THEORY AND DESIGN OF CHARGED PARTICLE BEAMS

by Martin Reiser

Wiley Series in Beam Physics and Technology, 1994

ERRATA SHEETS

The first printing of the book was in 1994; the second printing was three years later. There are two lists of errata sheets.

1. Errors in the 1st printing that were, with some exceptions, corrected in the 2nd printing. Those exceptions, which for the most part are due to printing mistakes, are marked by an asterisk (*).

2. Errors in the 1st printing that were discovered after the 2nd printing, hence remain uncorrected in both the 1st and 2nd printing of the book. Included in this list are the corrections for the printing mistakes, marked by an asterisk (*), which are mentioned in Item 1.

I wish to thank the many friends and colleagues who have pointed out some of the errors in the book to me. In the future, any new errors found will be added to the existing errata sheets on the website.

ERRATA

M. Reiser, *Theory and Design of Charged Particle Beams*

List 1: Errors in 1st printing that were corrected in the 2nd printing, with some exceptions marked by (*) (dated Sept. 19, 2002).

Page	Corrections
8	Eq. (1.2): add subscript B to k^2, to read k_B^2.
12	5th line from top: delete π after ϵ_n.
18	Sentence before Eq. (2.52): change "Section 2.2" to "Section 2.1".
44	Eq. (2.126) should read $y = \dot{y}_0 t$ (the t is missing); one line below this, (2.127) should read (2.126).
47	Eq. (2.142): insert a minus sign to read $-qE_r(r_e)$. Line after Eq. (2.143): insert a minus sign so that $E_e = -E_r(r_e)$.
48	Eq. (2.147): change $\frac{1+x}{r_e}$ to $1+\frac{x}{r_e}$ and $\frac{1-4x}{r_e}$ to $1-\frac{4x}{r_e}$.
49	Line before Eq. (2.158): change ν_0 (nu sub-0) to v_0 (v sub-0).
58	4th line, 2nd paragraph: change "that is gives" to "that it gives".
63	Eq. (3.15), last term on right-hand side: delete the parentheses around ∇n.
64	Eq. (3.19): delete the first part of the equation up to and including the first = sign.
67	2nd line above Eq. (3.19): change $z = 0$ to $r = 0$.
68	Eq. (3.30): second term on right-hand side: change $\frac{r^4}{4}$ to $\frac{r^2}{4}$.
69,70,72	Change Greek "nu" (ν) to lowercase v (vee) as indicated.
70	In sentence following Eq. (3.41) move ($\gamma-$ to second line so it reads: $(\gamma - 1)mc^2$ ....
73	Line before Eq. (3.54): change ν_θ (nu sub-theta) to v_θ (v sub-theta). Line above Eq. (3.55): change "(2.74) and (2.75)" to "(2.75) and (2.76)".
75,76	Change nu to v as marked.
80	Section 3.4.1, 2nd paragraph, 7th line: change $u(v)$ to $u(z)$.
82	Change nu to v as marked.

Page	Corrections
84	Eq. (3.104): change $B\nu(z)$ to $Bv(z)$ (i.e., change nu to v).
95	Add minus sign to the beginning of the displayed equation following Eq. (3.133b).
119	Eq. (3.199), last term: delete the minus sign.
123	2nd line below Eq. (3.219c): delete the slash so that $x_m = \epsilon_x\sqrt{c}$.
133	2nd and 3rd line above Eq. (3.272): insert $-\Delta\gamma/\gamma_0$ so the equation reads: $v = v_0(1 + \Delta v/v_0) = v_0(1 + \Delta P/P_0 - \Delta\gamma/\gamma_0)$.
136	1st line: change equation number to (3.276).
138	2nd line below Eq. (3.289): delete "in" after "matrix".
144	Last line, 2nd paragraph: change problem number from 3.16 to 3.17.
147	Line below Eq. (3.222): change the word "Wronskian" to "determinant".
151	1st line below Fig. 3.26: change the problem number from 3.17 to 3.19.
154	1st line of Eq. (3.356): change $\frac{L}{\ell}$ to $\frac{L}{\ell}\theta$; move closing bracket to end of equation.
161	Eq. (3.374): change $\frac{1+T}{E_0}$ to $1 + \frac{T}{E_0}$.
164	Eq. (3.382): change $\frac{d\gamma}{dt}$ to $\frac{dE}{dt}$.
171	Lines one and two below Eq. (3.406): change sentence so that it reads: Here m, n, p are integers and $\|m\| + \|n\| = \ell$ defines the *order of the resonance*.
195	Line above Eq. (4.19): relation should read: $\omega_p^2 = f_s/\gamma mr$ (i.e., add lower case r).
197	Delete both minus signs in Eq. (4.27c).
219	Eqs. (4.107a) and (4.107b): Change the plus signs to minus signs.
220	Last paragraph, beginning of 3rd line: change $a_0/a = 0.5$ to $R_0/a = 0.5$.
236	Eq. (4.177), 2nd terms: change κ_{x0} to κ_{y0}.
*	Eq. (4.179), 2nd term: change X to Y.
257	1st paragraph, last line: change 4.19 to 4.9.
301	Problem 4.11(a): add subscript r to F so it reads $F_r(r)$.
309	Eq. (5.12): change the first numerator from 9^r to $9I$.

	Page	Corrections
	310	2nd line of last paragraph (below the equation): insert "case" after "relativistic".
	311	10th line of first paragraph: add subscript θ to v so it reads: mv_θ^2/r.
	316	6th line above Eq. (5.34): change minus sign to an equal sign so it reads: $\omega = \omega_{\rm Lab}$.
	325	Eq. (5.66): change + sign to − sign in last term on left-hand side.
*	329	6th line below Eq. (5.80): delete "and" so it reads: $B_0 = 0.7$ T $= 7$ kG. (Note that the T stands for Tesla, so it should be set in roman, not italics.)
	339	17th line after Eq. (5.121b): change Greek nu to lower case v so it reads: $F_r = -qv_\theta B_z$.
	348	Eq. (5.148): change $H_\perp(r, r')$ to $H_\perp(r, r'_\perp)$. Eq. (5.149): eliminate the factor 1/2 in the last bracket so it reads: $d(r'^2_\perp)$; add subscript $\perp$ to $r'dr'$ so it reads $r'_\perp dr'_\perp$. 5th line above Eq. (5.149): add subscript $\perp$ to r' so it reads: $(r, \theta, r'_\perp, \psi)$.
	349	Eq. (5.151): eliminate the factor 1/2 in the last bracket so it reads: $d(r'^2_\perp)$.
	373	Eq. (5.250): first term inside the bracket: the "T" in $2k_bT$ did not print well.
	391	Eq. (5.306a): change $\tilde{x}'_{f\ell}$ to $\widetilde{x'}_{f\ell}$.
	397	Eq. (5.25b): add widetilde over ΔE, so it reads $\dfrac{\widetilde{\Delta E}}{qV_0}$.
	401	Eq. (5.345): change γ_{0f}^2 to γ_{0f}^3 in the denominator. Last line in paragraph below Eq. (5.345): change 6.32×10^{-8} to 2.10×10^{-8}.
	405	2nd line above Eq. (5.355): change "eccentricity" to "aspect ratio". 1st line below Eq. (5.355): change "eccentricities" to "aspect ratios".
	406	Eq. (5.356a): change $a^2 z_m$ to az_m^2 in denominator of last term. 14th line of 2nd paragraph: change "eccentricity" to "aspect ratio".
	409	Item 6, third line: change "eccentricity" to "aspect ratio". Heading of Table 5.3: change $g_0(0)$ to $g(0)$.
	411	2nd paragraph, 3rd line from bottom, change "6.2 and 6.3" to "6.3.2 and 6.3.3".
	451	Point 5: change "eccentricity" to "aspect ratio".

Page	Corrections
452	3rd line below Eq. (5.508): change "eccentricity" to "aspect ratio".
454	4th line in 1st paragraph: change $\tilde{\epsilon}_1$ to $\tilde{\epsilon}$.
	8th line in 1st paragraph: change $\tilde{x}'$ to $\widetilde{x'}$ (i.e., include the prime under the tilde).
455	Eq. (5.513): change $\tilde{v}_2$ to $\tilde{x}_2$.
457	4th line below Eq. (5.520): change (5.519) to (5.520).
459	1st line of last paragraph: change "if" to "of".
461	Ref. 3, last line should read: "Park, MD; *Part. Accel.* **49**, 15 (1995)."
476	First line: change "phase" to "trace".
501	6th line from top: the "a" in the word "waves" is not printing clearly.
559	Ref. 49: change the year 1979 to 1974.
583	Last term of Eq. (A5.4): change ks to $\sin ks$.
584	Last term of Eq. (A5.8): delete parentheses and close gaps so that it reads $[\sin\phi_0 + \Delta\phi\cos\phi_0]$.

Additional Corrections to List 1 (dated Nov. 15, 2002)

	Page	Corrections
*	16	Equation below the first paragraph: add parenthesis in denominator to read $$\vec{P} = \frac{m\vec{v}}{(1 - v^2/c^2)}^{1/2}.$$
	27	In the displayed equation four lines above Eq. (2.48), the last term on the right should read qE_x: $$\frac{d}{dt}(ym\dot{x}) = -q\frac{\partial\phi}{\partial x} = qE_x.$$
	67	2nd line above Eq. (3.26) instead of (3.19): change $z = 0$ to $r = 0$.
	397	Eq. (5.325b) instead of (5.25b): add widetilde over ΔE, so it reads $\frac{\widetilde{\Delta E}}{qV_0}$.

ERRATA

M. Reiser, *Theory and Design of Charged Particle Beams*

List 2: Errors in 1st printing that were not included in List 1 or were improperly corrected (*) in the 2nd printing (dated Sept. 19, 2002)

Page Corrections

22 Eq. (2.26) and line below: change 931.481A to 931.494A.

Table 2.1: change proton rest energy from 938.259 to 934.272 MeV.

Table 2.2: Change table to read:

Table 2.2 Rest energies of some isotopes and ions

Isotope	A (amu)	Rest Energy (MeV)	Ion	Rest Energy (MeV)
^{1}H	1.0078	938.783	$^{1}H^{+}$	938.272
			$^{1}H^{-}$	939.294
^{2}H	2.0141	1,876.030	$^{2}H^{+}$	1,875.519
^{3}He	3.0160	2,809.415	$^{3}He^{+}$	2,808.904
			$^{3}He^{2+}$	2,808.393
^{4}He	4.0026	3,728.399	$^{4}He^{+}$	3,727.888
			$^{4}He^{2+}$	3,727.377
^{6}Li	6.0151	5,603.051	$^{6}Li^{+}$	5,602.540
			$^{6}Li^{3+}$	5,601.518
^{12}C	12.0000	11,177.932	$^{12}C^{3+}$	11,176.399
			$^{12}C^{6+}$	11,174.856
^{14}N	14.0031	13,043.784	$^{14}N^{+}$	13,043.269
			$^{14}N^{7+}$	13,040.203

Page Corrections

58 Eq. (3.2b): delete $\tilde{x}'_{th}$ and change $\widetilde{x'_{th}}$ to $\widetilde{x}'_{th}$ [i.e., "widetilde(x-prime) sub th" rather than "widetilde(x-prime sub th)"] to read:
$\tilde{\epsilon}_x = \tilde{x}\widetilde{x}'_{th} = \tilde{x}\dfrac{\tilde{v}_{x,th}}{v_0}$.
8th line after Eq. (3.2b): change $\widetilde{x'_{th}}$ to $\widetilde{x}'_{th}$ [i.e., "widetilde(x-prime) sub th"] .

59 Eqs. (3.5a), (3.5b): change $\widetilde{x'_{th}}$ to $\widetilde{x}'_{th}$ [i.e., "widetilde(x-prime) sub th"], as in p. 58.

104 8th line after Eq. (3.159); change r_3 to r_4.

* 133 Lines 2 and 3 above Eq. (3.272): in-line equation is duplicated in second printing; delete second half so that equation reads:
$v = v_0(1 + \Delta v/v_0) = v_0(1 + \Delta P/P_0 - \Delta\gamma/\gamma_0)$.

198 Eq. (4.30), 2nd equation: delete r_0 to read: $R' = \dfrac{dR}{dZ} = \dfrac{1}{\sqrt{2|K|}} r'_m$,

* 236 Eq. (4.179): 2nd term: change X to Y so that $\kappa_{yo}X$ reads $\kappa_{yo}Y$.

269 Line above Eq. (4.271): change (2.269) to (4.269).

282 First paragraph, 5th line: change 10^{-6} to 10^{-5}.
First paragraph, 8th line: change $a_2 \approx 0.8\,\text{mm}$ to $a_2 \approx 2.5\,\text{mm}$,
$a_2/a_1 = 0.08$ to $a_2/a_1 \approx 0.25$.

* 296 Ref. 7: change page number from 89 to 890 (as noted in List 1, but not corrected in 2nd printing).

329 6th line after Eq. (5.80): delete comma between 0.7 and T: un-italicize "T" to read: $B_0 = 0.7$ T $= 7$ kG.

373 Eq. (5.254), 1st fraction: change (Δv_{lz}^2) to $(\Delta v_{lz})^2$.

376 Eq. (5.267), 1st fraction: change $(\Delta v_{lz}^2)^2$ to $(\Delta v_{lz})^2$.

380 Eq. (5.280): insert $E_s(r)dr$ in the last term so that the integral will read $\int_0^r E_s(r)dr$

* 392 Eqs. (5.308a) and (5.308b): The $\widetilde{x}'_{th}$ should be level with the $\tilde{x}$ that preceeds it: $\tilde{x}\widetilde{x}'_{th}$. ($x$'s should be on the same line.)
Eq. (5.310): change locations of superscript-2 to read:
$k_B T_\parallel = k_B T_z = \gamma_0^3 m(\widetilde{\Delta v}_{z,th})^2 = \gamma_0^3 m[(\widetilde{\Delta v}_z)^2 - (\widetilde{\Delta v}_{z,fl})^2]$.

Page	Corrections
393	Line above Sec. 5.4.6: letters missing in our copy - "im ng systems" should read "imaging systems".
429	5th and 6th lines after Eq. (5.431): insert R_0 to read $s_0(t) = R_0\dot{\theta}_0 t = R_0\theta_0$ and $s(t) = R_0(\dot{\theta}_0 + \Delta\dot{\theta})t = R_0(\theta_0 + \Delta\theta)$.
434	Eq. (5.448): the $\widetilde{z'}$ should be level with the $\widetilde{z}$ preceeding it: $\widetilde{z}\ \widetilde{z'}$. Line below equation: level $\widetilde{z'}$
448	Eq. (5.493): delete γ_0^2 from first set of parentheses, to read $\left(1 - \frac{g}{2}\frac{a^2}{\gamma_0^2 z_m^2}\right) = \frac{3}{2}\cdots$.
454	Third line above Eq. (5.510): level $\widetilde{x'}$ so $\tilde{\epsilon} = \tilde{x}\widetilde{x'} = \tilde{x}\tilde{v}_x/v_0$, where $\widetilde{x'}$ is ....
472	Second line from top: level $\widetilde{x'}$ so it reads $\gamma m v^2 \widetilde{x'}^2$.
476	2 lines above Eq. (6.18): change Eq. reference from (5.160b) to (3.345).
504	2 lines after Eq. (6.68b): change $\partial I/\partial/t$ to $\partial I/\partial t$.
539	First and second line above Eq. (6.181): change $\widetilde{x'}$ to $\widetilde{x'}$ and level so $\tilde{\epsilon}_x = \tilde{x}\widetilde{x'} = \widetilde{x'}^2/k$ (using $\widetilde{x'} = k\tilde{x}$).
540	4th line after Eq. (6.186): change 23×10^{-6} to 2.3×10^{-5}.
578	Eqs. (A.4.27), (A.4.28): change (A.4.27) to (A4.27); change (A.4.28) to (A4.28).
579	2nd line above Eq. (A4.30): change (4.10) to (A4.10).
580	Ref. 5: correct to read *Part. Accel.* **48**, 193 (1995). Ref. 6: correct to read *Phys. Plasmas* **2**, 965 (1995).
586	Eq. (A16): correct Eq. number to read (A5.16); correct denominator in 3rd fraction to read: $\beta_0^2\gamma_0^3$.
586	Eq. (A5.17): change denominator in 2nd fraction to read $\lambda mc^2\beta_0^2\gamma_0^3$.
587	Eq. (A5.19): change denominator in 2nd fraction to read $\lambda mc^2\beta_0^2\gamma_0^3$.

Additional Corrections to List 2 (dated Nov. 15, 2002)

Page	Corrections

372 In Eq. (5.249), the second term in exp [ ] should read $-C_2(v_x^2 + v_y^2 + v_z^2)$.

373 In Eq. (5.250), the numerator in the first term of exp [ ] should read $m(v_x^2+v_y^2+v_z^2)$.

417 Last term in Eq. (5.381) should have a minus $(-)$ sign:

$$= -\frac{\omega_{rf}}{c}\left(\frac{1}{\beta} - \frac{1}{\beta_0}\right).$$

485 Last term in Eq. (6.33) should be $= -0.2659$.

496 12th line from top: change Table 5.2 to Table 5.1.

504 In Eqs. (6.68a) and (6.68b), change order of subscripts

$$E_{sz} \to E_{zs}, \qquad E_{wz} \to E_{zw}.$$

527 In Eq. (6.153) the equal sign $(=)$ is missing; it should read

$$T_{\text{eff},0} = \left(\frac{8}{15\pi}\right)^{2/3} T_{\perp 0} = 0.307\ T_{\perp 0}.$$

Additional Corrections to List 2 (updated Jan. 23, 2003)

Page	Correction
342	Eq. (5.132b): in the bracket on the right-hand side change x' to y'.
358	In 1st line of paragraph above Eq. (5.198), delete "normalized". Change Eq. (5.198) to read: $\overline{x^2} = \frac{\iiint x^2 f(x,y,x',y')dxdydx'dy'}{\iiint f(x,y,x',y')dxdydx'dy'}$.
360	Change the sentence beginning in the 7th line from the top of the 2nd paragraph to read: These distributions, three of which are listed in Table 5.1 (together with the stationary K-V beam), are defined as functions of $r_4^2 = \left[r^2/a^2 + r'^2/a'^2 \right]$, where r_4 is the "radius"in four-dimensional trace space, and not as functions of the Hamiltonian $H_\perp$. Change the sentence beginning in the 13th line from the top of the 2nd paragraph to read: The normalization factors for each distribution in Table 5.1 have been chosen such that the integral over the four-dimensional trace-space volume yields I/(qv), where I is the total beam current. In the 11th line above Eq. (5.206), change $\exp(-r_4^2/2\delta)$ to $\exp(-r_4^2/2\delta^2)$.
361	To correct a few errors, the definition of r_4, and the normalization of the distribution functions so that the 4-D volume integral yields I/(qv), Table 5.1 should be replaced by the revised version provided below.
363	In Eq. (5.219b), change the term $k_{x0}^2 Y$ to $k_{y0}^2 Y$.
534	On the right side of Eq. (6.166), change r_0^2 to r_c^2, where r_c is the classical particle radius.
589	Ref. 12, change C. Yoshi to Chan Joshi.

Table 5.1 Definition and properties of K-V and three initially rms matched nonstationary distribution functions, f(r_4^2), often used in computer simulation studies for a uniform or "smooth" channel, with $r_4^2 = r^2/a^2 + r'^2/a'^2$.

Distribution Function	Definition f(r_4^2), normalized using beam current, I	Initial ratio of total to rms emittance $\varepsilon_t/\tilde{\varepsilon}$	Particle Density n (r)	Nonlinear Field Energy Factor, U/w_0, where $w_0 = I^2/16\pi\varepsilon_0 c^2\beta^2$
Kapchinsky–Vladimirsky (KV)	$\frac{I}{qv\pi^2 a^2 a'^2}\delta(r_4^2 - 1)$	4	$\frac{I}{qv\pi a^2}$	0
Waterbag (WB)	$\frac{2I}{qv\pi^2 a^2 a'^2}\theta(1 - r_4^2)$	6	$\frac{2I}{qv\pi a^2}(1 - r^2/a^2)$	0.0224
Parabolic (PA)	$\frac{6I}{qv\pi^2 a^2 a'^2}(1 - r_4^2)$	8	$\frac{3I}{qv\pi a^2}(1 - r^2/a^2)^2$	0.0470
Gaussian (GA)	$\frac{I}{4\delta^4 qv\pi^2 a^2 a'^2}\exp(-\frac{r_4^2}{2\delta^2})$ where $\delta^2 = \tilde{x}^2/a^2$	$\simeq n^2$ if truncated at $n\delta$, $n \geq 4$	$\frac{I}{2\delta^2 qv\pi a^2}\exp(-\frac{r^2/a^2}{2\delta^2})$	0.1544

Notes: 1. $r^2 = x^2 + y^2$, $r'^2 = x'^2 + y'^2$, $\varepsilon_t = x_{max}x'_{max} = y_{max}y'_{max} = aa'$ is the total emittance defined by the trace-space ellipse that represents the boundary of the particle distribution. $\tilde{\varepsilon} = x_{rms}x'_{rms} = \tilde{x}\tilde{x'}$ is the rms emittance.

2. $U = w_n - w_u$ denotes the initial field energy difference per meter between the nonuniform distributions and the uniform (KV) distribution, and U/w_0 is a dimensionless parameter whose value is listed in the table. [See p. 475].

Additional Corrections to List 2 (updated June 26, 2003)

Page	Corrections

583 Eq. (A5.4), second line should read:

$$\times \left[\frac{\partial E_m}{\partial s} \cos ks \cos \omega_{rf} t - E_m k \sin ks \cos \omega_{rf} t - \frac{\omega_{rf}}{c} \beta E_m \cos(ks) \sin(\omega_{rf} t) \right].$$

584 First sentence, change "an" to "can".

584 Eq. (A5.6), second line should read:

$$\times \left[-\frac{1}{kE_m} \frac{\partial E_m}{\partial s} \cos ks \cos(ks + \varphi) + \frac{1}{2}(1 + \beta) \sin(2ks + \varphi) - \frac{1}{2}(1 - \beta) \sin \varphi \right].$$

584 Eq. (A5.7) should read:

$$\frac{dP_r}{dt} = +\frac{r}{2} keE_m \sin(2ks + \varphi),$$

584 Eq. (A5.8) should read:

$$\frac{dP_r}{dt} = +\frac{r}{2} keE_m \sin(2ks + \varphi_0 + \Delta\varphi) \approx +\frac{r}{2} keE_m [\sin(2ks + \varphi_0 + \Delta\varphi) \cos(2ks + \varphi_0)],$$