MARKUS KLUTE: Welcome back to 8.701. In this section we want to look at how we can theoretically describe masses of neutrinos.

There is not just one way to do this and the judge is still out there which one is actually realized in nature, or perhaps both are realized in nature. So mass terms can be constructed by introducing so-called sterile neutrinos. The first way, and it's shown here in the Lagrangian, is very familiar to you where you have a left-handed component of a particle coupling via the Higgs boson to a right-handed component.

Now, if we now have a right-handed component or right-handed neutrino, that neutrino does not interact with the weak interaction and doesn't interact with any other interaction we know. Hence, this neutrino, this right-handed particle is a sterile neutrino. It's not interacting in any of known ways other than with the Higgs field with the rest of the standard model. The second part, the second way the mechanism is using Majorana particles, particles which are their own antiparticles, and we'll look in how this is being implemented.

So again, the first, the Dirac term is generated after electroweak symmetry breaking from Yukawa interactions. We have seen the very same thing for our charged leptons. What we see here is that the lepton number is conserved. Before and after the interaction we have the same number of leptons, but the lepton flavor is not conserved in this interaction.

We can rewrite this. We identify the sterile neutrino as the right-handed component of the spinor. I mentioned this already, and we basically couple the weak-doublet components as you would just expect that to appear.

The second term, the Majorana mass term, is interesting as we introduce another singlet into the standard model. So this then can appear as a bare mass term with some consequences. So here what we are trying to do is we are involved two neutrinos, right-handed fields. Those break the lepton number. So if those neutrinos are realized in nature, we have to observe lepton-- we should observe lepton number-violating processes. And so the search for the specific kind of neutrino is through searching for lepton number-violating processes.

So we can rewrite this part of the Lagrangian, this part of the math term here using this matrix. Let's see how this unfolds. If the math term now is much, much larger, or larger than the electroweak scale, you can try to diagonalize the master and it leads to three neutrinos, three light neutrinos, three light neutrinos you would expect, and one potentially-- one potential, or maybe multiple potential heavy neutrinos.

If you then rewrite the math term you find for the light ones, the term which goes is 1 over the scale of this [? known ?] neutrino. That is a nice motivation for this kind of physics as it automatically reduces the amount of the neutrino as we observe the math is to be very small in nature. And then the mass of the heavy neutrino is proportional to the mass.

This mechanism is called see-saw because it automatically moves the scales of those two neutrinos, the heavy ones and the light one apart so you happen to observe the heavy one, maybe because they're very, very heavy, and the light ones have light mass because of this mechanism of being proportional to 1 over the mass scale-- the mass eigenstate of those neutrinos.

However, if the mass scale of those eigenvalues is much-- not higher than the electroweak scale, the low energy spectrum contains these additional light states. So you have not just the three light neutrinos but you have additional light scales-- states which mix with these three light neutrinos. And that is kind of an interesting area to look for these particles as they would lead to small deviations in observed electroweak efficient properties, and they might yield to some interesting decays in nuclear physics, and we'll come to those specifics later.

We have seen in this lecture two different ways to generate masses. One's to recover interactions, same as the interaction with the Higgs field, and one, we have the see-saw mechanism introducing Majorana neutrinos.