Neutrino Questions

Peter B. Denton

June 10, 2026

Some questions have more than one reasonable answer. LLMs get a few right, many partially right partially wrong, and some entirely wrong. Numbers approximate the amount of effort/intuition required to get the complete answer. 1: easy, 2: medium, 3: hard.

1 Solar Neutrinos

1.1 Jump Probability in Solar Neutrinos (3)

What is the adiabaticity parameter and how big is the jump probability for solar neutrinos at 5 MeV?

Hint: $\Delta m^2_{21} \simeq 7.5 \times 10^{-5}$ eV^2 and $\sin^2\theta_{12} \simeq 0.31$.

Hint2: One can reasonably estimate astro-ph/0010346 the density profile of the Sun as:

$$\log_{10}\left(\frac{N_e \cdot \mathrm{cm}^3}{N_A}\right) = -4.58\frac{r}{R_\odot} + 2.39$$

1.2 Nighttime Solar Neutrinos (2)

Solar neutrinos are produced as electron neutrinos and we predominantly detect electron neutrinos. Solar neutrinos are detected 24/7 as the asborption rate through the Earth at these energies, ~ 0.1 to ~ 10 MeV, is negligible. Do neutrino detectors detect more neutrinos during the day or at night?

1.3 Reactor then Solar (1)

SNO measured a CC to NC ratio of $\sim 1/3$ of solar neutrinos at "high" energies ~ 10 MeV dominantly from ^{8}B flux. KamLAND and JUNO's measurements of reactor neutrinos confirmed the measurement of solar neutrinos by SNO and others. Given the reactor measurements, what other values of the ratio, if any, could SNO have measured?

Hint: the daytime high energy probability is

$$P_{ee}^{\odot,\mathrm{HE}} \approx \sin^2\theta_{12}$$

Hint2: the leading term in the long-baseline reactor neutrino disappearance probability is

$$P_{ee}^{\mathrm{reac}} \approx 1 - \sin^2 2\theta_{12} \sin^2 \frac{\Delta m^2_{21} L}{4E}$$

2 Astrophysical and Cosmological Neutrinos

2.1 High Energy Neutrino Production (2)

Beyond neutrinos coming from charged pion decay or muon decay, what other mechanisms are there to produce neutrinos at high energy that are qualitatively different?

2.2 Skimming Neutrino Flavor (3)

At ultrahigh energies, above PeV, absorption through the Earth is significant and Earth-skimming or mountain-skimming trajectories are expected to dominate. Why is the detected flux of neutrinos expected to be dominantly ν_τ?

2.3 Cosmic Neutrino Background and Mass Generation (2)

The cosmic neutrino background is mostly nonrelativistic today. While extremely challenging to detect, if we do detect it, is the rate larger for Dirac or Majorana neutrinos, and by how much? What further corrections can there be to the difference in the rate? What is it if $m_{\rm lightest}=0$ in the normal ordering? What about the inverted ordering?

2.4 Distance to Last Scattering (1)

The cosmic microwave photons comes from the point of last scattering for photons, at a temperature of $\sim$ eV. The cosmic neutrino background comes from the point of last scattering for neutrinos, at a temperature of $\sim$ MeV. That is, the CνB came from much earlier than the photons by a factor of about a million in redshift or temperature. Which came from farther away?

3 Accelerator Neutrinos

3.1 Approximate Frequency For Muon Neutrino Disappearance (2)

In vacuum, we often approximate the muon neutrino disappearance probability in the atmospheric regime as a two flavor probability:

$$P_{\mu\mu}\simeq 1-\sin^2 2\theta_{23}\sin^2\frac{\Delta m_{32}^2 L}{4E}$$

Why do we use Δm_{32}^2 and not the very similar Δm_{31}^2 (which differs by $\sim 3\%$) or some other value?

Hint: See e.g. H. Nunokawa, S. Parke, R. Funchal hep-ph/0503283

4 Neutrino Oscillation Theory

4.1 Majorana Phases in Oscillations (2)

In oscillations we parameterize the PMNS matrix with four parameters. A general 3×3 unitary matrix has nine degrees of freedom. Where do the other five go? What is different if neutrinos are Majorana and why do we not discuss this in neutrino oscillations?

4.2 Mass Squared Differences (1)

Neutrino oscillations always talk about Δm_{ij}^2, but never m_i or m_i^2. Why?

4.3 Neutral Current Matter Effect (1)

The charged current, $\nu_e+e^-\to\nu_e+e^-$ and $\bar\nu_e+e^-\to\bar\nu_e+e^-$ both via a W, contribution is included in the matter effect. But the neutral current term, any neutrino scattering off an electron, up, or down, is not included. Why? In what (hint: new physics) scenarios do we include the neutral current term?

4.4 Momentum Does Not Contribute to Amplitude (1)

When computing oscillation probabilities, one takes $E_i \simeq p + m_i^2/2E$ for $E \gg m$. Derive this approximation. Then, show why the p part does not contribute to oscillations.

4.5 Definition of Mass States (2)

If one defines the mass states by $|U_{e1}| > |U_{e2}| > |U_{e3}|$, the allowed ranges for the mixing angles are $\theta_{12} \in [0, 45°]$ while $\theta_{13}, \theta_{23} \in [0, 90°]$. Why is θ_{12} different?

4.6 Heavier Active Neutrinos (3)

LEP says that there are exactly three neutrinos lighter than $M_Z/2$. Can there be heavier active neutrinos?