

## Week 6

May 5, 2018

# The Small Things: Neutrino Mass & Double Beta Decay



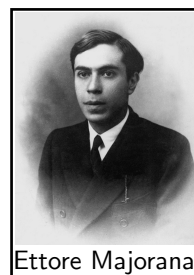
The mass of the neutrino is among the most interesting subjects in particle physics. Neutrino oscillations tell us that neutrinos must have a nonzero mass, but do not reveal the absolute scale of the masses. What we do know is that the neutrino masses are very small compared to other elementary particles, and this could be a hint of new laws of physics beyond the Standard Model. Many different experiments are pursuing measurements of the neutrino mass, using a diverse array of approaches.

*This week, we will discuss the mass of the neutrino, how it relates to the Standard Model and possible new physics, and experimental efforts to measure it.*

## I. Neutrino Mass

Since the first experimental hints of neutrinos existence through nuclear beta decay, it has been known that neutrinos must have a very small mass, or even no mass at all. Indeed, the Standard Model as originally conceived contained massless neutrinos. Neutrino oscillations imply that the neutrino must indeed have some small but finite mass, but only allow us to measure mass *differences*, not the absolute scale. The data so far have demonstrated that the neutrinos are far lighter than other elementary particles. This may be a peculiarity of Nature, or may suggest that neutrino masses are somehow different, involving physics beyond the current Standard Model.

*Majorana Neutrinos:* We define "neutrinos" and "antineutrinos" based on how they interact (i.e., creating matter or antimatter). But since they are neutral, it is possible that they are in fact differently-interacting forms of the same particle, and in this sense the neutrino would be its own antiparticle (a *Majorana* particle). This possibility is theoretically well-motivated, and it can help explain the small masses as well as the matter/antimatter imbalance in the universe. If this is realized in Nature, we can discover it — and measure the neutrino mass — through a rare nuclear decay process called neutrinoless double beta decay.



Ettore Majorana

## II. Experimental Tools

*Beta Decay:* A little extra energy is required to produce a massive neutrino compared to a massless one, and this reduces the maximum energy available for electrons coming out of nuclear beta decays. A measurement of beta decays could thus reveal

the mass of the electron-type neutrino, and several experiments are proceeding to improve precision. KATRIN, a large experiment being built in Germany, will soon make the most detailed measurement yet, down to 0.00004% of the electron mass.

*Cosmology:* As discussed in Week 4 (*Neutrinos in Cosmology: Little Particles on the Biggest Scale*, Dr. Marco Raveri), neutrinos can affect the formation of large-scale structures in the universe. In particular, their presence tends to blur out the distribution of matter. By mapping out the matter in exquisite detail, we can make inferences about the abundance and total mass of neutrinos. Recent measurements by the Planck satellite experiment have placed stringent upper limits on the sum of the neutrino masses.

*Neutrinoless Double Beta Decay:* If neutrino is a Majorana particle, a new form of nuclear decay is allowed, in which two beta decays happen at once, but the neutrinos are absorbed internally and only the two electrons emerge. This process would be extremely rare, but happen at a rate proportional to the neutrino mass. Observation of this decay would not only provide a measurement of the neutrino mass, but confirm the particle/antiparticle nature of the neutrino, and the existence of physics beyond the Standard Model. Given the stakes, several experimental searches are underway!

### III. The SNO+ Experiment

SNO+ is aiming to measure neutrinoless double beta decay, reusing the Sudbury Neutrino Observatory (solar neutrino) detector, but filled with liquid scintillator and  $^{130}\text{Te}$  (Tellurium-130), an isotope believed to undergo this decay. We face interesting challenges in terms of physics (weeding out background noise to find these rare events) and in operating an ultra-pure experiment a mile underground in a mine. SNO+ is currently running filled with water. This will be replaced with scintillator in the fall, and the  $^{130}\text{Te}$  added next spring.



*Future:* As we work toward probing ever smaller neutrino masses, we are developing a future experiment called THEIA, which would be about 50 times the size of SNO+. Such a detector could be sensitive to the very smallest masses theoretically allowed, and we are conducting an extensive R&D program to develop the required technologies.