

Table of Contents

Preface	xi
1 Introduction	1
1.1 Motivation and overview	1
1.2 Direct-voltage accelerators	3
1.3 A review of relativistic particle motion	6
1.4 Linear accelerators with oscillating electric fields	8
1.5 Circular machines	12
1.6 Momentum compaction and the synchronous particle	14
2 Equations of Motion for Weak Focusing	19
2.1 Reference system for a circular machine	19
2.2 Equations of motion	19
2.3 Solutions of the motion equations and transfer matrices	22
2.4 Momentum dispersion	25
2.5 Weak focusing synchrotron	27
2.6 Momentum compaction factor	31
3 Mechanics of Trajectories	33
3.1 Liouville's Theorem	33
3.2 General transformations	37
3.3 Hamiltonian formalism and canonical coordinates	38
3.4 Symplectic transformations and matrices	42
3.5 The standard canonical coordinates	45
3.6 Symplectic Generators	47
4 Optical Elements with Static Magnetic Fields	55
4.1 Transverse fields and multipoles	56
4.2 Equipotential surfaces and pole face contours	58
4.3 Quadrupole lenses	61
4.4 End field effects in a dipole	62
5 Strong Focusing	69
5.1 Transfer matrix approach and stability of the linear system	70
5.2 Analytical approach	73
5.3 Emittances	77
5.4 Adiabatic invariants	80
5.5 Dispersion	81
5.6 Momentum compaction	83
6 Lattice Exercises	87
6.1 The FODO Lattice	87

6.2	Stability Diagrams	88
6.3	FODO Cell Dispersion	89
6.4	A few explicit forms of the Twiss Matrix	91
6.5	Insertions	93
6.6	Dispersion Suppressors	94
6.7	Low beta insertion	97
6.8	Coupled motion	99
6.9	Chromaticity	102
7	Synchrotron Oscillations	107
7.1	Transition Energy	107
7.2	The Phase Stability Principle	108
7.3	Resonant Acceleration	109
7.4	The phase oscillation equation	111
7.5	Large oscillations	113
7.6	Hamiltonian formalism	116
7.7	Adiabatic invariant	122
7.8	Bunch manipulations	123
8	Synchrotron Radiation	130
8.1	Radiated Power	130
8.2	Radiation Damping of Energy Oscillations	133
8.3	Damping of the Vertical Oscillations	135
8.4	Damping of the Horizontal Oscillations	137
8.5	Damping Partition Numbers	140
8.6	Frequency Spectrum of the Radiation	141
8.7	Energy Spread and Bunch Length	143
8.8	Transverse Excitations	146
8.9	Beam Lifetime Considerations	148
9	RF Linear Accelerators	152
9.1	Maxwell's equations and waves	152
9.2	Cylindrical waveguides	155
9.3	Electron capture	160
9.4	Cylindrical cavities	162
9.5	Longitudinal equations of motion in a linac	168
9.6	Transverse defocusing	170
9.7	Radio frequency quadrupoles	172
10	Resonances	177

10.1 Integer Resonance	177
10.2 Linear coupling	178
10.3 Assessment of resonances	179
10.4 Krylov-Bogoliubov method	182
10.5 Half-integer resonance	184
10.6 The nonlinear third-integer resonance	186
10.7 Recapitulation	189
11 Space-Charge Effects	192
11.1 Transverse effects: tune shift	192
11.2 Luminosity and collider rings	195
11.3 Transverse effects: beam-beam interaction	196
11.4 Longitudinal effects	199
12 How to Baffle Liouville	204
12.1 Beam temperatures	204
12.2 Electron cooling	207
12.3 Stochastic cooling	213
12.4 Center of mass of a system of oscillators	217
12.5 Noise	219
12.6 Mixing	221
A Confusion of Definitions in Other Sources	226
A.1 Coordinates	226
A.2 Emittance	226
A.3 Tunes: Q or ν	227
A.4 Betatron functions	227
A.5 Dispersion function	227
A.6 Chromaticity	228
A.7 Momentum compaction	228
A.8 Multipole numbering	228
A.9 Phase slip	228
A.10 Longitudinal canonical momentum W	229
B Luminosity	230
C Generating Functions	232
D Properties of a Generic Optical System	235
E Some Useful Mathematical Formulae	237
Index	240