20.4: Grand Unification?

Generation	Leptons	Quarks
1	electron	down
	electron neutrino	up
2	muon	strange
	mu neutrino	charm
3	tau	bottom
	tau neutrino	top

Table 20.4: Generations of leptons and quarks. Members of each generation tend to fit together.

The standard model is a great achievement, but it leaves a number of questions unanswered. As table 20.4 shows, nature seems to have produced more particles than are needed to construct the universe. Virtually everything we know of is composed of electrons, electron neutrinos, up quarks, and down quarks. These four particles seem to fall naturally together in a *family* or *generation*. Why then are there apparently unneeded additional generations? What role do muons, taus, and the exotic quark forms play in the universe?

Another question concerns the dichotomy between leptons and quarks. Electrons and electron neutrinos can be converted into each other by weak interactions, as can up and down quarks. Why then can't quarks be converted into leptons and vice versa?

In the standard model, electromagnetic and weak forces are truly united as aspects of a single phenomenon. However, quantum chromodynamics stands more on its own. One could imagine further advances that would show that the electroweak and strong forces were in fact different aspects of the same phenomenon. This could be characterized as a *grand unification* of the forces of nature.

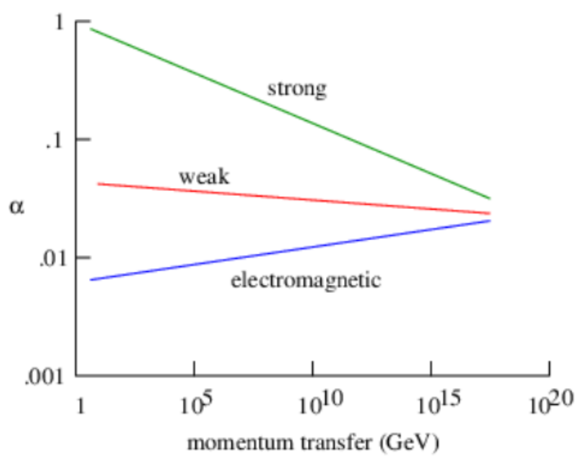

Figure 20.4.4:: Speculated behavior of the dependence of the coupling constant α on momentum transfer for each of the forces. Extrapolation based on current measurements suggests that these constants come together to a common value at very high momentum transfer.

As previously noted, the strong force coupling constant, α_s, gets smaller with increasing momentum transfer. It turns out that the weak coupling constant, α_w, exhibits similar behavior, while the electromagnetic coupling constant, the fine structure constant α, becomes stronger at higher energies. This behavior is illustrated in Figure 20.4.4, though it is based on data only up to about 10^3 GeV/c. Figure 20.4.4 is thus largely speculative. However, if the observed trends do continue to very high momentum transfers, this would be evidence in favor of grand unification.

A number of speculative grand unification theories have been proposed. Most such theories view leptons and quarks as being different states of the same particle and also predict that leptons can turn into quarks and vice versa, albeit at very low rates. One of the consequences of such theories is that the proton would be an unstable particle, but with a very long lifetime, of order 10^{30} yr.

Experiments have been done to detect the decay of the proton, but so far without success. These experiments are sufficient to rule out some but not all of the proposed grand unification theories.

One task that would not be accomplished by grand unification is the incorporation of gravity into a common framework with the strong, weak and electromagnetic forces. Creation of a satisfactory quantum theory of gravity has been a very difficult problem and is unsolved to this day, though many people are working on it.

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