Short HW 4: **Flavor Indices**

Course: Physics 165, *Introduction to Particle Physics* (2020)
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Due by: **Thursday**, Feb 27

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 Flavor

The Standard Model has *three* copies of the 'cuddly' ($Q\bar{u}\bar{d}L\bar{e}$) particles. These copies are called *generations*. Each generation has the same charges and indices (quantum numbers), thus a second-generation Q has the same charges and indices as the first-generation Q. The particle content is as follows:

1. up quark, down quark, electron-neutrino, electron
2. charm quark, strange quark, muon-neutrino, muon
3. top quark, bottom quark, tau-neutrino, tau .

Each generation is heavier than the generation before it. This means that the generations are not actually a good symmetry of the Standard Model. The way in which flavor symmetry is broken will tell us about how these generations mix quantum mechanically.

We can write these generations as an additional index on our matter particles. let $I, J = 1, 2, 3$ be generation (or *flavor*) indices. The **Yukawa interactions** are the couplings of pairs of matter particles to the Higgs.

Suppressing the spin indices for simplicity, the Yukawa interactions of *one* flavor of matter are:

$$y_u \epsilon_{ij} H^i Q^j \bar{u} + y_d \left(H^\dagger\right)_i Q^i \bar{d} + y_\ell \left(H^\dagger\right)_i L^i \bar{e} + \text{h.c.} \,. \tag{.1}$$

1.1 Fill in the Indices

Rewrite these terms with flavor indices. Every matter particle picks up an upper index I or J. The Yukawa couplings now have to be promoted to matrices in 'flavor-space' so that these indices are fully contracted.

1.2 What would flavor invariance look like?

The Yukawa matrices are constants—they are not particles. What would the Yukawa matrices have to look like in order for the theory to be flavor invariant?

Comment: the fact that different generations have different masses means that flavor symmetry is *not* a good symmetry of our universe.