Errata for *An Introduction to Particle Physics and the Standard Model*

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To my chagrin, and despite my best efforts at proofreading, a number of omissions, errors, and typos are present in the textbook. To address this issue I have included a full list of errata. I have generally included much more detail than is strictly necessary, so that readers can see the full context of where the correction is.

As of this writing these are all of the errors that I know of. If you find any others, please let me know and I will make changes accordingly. My apologies for the irritation that I am sure this has caused both students and instructors.

Errata

Correction 1.1 *Table 1.7 should read*

Quark Bound States

BARYONS:	qqq	(a 3-quark bound state)	HADRONS
MESONS:	$q \neq q$	(a quark-antiquark bound state)	

(big bracket now in correct place)

Correction 2.1 *Equation (2.15) should read*

$$g_{\mu\nu}x'^{\mu}x'^{\nu} = g_{\mu\nu}\left(\Lambda^{\mu}{}_{\alpha}x^{\alpha}\right)\left(\Lambda^{\nu}{}_{\beta}x^{\beta}\right) = \left(g_{\mu\nu}\Lambda^{\mu}{}_{\alpha}\Lambda^{\nu}{}_{\beta}\right)x^{\alpha}x^{\beta}$$

Correction 2.2 *Equation (2.16) should read*

$$\boxed{g_{\mu\nu}\Lambda^{\mu}{}_{\alpha}\Lambda^{\nu}{}_{\beta} = g_{\alpha\beta}}$$

(indices now fixed)

Correction 2.3 *Table 2.1 should read*

Rotations compared to Lorentz transformations

Rotations		Lorentz Transformations
$R_{ik}R_{jk} = \delta_{ij}$		$g_{\mu\nu}\Lambda^{\mu}{}_{\alpha}\Lambda^{\nu}{}_{\beta} = g_{\alpha\beta}$
$\phi'(\vec{x}) = \phi(R^{-1}\vec{x})$	SCALAR	$\phi'(x^{\mu}) = \phi(\left(\Lambda^{-1}\right)^{\mu}{}_{\nu}x^{\nu})$
$V'_i(\vec{x}) = R_i{}^{j}V_j(R^{-1}\vec{x})$	VECTOR	$V'^{\alpha}(\vec{x}) = \Lambda^{\alpha}{}_{\mu}V^{\mu}(\left(\Lambda^{-1}\right)^{\mu}{}_{\nu}x^{\nu})$
$T'_{ij}(\vec{x}) = R_i{}^{k}R_i{}^{l}T_{kl}(R^{-1}\vec{x})$	TENSOR	$T'^{\alpha\beta}(\vec{x}) = \Lambda^{\alpha}{}_{\mu}\Lambda^{\beta}{}_{\nu}T^{\mu\nu}(\left(\Lambda^{-1}\right)^{\mu}{}_{\nu}x^{\nu})$

(indices now fixed in right-hand column)

Correction 2.4 *Equation (2.20) should read*

$$\begin{aligned} A'_{\mu}B'^{\mu} &= g_{\mu\nu}A'^{\mu}B'^{\nu} = g_{\mu\nu}\left(\Lambda^{\mu}{}_{\alpha}A^{\alpha}\right)\left(\Lambda^{\nu}{}_{\beta}B^{\beta}\right) \\ &= \left(g_{\mu\nu}\Lambda^{\mu}{}_{\alpha}\Lambda^{\nu}{}_{\beta}\right)A^{\alpha}B^{\beta} = g_{\alpha\beta}A^{\alpha}B^{\beta} = A_{\beta}B^{\beta} \end{aligned}$$

Correction 2.5 *Equation (2.30) should read*

$$\begin{aligned} p^0 &= mu^0 = \gamma mc = \frac{mc}{\sqrt{1 - v^2/c^2}} \\ &= \frac{1}{c}\left[mc^2 + \frac{1}{2}mv^2 + \frac{3}{8}m\frac{v^4}{c^2} + \cdots\right] \end{aligned}$$

Correction 2.6 *Eq (2.37) should read*

$$(mc)^2 + (mc)^2 + 2\left(\frac{E_1 E_2}{c^2} - \vec{p}_1 \cdot \vec{p}_2\right) = (Mc)^2$$

This is just a correction in the font size of a subscript.

Correction 2.7 *The first line of question 8 on page 42 should read*

A pion travelling at speed v decays into a lepton of mass m_ℓ and its corresponding antineutrino.

Part (a) of this question should read (a) Find an expression for the angle that the lepton is emitted relative to the original direction of motion.

Correction 3.1 *Equation (3.6) should read*

$$\mathcal{R} = \left\{ \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_x & \sin\theta_x \\ 0 & -\sin\theta_x & \cos\theta_x \end{pmatrix}, \begin{pmatrix} \cos\theta_y & 0 & -\sin\theta_y \\ 0 & 1 & 0 \\ \sin\theta_y & 0 & \cos\theta_y \end{pmatrix}, \begin{pmatrix} \cos\theta_z & \sin\theta_z & 0 \\ -\sin\theta_z & \cos\theta_z & 0 \\ 0 & 0 & 1 \end{pmatrix} \right\}$$

Correction 3.2 *Question 3.7 should read*

Consider a set of three objects $\{i, j, k\}$ with the following properties

$$ij = k \qquad jk = i \qquad ki = j$$

and where $i^2 = j^2 = k^2 = -1$. Show that the set $\pm\{1, i, j, k\}$ forms a group under multiplication using these rules.

Correction 4.1 *Pg 67, chapter 4, 2nd last paragraph last line should read*

"... based on an action principle."

Correction 4.2 *Question 4.5 should read*

Show that the operators $\vec{\mathbf{P}} \cdot \vec{\mathbf{P}}$ and $\vec{\mathbf{P}} \cdot \vec{\mathbf{L}}$ commute with all elements of the algebra in question #4.

Correction 4.3 *Question 4.7 should read*

Consider the operator $U = \exp\left(-\frac{i\theta}{\hbar}\hat{n} \cdot \vec{\mathbf{L}}\right)$ where $\vec{\mathbf{L}} = \vec{x} \times (-i\hbar\vec{\nabla})$ is the angular momentum operator and $\hat{n}$ is a unit vector. How does U act on a wavefunction $\Psi(\vec{x}, t)$?

Correction 5.1 *The last line of eq (5.18) should read*

$$= -\psi_a$$

Correction 5.2 *Question 5.6 (a) should read*

(a) $\exp\left[i\vec{\theta}\cdot\vec{\sigma}\right] = \sum_{n=0}^{\infty}\frac{\left(i\vec{\theta}\cdot\vec{\sigma}\right)^n}{n!} = \cos\theta + i\widehat{\theta}\cdot\vec{\sigma}\sin\theta$

Correction 6.1 *Page 96, just before eq (6.11) should read*

are the spherical harmonics, given in appendix F.

Correction 6.2 *Page 102, just before eq (6.23) should read*

Using the Clebsch-Gordon tables in appendix F we have

Correction 6.3 *The equations in Question 6.2 should read*

(a) $\bar{n} \longrightarrow \bar{p} + e^+ + \nu_e$ (b) $\gamma + Z^0 \longrightarrow \nu_e + \pi^0$

(c) $\mu^+ + \tau^- \longrightarrow \gamma + \gamma + \gamma$ (d) $Z^0 \longrightarrow \bar{\nu}_\mu + \nu_\mu$

(e) $D^0 \longrightarrow K^- + \rho^+$ (f) $e^- + \bar{\nu}_e \longrightarrow \bar{t} + b$

Correction 6.4 *Question 6.7 (b) should read*

(b) Given that $\mathbb{T}\vec{\mathbb{J}} = -\vec{\mathbb{J}}\mathbb{T}$ where $\vec{\mathbb{J}}$ is the angular momentum operator, show that

$$|\chi_1\rangle \equiv -\mathbb{T}\left|\frac{1}{2},-\frac{1}{2}\right\rangle \quad \text{and} \quad |\chi_2\rangle \equiv \mathbb{T}\left|\frac{1}{2},\frac{1}{2}\right\rangle$$

form a spin-1/2 doublet in the time-reversed system.

Correction 7.1 *Equation (7.5) and the sentence before it should read*

Because the charge of the electron is $1.60217733 \times 10^{-19}$ Coulombs $\times(3 \times 10^9)$esu/Coulomb, we find from eq.(7.3)

$$Br = \frac{pc}{q} = \frac{1.42 \times 10^6 \times 10^7}{3 \times 10^9} = 4.73 \times 10^3 \text{ Gauss-cm}$$

Correction 8.1 *Equation (8.2) should read*

$$\left(\frac{dE}{dx}\right)_{\text{ionization}} = -\frac{4\pi N_A (ze)^2 e^2}{m_e c^2 \beta^2}\left(\frac{\rho Z}{A}\right)\left[\ln\left(\frac{2m_e c^2\beta^2}{\overline{I}}\gamma^2\right) - \beta^2\right]$$

(factor of density ρ included)

The two sentences after this equation should read

This formula was derived by Hans Bethe and Felix Bloch [77], and describes the mean rate of energy loss of a particle of charge $q = ze$ due to ionization of a medium with ionization potential $\overline{I}$, atomic number Z and nucleon number A and density ρ. Here e is the charge on the electron (mass m_e) and N_A =$6.02\times10^{23}\mathtt{mol}^{-1}$ is Avagadro's number.

Correction 8.2 *Equation (8.3) should read*

$$\left(\frac{dE}{dx}\right)_{\text{ionization}} \to -\frac{4\pi N_A (ze)^2 e^2}{m_e c^2 \beta^2}\left(\frac{\rho Z}{A}\right)\left[\ln\left(\frac{2m_e c^2 \beta^2}{\bar{I}}\right)\right]$$

(factor of density ρ included)

Correction 8.3 *Equation (8.5) should read*

$$\left(\frac{dE}{dx}\right)_{\text{ionization}} \simeq -2\rho \quad \text{MeV cm}^2/\text{g}$$

(spacing and units corrected)

Correction 8.4 *Question 8.5 should read*

The rate of energy loss of protons traveling a material of density ρ typically follows a power law

$$\frac{dE}{dx} = -K\rho\left(\frac{E}{E_0}\right)^{-p}$$

where the constants K and p are characteristic of the material and E_0 is a reference calibration energy that we can take to be 1 MeV.

(a) Find an expression for the thickness of material that will reduce the energy of a proton by half the value it has upon entering the material.

(b) For Carbon, $K = 212$ MeV cm^2/g, and $p = 0.757$; for Lead, $K = 89.5$ MeV cm^2/g, and $p = 0.694$. How much thicker must a slab of Carbon be than a slab of Lead in order to reduce a proton of incident energy 150 MeV by half?

Correction 9.1 *The bottom of page 175 to the top of page 176 should read*

Independent measurements indicate that the proton spin is $\frac{1}{2}$ and the deuteron spin is 1, so for $|\vec{p}_\pi|^2 = |\vec{p}_p|^2$

$$\frac{2\sigma\left(p + p \longrightarrow \pi^+ + \text{D}\right)}{3\left(2s_\pi + 1\right)} = \sigma\left(\pi^+ + \text{D} \longrightarrow p + p\right) \tag{9.45}$$

Measurements by Cartwright, Clark and Durbin [102] showed that

$$\sigma\left(\pi^+ + \text{D} \longrightarrow p + p\right) = 3.1\pm0.3\,\text{mb} \qquad \frac{2\sigma\left(p + p \longrightarrow \pi^+ + \text{D}\right)}{3\left(2s_\pi + 1\right)} = 3.0\pm1.0\,\text{mb} \tag{9.46}$$

from which we empirically determine that the pion is a spin-0 particle!

Correction 10.1 *Equation (10.14) should read*

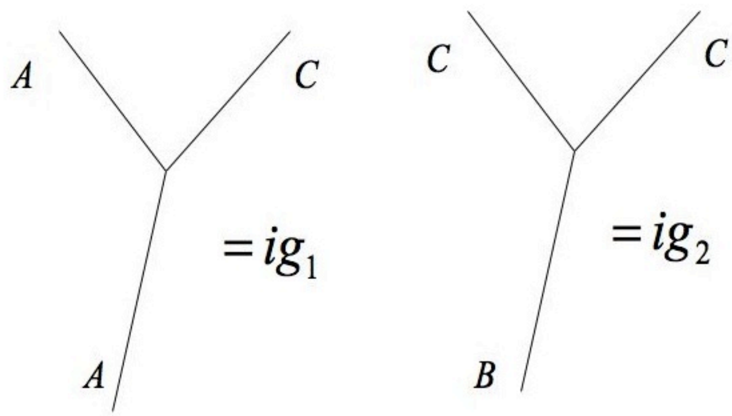
$$\begin{aligned}(p_1' - p_1)^2 - m_B^2 &= (p_1')^2 + (p_1)^2 - 2p_1' \cdot p_1 - m^2 \\ &= 0 + m^2 - 2\left(E'E - |\vec{p}||\vec{p}\,'|\cos\theta\right) - m^2 \\ &= -2E\left(E - |\vec{p}|\cos\theta\right)\end{aligned}$$

(middle line corrected)

Correction 10.2 *The first paragraph after eq (10.16) should read*

Let's pause to note some things about this formula. At high energies $|\vec{p}c| \simeq E$, and $\frac{d\sigma}{d\Omega} \to \frac{(\hbar c)^2 (cg)^4}{E^6 (1-\cos^2\theta)^2} \sim \frac{(\hbar c)^2 (cg)^4}{E^6 \sin^4\theta}$. The cross-section . . .

Correction 10.3 *In figure 10.12, one B-particle should be a C-particle. The correct diagram should be*



Correction 11.1 *Question 11.2 should read*

Find spinors u that satisfy $(\gamma^\mu p_\mu - m)\, u(p) = 0$ that have positive energy and that are eigenstates of the operator $\hat{p} \cdot \vec{S}$ where $\hat{p}$ is the unit vector of the 3-momentum of the spinor and

$$\vec{S} = \frac{\hbar}{2}\vec{\Sigma} = \frac{\hbar}{2}\begin{pmatrix} \vec{\sigma} & 0 \\ 0 & \vec{\sigma} \end{pmatrix}$$

is the spin angular momentum operator.

Correction 12.1 *Equation (12.4) should read*

$$\begin{aligned}&\overline{\psi}^{(\uparrow)}\psi^{(\uparrow)} \\ &= \overline{u}^{(\uparrow)}(p) u^{(\uparrow)}(p) \\ &= 2m\psi_0^2 \begin{pmatrix} \sqrt{\frac{E+m}{2m}}\xi^{(\uparrow)\dagger} & \sqrt{\frac{E-m}{2m}}\xi^{(\uparrow)\dagger}\left(\hat{p}\cdot\vec{\sigma}^\dagger\right) \end{pmatrix} \begin{pmatrix} I & 0 \\ 0 & -I \end{pmatrix} \begin{pmatrix} \sqrt{\frac{E+m}{2m}}\xi^{(\uparrow)} \\ \sqrt{\frac{E-m}{2m}}\left(\hat{p}\cdot\vec{\sigma}\right)\xi^{(\uparrow)} \end{pmatrix}\end{aligned}$$

$$
\begin{aligned}
&= 2m\psi_0^2 \begin{pmatrix} \sqrt{\frac{E+m}{2m}}\xi^{(\uparrow)\dagger} & \sqrt{\frac{E-m}{2m}}\xi^{(\uparrow)\dagger}\left(\hat{p}\cdot\vec{\sigma}^\dagger\right) \end{pmatrix} \begin{pmatrix} \sqrt{\frac{E+m}{2m}}\xi^{(\uparrow)} \\ -\sqrt{\frac{E-m}{2m}}\left(\hat{p}\cdot\vec{\sigma}\right)\xi^{(\uparrow)} \end{pmatrix} \\
&= 2m\psi_0^2 \left[\left(\frac{E+m}{2m}\right)\xi^{(\uparrow)\dagger}\xi^{(\uparrow)} - \left(\frac{E-m}{2m}\right)\xi^{(\uparrow)\dagger}\left(\hat{p}\cdot\vec{\sigma}^\dagger\right)\left(\hat{p}\cdot\vec{\sigma}\right)\xi^{(\uparrow)}\right] \\
&= 2m\psi_0^2 \left[\left(\frac{E+m}{2m}\right) - \left(\frac{E-m}{2m}\right)\right] \\
&= 2m\psi_0^2
\end{aligned}
$$

(correct brackets inserted into 3rd line)

Correction 12.2 *Question 12.8 should read*

Consider a theory of one complex scalar particle with wavefunction φ and two spin-$\frac{1}{2}$ particles ψ and χ, each of which couples to the photon via the equations

$$
\begin{aligned}
\left(i\gamma^\mu D_\mu - m_\psi\right)\psi &= g\varphi^*\chi \\
\left(i\gamma^\mu D_\mu - m_\chi\right)\chi &= g\varphi\psi \\
D^\mu D_\mu\varphi - m_\varphi^2\varphi &= g\bar{\psi}\chi
\end{aligned}
$$

where m_φ^2 , m_ψ, and m_χ are the respective masses of the φ , ψ and χ particles.

(a) Find the most general local phase transformation of φ , ψ and χ that leaves this system gauge-covariant.

(b) What is the relationship between the charges of φ , ψ and χ ?

(c) In Maxwell's equations

$$\partial^\mu F_{\mu\nu} = \mathcal{J}_v$$

what is the current $\mathcal{J}_v$ for this theory?

Correction 13.1 *Equation (13.10) should read*

$$
\begin{aligned}
-i\mathcal{M} &= -i\mathcal{M}_{\text{left}} - \left(-i\mathcal{M}_{\text{right}}\right) \\
&= \left[\overline{u}^{(i_1')}(p_1')\gamma^\mu v^{(i_2')}(p_2')\right]\frac{ig_e^2}{\left(p_1+p_2\right)^2}\left[\overline{v}^{(i_2)}(p_2)\gamma_\mu u^{(i_1)}(p_1)\right] \\
&\quad - \left[\overline{u}^{(i_1')}(p_1')\gamma^\mu u^{(i_1)}(p_1)\right]\frac{ig_e^2}{\left(p_1'-p_1\right)^2}\left[\overline{v}^{(i_2)}(p_2)\gamma_\mu v^{(i_2')}(p_2')\right]
\end{aligned}
$$

Correction 13.2 *Equation (13.24) should read (note – only the last line of this equation has changed)*

$$
\begin{aligned}
&\mathrm{Tr}\left[\overline{\gamma}^\mu\left(\not{p}_1'+m\right)\gamma^\nu\left(\not{p}_1+m\right)\right] \\
&= \mathrm{Tr}\left[\overline{\gamma}^\mu\not{p}_1'\gamma^\nu\not{p}_1\right] + m^2\mathrm{Tr}\left[\overline{\gamma}^\mu\gamma^\nu\right] \\
&= \mathrm{Tr}\left[\gamma^\mu\not{p}_1'\gamma^\nu\not{p}_1\right] + m^2\mathrm{Tr}\left[\gamma^\mu\gamma^\nu\right] \\
&= \mathrm{Tr}\left[\gamma^\mu\left(p_{1\lambda}'\gamma^\lambda\right)\gamma^\nu\left(p_{1\eta}\gamma^\eta\right)\right] + 4m^2 g^{\mu\nu} \\
&= p_{1\lambda}'p_{1\eta}\mathrm{Tr}\left[\gamma^\mu\gamma^\lambda\gamma^\nu\gamma^\eta\right] + 4m^2 g^{\mu\nu} \\
&= 4p_{1\lambda}'p_{1\eta}\left(g^{\mu\lambda}g^{\nu\eta} - g^{\mu\nu}g^{\lambda\eta} + g^{\mu\eta}g^{\nu\lambda}\right) + 4m^2 g^{\mu\nu} \\
&= 4\left(p_1'^\mu p_1^\nu + p_1'^\nu p_1^\mu + g^{\mu\nu}\left[m^2 - p_1'\cdot p_1\right]\right) \\
&\equiv L^{\mu\nu}(p_1', p_1; m^2)
\end{aligned}
$$

(definition of $L_{\mu\nu}$ corrected to be consistent with chapter 17)

Correction 13.3 *Equation (13.26) should read*

$$\begin{aligned} \mathrm{Tr}\left[\overline{\gamma}_\mu\left(\not{p}'_2+M\right)\gamma_\nu\left(\not{p}_2+M\right)\right] &= 4\left(p'_{2\mu}p_{2\nu}+p'_{2\nu}p_{2\mu}+g_{\mu\nu}\left[M^2-p'_2\cdot p_2\right]\right) \\ &= L_{\mu\nu}(p'_2,p_2;M^2) \end{aligned}$$

(definition of $L_{\mu\nu}$ corrected to be consistent with chapter 17)

Correction 13.4 *Equation (13.27) should read (note – only the first line of this equation is changed)*

$$\begin{aligned} \left|\overline{\mathcal{M}}\right|^2 &= \frac{1}{4}\left(\frac{e^2}{(p'_1-p_1)^2}\right)^2 L^{\mu\nu}(p'_1,p_1;m^2)L_{\mu\nu}(p'_2,p_2;M^2) \\ &= 4\left(\frac{e^2}{(p'_1-p_1)^2}\right)^2\left(p'^\mu_1 p^\nu_1+p'^\nu_1 p^\mu_1+g^{\mu\nu}\left[m^2-p'_1\cdot p_1\right]\right) \\ &\quad\times\left(p'_{2\mu}p_{2\nu}+p'_{2\nu}p_{2\mu}+g_{\mu\nu}\left[M^2-p'_2\cdot p_2\right]\right) \\ &= 4\left(\frac{e^2}{(p'_1-p_1)^2}\right)^2\left[2\left(p'_1\cdot p'_2\right)\left(p_1\cdot p_2\right)+2\left(p'_1\cdot p_2\right)\left(p_1\cdot p'_2\right)\right. \\ &\quad+2\left(p'_2\cdot p_2\right)\left[m^2-p'_1\cdot p_1\right]+2\left(p'_1\cdot p_1\right)\left[M^2-p'_2\cdot p_2\right] \\ &\quad\left.+4\left[m^2-p'_1\cdot p_1\right]\left[M^2-p'_2\cdot p_2\right]\right] \\ &= 8\left(\frac{e^2}{(p'_1-p_1)^2}\right)^2\left[\left(p'_1\cdot p'_2\right)\left(p_1\cdot p_2\right)+\left(p'_1\cdot p_2\right)\left(p_1\cdot p'_2\right)\right. \\ &\quad\left.-\left(p'_1\cdot p_1\right)M^2-\left(p'_2\cdot p_2\right)m^2+2m^2M^2\right] \end{aligned}$$

(definition of $L_{\mu\nu}$ corrected to be consistent with chapter 17)

Correction 14.1 *Part (c) of problem 14.2, bottom of pg 269 should read*

(c) Use this to obtain a differential cross-section that is averaged over initial photon polarizations and summed over final photon polarizations. Work in the lab-frame.

Correction 15.1 *Page 276, just before eq. (15.21) should read*

... a job easily done using the $1\otimes\frac{1}{2}$ Clebsch-Gordon tables in appendix F:

Correction 15.2 *Page 280, sentence after eq. (15.37) should read*

Clearly the antiparticles K^- and Σ^+ have $S=-1$ and $S=+1$ respectively.

Correction 15.3 *Page 285, just before eq. (15.41) should read*

To get the spin part of the wavefunction, we just use the Clebsch-Gordon tables in appendix F twice to get $\frac{1}{2}\otimes\frac{1}{2}\otimes\frac{1}{2}=(1\oplus 0)\otimes\frac{1}{2}=\left(1\otimes\frac{1}{2}\right)\oplus\left(0\otimes\frac{1}{2}\right)=\frac{3}{2}\oplus\frac{1}{2}\oplus\frac{1}{2}$:

Correction 16.1 *Eq. (16.29) should read*

$$\Delta E_{\text{H.F.}} = \langle H_{\text{dipole}} \rangle_{\text{directions}} = \left(\frac{8\pi}{3} \right) \frac{4\pi\alpha}{m_e m_p c^2} \vec{S}_e \cdot \vec{S}_p \left| \Psi_{n=0}(0) \right|^2$$

(factor of $\hbar^2$ removed)

Correction 17.1 *Eq. (17.26) should read*

$$\overline{|\mathcal{M}|}^2 = \frac{1}{4} \left[\frac{-e^2}{q^2} \right]^2 L^{\mu\nu}(p_1', p_1; m^2) L_{\mu\nu}(p_2', p_2; M^2)$$

Correction 17.2 *Eq. (17.46) should read*

$$d\sigma = \frac{\hbar^2 \pi M}{2\sqrt{(p_1 \cdot p_2)^2 - p_1^2 p_2^2}} \left(\frac{e^2}{q^2} \right)^2 \frac{c\left(d^3 p_1'\right)}{2E_1' \, (2\pi)^3} L^{\mu\nu}(p_1', p_1; m^2) W_{\mu\nu}(p_2', p_2; M^2)$$

Correction 17.3 *Eq. (17.49) should read*

$$d\sigma = \frac{\pi}{E} \left(\frac{\hbar e^2}{c q^2} \right)^2 \frac{E' \, (dE' d\Omega)}{4 \, (2\pi)^3} L^{\mu\nu}(p_1', p_1; m^2) W_{\mu\nu}(p_2', p_2; M^2)$$

Correction 17.4 *Eq. (17.50) should read*

$$\frac{d\sigma}{dE' d\Omega} = \left(\frac{\hbar\alpha}{c q^2} \right)^2 \frac{E'}{2E} L^{\mu\nu} W_{\mu\nu}$$

Correction 17.5 *Eq. (17.55) should read*

$$L^{\mu\nu} W_{\mu\nu} = 8EE' \left[2W_1 \left(q^2, q \cdot p_2\right) \sin^2 \frac{\theta}{2} + W_2 \left(q^2, q \cdot p_2\right) \cos^2 \frac{\theta}{2} \right]$$

Correction 18.1 *Eq. (18.39) should read*

$$\mathbf{F}_{\mu\nu} \Phi = (ig)^{-1} \left[\mathbf{D}_\mu, \mathbf{D}_\nu \right] \Phi$$

Correction 18.2 *Question 18.4 should read*

Show that the 2 constituents of a meson in the colour singlet state $\frac{1}{\sqrt{3}} \left| R\overline{R} + B\overline{B} + G\overline{G} \right\rangle$ experience a potential $V = -\frac{4}{3}\frac{1}{r}$.

Correction 18.3 *Question 18.8 should read*

(a) Given

$$\mathbf{F}_{\mu\nu}\Phi = (ig)^{-1}\left[\mathbf{D}_\mu\Phi\right]$$

show that

$$\mathbf{F}_{\mu\nu} = \partial_\mu\mathbf{A}_\nu - \partial_\nu\mathbf{A}_\mu + ig\left[\mathbf{A}_\mu, \mathbf{A}_\nu\right]$$

or alternatively

$$F^{\mathfrak{a}}_{\mu\nu} = \partial_\mu A^{\mathfrak{a}}_\nu - \partial_\nu A^{\mathfrak{a}}_\mu - g\mathrm{f}^{\mathfrak{a}}_{\mathfrak{bc}}A^{\mathfrak{b}}_\mu A^{\mathfrak{c}}_\nu$$

(b) Show that for a given representation R

$$\left(\left(D_\mu D_\nu - D_\nu D_\mu\right)\Phi\right) = igF^{\mathfrak{a}}_{\mu\nu}\mathbf{T}^{\mathfrak{a}}_{\mathsf{R}}\Phi$$

Correction 19.1 *Question 19.5 should read*

You make contact with alien physicists through a wormhole into another part of the multiverse, and soon develop a common language of communication with them. They have developed methods of traveling through the wormhole in short times and are considering visiting Earth. However, before they visit, you want to be sure that they are not made of antimatter. Because of this lack of knowledge, it's too dangerous to send objects through the wormhole, but you can ask them any questions you want about experiments they have performed, and you are able to communicate with them results of experiments performed here.

(a) Can you determine if they are made of antimatter if each of $\mathbb{C}$, $\mathbb{P}$, or $\mathbb{T}$ are conserved in all interactions in their universe?

(b) Can you determine if they are made of antimatter if $\mathbb{CP}$ is conserved by $\mathbb{C}$ and $\mathbb{P}$ are both violated in their universe?

(c) Can you determine if they are made of antimatter if $\mathbb{CP}$, $\mathbb{C}$ and $\mathbb{P}$ are each violated in their universe?

Correction 20.1 *Question 20.4 should read (note: only part (d) has changed)*

Consider muonium, a bound state of μ^+ with e^-.

(a) What are the possible spins of the two lowest-energy states? Which has the lowest energy?

(b) There are two possible ways that muonium can decay. What are they?

(c) Draw a diagram for each decay mode in part (b).

(d) Only one decay mode is possible for one of the lowest energy states. Which one is it, and why?

(e) Compute the ratio of the decay rates for the state in which both decay modes are allowed. Which is the more likely decay?

Correction 21.1 *The last line of equation (21.22) should read*

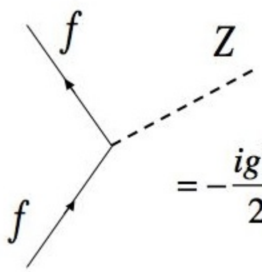
$$(p \cdot p_1') = p_1'^2 + (p_2' \cdot p_1') = m_\ell^2 + \frac{1}{2}\left(m_\pi^2 - m_\ell^2\right) = \frac{1}{2}\left(m_\pi^2 + m_\ell^2\right)$$

Correction 22.1 *Table 22.1 should read*

Neutral Current Candidates from the Gargamelle Experiment

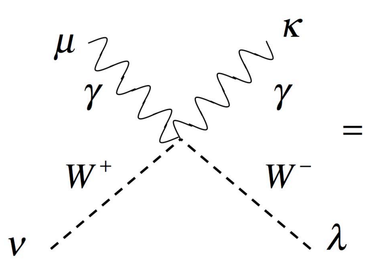
	ν-exposure	$\bar{\nu}$-exposure
# of Neutral current candidates	102	64
# of Charged current candidates	428	148

Correction 22.2 *Figure 22.3 should not have a factor of* $\sqrt{2}$ *in the denominator. The correct figure is*

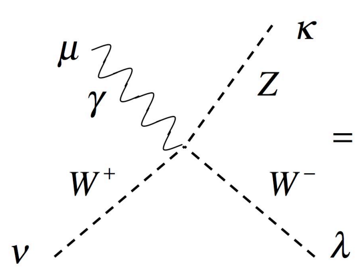


$$= -\frac{ig^Z}{2}\gamma^\mu\left(c_V^f - c_A^f\gamma^5\right)$$

Correction 23.1 *Figure 23.5 should not have a factor of* $\sqrt{2}$ *in the denominator. The correct figure is*



$$= -ie^2\left(2g_{\nu\lambda}g_{\mu\kappa} - g_{\lambda\mu}g_{\kappa\nu} - g_{\mu\nu}g_{\lambda\kappa}\right)$$



$$= -ieg_W\cos\theta_W\left(2g_{\nu\lambda}g_{\mu\kappa} - g_{\lambda\mu}g_{\kappa\nu} - g_{\mu\nu}g_{\lambda\kappa}\right)$$

Correction 23.2 *Equation (23.60) should read*

$$
\begin{aligned}
g_Z j^{\mathrm{Z}}_\nu &= -\frac{g_{\mathrm{Y}} \sin\theta_{\mathrm{W}}}{2} \left[Y^{\mathfrak{L}}_L \overline{\chi}^{\mathfrak{L}}_L \gamma_\nu \chi^{\mathfrak{L}}_L + Y^{\mathfrak{L}}_R \overline{\chi}^{\mathfrak{L}}_R \gamma_\nu \chi^{\mathfrak{L}}_R + Y^{\mathfrak{Q}}_L \overline{\chi}^{\mathfrak{Q}}_L \gamma_\nu \chi^{\mathfrak{Q}}_L + Y^{\mathfrak{Q}}_R \overline{\chi}^{\mathfrak{Q}}_R \gamma_\nu \chi^{\mathfrak{Q}}_R \right] \\
&\qquad + g_{\mathrm{W}} \cos\theta_{\mathrm{W}} j^3_\nu \\
&= g_{\mathrm{W}} \cos\theta_{\mathrm{W}} j^3_\nu - \frac{\sin\theta_{\mathrm{W}}}{\cos\theta_{\mathrm{W}}} \left[g_e j^{\mathrm{em}}_\nu - g_{\mathrm{W}} \sin\theta_{\mathrm{W}} j^3_\nu \right] \\
&= \frac{g_e}{\sin\theta_W \cos\theta_W} \left((j^3)^\mu - \sin^2\theta_W \, (j^{\mathrm{em}})^\mu \right)
\end{aligned}
$$

(factor of 2 corrected in last term of first line)

Correction 23.3 *Question 23.4 should read (note: only the last line has been changed)*

Show that if

$$
\Phi = \begin{pmatrix} 0 \\ v + \mathsf{h}(x) \end{pmatrix}
$$

then

$$
D_\mu \Phi = -i g_{\mathrm{W}} \frac{v}{2} \begin{pmatrix} \left(W^1_\mu - i W^2_\mu \right) \\ -\frac{Z_\mu}{\cos\theta_{\mathrm{W}}} \end{pmatrix} + \mathcal{O}(\mathsf{h})
$$

and

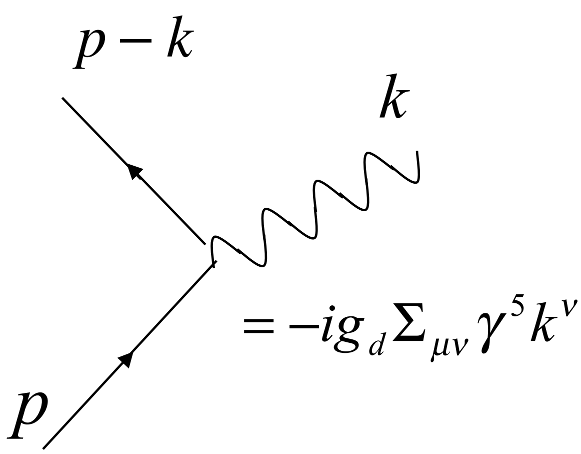
$$
\begin{aligned}
\frac{i g_{\mathrm{W}}}{2} \left(\Phi^\dagger \sigma^{\mathfrak{a}} D_\mu \Phi - (D_\mu \Phi)^\dagger \sigma^{\mathfrak{a}} \Phi \right) &= \left(\frac{g_{\mathrm{W}} v}{2} \right)^2 \left\{ W^1_\mu, W^2_\mu, \frac{1}{\cos\theta_{\mathrm{W}}} Z_\mu \right\} + \mathcal{O}(\mathsf{h}) \\
\frac{i g_{\mathrm{Y}}}{4} \left(\Phi^\dagger D_\nu \Phi - (D_\nu \Phi)^\dagger \Phi \right) &= -\left(\frac{v}{2} \right)^2 \frac{g_{\mathrm{W}} g_{\mathrm{Y}}}{\cos\theta_{\mathrm{W}}} Z_\mu + \mathcal{O}(\mathsf{h})
\end{aligned}
$$

(minus sign corrected in last line)

Correction 25.1 *Equation (25.10) should read*

$$
P\left(\nu_\mu \longrightarrow \nu_\tau, t\right) = \sin^2\left(2\vartheta_{23}\right) \sin^2\left(\frac{(E_2 - E_3)\, t}{2\hbar} \right)
$$

Correction 25.2 *Figure 25.6 should be (variables appropriately repositioned)*

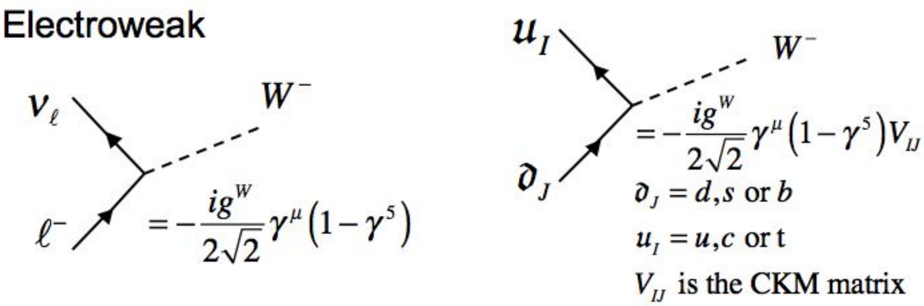


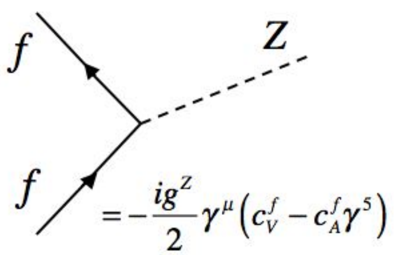
Correction 0.1 *Table H.4 should read (quark content of Ξ^0 and Ξ^- corrected)*

Baryons (Spin-1/2)

Symbol	Quark Content	Mass (MeV)	Charge	Lifetime (sec)	Main Decays
p	uud	938.272	1	∞	none
n	udd	939.565	0	885.7	$p\ e^-\bar{\nu}_e$
Λ	uds	1115.68	0	2.63×10^{-10}	$p\ \pi^-$, $n\ \pi^0$
Σ^+	uus	1189.37	1	8.02×10^{-11}	$p\ \pi^0$, $n\ \pi^+$
Σ^0	uds	1192.64	0	7.4×10^{-20}	$\Lambda\gamma$
Σ^-	dds	1197.45	-1	1.48×10^{-10}	$n\ \pi^-$
Ξ^0	uss	1314.8	0	2.90×10^{-10}	$\Lambda\pi^0$
Ξ^-	dss	1321.3	-1	1.64×10^{-10}	$\Lambda\pi^-$
Λ_c	udc	2286.5	1	2.00×10^{-13}	$\Lambda\pi\pi$, $\Sigma\pi\pi$, $p\ K\pi$
Σ_c	uuc, udc, ddc	2452	2, 1, 0	3.3×10^{-22}	$\Lambda_c\pi$
Ξ_c	usc, dsc	2469	1, 0	1.1×10^{-13}	$S = -2$ Hadrons
Ω_c	ssc	2697	0	6.9×10^{-14}	$S = -3$ Hadrons
Λ_b	udb	5624	0	1.23×10^{-12}	$\Lambda_c + \cdots$

Correction 0.2 *On page 553, the Z-vertex factor should not have a factor of* $\sqrt{2}$ *in the denominator. The corrected diagram is*





f	c_V	c_A
ν_ℓ	$\frac{1}{2}$	$\frac{1}{2}$
ℓ	$-\frac{1}{2}+2\sin^2\theta_W$	$-\frac{1}{2}$
u,c,t	$\frac{1}{2}-\frac{4}{3}\sin^2\theta_W$	$\frac{1}{2}$
d,s,b	$-\frac{1}{2}+\frac{2}{3}\sin^2\theta_W$	$-\frac{1}{2}$

Correction 0.3 *On page 542 the entry for the weak mixing angle should read*

Weak Mixing Angle	$\sin^2\theta_W$	0.23116(13)	560000 ppb