# Exercises: Particle Detectors WS 2016/17

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Problem Set No. 10

**Solutions have to be handed in by Wednesday 3pm, 25.1.2017 in letter box no. 3, in the ground floor of Gustav-Mie building!**

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1. **Cherenkov Detector**
   Consider neutrino detection in a cylindrical tank filled with ultra-pure water via the scattering process $\nu + e \rightarrow \nu + e$. Part of the neutrino energy is being transferred to the electron. Photomultipliers with a quantum efficiency of 0.2 cover 40% of the detector wall to detect Cherenkov photons radiated by relativistic recoil electrons.

   (a) Electrons in the MeV range loose about 2 MeV of energy per cm in water, predominantly due to ionisation, and produce $\approx$ 220 Cherenkov photons per cm. Estimate the number of detected Cherenkov photons per MeV of initial electron energy.

   (b) Using momentum and energy conservation, formulate an expression for the angle between the direction of the scattered electron and the direction of the incident neutrino, in terms of electron mass $m_e$, electron kinetic energy $T_e$ and incident neutrino energy $E_\nu$.
   *Hint: The angle of the outgoing neutrino can be eliminated using a trigonometric identity. For this exercise energy conservation is best expressed using $T_e$, and the electron momentum $p_e$ only expressed in $T_e$ and $m_e$ at the very end.*

   (c) Calculate the maximum electron angle for a maximum solar neutrino energy of about 20 MeV and a minimum observable electron energy of 4.5 MeV. How does this help to detect solar neutrinos? In case you couldn't solve b) use the formula: $\sqrt{T}/\sqrt{T+2m} * (E+m)/E$.

   **[6 points]**

2. **Threshold Cherenkov Counter**
   A detector built for particle identification of charged hadrons consists of three threshold Cherenkov counters. The radiators of the counters consist of A) Aerogel with a refractive index $n_A = 1.022$, B) Aerogel with $n_B = 1.005$ and C) Neopentane with $n_C = 1.00177$. The momentum of incident particles was determined by a preceding detector.

   (a) For the general case show that the minimum momentum $p_{min}$ required for a particle to emit Cherenkov radiation can be expressed as $p_{min} = m_0 c/\sqrt{n^2 - 1}$.

   (b) Determine the momentum ranges in which pions, kaons or protons can be uniquely distinguished from the other two deploying the the above setup.

   (c) Would an improvement of the setup be achieved by removing Aerogel B) and filling the gap with Freon14 ($n_F = 1.00049$)?

   (d) Consider adding a time of flight system using two scintillators, with a time resolution of 50 ps each. What length of flight path is required to cover the low momentum range with a 3-$\sigma$ separation between particle type pairs and leaving no momentum gap to the threshold Cherenkov detector?

   **[8 points]**