8.701

Introduction to Nuclear and Particle Physics

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8. Neutrinos

8.5 Experimental Results

Experimental Analysis of Neutrino Oscillations

- Atmospheric ν_μ and $\bar{\nu}_\mu$ disappear most likely converting to ν_τ and $\bar{\nu}_\tau$. The results show an energy and distance dependence perfectly described by mass-induced oscillations.
- Accelerator ν_μ and $\bar{\nu}_\mu$ disappear over distances of ~ 200 to 800 km. The energy spectrum of the results show a clear oscillatory behaviour also in accordance with mass-induced oscillations with wavelength in agreement with the effect observed in atmospheric neutrinos.
- Accelerator ν_μ and $\bar{\nu}_\mu$ appear as ν_e and $\bar{\nu}_e$ at distances ~ 200 to 800 km.
- Solar ν_e convert to ν_μ and/or ν_τ. The observed energy dependence of the effect is well described by massive neutrino conversion in the Sun matter according to the MSW effect
- Reactor $\bar{\nu}_e$ disappear over distances of ~ 200 km and ~ 1.5 km with different probabilities. The observed energy spectra show two different mass-induced oscillation wavelengths: at short distances in agreement with the one observed in accelerator ν_μ disappearance, and a long distance compatible with the required parameters for MSW conversion in the Sun.

Experimental Analysis of Neutrino Oscillations

Neutrino masses have not been measured so far. Information on neutrino masses from oscillation measurements which requires assumptions on the number of neutrinos. Two orderings of neutrinos assuming 3v mixing.

- Spectrum with Normal Ordering (NO) with $m_1 < m_2 < m_3$
- Spectrum Inverted ordering (IO) with $m_3 < m_1 < m_2$

Data shows: $\Delta m^2_{21} \ll |\Delta m^2_{31}| \simeq |\Delta m^2_{32}|$

Experimental Analysis of Neutrino Oscillations

Classification

– Normal Hierarchical Spectrum (NH): $m_1 \ll m_2 < m_3$,

$$\Rightarrow m_2 \simeq \sqrt{\Delta m^2_{21}} \sim 8.6 \times 10^{-3}\text{eV}, m_3 \simeq \sqrt{\Delta m^2_{32} + \Delta m^2_{21}} \sim 0.05\text{eV},$$

– Inverted Hierarchical Spectrum (IH): $m_3 \ll m_1 < m_2$,

$$\Rightarrow m_1 \simeq \sqrt{|\Delta m^2_{32} + \Delta m^2_{21}|} \sim 0.0492\text{eV}, m_2 \simeq \sqrt{|\Delta m^2_{32}|} \sim 0.05\text{eV},$$

– Quasidegenerate Spectrum (QD): $m_1 \simeq m_2 \simeq m_3 \gg \sqrt{|\Delta m^2_{32}|}$.

Experimental Analysis of Neutrino Oscillations

Experiment	Dominant	Important
Solar Experiments	θ_{12}	Δm^2_{21} , θ_{13}
Reactor LBL (KamLAND)	Δm^2_{21}	θ_{12} , θ_{13}
Reactor MBL (Daya-Bay, Reno, D-Chooz)	θ_{13}, $\lvert\Delta m^2_{31,32}\rvert$	
Atmospheric Experiments (SK, IC-DC)		θ_{23},$\lvert\Delta m^2_{31,32}\rvert$, θ_{13},δ_{CP}
Accel LBL ν_μ,$\bar{\nu}_\mu$, Disapp (K2K, MINOS, T2K, NOνA)	$\lvert\Delta m^2_{31,32}\rvert$, θ_{23}	
Accel LBL ν_e,$\bar{\nu}_e$ App (MINOS, T2K, NOνA)	δ_{CP}	θ_{13} , θ_{23}