Can Neutrinos Drive a Breakthrough in Particle Physics?

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Neutrinos occupy a unique position in particle physics, as several of their fundamental properties remain unknown. Learning these properties itself is important for particle physics, but it may also help us understand what happened in the early universe and how elementary particles first appeared. In this way, neutrinos connect small-scale physics with large-scale questions about the origin of the universe.

Three major questions guide current research: whether neutrinos show CP violation, the ordering of their masses, and whether they are Dirac or Majorana particles. These issues are closely related to the matter–antimatter imbalance, the formation of particle masses, and possible new physics at very high energy scales.

Many experiments worldwide are working to answer these questions, including long-baseline accelerator experiments, neutrinoless double-beta decay searches, reactor and short-baseline experiments, cosmological observations, and astrophysical neutrino detectors.

Within the global effort to uncover the fundamental properties of neutrinos, Japan has played a leading role in the past and is expected to continue to do so in the future. The discovery of neutrino oscillations, to which experiments in Japan such as Kamiokande, Super-Kamiokande, K2K, and KamLAND made major contributions, changed the direction of particle physics. The ongoing T2K experiment has produced important results and strong hints of CP violation. The upcoming Hyper-Kamiokande will greatly improve sensitivity to CP violation and allow detailed studies of atmospheric, solar, and astrophysical neutrinos, and it will also carry out searches for proton decay, which, like neutrinos, may provide clues to the origin of elementary particles. KamLAND2 will enhance the sensitivity to neutrinoless double-beta decay, offering a direct probe of the Majorana nature of neutrinos. Cosmological observations are also attempting to measure the some of the absolute neutrino masses through their impact on the evolution of large-scale structure. There are new detector technologies and experimental concepts being developed in Japan that will improve the sensitivities of neutrino measurements.

I will describe how these experiments or observations aim to determine the fundamental properties of neutrinos and how their results may help us understand the early universe and the origin of elementary particles.

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