CONTENTS

	Preface pa	ge v
1	INTRODUCTORY	
	1.1 Units	1
	1.2 Electric Fields	2
	1.3 Magnetic Fields	3
	1.4 Relativistic Mechanics	5
	1.5 Numerical Values for Common Particles	8
2	PROPERTIES OF BEAMS	
	2.1 Phase Space	9
	2.2 Liouville's Theorem	10
	2.2.1 Beam Transport Laws derived from Liouville's	
	Theorem	12
	2.2.2 Emittance and Acceptance	14
	2.2.3 Real or Apparent Violation of Liouville's	
	Theorem	15
	2.3 Properties of Finite Emittance Beams	18
	2.3.1 Phase Space Parallelograms	18
	2.3.2 The Origin of Phase Space Ellipses	19
	2.3.3 The Profile of a Normal Beam in a Field Free	
	Region	23
	2.3.4 The Action of a Thin Lens on a Normal Beam	25
	2.3.5 Normal Beams in Lens-Drift Length Combina-	
	tions	26
	2.4 Point Source Optics – Zero Emittance	29
3	MATRIX METHODS	
	3.1 Basic Matrix Algebra	33
	3.2 Matrices in Symmetrical Systems	35
	3.3 Unit Determinants as a Consequence of Liou-	
	ville's Theorem	37

viii	TF	RANSPORT OF CHARGED PARTICLE BEAMS	
	3.4	Matrix Representation of Simple Optical Com-	
		ponents	38
		3.4.1 The Field Free Drift Space	38
		3.4.2 The Thin Lens	38
		3.4.3 Optical Imaging by a Thin Lens	40
		3.4.4 Decomposition of the General 2×2 Matrix	40
	3.5	The Significance of Zero Elements in a Matrix	4]
		3.5.1 Optical Imaging and Size Collimation	41
		3.5.2 Angular Collimation	42
		3.5.3 Telescopic Systems	42
	3.6	Waist to Waist Transport	43
		3.6.1 Waist to Waist Transport with One Thin Lens	44
4	BE	CAMS DELIVERED BY ACCELERATORS	
	4.1	Ion Sources	46
		4.1.1 Types of Ion Source	47
		4.1.2 Emittance of Ion Source Beams	48
	4.2	Particle Motion during Acceleration	5(
		Beam Extraction from Circular (Orbital) Accelera-	
		tors	53
		4.3.1 Scattering-out and Targetting	54
		4.3.2 Electrostatic Deflection	55
		4.3.3 Use of Machine Resonances	58
		4.3.4 Regenerative Extraction	56
		4.3.5 The Piccioni System	56
	4.4	Measurement of Emittance	5
5		AGNETIC AND ELECTRIC BEAM BEND-	
		G DEVICES	
	5.1	Motion in Magnetic Fields	63
		5.1.1 Radial Motion inside the Field	64
		5.1.2 Vertical Motion inside the Field	66
		5.1.3 Radial Motion at the Magnet Edge	6
		5.1.4 Vertical Motion at the Magnet Edge	69
		5.1.5 The Uniform Field Magnet with Normal	
		Entry and Exit	7
		5.1.6 The Uniform Field Magnet with Inclined	
		Entry and Exit Faces - the Wedge Magnet	73
		5.1.7 Non-Uniform Fields	76
		5.1.8 The Effects of Beam Momentum Spread	77

		CONTENTS	ix
		5.1.9 Magnet Fringe Fields	80
		5.1.10 Magnet Design	81
	5.2	Motion in Electrostatic Fields	84
		5.2.1 The Uniform Electric Field	84
		5.2.2 Radial Electric Fields	84
		5.2.3 Production of Electric Fields	88
	5.3	Combined Magnetic and Electric Fields	88
	5.4	Spectrometers and Spectrographs	89
6	QU	JADRUPOLE LENSES	
	6.1	The Quadrupole Field	92
	6.2	Motion in a Magnetic Quadrupole Field	94
		6.2.1 Motion in the Focussing Plane	95
		6.2.2 Motion in the Defocussing Plane	97
	6.3	Motion in an Electrostatic Quadrupole Field	99
		6.3.1 Motion in the Focussing Plane	99
		6.3.2 Motion in the Defocussing Plane	100
	6.4	Design of Quadrupole Lenses	100
	6.5	Lens Lengths - Physical and Effective	103
	6.6	Comparison of Magnetic and Electrostatic Lenses	104
	6.7	Quadrupole Combinations	105
		6.7.1 The Quadrupole Doublet	106
		6.7.2 The Quadrupole Triplet	108
		6.7.3 Periodic Combinations of Quadrupoles	110
		Aberrations	112
	6.9	Quadrupoles of Unusual Design	115
7	SP	ECIALIZED TRANSPORT DEVICES	
	7.1	Particle Separators	121
		7.1.1 The Crossed Field Separator	121
		7.1.2 Radio Frequency Separators	125
		7.1.3 Other Separation Methods	127
	7.2	Sextupole Magnets	128
		Focussing by Solenoids	129
		Control of Spin Direction	135
		Beam Steering	135
	7.6	Collimation	137
	7.7	Degraders	139
	7.8	Beam Dumping	140

x	TRANSPORT OF CHARGED PARTICLE BEAMS	
	7.9 Control of Axial Motion	141
	7.9.1 The Radio-Frequency Debuncher	141
	7.9.2 Bunching Magnets	144
	7.10 The Beam Guide	147
	7.11 The Beam Horn	148
	7.12 Focussing by Axial Currents	148
	7.13 Beam Splitting	149
	7.14 High Magnetic Fields	149
8	BEAM DESIGN METHODS	
	8.1 Unanalysed Beams	154
	8.1.1 Numerical Calculation	156
	8.1.2 Special Charts	159
	8.1.3 Analogue Computers	161
	8.1.4 Digital Computer Programmes	163
	8.2 Momentum Selection Systems	165
	8.3 Achromatic Systems	167
	8.4 Separated Beam Design	169
9	OPERATIVE BEAM SYSTEMS	
	9.1 Unanalysed Beams	173
	9.1.1 Beams from Linacs and D.C. Machines	174
	9.1.2 Beams from Circular Accelerators	175
	9.2 Achromatic Systems	177
	9.3 Separated Beams	178
	9.4 Muon Beams	180
10	INSTALLATION, COMMISSIONING AND	
	OPERATION	
	10.1 Alignment	184
	10.2 The Floating Wire Analogue	185
	10.3 Energizing the System	187
	10.4 Measurement of Magnetic Fields	188
	10.5 Vacuum Systems, Gas Bags and Beam Windows	189
	10.6 Measurement of Beam Size and Position	190
	10.7 Radiation Problems	192
	Classified Bibliography	197
	Author Index	210
	Subject Index	221