NON-ENDPOINT β DECAY MEASUREMENT OF THE ANTINEUTRINO MASS?

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ABSTRACT

Possibilities for further β decay experiments are considered.

INTRODUCTION

The recent I.T.E.P. positive measurement of $m_{\bar\nu}$ ~ 35 eV has generated an exact sensitivity criteria for the design of new experiments to confirm this result.[1] The importance of the result requires a systematic appraisal of possible experiments, especially ones with entirely different systematic error sources than the classical endpoint determinations.[2] In this regard the proposed Los Alamos experiment to measure the endpoint energy of freely decaying H^3 will be crucial.[3]

Is there any other region of the β decay spectrum offering unique experimental advantages for measurement of either $m_{\bar\nu}$ directly (kinematically) or of the $\bar\nu$ helicity? Generally, we expect difficulties since the antineutrino polarization = $p_{\bar\nu}/E_{\bar\nu} \approx 1 - \frac{1}{2}m_{\bar\nu}^2/p_{\bar\nu}^2$ and $E_{\bar\nu} \approx p_{\bar\nu}(1 + \frac{1}{2}m_{\bar\nu}^2/p_{\bar\nu}^2)$ for $p_{\bar\nu} >> m_{\bar\nu}$. Nonetheless, the phenomena of bound state β decay does provide a unique mode which allows new experiments, in principal. However, the experimental signals would be extremely small; no plausible experiment has yet been invented.

BOUND STATE β DECAY

If one considers K capture, then under crossing symmetry the t channel reaction is a β decay whose final state has the β^- bound to the final state nucleus.[4] The rate is most conveniently stated as the ratio to that for free $\beta^-\beta$ decay. As expected, there is a K capture Z dependence, as well as an inverse dependence on allowed free electron phase space. For tritium we have a uniquely large relative capture probability amongst light nuclei (1%!). Bahcall has pointed out high Z cases where the capture probability dominates.[5]

MEASUREMENT OF $\bar\nu$ HELICITY

If we observe the bound state subset of neutral tritium β decays, there are two experimental advantages. First, this subset has a unique signature: a single neutral He^3 recoil. As with K capture, only S states (with nuclear overlap) are involved. With some fraction of the total capture probability the $He^3 2s_0$ state, e.g., is populated, which can be unambiguously identified. Second, this final state is a true body decay. Any correlation to the $\bar\nu$ momentum is equivalent to correlation with the He^3 recoil momentum.

The following experiment is, in principal, possible. An initial polarized H^3 ground state is prepared (F = +1) (by optical pumping or in an atomic beam). Then if we select only He^3 recoils along the initial polarization direction nS_0 final states will be disallowed for $\bar\nu$ helicity exactly +1. Some final nS_0 population occurs for any negative helicity probability. An early hope in this study was that some situation could be devised where the relative probability of such a disallowed state would be ~ $m_{\bar\nu}/Q$(~ 35 eV/18 KeV ~ 2×10^{-3}). However, it is obvious that any final state with helicity = -1 must have probability polarization ($\approx 1 - 2m_{\bar\nu}^2/Q^2$) ≈ 8×10^{-6}.

In the region of the free β^- decay spectrum where $p_{\bar\nu} \leq m_{\bar\nu}$, $1-P_{\bar\nu}$ would be large. It is just this limit where information is lost on the direction, so that observation is integrated over $p_{\bar\nu}/|p_{\bar\nu}|$ and no helicity information remains.

MEASUREMENT OF THE He^{3+} MOMENTUM

Taking advantage of the two-body decay (this time of H^{3+}) it is possible to measure the tritium decay Q^* value by precise measurement of the He^{3+} recoil momentum. If Q were known precisely enough from atomic and nuclear mass information, then Q^*-Q could measure $m_{\bar\nu}$. Unfortunately, $Q^*-Q \sim 2(m_{\bar\nu}/Q)^2$ and Q is known only to 500 ppm.

One possible method of measuring Q^* could take advantage of modern ion trapping/storage techniques. Trapped H^{3+} ions would be sufficiently cooled and localized to measure He^{3+} velocity by T.O.F. (2000 m/s). Time resolution of 1 ns would be required. The real difficulty is absolute localization of the H^{3+} ions (few microns); and the extremely low effective source temperature required. "Start" time would be determined by observing only bound state decays to 2S which can have prompt (induced) γ deexcitation. The He^{3+} trajectory and timing would have to be precisely corrected for the recoil from γ emission.

REFERENCES

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