Short HW 5: **Prelude to Quarks**

Course: Physics 165, *Introduction to Particle Physics* (2018)
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Due by: **Thursday**, February 8

Note that this short assignment is due in class on Thursday. You have only *two days* to do it. This should be quick, I recommend doing it right after class on Tuesday.

1 Warm up

In the "leptonic electroweak theory" of the past two weeks, we had two fermions: the **lepton doublet**, $L^{\alpha a}$, and the "positron," $\bar{E}^{\alpha}$. Recall that:

- L has hypercharge $Y = -1/2$, and two SU(2) components: ν_L and e_L.
- $\bar{E}$ has hypercharge $Y = +1$ and is an SU(2) singlet (no index).

As a quick reminder: after **electroweak and chiral symmetry breaking** by the Higgs vacuum expectation value, how do these degrees of freedom combine into mass eigenstates?

2 Neutrino mass, the naïve way

Suppose a student really, really wants to write a theory where the neutrino has mass. Introduce a new particle, N (analogous to $\bar{E}$) that can act as the right-chiral partner of the ν_L to form a massive neutrino. Assume that N has no SU(2) index, but has hypercharge Y_N.

Write down an interaction that connects the new particle, the lepton doublet, and the Higgs doublet in a way that gives the neutrino a mass from the Higgs vacuum expectation value. What is the required value of Y_N?

Hint: Recall that the Higgs has $Y = 1/2$ and is an SU(2) doublet. Also recall that you need to use $\langle H \rangle = (0,\ v/\sqrt{2})^T$ or $\langle H^\dagger \rangle = (0,\ v/\sqrt{2})$ to determine if particles mix and get a mass. You should find that you need to use ε_{ab} or ε^{ab} to do this. Recall that ε_{ab} is totally antisymmetric and so is only nonzero for $a \neq b$.

Remark: this is one way to give neutrinos a mass. It's not the only way.