Exercises for Neutrino Physics: Theory and Experiment

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Sheet 2: Experiment

1. **Tritium Beta Decay and the Search for Neutrino Mass [10 Points]**

   One posibility to search for the absolute neutrino mass is to study the endpoint region of the tritium decay beta spectrum. The tritium decay is given by $^3\mathrm{H} \rightarrow ^3\mathrm{He} + e^- + \overline{\nu}_\mathrm{e}$. The present best limit on the $\overline{\nu}_\mathrm{e}$-mass is set by the KATRIN experiment.

   (a) How is the endpoint of the beta spectrum related to the neutrino mass? (How does the presence of a neutrino mass influence the endpoint?)
   Calculate the endpoint energy via the maximum kinetic energy of the electron in tritium beta decay.

   (b) The KATRIN experiment uses a spectrometer based on a MAC-E-filter principle scetched in Figure 1.
   Why is this filter used? Read the publication (Phys. Rev. Lett.123 no. 22, (2019) 221802, arXiv:1909.06048) and explain the working principle of the MAC-E-filter. Why is the transformation of the transverse kinetic energy of the electron $E_\perp$ into longitudinal energy $E_\parallel$ necessary and how is it achieved?

   (c) KATRIN also uses a Windowless Gaseous Tritium Source (WGTS) which provides about 10^{11} decays/s. What is the mass of tritium which is constantly present in the source?

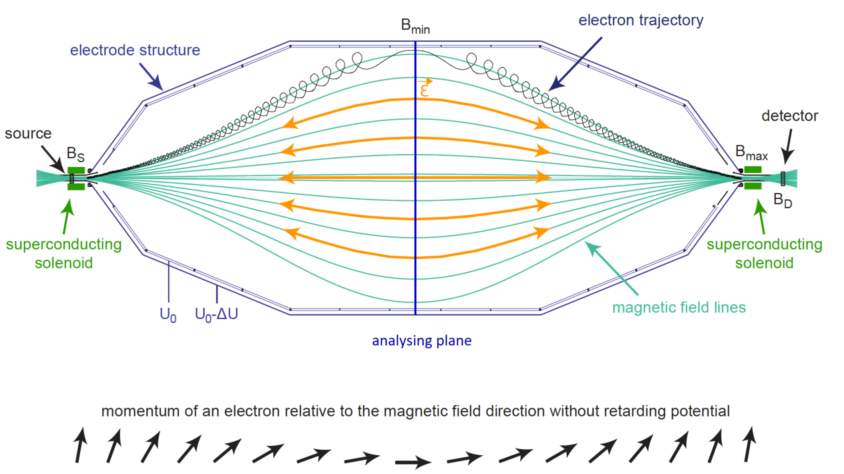

Figure 1: The MAC-E-filter principle of the KATRIN experiment

2. Neutrino Mass Limit from Supernovae [10 Points]

A limit on the neutrino mass can be calculated by the detection of neutrinos from the Supernova SN1987A by the Kamiokande experiment.
The distance from the Earth to the supernova is $L = 1.5 \cdot 10^{18}\,\mathrm{km}$. Assume two neutrino events with energies of $E_1 = 36\,\mathrm{MeV}$ and $E_2 = 13.0\,\mathrm{MeV}$. The time between the detection of neutrino 1 and the detection of neutrino 2 is $\Delta T \approx 11\,\mathrm{s}$.

(a) Derive Equation (3) $t_{\mathrm{obs}} - t_{\mathrm{em}} = t_0 \left(1 + \frac{m_\nu^2}{2E_\nu^2}\right)$ of the lecture with $t_0 = \frac{L}{c}$.
Hint: use a binomial expansion.

(b) Calculate the limit of the neutrino energy mass of $m(\nu_{\mathrm{e}}) < 30\,\mathrm{eV}$. Assume that the neutrinos are emitted at the same time.