



Theoretical Physics

HOMWORK PROBLEMS #3
SI2400 THEORETICAL PARTICLE PHYSICS, 7.5 CREDITS
SPRING 2019

Deadline: May 22, 2019 @ 17:00
Teachers: Dr. Sofiane Boucenna (boucenna@kth.se)
Marcus Pernow (pernow@kth.se)
Examiner: Prof. Tommy Ohlsson (tohlsson@kth.se)

[Use the Particle Data Booklet whenever necessary to get the experimental values of relevant parameters. State clearly what value you used in the calculation.]

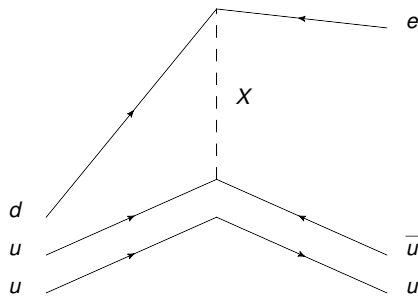
1. A neutrino detector is positioned at a distance L from a neutrino source (e.g. nuclear reactor) of mean energy $E = 3$ MeV.
 - (2 pts) Assuming the oscillation involves the second and third neutrino mass eigenstates, at what L would the oscillation probability reach its first maximum?
 - (3 pts) At $L = 1$ km, the experimentalists found that $P_{ee} \equiv P(\nu_e \rightarrow \nu_e) = 1.01 \pm 0.04$. Show that $P_{ee} \approx 1 - \sin^2 2\theta_{13} \sin^2 \Delta_{23}$, with $\Delta_{23} \equiv \Delta m_{23}^2 L / (4E)$. (hint: neglect what is negligible.)
 - (2 pts) In the limit of large splitting between the second and third mass eigenstates (i.e., $|\Delta m_{23}^2| \gg E/L$) in the previous question, simplify P_{ee} and obtain an expression for $\sin^2 \theta_{13}$ as a function of P_{ee} . Show that $\sin^2 \theta_{13} \propto (\Delta m_{23}^2)^{-2}$ in the opposite limit, $|\Delta m_{23}^2| \ll E/L$.

2. • (2 pts) What are the possible decays of the Higgs boson in the Standard Model (limit the answer to 2 body decays)?
- (3 pts) Show that the decay rate of the Higgs boson to two charged fermions is

$$\Gamma_{H \rightarrow f\bar{f}} = N_c \frac{G_F}{\sqrt{2}} \frac{M_f^2 M_H}{4\pi} \left(1 - 4 \frac{M_f^2}{M_H^2} \right)^{3/2},$$

where G_F is Fermi's constant, $M_{f,H}$ is the mass of the fermion and Higgs, and N_c the number of color degrees.

- (2 pts) *Estimate* the total decay width of the Higgs. What are its 3 largest branching ratios?
3. Leptoquarks are hypothetical bosons that can couple quarks to leptons, arising in various Beyond Standard Model scenarios. Consider a model in which the proton decays as $p \rightarrow e^+ \pi^0$, a process that is mediated by the leptoquark X as shown in the diagram.



- (2 pts) Using dimensional analysis, estimate the decay rate of the proton in terms of the leptoquark mass M_X and coupling g_X . (The actual decay rate also involves a numerical factor involving powers of (2π) , etc. You may assume this factor to be around 10^{-3} .)
- (2 pts) The Super-Kamiokande detector in Japan is looking for proton decay in a tank containing 50 kilotons of water. Over the last 20 years, no such process has been observed. Use this information to put a constraint on M_X and g_X . Plot your result in the M_X - g_X plane.