

# Errata to “An Introduction to the Physics of Particle Accelerators”, 1st Ed.

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## Chapter 1

1. p. 3, line 2: “...If more there...” should read “...If there...”.
2. p. 3, line 21: “band width” should read “bandwidth”.
3. Eq. (1.5) should read:

$$d\Phi_{\Omega} = 1000 \frac{d^4 n}{dt d\Omega (d\lambda/\lambda)}. \quad (1.5)$$

4. p. 5, 5th line from bottom: “ $2V(t)$ ” should read “ $2V_0$ ”.
5. p. 15, Eq. (1.41) should read:

$$\frac{dr}{dp} = -\frac{2pr^2}{GMm^2}, \quad (1.41)$$

6. p. 15, Eq. (1.42) should read:

$$\alpha_p = \frac{dr}{dp} = \frac{p}{r} \frac{dr}{dp} = -\frac{2p^2 r}{GMm^2} = -2. \quad (1.42)$$

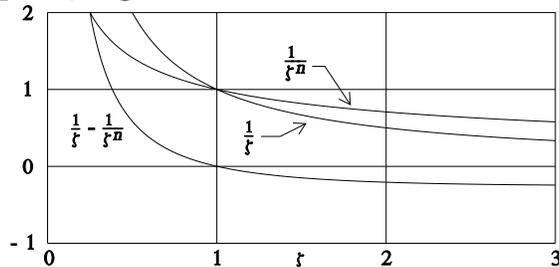
7. p. 17, in Problem 1–2, “NdYAG” should read “Nd:YAG”.

## Chapter 2

8. p. 19, Eq. (2.1) should read

$$F_x = \frac{d}{dt}(\gamma m \dot{x}) = -q\beta c B_y, \quad \text{and} \quad (2.1)$$

9. p. 21, line after Eq. 2.12 should read: “... $(x/\rho)^2$  or higher, ...”
10. p. 22, caption to Fig. 2.2 should have “c) Vertical focusing...” and “d) Vertical defocusing...”
11. p. 22 first line of § 2.3 should read: “Equation (2.12)...”
12. p. 23, Fig. 2.3 should have labels reversed:



- 13. p. 23, Eq. (2.24) should start with  $x(\theta) = \dots$ .
- 14. p. 23, Eq. (2.25) should start with  $x'(\theta) = \dots$ .
- 15. p. 25, line before Eq. (2.37) should read "...when  $n > 1$ ,"
- 16. p. 25, Eq. (2.38) should read:

$$\frac{d^2x}{d\theta^2} + \left[ \left(1 - \frac{\delta p}{p}\right) \left(1 + \frac{1}{B_0} \frac{\partial B_y}{\partial x} x\right) \left(1 + \frac{x}{\rho}\right) - 1 \right] \rho \left(1 + \frac{x}{\rho}\right) = 0, \quad (2.38)$$

- 17. p. 26, Eq. (2.40) should read:

$$\frac{d^2y}{d\theta^2} + \left(1 - \frac{\delta p}{p}\right) ny \left(1 + \frac{2x}{\rho}\right) \simeq \frac{d^2y}{d\theta^2} + ny = 0, \quad (2.40)$$

- 18. p. 29, first line of Eq. (2.56) should read:

$$\cos \frac{\sqrt{1-n}\pi}{2} - \frac{l_0}{2\rho} \sqrt{1-n} \sin \frac{\sqrt{1-n}\pi}{2} \simeq \cos \left[ \left(1 + \frac{l_0}{\rho\pi}\right) \frac{\sqrt{1-n}\pi}{2} \right] \quad (2.56)$$

- 19. p. 29, last line of text should be "Taking into account Eq. (2.57),..."
- 20. p. 29, Eq. (2.63) should read:

$$\sin \mu_H \simeq \sin \psi + \frac{l_0}{2\lambda} \cos \psi, \quad (2.63)$$

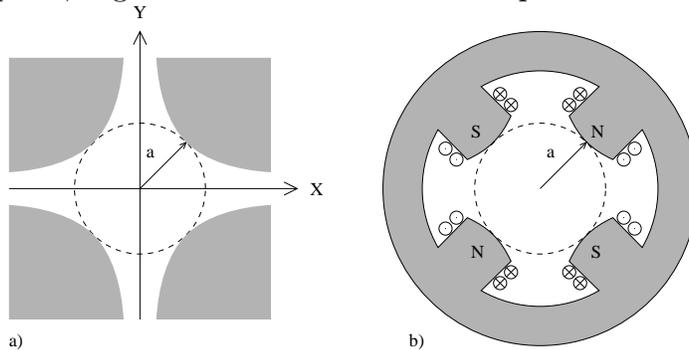
- 21. p. 31, last sentence should read: "But  $\omega_H$  is just  $2\pi/\tau_H = 2\pi v/\lambda_H$ , therefore  $\lambda_H = 2\pi/\beta_H = L/Q_H$ ."

### Chapter 3

- 22. p. 35, Eq. 3.5 needs an extra factor of  $c^2$  to keep the units correct.

### Chapter 4

- 23. p. 54, Ref. 9, The second editor's name should read "F. R. Huson".
- 24. p. 59, Fig. 4.2b has North and South poles reversed. Fig. 4.2 should be:



- 25. p. 59, Eq. (4.16) should be

$$r^2 \sin 2\theta = 2xy = a^2, \quad (4.16)$$

26. p. 64, line after Eq. (4.42) should read: “the horizontal matrix can be written as”  
 27. p. 66, Eq. (4.54) should be:

$$\mathbf{M}_H = \begin{pmatrix} 1 & \rho\theta & \frac{1}{2}\rho\theta^2 \\ 0 & 1 & \theta \\ 0 & 0 & 1 \end{pmatrix}, \quad (4.54)$$

### Chapter 5

28. p. 76, Eq. (5.49) should be

$$-w'_0 w(s) = -\frac{w(s)}{w_0} w_0 w'_0 = \sqrt{\frac{\beta(s)}{\beta_0}} \alpha_0, \quad (5.49)$$

29. p. 82, Append text to sentence containing Eq. (5.86):

$$\begin{pmatrix} \eta \\ \eta' \\ 1 \end{pmatrix} = \begin{pmatrix} C(s) & S(s) & D(s) \\ C'(s) & S'(s) & D'(s) \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \eta \\ \eta' \\ 1 \end{pmatrix}, \quad (5.86)$$

where the matrix elements are evaluated for the periodic cell starting at position  $s$ .

30. p. 85, last equation in Problem 5–8 should be

$$\eta(s) = \frac{\sqrt{\beta(s)}}{2 \sin(\pi Q_H)} \int_s^{s+L} \frac{\sqrt{\beta(\tau)}}{\rho(\tau)} \cos[\phi(\tau) - \phi(s) - \pi Q_H] d\tau.$$

### Chapter 6

31. p. 93, first line of Eq. (6.38) should be

$$\mathbf{M} = \begin{pmatrix} 1 - \frac{l_1 l_2}{f^2} + \frac{l_2}{f} & 2l_1 + l_2 - \frac{l_1^2 l_2}{f^2} \\ -\frac{l_2}{f^2} & 1 - \frac{l_1 l_2}{f^2} - \frac{l_2}{f} \end{pmatrix}$$

32. p. 96, Eq. (6.50) should be

$$\begin{aligned} M_{23} = & -\frac{\sin \mu}{\beta} \frac{1}{2} l \left( 1 + \frac{l}{8f} \right) \theta_1 + \cos \mu \left( 1 - \frac{l}{8f} - \frac{l^2}{32f^2} \right) \theta_1 \\ & + \left( 1 - \frac{l}{8f} - \frac{l^2}{32f^2} \right) \theta_2, \end{aligned} \quad (6.50)$$

33. p. 100, line after Eq. 6.80 should read: “By analogy with § 5.1, the block components of  $\mathbf{U}$ , may be written as”

34. p. 104, replace text from Eq. (6.105) to Eq. (6.111) with:

$$\xi_{xN} = -\frac{1}{4\pi Q_H} \frac{e}{p} \oint \beta_x(s) G(s) ds. \quad (6.105a)$$

Actually there are two different natural chromaticities for the horizontal and vertical planes with the vertical given by

$$\xi_{yN} = \frac{1}{4\pi Q_V} \oint \beta_y(s) k_0(s) ds, \quad (6.105b)$$

since a horizontally focussing quadrupole defocusses in the vertical plane.

If some magnetic field imperfections give rise to a perturbation of the kind

$$B_y = \sum_{n=2}^{\infty} b_n x^n, \quad (6.106)$$

then in Eq. (6.92)  $k - k_0$  must be replaced by

$$\left( -\frac{qG}{p_0} + 2\frac{q}{p_0} b_2 \eta_x \right) \frac{\Delta p}{p} + \dots, \quad (6.107)$$

which yields the additional *residual chromaticity* in the horizontal plane:

$$\xi_{xR} = \frac{1}{4\pi Q_H} \frac{q}{p_0} \oint \beta_x(s) 2b_2(s) \eta_x(s) ds + \dots \quad (6.108)$$

The total chromaticity will then be

$$\xi_{x\text{total}} = -\frac{1}{4\pi Q} \frac{q}{p} \oint \beta(s) [G(s) - 2b_2(s) \eta(s)] ds, \quad (6.109)$$

which may vanish, at least in principle, if

$$b_2(s) = \frac{G(s)}{2\eta(s)}. \quad (6.110)$$

Appropriately placed sextupole lenses may then compensate the natural chromaticity. For the vertical direction in a planar accelerator, the vertical residual chromaticity will be

$$\xi_{yR} = -\frac{1}{2\pi Q} \frac{q}{p_0} \oint \beta_y(s) b_2(s) \eta_x(s) ds, \quad (6.111)$$

**Chapter 7**

35. p. 116, Change the 2nd line before § 7.6 to: “Fig. 7.5 shows how...”

36. p. 117, Change Eq. (7.41) to

$$\frac{dW}{dt} = -\frac{\partial H}{\partial \varphi} = \frac{qV}{2\pi h} [\sin \phi_s - \sin(\phi_s + \varphi)], \quad (7.41)$$

37. p. 118, Eq. (7.50) should read

$$t_s = \frac{2\pi h}{\omega_{\text{rf}} L} s$$

38. p. 188, between Eqs. (7.51 and 7.52), change “electric” to “magnetic”.

39. p. 118, Eq. (7.53) should read:

$$A_s \approx -\frac{p_s x}{q\rho} - \frac{p_s K}{2q} x^2 + \frac{V}{\omega_{\text{rf}}} \sum_{n=-\infty}^{\infty} \delta(s - nL) \cos(\omega_{\text{rf}} t + \phi_s), \quad (7.53)$$

40. p. 119, last term of Eq. (7.59) should read:

$$\dots + \frac{qV\pi h \sin \phi_s}{L^2 \omega_{\text{rf}}} s^2. \quad (7.59)$$

41. p. 119, middle line of Eq. (7.61) should read:

$$\approx -p_s + \frac{p_s K}{2} x^2 - \frac{qV}{\omega_{\text{rf}}} \sum_{n=-\infty}^{\infty} \delta(s - nL) \cos\left(\phi_s + \delta\phi + \frac{2\pi h s}{L}\right) - \frac{2\pi h}{L} W$$

42. p. 121, first line should read: “The partial derivative  $\partial \mathcal{F}_2 / \partial s$  is actually...”

43. p. 121, middle line of Eq. (7.61) should read:

$$- \frac{qV}{\omega_{\text{rf}}} \sum_{n=-\infty}^{\infty} \delta(s - nL) \cos\left[\phi_s + \varphi + \frac{2\pi h s}{L} - \frac{\omega_{\text{rf}} U_s}{(p_s c)^2} (\eta_x p_\beta - p_s \eta'_x x_\beta)\right]$$

44. p. 122, Eq. (7.90) should read:

$$W_m = \frac{\Omega_s \beta^2 U_s}{\omega_{\text{rf}}^2 \eta_{\text{tr}}} \varphi_m. \quad (7.90)$$

45. p. 123, Eq. (7.91) should read:

$$I_L = \frac{h^2 \omega_s^2 \eta_{\text{tr}}}{\beta^2 U_s} \oint \frac{\Omega_s \beta^2 U_s}{h^2 \omega_s^2 \eta_{\text{tr}}} \varphi_m W_m \cos^2(\Omega_s t + \psi_0) dt = \pi \varphi_m W_m, \quad (7.91)$$

46. p. 125, first line of Eq. (7.103) should read:

$$A_{\text{bk}} = 2 \int_{-\pi}^{\pi} W d\phi$$

47. p. 128, last equation of Problem 7–1 should read:

$$\left(\frac{\Delta p}{p}\right) = \left[ \frac{(\gamma_i^2 - 1)^2 \gamma}{(\gamma^2 - 1)^2 \gamma_i} \right]^{\frac{1}{4}} \left(\frac{\Delta p}{p}\right)_i,$$

## Chapter 8

48. p. 134, first line should read: "... , can be calculated..."

49. p. 137, the second line after Eq. (8.48) should read "... ( $Q_s/Q_H \ll 1$ ), ..."

50. p. 139, the last half of Eq. (8.66) should be:

$$\dots \text{ and } \langle x_\beta^2 \rangle = \frac{A^2 \beta_H}{2}. \quad (8.66)$$

51. p. 142, Eq. (8.88) should read:

$$N_r = \frac{5\alpha_f}{2\sqrt{3}}\gamma, \quad (8.88)$$

Note: In Jackson's 3rd Edition, he defines the critical frequency as in Eq. 8.84.

52. p. 144, Eq. (8.93) should read

$$\varphi = \frac{\omega_{\text{rf}} \alpha_p}{U_s \Omega_s} A \sin[\Omega_s(t - t_0)], \quad (8.93)$$

53. p. 144, Eq. (8.94) should read

$$\xi = \frac{U_s \Omega_s}{\omega_{\text{rf}} \alpha_p} \varphi. \quad (8.94)$$

54. p. 145, Eq. (8.97) should read

$$\Delta(A^2) \simeq -2u \oint N_\gamma \langle u_\gamma \rangle \frac{ds}{c} + \oint N_\gamma \langle u_\gamma^2 \rangle \frac{ds}{c}. \quad (8.97)$$

55. p. 145, Eq. (8.98) should read

$$\left(\frac{d(A^2)}{dt}\right)_{\text{QF}} \simeq \frac{\Delta(A^2)}{\tau_s} = \frac{1}{c\tau_s} \oint N_\gamma \langle U_\gamma^2 \rangle ds \quad (8.98)$$

56. p. 145, Eq. (8.99) should read

$$A = A_0 e^{-t/\tau_u}, \quad (8.99)$$

57. p. 145, Eq. (8.100) should read

$$\left( \frac{d(A^2)}{dt} \right)_{\text{damping}} = -\frac{2}{\tau_u} A^2. \quad (8.100)$$

58. p. 147, Eq. (8.112) should read

$$\Delta(A^2) = \left( \frac{u_\gamma}{U_s} \right)^2 [\beta_H \eta'^2 + 2\alpha_H \eta \eta' + \gamma_H \eta^2 + \beta_H \theta_x^2 - 2(\beta_H \eta' + \alpha_H \eta) \theta_x]. \quad (8.112)$$

59. p. 148, The equation after Eq. (8.119) should have been numbered. This would bump all the remaining equation numbers and references in Chapter 8 by one, although for this list we keep the old numbers.

60. p. 149, Eq. (8.120) should read:

$$\sigma_x = \sqrt{\beta_H \epsilon_H + \left( \eta \frac{\sigma_u}{U_s} \right)^2}. \quad (8.120)$$

61. p. 150, Eq. (8.124) should read:

$$\frac{dE}{dt} = -\frac{2}{\tau_x} E, \quad (8.124)$$

62. p. 150, Eq. (8.125) should read:

$$\frac{dN}{dt} = -\frac{NE}{\tau_x \epsilon} e^{-E/2\epsilon} = -\frac{N}{\tau_N}, \quad (8.125)$$

## Chapter 9

63. p. 155, Eq. (9.24) should read:

$$\left[ \frac{1}{r} \frac{\partial}{\partial r} \left( r \frac{\partial}{\partial r} \right) + \frac{1}{r^2} \frac{\partial^2}{\partial \theta^2} + \frac{\partial^2}{\partial z^2} + k^2 \right] E_z = 0, \quad (9.24)$$

64. p. 156, the first line should start: “where  $k^2 = \omega^2/c^2$  is . . .”

65. p. 162, last sentence of first paragraph of § 9.4 should be: “For standing waves the waveguide is usually replaced by a quasi-periodic structure, e. g., a series of drift tubes as in an Alvarez linac, or a series of resonant cavities.”

66. p. 163, Eq. (9.75) should be

$$E_z = E_0 J_0 \left( \frac{X_{01}}{a} r \right), \quad \text{and} \quad (9.75)$$

67. p. 174, second line of last paragraph should start: “Arbitrarily picking  $z = 0$  at one of the peaks...”

68. p. 175, Eq. (9.133) should read:

$$\begin{aligned} \Delta U &= \int_0^{\beta\lambda_{\text{rf}}/2} q E_z(0, 0, z, t) dz \\ &= \frac{qk A_{10} V}{2} I_0(0) \int_0^{\beta\lambda_{\text{rf}}/2} \sin kz \sin(kz + \phi_s) dz \\ &= \frac{\pi q A_{10} V}{4} \cos \phi_s. \end{aligned} \quad (9.133)$$

## Chapter 10

69. p. 178, Eq. (10.9) should read:

$$\frac{d^2 x}{d\theta^2} + Q_H^2 x = \varepsilon \cos(m\theta) y, \quad \text{and} \quad (10.9)$$

70. p. 178, Eq. (10.10) should read:

$$\frac{d^2 y}{d\theta^2} + Q_V^2 y = \varepsilon \cos(m\theta) x. \quad (10.10)$$

71. p. 179, Eq. (10.11) should read:

$$\frac{d^2 x}{d\theta^2} + Q_H^2 x = \frac{1}{2} \varepsilon_y [\cos(Q_V + m)\theta + \cos(m - Q_V)\theta], \quad \text{and} \quad (10.11)$$

72. p. 179, Eq. (10.12) should read:

$$\frac{d^2 y}{d\theta^2} + Q_V^2 y = \frac{1}{2} \varepsilon_x [\cos(Q_H + m)\theta + \cos(m - Q_H)\theta], \quad (10.12)$$

73. p. 180, Eq. (10.22) should start with

$$\begin{aligned} \cos(m\theta) \cos^p(Q_H\theta) \cos^q(Q_V\theta) \\ \dots \end{aligned} \quad (10.22)$$

74. p. 182, three lines after Eq. (10.28) should read: “the normal sextupole and decapole are shown in Fig. 10.2b.”

75. p. 185, Eq. (10.51) should read:

$$2 \sin(2\phi) \frac{d\phi}{da} = -\frac{d}{da}[\cos(2\phi)] = \frac{4\delta}{\varepsilon a} + \frac{2}{a} \cos(2\phi). \quad (10.51)$$

76. p. 186, Eq. (10.58) should read:

$$\sqrt{\alpha} \frac{\varepsilon}{m} \theta = \ln \left( \frac{2\sqrt{\alpha} \sqrt{\alpha a^4 + ba^2 + c} + 2\alpha a^2 + b}{W_0} \right), \quad (10.58)$$

77. p. 186, Eq. (10.59) should read:

$$W_0 = 2\sqrt{\alpha} \sqrt{\alpha a_0^4 + ba_0^2 + c} + 2\alpha a_0^2 + b. \quad (10.59)$$

78. p. 186, Eq. (10.61) should read:

$$\sqrt{-\alpha} \frac{\varepsilon}{m} \theta = \sin^{-1} \left( \frac{\alpha a_0^2 + \frac{1}{2}b}{A_0} \right) - \sin^{-1} \left( \frac{\alpha a^2 + \frac{1}{2}b}{A_0} \right). \quad (10.61)$$

79. p. 186, Eq. (10.62) should read:

$$a^2 = \frac{A_0}{(2\delta/\varepsilon)^2 - 1} \left( \frac{2\delta}{\varepsilon} + \sin(\Omega\theta - S_0) \right), \quad (10.62)$$

80. p. 186, Eq. (10.64) should read:

$$S_0 = \sin^{-1} \left( \frac{\alpha a_0^2 + b/2}{A_0} \right). \quad (10.64)$$

81. p. 187, line before Eq. (10.73) should have: "... , and we find that a particle..."

### Chapter 11

82. p. 193, Eq. (11.8) should read:

$$\frac{d^2y}{d\theta^2} + Q_V^2 y = \frac{R^2}{\beta^2 \gamma m c^2} F(y), \quad \text{or} \quad (11.8)$$

83. p. 193, before Eq. (11.10) should say: "... in a Maclaurin's series"

84. p. 193, Eq. (11.10) should read:

$$f(y) = \frac{1 - \exp\left(-\frac{y^2}{2\sigma_V^2}\right)}{y} = \frac{y}{2\sigma_V^2} - \sum_{n=2}^{\infty} \frac{(-1)^n y^{2n-1}}{2^n n! \sigma_V^{2n}}, \quad (11.10)$$

85. p. 194, Eq. (11.12) should read:

$$\frac{d^2y}{d\theta^2} + (Q_V + \delta Q_{sc})^2 y \simeq 0 \quad \text{with} \quad (11.12)$$

86. p. 194, Eq. (11.13) should read:

$$\delta Q_{sc} = -\frac{Nr_0 R^2}{2lQ_V \sigma_V^2 \beta^2 \gamma^3} = -\frac{Nr_0}{4\pi B_f \epsilon_{V,rms}^* \beta \gamma^2}. \quad (11.13)$$

87. p. 194, Two lines above Eq. (11.17), the last expression should read

$$2\sigma_H(\sigma_V + \sigma_H)/\beta_V.$$

88. p. 194 Eq. (11.17) should read

$$\delta Q_V = -\frac{\beta_V Nr_0}{2\pi B_f \sigma_V (\sigma_H + \sigma_V) \beta^2 \gamma}. \quad (11.17)$$

Note: In several places in Chapters 11 and 12, the conversion between rms and 90% emittances for a Gaussian distribution should have used the ratio  $\epsilon_{90\%}/\epsilon_{rms} = 4.6$  rather than 4.

89. p. 194, Eq. (11.14) and preceding line should read:

... that the rms normalized emittance for a Gaussian beam is

$$\pi \epsilon_{V,rms}^* = \pi \frac{(\sigma_V)^2}{\beta_V \beta \gamma} \quad (11.14)$$

90. p. 196, just below figure caption: “where  $N_2$  is...”

91. p. 198. To clarify the argument, the paragraph containing Eq. (11.34) should be replaced by:

Why does this occur? The question is still open, in spite of several trials to give a satisfactory answer. Definitely, the sums of nonlinear terms give rise to overlapping resonances. In fact, bunched beams introduce azimuthal dependence with terms like  $y^{2n-1} \cos 2k\theta$  which drive the resonances

$$Q_V = \frac{2k}{2n-1+1} = \frac{k}{n}. \quad (11.34)$$

Coupled motion should be considered in addition to the single-resonance approach. Even in the single-resonance model, the superposition of high-order

resonances yields<sup>12</sup> stochasticity, in a way similar<sup>13</sup> to the transition from laminar flow to turbulence for a viscous incompressible fluid.

### Chapter 12

92. p. 205, Eq. (12.5) should read:

$$\langle p_{\perp}^2 \rangle = \frac{p^2}{4.6} \left( \frac{\varepsilon_{\text{H}}}{\beta_{\text{H}}} + \frac{\varepsilon_{\text{V}}}{\beta_{\text{V}}} \right), \quad (12.5)$$

93. p. 205, Eq. (12.6) should read:

$$k_{\text{B}}T_{\perp} = \frac{1}{9.2} mc^2 (\beta_0 \gamma_0)^2 \left( \frac{\varepsilon_{\text{H}}}{\beta_{\text{H}}} + \frac{\varepsilon_{\text{V}}}{\beta_{\text{V}}} \right). \quad (12.6)$$

94. p. 205, Eq. (12.7) should read:

$$k_{\text{B}}T_{\perp} = \frac{1}{9.2} mc^2 \beta_0 \gamma_0 \left( \frac{\varepsilon_{\text{H}}^*}{\beta_{\text{H}}} + \frac{\varepsilon_{\text{V}}^*}{\beta_{\text{V}}} \right); \quad (12.7)$$

95. p. 206, Eq. (12.13) should read:

$$\frac{1}{2} k_{\text{B}}T_{\parallel} = \frac{1}{2} mc^2 \left\langle \left( \frac{\Delta\gamma}{\beta_0 \gamma_0} \right)^2 \right\rangle = \frac{1}{2} mc^2 \beta_0^2 \left\langle \left( \frac{\Delta p}{p} \right)^2 \right\rangle, \quad (12.13)$$

96. p. 206, Eq. (12.14) should read:

$$\frac{3}{2} k_{\text{B}}T = \frac{mc^2}{2} (\beta_0 \gamma_0)^2 \left[ \frac{\varepsilon_{\text{H}}}{4.6\beta_{\text{H}}} + \frac{\varepsilon_{\text{V}}}{4.6\beta_{\text{V}}} + \frac{1}{\gamma_0^2} \left( \frac{\sigma_p}{p} \right)^2 \right]. \quad (12.14)$$

97. p. 207, second sentence after Eq. (12.18) should start: “When an antiproton of velocity  $v_{\bar{p}}^*$  passes an electron...”

98. p. 208, last part of Eq. (12.20) should read:

$$= -\frac{q^2}{2\pi\epsilon_0 v_{\bar{p}}^*} \frac{1}{r}. \quad (12.20)$$

99. p. 208, Eq. (12.22) should read:

$$\Delta W_{\bar{p}}^* = -W_e^* = -\frac{q^2 r_e c^2}{2\pi\epsilon_0 v_{\bar{p}}^{*2} r^2}. \quad (12.22)$$

100. p. 210, Eq. (12.41) should read:

$$\tau^* = \frac{\beta_0^3 \gamma_0^3}{4\pi r_e r_p c n_e^* \ln(\Lambda)} \left[ \frac{\varepsilon_{\text{H}}}{4.6\beta_{\text{H}}} + \frac{\varepsilon_{\text{V}}}{4.6\beta_{\text{V}}} + \frac{1}{\gamma_0^2} \left( \frac{\sigma_p}{p} \right)^2 \right]^{\frac{3}{2}}. \quad (12.41)$$

101. p. 211, Eq. (12.44) should read:

$$\tau = \frac{q\beta_0^4 \gamma_0^5}{4\pi r_e r_p \eta J_e \ln(\Lambda)} \left[ \frac{\varepsilon_H}{4.6\beta_H} + \frac{\varepsilon_V}{4.6\beta_V} + \frac{1}{\gamma_0^2} \left( \frac{\sigma_p}{p} \right)^2 \right]^{\frac{3}{2}}, \quad (12.44)$$

102. p. 211, should read at bottom of page: "...from some external source of heat,..."

103. p. 212, second line from bottom should read: "...in a dispersion-free straight section,..."

104. p. 213, eighth line should have: "...result  $\tau \simeq 15$ s for..."

105. p. 214, end of first paragraph should have: "...the group of particles is coherent."

106. p. 218, second line of Eq. (12.76) should be:

$$-\frac{2GA_{\text{cm}}}{N_s} \left[ \cos \phi_{\text{cm}} \sum_{k=1}^{N_s} A_k \cos \phi_k + \sin \phi_{\text{cm}} \sum_{k=1}^{N_s} A_k \sin \phi_k \right]. \quad (12.76)$$

107. p. 218, first line of Eq. (12.77) should be:

$$e^{i\omega_{\text{cm}} t} e^{i\phi_{\text{cm}}} = \frac{1}{N_s A_{\text{cm}}} \sum_{k=1}^{N_s} A_k e^{i\omega_k t} e^{i\phi_k}$$

108. p. 219, at Eq. (12.81) should have:

$$\frac{d\langle A^2 \rangle}{dt} \simeq \frac{\langle A'^2 \rangle - \langle A^2 \rangle}{\tau_s} = -\frac{2G - G^2}{\tau_s} A_{\text{cm}}^2, \quad (12.81)$$

or since  $A_{\text{cm}}^2 \simeq \langle A^2 \rangle / N_s$ ,

109. p. 220, after Eq. (12.93) should have: "After substitution..."

110. p. 221, Eq. (12.96) should read

$$\frac{d\langle A^2 \rangle}{dt} = -\frac{1}{NT_s} [2G - G^2(1 + R_n)] \langle A^2 \rangle, \quad (12.96)$$

111. p. 221, Eq. (12.98) should read

$$R_n = \frac{\langle A_n^2 \rangle}{\langle A^2 \rangle} N_s \quad (12.98)$$

112. p. 221, in eight line of § 12.6: "...centroid..."

### Appendix A

113. p. 228, Eq. (A.5) should read:

$$\eta_{\text{tr}} = \frac{1}{\gamma^2} - \alpha_p. \quad (\text{A.5})$$

### Appendix B

114. p. 231, Eqs. (B.7) should read:

$$N = |\vec{v}_+ - \vec{v}_-| \sigma \int \rho_+(\vec{x} - \vec{v}_+ t) \rho_-(\vec{x} - \vec{v}_- t) d^3x dt. \quad (\text{B.7})$$

115. p. 231, Eqs. (B.8) should read:

$$\frac{dN}{dt} = |\vec{v}_+ - \vec{v}_-| f_0 N_b \sigma \int \rho_+(\vec{x} - \vec{v}_+ t) \rho_-(\vec{x} - \vec{v}_- t) d^3x dt. \quad (\text{B.8})$$

116. p. 231, Eqs. (B.9) should read:

$$\mathcal{L} = |\vec{v}_+ - \vec{v}_-| f_0 N_b \int \rho_+(\vec{x} - \vec{v}_+ t) \rho_-(\vec{x} - \vec{v}_- t) d^3x dt, \quad (\text{B.9})$$

### Appendix C

117. p. 232, Eq. (C.7) should read:

$$\delta \int_{s_1}^{s_2} (\vec{P} \cdot d\vec{X} - K ds) = 0. \quad (\text{C.7})$$

118. p. 233, Eq. (C.15) should read:

$$\frac{dF}{ds} = \frac{\partial F_2}{\partial s} + \sum_i \left( \frac{\partial F_2}{\partial x_i} x'_i + \frac{\partial F_2}{\partial P_i} P'_i - P_i X'_i - P'_i X_i \right), \quad (\text{C.15})$$

### Appendix D

119. p. 235, Eq. (D.4) should read:

$$\begin{pmatrix} x_2 \\ x'_2 \end{pmatrix} = \begin{pmatrix} \overline{M}_{11} & \overline{M}_{12} \\ \overline{M}_{21} & 0 \end{pmatrix} \begin{pmatrix} 0 \\ x'_1 \end{pmatrix} = \begin{pmatrix} \overline{M}_{12} x'_1 \\ 0 \end{pmatrix}. \quad (\text{D.4})$$

### Appendix E

120. p. 238, Formula 12 in top section should read:

$$12. \quad \vec{v} \times (\nabla \times \vec{B}) = \nabla(\vec{v} \cdot \vec{B}) - (\vec{v} \cdot \nabla) \vec{B}, \quad \text{if } \vec{v} = \frac{d\vec{x}}{dt}$$

121. p. 238, 2/3 of the way down should have: "...Bessel function relations for..."