

Comments on the standard model (5 October 2012)

Gauges Srednicki works in unitary gauge; it might be amusing to see the standard model in R_ξ gauge, but I don't have either of the references he cites for that.

Groups An important result of the gauge theory group structure of the standard model, which I took for granted until Oliver emphasized it, is that each group in the overall (non-semi-simple) product group $SU(3)\times SU(2)\times U(1)$ only has a single coupling.

Chiral gauge theory I tend to think of chiral gauge theories as those that treat right- and left-handed Weyl fields differently.¹ Since Srednicki works entirely in terms of left-handed fields, it is more convenient for him to discuss chiral gauge theories as those in which these left-handed fields transform under a complex rep. These two facts are equivalent, since the hermitian conjugates of the left-handed fields transform as right-handed fields. So given a complex rep R for all left-handed fields, the right-handed fields transform under $\bar{R} \neq R$. We will review Srednicki's chapter 75 on chiral gauge theories next week.

Currents The electroweak effective lagrangian in terms of charged and neutral currents that Srednicki writes in Eqn. 88.30 is a classic example of effective field theory. Srednicki reaches this result by "integrating out" the massive W and Z bosons, but one (if one were Fermi) could just as well start by writing down (non-renormalizable) dimension-six operators involving four fermion fields. Srednicki discusses effective field theory at a more general level in chapter 29, which may be worth looking at more closely in the future (perhaps along with some other resources that I added to the Web page).

CKM The CKM matrix (and its CP-violating phase) pop out of diagonalizing the most general Yukawa term for three generations of quarks, which introduces the matrices $V = U^\dagger D$ and V^\dagger into the charged currents. The same thing would have happened for the leptons had Srednicki included a $\bar{\nu}$ field in the second paragraph of chapter 88. I was able to follow the words describing how the number of degrees of freedom in V is reduced from nine to four (by absorbing phases into field redefinitions for all six quark fields, one of which is redundant with an overall phase), but didn't work this out carefully. Since the fact that 3×3 unitary mixing matrices are specified by three real angles and a phase is so basic, this derivation may be a good exercise.

Seesaw I found it interesting that the neutrino mass seesaw mechanism follows directly from the standard procedure of including all possible terms of a given dimension that respect required symmetries and conservation laws – so long as the conserved quantities don't include lepton number. As Oliver pointed out, the matter/anti-matter asymmetry of the universe suggests that some high-scale physics violates either or both of baryon number and lepton number in order to produce leptogenesis or baryogenesis.

Flavor changing More generally, the existence of massive neutrinos would violate the individual electron number, muon number and tau number: this is why neutrino oscillations imply non-zero neutrino mass. By the same token, we should also expect charged lepton flavor violation, which has not yet been observed. The [Mu2e](#) experiment at Fermilab has a brief introduction into the potential implications of future (non-)observation of muon-to-electron conversion.

¹For the standard model, the left-handed fermions are $SU(2)$ doublets, while the right-handed fermions are singlets.

FCNC! In addition to flavor changing from the charged currents that we get via the CKM matrix, Oliver mentioned that many theories of new physics beyond the standard model predict the existence of flavor-changing neutral currents (FCNCs). Stringent experimental bounds on such processes lead to challenging constraints on many such models (including extended technicolor, as I recently discussed with Anna and Anqi).

Custodial symmetry I meant to bring this up since Srednicki doesn't mention it (although Peskin and Schroeder do). If it is of interest, we can revisit it in the future.