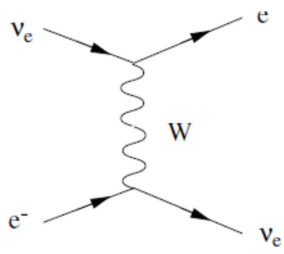
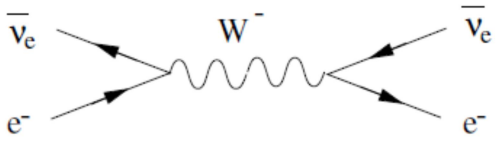
Lecture 12 : Neutrinos -2

- Solar neutrino problem
- Explanation via solar neutrino oscillations
- MSW effect and resonant flavor transition



Neutrino-electron scattering via W exchange



Antineutrino-electron scattering via W exchange

Effective Hamiltonian

$$\mathcal{H}_M = \frac{\Delta m^2}{4E}\begin{bmatrix} -(\cos 2\theta - x) & \sin 2\theta \\ \sin 2\theta & (\cos 2\theta - x) \end{bmatrix}$$

where

$$x \equiv \frac{V_W/2}{\Delta m^2/4E} \qquad V_W = +\sqrt{2}\, G_F\, N_e$$

So

$$\mathcal{H}_M = \frac{\Delta m^2_M}{4E}\begin{bmatrix} -\cos 2\theta_M & \sin 2\theta_M \\ \sin 2\theta_M & \cos 2\theta_M \end{bmatrix}$$

and oscillation formula becomes :

$$\mathrm{P}_M(\nu_e \to \nu_\mu) = \sin^2 2\theta_M \sin^2(\Delta m^2_M \frac{L}{4E})$$

Atmospheric neutrino oscillations :

- Decays of the pions and muons at the upper levels of the atmosphere
- Resulting ratio for muonic and electronic neutrinos+antineutrinos

$$R = \frac{N(\nu_\mu + \bar{\nu}_\mu)}{N(\nu_e + \bar{\nu}_e)} = 2$$

Data from SuperKamiokande and SNO :

Parameter	Best fit	3σ
Δm^2_{21} $[10^{-5}$ eV $^2]$	7.37	$6.93 - 7.96$
$\Delta m^2_{31(23)}$ $[10^{-3}$ eV $^2]$	2.56 (2.54)	$2.45 - 2.69$ $(2.42 - 2.66)$
$\sin^2\theta_{12}$	0.297	$0.250 - 0.354$
$\sin^2\theta_{23}$, $\Delta m^2_{31(32)} > 0$	0.425	$0.381 - 0.615$
$\sin^2\theta_{23}$, $\Delta m^2_{32(31)} < 0$	0.589	$0.384 - 0.636$
$\sin^2\theta_{13}$, $\Delta m^2_{31(32)} > 0$	0.0215	$0.0190 - 0.0240$
$\sin^2\theta_{13}$, $\Delta m^2_{32(31)} < 0$	0.0216	$0.0190 - 0.0242$
δ/π	1.38 (1.31)	2σ: (1.0 - 1.9) (2σ: (0.92-1.88))

Taken form Particle Data Group (PDG) 2018 data.

- Roles of the mixing angles
- Nonzero value of the mixing angle θ_{13}
- Mass measurements
- Search for the sterile neutrinos

Homework :

Solve the following problems at the end of the Chapter XI of the textbook "Intr. to Elementary Particle Physics by D.Griffiths 2nd Ed. J.Wiley."

Solve Problem 11.5

Solve Problem 11.5

Solve Problem 11.7

Solve Problem 11.8