$, for $\theta_e = \pi/2$, $E_e = 1$ MeV. $|\eta| = 0.2$ (dotted line), $|\eta| = 0.2$ (solid line)

- superposition L chiral with R chiral neutrinos

Fig. 6. Dependence of $d^2\sigma/d\omega d\Phi$ on $\phi$, for $\theta_e = \pi/2$, $E_e = 1$ MeV. $|\eta| = 0.2$ (dotted line), $|\eta| = 0.2$ (solid line)

- upper plot for TRSv standard $V - A$ interaction (solid line): the combination of $V - A$ and $T R S v$ when $|\eta| = 0.2$ (dashed line)
- lower plot for TRSv standard $V - A$ interaction (solid line): the combination of $V - A$ and $T R S v$ when $|\eta| = 0.2$ (dashed line)

Fig. 7. Dependence of $d^2\sigma/d\omega d\Phi$ on $\phi$, for $\theta_e = \pi/2$, $E_e = 1$ MeV. $|\eta| = 0.2$ (dotted line), $|\eta| = 0.2$ (solid line)

- upper plot for TRSv standard $V - A$ interaction (solid line): the combination of $V - A$ and $T R S v$ when $|\eta| = 0.2$ (dashed line)
- lower plot for TRSv standard $V - A$ interaction (solid line): the combination of $V - A$ and $T R S v$ when $|\eta| = 0.2$ (dashed line)

Conclusions

- Asymmetry asymmetry and other observables contain information about $V - A$ and exotic $S_R, T_R, P_R$ couplings proportional to $(\Phi_{\text{axis}})$ related to production process (supersymmetry of L-R chiral states). It allows to search for TRSv and distinguish between Dirac and Majorana $\nu_e$
  - When incoming $v_e$ are Dirac purely L-chiral fermions, but S, T interactions participate then azimuthal asymmetry is also sensitive to TRSv. Properties require intense low-energy $\nu_e$ sources, PET, and detector sensitive to azimuthal angle and polar angle of scattered electrons with good angular resolution. Detectors measuring recoil electron spectrum should be constructed from magnetic materials and scintillating media (feasibility of electron polarized scintillating GSO target has been verified by [6]).

References