Some Comments on Jeff's Study Guide

Dave Peterson, Re: http://www.sackett.net/SchummStudyGuide.pdf, 3/18/23

Jeff Grove's **red-lines** asking some deep questions—some of which I can't yet answer. Other red-lines are his correct interpretations rather than outstanding questions to be answered. His study guide is rich with both information and questions.

SU(2): { Jeff pgs 10-12 Schumm 183, 191} The abstract space is an internal symmetry space beyond and different from "physical" space. For fermions, I've always lumped this under the name "The square-root of Reality" which might use hypercomplex numbers such as γ-matrices. Note that $e^{i\theta}$ can represent a physical rotation for U(1) or R_3 ; but $\sqrt{e^{i\theta}} = e^{i\theta/2}$ lives in SU(2) and uses generators called quaternions *which were the first hyper-complex* numbers {and $e^{i(4\pi)/2}$ makes 720 degrees rotation looks like zero (back to original setting)}.

The standard model (SM) is the group $G_{SM} = SU(3)_c \times SU(2)_L \times U(1)_{\{Y \text{ or } Bo\}}$ with subscripts shown. "c" is color, Y is weak hypercharge or using the B^o boson, and "L" means that this SU(2) operates on left-handed isospin doublets (like the electron and its neutrino). All the SU(2)'s use quaternion (or Pauli matrices) generators with σ_1, σ_2, σ_3 corresponding to the weak bosons W^1, W^2, W^3. "Physical" weak bosons are superpositions of these bosons W^1 W^2 along with the B^o and W^3. Weak Hypercharge Y_w is zero for these physical bosons.

Jeff p 12 Schumm 195: Dot **representation**: Lie Groups like SU(2) can use combinations of generators to form "raising and lowering" operators, S^+ and S^- that can increase or decrease spin `values. Representation of a chain of spins in increments of $\hbar$ can be shown as a chain of dots {e.g., Schuum page 197}. We "represent" Lie groups and Lie algebras by matrices. So, we can use linear algebra; and many problems can be formulated on the level of Lie algebras and vector spaces. Formally, "In mathematics and theoretical physics, a representation of a Lie group is a linear action of a Lie group on a vector space." Representation theory is a huge realm of math-physics – most often discussed using advanced mathematical language. We need some simple examples……

Heisenberg's p and n (or u and d) isospin should be labeled $SU(2)_B$ for Baryon (or quark flavor). This is not intuitive since you cannot really rotate a proton into a neutron as seen by strong interactions (that usually requires pions nuclear glue – OR $u \rightarrow d + W^+$). The "eightfold way" using u d and s quarks is $SU(3)_B$ – but is not really appropriate since the strange quark is much more massive than u or d. We could say electron spin is $SU(2)_{spin}$ and never really has spins up or down (more like a longer more sideways rotating spin vector that has z-projection of ± ½ $\hbar$). An example is neutron spin which precesses like a sideways top in a magnetic field – and a precession twice around takes its wavefunction back to its original state (zero around – and this was proven experimentally by neutron interferometry).

{Mid pg 17 red notes by Jeff}: I think a photon producing an e+e- pair begins as a virtual pair becoming real. It has to happen near a nucleus in order to conserve energy-momentum. At the LHC, heavy ion near misses can radiate photons which in turn can have high-energy photon-photon collisions (they needs a fermion-antifermion) pair in-between for coupling.

Good Question – Jeff page 17: I do not know the physical implication of being non-abelian. Hints: " the physical fact that U(1) electromagnetic photons do not interact among themselves, while, for example, SU(3) gluons do." "the asymptotic freedom of quantum non-abelian gauge theory was discovered in 1973. Also Schumm p 343-344 discuss some feedback effects such as determining the direction of scaling with high energies.

Pg 21-22: discussion of the Nature of the Electro-Weak transition. We now live in the broken symmetry: that is, $SU(2)_L \times U(1)_y \rightarrow U(1)_{em}$. The electroweak scale is near 160 GeV – *something near the Higgs vacuum 246 GeV (around 10^{15} degrees kelvin).* Electroweak is a single unified interaction. At this time, we are not able to characterize what happens at this transition. E.g.,"a strong first order **electroweak** phase transition cannot be obtained in the Standard Model for experimentally-favoured Higgs mass and hence the cosmological events associated with this kind of phase transition cannot be explained in this model. However, this phase transition can be achieved in a number of Beyond Standard Models. https://arxiv.org/pdf/1507.01576.pdf ." It is hoped that early transitions would explain the asymmetry between our matter universe versus anti-matter – still a mystery.

Now we are left with electromagnetism (which we think we understand – but it is intuitively strange to think of a photon as composite B^o and W^3) nd "normal" everyday examples of $W^\pm$ interactions such as neutron decay: $n^o \rightarrow p^+ + W^-$ and $W^- \rightarrow e^- + \overline{\nu}_e$ {mean decay in 880 seconds). Another is upper-atmosphere muon decay : $\mu^- + W^+ \rightarrow \nu_\mu$.
And we know that "the fusion process in the sun, whereby hydrogen atoms glom onto one another to become helium, is an example of the weak force in action. A critical step in that reaction chain takes place through the weak force, so in fact the weak force drives the sun's nuclear furnace."

The QCD quark-gluon plasma transition {confinement/deconfinement} was much later than electroweak – about 175 MeV per nucleon and ~ 20 µs after the big-bang.

"All particles have a property called weak isospin (symbol T3), which serves as an additive quantum number that restricts how the particle can interact with the $W^\pm$ of the weak force."

Jeff page 21 says: "For some reason, the W0 and B0 also decide to reorganize themselves into the Z0 and the photon at about (exactly?) the same temperature" (his W0 is W3).
Weinberg's Paper: http://astrophysics.fic.uni.lodz.pl/100yrs/pdf/12/066.pdf 1967 shows that the transformation from massless field to physical bosons is one unified process: Once he picks his Higgs field ϕ , his complex general Lagrangian (eqn 4) becomes a new Lagrangian (eqn 7) which jointly separates the W^1 and W^2 fields from the W^3 and B^o fields (his A is our W). He skips a lot of math steps in his much too short paper – so why this separation occurs is opaque to me.
At high enough energy (>1 TeV? *Probably much less*) we will see W0 and B0 bosons separate themselves.

On page 21 Jeff asks a lot of questions such as "Did this occur abruptly or gradually?" – it seems that we have a complex bubble nucleation phase transition that should have taken some time {but still less than a nanosecond duration near the picoseconds after big bang}.
"Is it a coincidence that the energy at which the symmetry breaks only a couple of times the mass energy of the W and Z bosons?" No, all of these energies are related to the Higgs potential energy (not too far below it).

Page 22: Does Real mass exist at all? My perspective is that rest mass of a fermion is the same as its vibration rate and that is related to how rapidly a particle exchanges hypercharge to and from the "vacuum." I haven't seen this claim in print – is the exchange at a regular rate. Internal $E = mc^2$ energy also dovetails with $E = hf$ – but appears to be a separate mechanism. Jumping from hairy math to intuitive physics is far from clear. Chirality has some differences from "spin." Jeff has some good comments on this.

A FEW OF MY added NOTES: dp

Schuum page 123: quark masses update: u 1.9MeV, d 4.4, s 87, c 1320, b 4240 MeV and top t at 172 GeV! (because it interacts a lot with the Higgs field – potential 246 GeV).

Page 132: colors for SU(3)c are red, green, blue – picture an artist color circle. Anti-colors lie opposite these: $\overline{b}$ = yellow, $\overline{r}$ = cyan, $\overline{g}$ is magenta.

We like to represent lie groups using matrices. If they have determinant = 1, they are "special." So, the circle rotation $S^1 = U(1) = R(2) = SO(2) \subset O(2)$, SO(1) is just the number one {1}. Schuum's rotation names $R(3) = SO(3)$, $SU(2) \subset U(2)$

Page 209: Cheating terms plugged back into a Lagrangian reveals interactions like $J^\mu A_\mu$ --e.g., $qv \cdot A$, how charged current flows couple with the vector potential A field.

Schuum page 223 says the cheating term is $qA(x)\psi(x)$. The Aharonov-Bohm phase change effect $\psi(x) = \psi_{o(A=0)} \exp[(iq/\hbar)\int A(x)\cdot d\ell\,] = \psi_o e^{i\Phi}$ -- covers **both** the A and the del-chi = $\nabla\chi$ terms together because $\int \nabla\chi(x)\cdot d\ell \equiv \int d\chi = \Delta\chi$ phase change from one point to another. In contrast, the AB effect is path dependent!

Neutrino Oscillations: predicted by Bruno Pontecorvo 1957, Homestake detections only saw 1/3rd of expected neutrino count in the 1960's, Nobel Prize 2015 (after this book was written) to Takaaki Kajita and Arthur McDonald for neutrino oscillations. Tests at Kamioka KamLAND used 53 nearby reactors as sources of antineutrinos 2005

Page 308: $\theta \rightarrow 2\pi$ for Kaon K_s^o short and $\tau \rightarrow 3\pi$ for K_L^o Long We have $K_s \rightarrow K_L \rightarrow K_s$ again oscillations from traveling through matter. We now also have an analog using bottom B mesons.

P 318 value of $\sin^2\theta$w (Weinberg angle) for precision measurement versus theory. $0.23156 > 0.21215$ discussion on pg 321.

Pg 326 guess mass 85 GeV turned out to really be 125 GeV for the Higgs particle.

Pg 347 At present, Supersymmetry seems to be a failure. Despite predictions, no supersymmetric particles have been seen at the LHC.

Pg 360 A nobel prize was awarded to Kobayashi and Maskawa in 2008 (after this book was written)

{I just finished reading Neil deGrasse Tyson's little book called Astrophysics for People in a Hurry, 2017, 223 pages – a nice little reminder of what we are supposed to know from our studies. }