Additions, corrections, typos, comments

April 9, 2017

Changes and comments

Chapter 1

- Comment on p.1: this book differs from (Langacker, 1981) in the sign conventions for gauge couplings g, the matrix γ^5, and the Lie group parameters β^i, as well as in the convention of p. 129 for upper and lower $SU(m)$ indices.
- Table 1.1 caption: G_N is the gravitational constant.
- (1.7) (last expression): $(\vec{A}\cdot\vec{C})(\vec{B}\cdot\vec{D})-(\vec{A}\cdot\vec{D})(\vec{B}\cdot\vec{C})$

Chapter 2

- p7 footnote, $p_i = n_i \frac{2\pi}{L}, n_i = 0, \pm 1, \pm 2, \cdots,$
- Above (2.76): $M_{fi} = -i\tilde{\Phi}(\vec{q})$
- pp 38, 39: Equation references (2.43) and (2.62) just above (2.142) and (2.143) should be (2.45) and (2.63), respectively.
- p41, line 3: $\{a(\vec{p},s), a^\dagger(\vec{p}\,', s')\} = (2\pi)^3 2E_p \delta^3(\vec{p}-\vec{p}\,')\delta_{ss'}$
- p49, 3rd line of 2.207: $u_2\bar{u}_1 \to u_2\bar{u}_2$
- p50, remove e from definition of $J^\mu_Q(x)$ in (2.217)
- p50, line after (2.217): is the (conserved) *electromagnetic current.*
- Remove $|\vec{p}|$ from definition of helicity in (2.182) and (2.186), i.e.,

$$h\phi_\pm \equiv \frac{1}{2}\vec{\sigma}\cdot\hat{p}\,\phi_\pm = \pm\frac{1}{2}\phi_\pm, \qquad \frac{1}{2}\vec{\sigma}\cdot\hat{p}\,\chi_\pm = \mp\frac{1}{2}\chi_\pm$$

- p53, 3 below (2.220): $\pi \to \pi^2$
- Interchange μ and ν in (2.223). (The equation is correct as written, but it follows more directly from (2.222) with interchange.)
- p60, (2.257): $P\bar{\psi}\,(t,\vec{x})\,\psi\,(t,\vec{x})\,P^{-1}$
- p60, below (2.259): from (2.152)
- Discussion after (2.272) is incorrect. η can depend on spinor conventions. $M(a_i(-\vec{p}_i,-h_i)) = M(a_i(\vec{p}_i,-h_i))$ is less general than stated. It holds for $2\to 2$ in CM or for $1\to 2$ or 3 in rest frame of spinless particle.

- (2.331), p72: $\bar{\psi}_a \gamma^\mu \gamma^5 \psi_b = -\Psi^\dagger_{aL} \bar{\sigma}^\mu \Psi_{bL} + \Psi^\dagger_{aR} \sigma^\mu \Psi_{bR}$
- (2.390), p92: $\vec{\mu}_p = +g_p \mu_N \vec{S}_p, \qquad g_p = 2(1+\kappa_p)$
- Problem 2.2: should be for the special case $m_1 = m_3 = 0$ and $m_2 = m_4$
- Problem 2.12: Suppose a fermion $\psi \cdots$

Chapter 3

- 3 lines below (3.13): $L^i_{3*} \Rightarrow L^i_{3^*}$
- Below (3.64): $\lambda_{abcd} = \lambda_{cdab} = \lambda_{cbad}$
- (3.100): $q_1 \Rightarrow q$ on r.h.s.
- Caption to Figure 3.5: Quartic and induced cubic self-interactions for ϕ'
- (3.109) p127: the 22 entry of Q should be $-1/3$
- (3.135) p134: $\frac{d^2\phi}{dt^2}$
- (3.165) p142: add h.c. of last term
- (3.186) p148: evaluate at $\nu_{1,3} \neq 0,\ \nu_{2,4} = 0$
- Problems 3.8 and 3.11: use infinitesimal transformations

Chapter 4

- $\not{A}$ should precede L in (4.13)
- Figure 4.2: vertex of right figure should be $i\frac{g^2}{\xi}\nu_a (L^i L^j)_{ab}$

Chapter 5

- Add two color identities to Table 5.1:

$$f_{ijm} f_{klm} f_{ijn} f_{kln} = 72, \qquad f_{ijm} f_{klm} f_{ikn} f_{jln} = 36$$

- (5.10) is for 5 flavors
- (5.17), p194: reverse positions of $L^i_{\alpha\beta}$ and $L^k_{\gamma\delta}$ in first line:

$$M_{fi} = (-ig_s\ \bar{u}_3 \gamma_\mu L^k_{\gamma\delta} v_4) \left(\frac{-ig^{\mu\rho}\delta^{ik}}{s} \right) (-ig_s\ \bar{v}_2 \gamma_\rho L^i_{\alpha\beta} u_1)$$

- p. 202, middle: refer to Section 3.3.3 rather than 3.3.4
- (5.94): $\sum_r^\alpha \Rightarrow \sum_{r\alpha}$

- 4 below (5.94): $B(B_A) = B_R \pm B_L$
- Below(5.108): F^{i5} generates a symmetry
- (5.142): $\frac{1}{2}(\partial_\mu \vec{\pi})^2$
- Problem 5.3: $b_3/b_2 \to b_3/b_2^2$ in second term of final expression

Chapter 6

- p.239: continuous β decay spectrum was established by J. Chadwick in 1914.
- p. 247, below(6.21); p. 249, 6 below (6.28); p. 249, footnote: $\pi^+\pi^+\pi^0 \Rightarrow \pi^+\pi^-\pi^0$
- p. 250: $\nu_2 \to v_2$ in (6.33)
- p. 258, line 2: developed, and since then
- p. 259, 2 lines below (6.66): omit "(denoted f in (5.107))"
- p. 260, last paragraph: suppression holds for any combination of V and A;
  above (6.71): from the larger phase space $\Rightarrow$ from the larger phase space and from the trace;
  below (6.71): The value of R_π can also set limits on small S, P perturbations on the dominant $V - A$ and to violations of universality.
- (6.79): factor of $1/8\pi$ on right
- (6.83): $\pi^+ \to K^+$.
- p. 265, 7 lines below (6.97): $1.22 f_K/f_\pi \Rightarrow 1.19 f_K/f_\pi$
- (6.123): remove $\cos^2\theta_c$. ($\cos\theta_c$ is included in definition of $g_{V,A}$.)
- Line below (6.123): 1.29 GeV $\Rightarrow$ 1.29 MeV
- (6.128): $\bar{u}_k \gamma_\mu \gamma^5 u_j$
- Problem 6.5: maximum allowed energy $m_\mu/2$,

Chapter 7

- 4 lines below (7.6): $\mathcal{L}_{gauge} \Rightarrow \mathcal{L}_f$
- (7.13): $\bar{\ell}^{\,0}_{mn} \to \bar{\ell}^{\,0}_{mL}$
- (7.30): remove subscripts μ

- Replace parenthetical remark above (7.47) by footnote: "The special case of a Hermitian (symmetric) M can be diagonalized by $A_L = A_R$ ($A_L = A_R^*$). However, additional phases in A_R, analogous to (7.51), may be re required to ensure positive (and real) eigenvalues."
- p. 304, footnote: $t^3_{RL} \to t^3_{rL}$
- Remove factor of x from expressions for F_3 in (7.103), (7.104), and (7.105)
- Figure 7.16, p 335: third diagram should have one vector and one scalar in loop
- (7.194): $\tan\theta_W \to \tan^2\theta_W$
- Below (7.204): Figure 7.33. (We have ignored smaller terms which vanish for $g, g' \to 0$.) If one
- Below (7.227): $m_{K^0} = 497.6$ MeV
- Footnote on p. 379 should refer to Problem 7.17, not 2.5
- Below (7.230): But $L = 0$ for K decays, $\Rightarrow L$ must be even for $|\pi^0\pi^0\rangle$ by Bose statistics,
- (7.295): In second equation: $\tilde{\epsilon}_i = \frac{i\Im m\, M_{B_i\bar{B}_i}}{\Delta m_i \cos^2\sigma/2} \sim \frac{i\Im m\, M_{B_i\bar{B}_i}}{\Delta m_i}$, where σ is the phase of $M_{B_i\bar{B}_i}$.
- Three below (7.297): interchange ν_ℓ and $\bar{\nu}_\ell$
- p. 393 footnote: same-sign $\to$ same-side
- p. 397, line 7: $\pi^0 K_S$
- (7.325): add absolute value bars, $\sqrt{|c_{LL}|}$ and $\sqrt{|\Im m\, c_{LL}|}$
- (7.394): remove extra t's in exponents in first line
- After (7.394): sign of last term reversed for $\bar{\nu}$
- After (7.398): need $a \neq b$ for CP violation
- Add to Figure 7.45 caption: (In the full three-neutrino case the state orthogonal to ν_e is actually a linear combination of ν_μ and ν_τ.)
- Remove "$\bar{p}$-induced" on p 437, second from last line
- After (7.419): replace "phases of $m_{1,2}$" by "Majorana phases, which have been absorbed into $m_{1,2}$"
- Problem 7.3, line 4: $y_n = -\frac{1}{2} \Rightarrow y_n = +\frac{1}{2}$; ignore terms involving "tilde" fields analogous to (7.14)

- Problem 7.4: $\nu_\sigma/\sigma \to \nu_\sigma/\nu$ (twice)
- Problem 7.9: $F \Rightarrow \sigma_F, \quad B \Rightarrow \sigma_B$

Chapter 8

- Figure 8.2 caption: $\phi_k \Rightarrow \phi_r$
- (8.37): missing bar in second expression, $\bar{\eta}_1\bar{\eta}_2 \equiv \bar{\eta}_{1\dot{\alpha}}\bar{\eta}_2^{\dot{\alpha}} = \bar{\eta}_2\bar{\eta}_1$
- Below (8.4): $\Lambda_{obs}/8\pi G_N \sim (0.0024 \text{ eV})^4$
- (8.57): $\sigma_{\mu\nu} \to \mathfrak{s}_{\mu\nu}$ and $\bar{\sigma}_{\mu\nu} \to \bar{\mathfrak{s}}_{\mu\nu}$ in last line
- p. 477, line 8 of text: $\sigma_{\alpha\beta} \to \epsilon_{\alpha\beta}$
- (8.64): $\int d^2\theta\theta^2 = \int d^2\bar{\theta}\bar{\theta}^2 = 1, \qquad \int d^4\theta\theta^2\bar{\theta}^2 = 1$
- (8.69): $\sigma_{\mu\nu} \to \mathfrak{s}_{\mu\nu}$ and $\bar{\sigma} \to \bar{\mathfrak{s}}_{\mu\nu}$ in last line
- (8.114): add $F_a^\dagger F_a$ to rhs
- (8.146): $\bar{\tilde{W}}^i\bar{\tilde{W}}^- \to \bar{\tilde{W}}^i\bar{\tilde{W}}^i$
- (8.164): $\tilde{h}_d- > -\tilde{h}_d$
- (8.172): $H^+ \to H^-$ in second occurence in last line
- (8.178): $\phi_{u,d}^\dagger \to h_{u,d}^\dagger$
- p. 503, 4 below (8.180): $\tilde{W}^\pm = (\tilde{W}^1 \mp \tilde{W}^2)/\sqrt{2}$
- p. 506, line 8: $qq\bar{q} \to qqq$
- p. 514, 3 below (8.209): $\Delta \to \Delta^2$ (twice)
- p. 515, bottom: unique nontrivial family-universal $U(1)'$ extensions of the SM that do not require

Appendix

- Last expression in (H18) is for M_{WT}^2
- Below (I6): degeneracy of n is $n+1$

Bibliography/Web Sites

- Add: **FeynCalc:** Mathematica package for algebraic calculations (Mertig et al., 1991), `http://www.feyncalc.org/`.
- Add: **ALPGEN:** `http://mlm.home.cern.ch/mlm/alpgen/` (Mangano et al., 2003).
- Add (Djouadi, 2008a) to Higgs references on p362, and (Djouadi, 2008b) to SUSY Higgs references on p495, footnote §.

- Correct authors for the book *Fundamentals of neutrino physics and astrophysics* in Neutrinos bibliography are Giunti, C. and C. W. Kim

Index

- Electric charge: fractional, p. 454
- Dynkin index, p. 504
- Cosmology: cold dark matter, p. 519
- Exotic fermions, p. 353, 519
- $U(1)'$: exotic fermions, p. 519
- International Linear Collider, p. 519
- ILC: see International Linear Collider

Solutions Manual

- Problem 2.8 solution: each term in $ms_\pm$ should have $\pm$
- Problem 2.12 solution: remove $-4m^4$ from the trace of the cross term
- Problem 2.14 solution: replace g by e (3 times)
- Problem 2.17 solution:

$$\mathcal{L}_p = Ze^2\bar{\psi}(x)\gamma^0\psi(x), \qquad \Phi(0,\vec{x}) = \frac{1}{4\pi|\vec{x}|}, \qquad \tilde{\Phi}(\vec{q}) = \frac{1}{|\vec{q}|^2}.$$

- Problem 2.18 solution: $p_f = \frac{\sqrt{M_Z^2-4m^2}}{2}$ in second equation, and $p_1 \cdot p_2 = p_1 \cdot p_3 = M_Z^2/2$ in line above last equation
- Problem 2.19 solution: (b) add factor p_f to last term, $2\Re e\,(g_P g_S^*)\,p_f\cos\theta$; (c): expression for u_p is missing upper component ϕ_{s_p}
- Problem 2.22 solution: (b) $\tilde{\vec{E}}(\vec{q}) = -i\vec{q}\tilde{A}_0(\vec{q})$
- Problem 2.24 solution: (b) $i \to -1$ in $\tilde{V}(\vec{q})$; (e) $-$ sign in M and $\vec{\sigma}\cdot\vec{p}_2 \to \vec{\sigma}\cdot\vec{p}_3$
- Problem 2.25 solution: add factor e^2 to second expression for $|\bar{M}|^2$
- Problem 3.8 solution: $U = e^{+i\vec{\beta}\cdot\vec{L}}$
- Problem 3.9 solution: $-i\frac{\delta\mathcal{L}}{\delta\partial^\mu\psi_{a\beta}} = \bar{\psi}_{a\alpha}(\gamma_\mu)_{\alpha\beta}$; 3 lines from end: $\epsilon \to c$

- Problem 3.17 solution: g_π is the coefficient of $\bar{p} i\gamma^5 p\,\pi^0$
- Problem 3.20 solution: $\psi_{U^0} = (\sqrt{3}\psi_3 + \psi_8)/2$
- Problem 3.21 solution: $M \to -M$ in fourth line
- Problem 3.27: last three terms in $\mathcal{L}$ should have $-$ sign.
- Problem 3.32 solution: *(c)i*, $m_2^2 = \mu^2 + \lambda\nu^2 \sim \mu^2 + \frac{2\lambda a^2}{\mu^4}$; *(c)ii*, $m_\psi = h\frac{\nu_0+\epsilon}{\sqrt{2}}$
- Problem 4.4 solution: $g/2 \to g/8$ in next to last line
- Problem 5.1 solution: $-$ sign for quark vertex: $-ig_s L^i_{21}$
- Problem 6.1 solution: the Lorentz invariant I is conveniently evaluated in the two-neutrino rest frame
- Problem 6.10 solution: remove $\cos\theta_c$ from first expression for M
- Problem 6.11 solution: add factor of i to expressions for M.
- Problem 6.12 solution: change sign of $\bar{v}_2\gamma_i u_1$ and M expressions
- Problem 7.4 solution: can include $\kappa_{\phi\sigma}\sigma\phi^\dagger\tilde{\phi} + h.c.$. in potential. Set $\kappa_{\phi\sigma} = 0$ in *(b)*. Part (d) end: longitudinal mode of A.
- Problem 7.6 solution: the matrix at the end of *(a)* is $A_L^\dagger$ rather than A_L, and the off-diagonal terms in *(b)* should have the opposite sign.
- Problem 7.7 solution: the trace in $|\bar{M}|^2$ involves p_3 rather than p_2
- Problem 7.8 solution: $\sqrt{2m_p} \to 2m_p$ (twice)
- Problem 7.9 solution: $F \Rightarrow \sigma_F, \quad B \Rightarrow \sigma_B$
- Problem 7.10 solution: $\epsilon^\mu \to \epsilon^{\mu *}$ and $\epsilon^{\nu *} \to \epsilon^\nu$ throughout; $\pm 4\hat{g}^2\epsilon_{\mu\rho\nu\sigma}\epsilon_1^\mu p_t^\rho \epsilon_2^\nu p_b^\sigma = \pm 4\hat{g}^2 m_t E_b \Big[\underbrace{-\epsilon_{ijk}\epsilon_1^i\epsilon_2^j\hat{p}_b^k}_{1}\Big]$
- Problem 7.16: $i\mathcal{L}_{VVH} = 2i(M_V^2/\nu)\epsilon_1^* \cdot \epsilon_2^*$
- Problem 7.18 solution: $|\pi^-\pi^+\rangle \Rightarrow |\pi^+\pi^-\rangle, \quad |\pi^-\pi^+\pi^0\rangle \Rightarrow |\pi^+\pi^-\pi^0\rangle$
- Problem 8.1 solution: $\cosh\zeta = \gamma$
- Problem 8.5 solution: $\sigma^\mu \to \bar{\sigma}^\mu$ in last (next to last) term of first (second) equation
- Problem 8.7 solution: g missing in third equation
- Problem 8.11 solution: $\omega = \pi/2 \to 1 + |\zeta|^2 \lesssim 1.0009$ or $|\zeta| \lesssim 0.03$

Acknowledgments

I am grateful to Conrado Badenas, Mirjam Cvetič, Sarah Eno, Jens Erler, Alejandro Jaramillo, Hye-Sung Lee, Gil Paz, Josef Pradler, Ben Safdi, Suresh Tiwari, Liantao Wang, Jack Wimberley, and Itay Yavin for making suggestions or pointing out corrections.

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