

Contents

Part I Trap Operation Theory

1	Introduction	3
1.1	Historical Background	3
1.2	Principles of Particle Confinement	10
2	The Paul Trap	17
2.1	Theory of the Ideal Paul Trap	17
2.2	Motional Spectrum in Paul Trap	23
2.3	Adiabatic Approximation	24
2.3.1	Potential Depth	25
2.3.2	Optimum Trapping Conditions	26
2.4	Real Paul Traps	27
2.4.1	Models for Ion Clouds	28
2.5	Instabilities in an Imperfect Paul Trap	33
2.6	The Role of Collisions in a Paul Trap	36
2.7	Quantum Dynamics in Paul Traps	39
2.7.1	Quantum Parametric Oscillator	39
2.7.2	Quantum Dynamics in Ideal Paul Trap	43
2.7.3	Effective Potentials	46
3	The Penning Trap	51
3.1	Theory of the Ideal Penning Trap	51
3.2	Motional Spectrum in Penning Trap	56
3.3	Real Penning Traps	57
3.4	Shift of the Eigenfrequencies	59
3.4.1	Electric Field Imperfections	59
3.4.2	Magnetic Field Inhomogeneities	62
3.4.3	Distortions and Misalignments	64
3.4.4	Space Charge Shift	67
3.4.5	Image Charges	68
3.5	Instabilities of the Ion Motion	68
3.6	Tuning the Trap	70
3.7	Quantum Dynamics in Ideal Penning Trap	72
3.7.1	Spinless Particle Dynamics	72
3.7.2	Spin Motion	78

3.8	Quantum Dynamics in Real Penning Traps	81
3.8.1	Electric Field Perturbations	81
3.8.2	Magnetic Field Perturbations	83
3.8.3	The General Hamiltonian	84
4	Other Traps	87
4.1	Combined Traps	87
4.1.1	Equations of Motion	87
4.1.2	Magnetron-free Operation	90
4.1.3	Quantum Dynamics in Combined Traps	91
4.2	Cylindrical Traps	95
4.2.1	Electrostatic Field in a Cylindrical Trap	96
4.2.2	Inherent Anharmonicity of the Field	98
4.2.3	Control for Anharmonicity	99
4.2.4	Dipole Field in a Cylindrical Trap	102
4.2.5	Open-ended Cylindrical Traps	105
4.3	Nested Traps	107
4.4	Multipolar Traps	108
4.5	Linear Traps	109
4.5.1	The Ideal Linear Trap	109
4.5.2	Electrostatic Field in a Linear Quadrupole Trap	113
4.5.3	Electric Field in a Linear Multipole Trap	115
4.6	Ring Traps	117
4.7	Planar Paul Traps	118
4.8	Electrostatic Traps	123
4.9	Kingdon Trap	124

Part II Trap Techniques

5	Loading of Traps	131
5.1	Ion Creation Inside Trap	131
5.2	Ion Injection from Outside the Trap	133
5.3	Positron Loading	135
6	Trapped Charged Particle Detection	139
6.1	Destructive Detection	139
6.1.1	Nonresonant Ejection	139
6.1.2	Resonant Ejection	140
6.2	Nondestructive Detection	141
6.2.1	Electronic Detection	141
6.2.2	Bolometric Detection	142
6.2.3	Fourier Transform Detection	145
6.2.4	Optical Detection	146

Part III Nonclassical States of Trapped Ions

7	Quantum States of Motion	153
7.1	Fock States	153
7.2	Oscillator Coherent States	154
7.2.1	The Ideal Penning Trap	155
7.2.2	The Harmonic Paul Trap	156
7.3	Squeezed States	159
8	Coherent States for Dynamical Groups	161
8.1	Trap Symmetries	161
8.2	Quasienergy States for Combined Traps	162
8.2.1	A Single Trapped Charged Particle	162
8.2.2	Quantum Multiparticle States	165
9	State Engineering and Reconstruction	169
9.1	Trapped Ion-Laser Interaction	169
9.1.1	Atom-Field Hamiltonians	169
9.1.2	Two-Level Approximation	170
9.2	State Creation	173
9.2.1	Number States	173
9.2.2	Coherent States	174
9.2.3	Squeezed States	175
9.2.4	Arbitrary States	176
9.2.5	Thermal States	177
9.2.6	Schrödinger-Cat States	178
9.3	State Reconstruction	183
9.3.1	Wigner Functions	183
9.3.2	Experimental State Reconstruction	185

Part IV Cooling of Trapped Charged Particles

10	Trapped Ion Temperature	193
10.1	Measurement of Ion Temperature	194
11	Radiative Cooling	197
12	Buffer Gas Cooling	203
12.1	Paul Trap	204
12.2	Penning Trap	206
13	Resistive Cooling	211
13.1	Negative Feedback	215
13.2	Stochastic Cooling	216

14 Laser Cooling	221
14.1 Physical Principles	221
14.2 Doppler Cooling: Semi-classical Theory	223
14.3 Resolved Sideband Cooling	226
14.4 EIT Cooling	233
14.5 Sisyphus Cooling	236
14.6 Stimulated Raman Cooling	246
14.7 Sympathetic Cooling	250

15 Adiabatic Cooling	257
-----------------------------------	-----

Part V Trapped Ions as Nonneutral Plasma

16 Plasma Properties	263
16.1 Coulomb Correlation Parameter	263
16.2 Weakly Coupled Plasmas	263
16.2.1 Penning Traps	263
16.2.2 Paul Traps	266
17 Plasma Oscillations	269
17.1 Rotating Wall Technique	272
18 Plasma Crystallization	275
18.1 Phase Transitions	275
18.2 Chaos and Order	278
18.3 Crystalline Structures	280
18.3.1 Crystals in Paul Traps	281
18.3.2 Crystals in Penning Traps	290
18.3.3 Crystals in Storage Rings	291
19 Sympathetic Crystallization	295
A Mathieu Equations	299
A.1 Parametric Oscillators	299
B Orbits of Trapped Ions	303
C Nonlinear Oscillator	309
C.1 Multipole Expansions	309
C.2 Normal Forms	310
C.3 Nonlinear Resonances	312

D	Generating Functions for Quantum States	315
D.1	Uncertainty Relations	315
D.2	Generating Functions	316
D.2.1	Hermite functions	316
D.2.2	Laguerre Polynomials	317
D.3	Displacement Operators	319
D.4	Time Dependent Oscillators	320
D.4.1	Gaussian Packets	320
D.4.2	Linear Invariants	322
D.4.3	Quadratic Invariants	322
D.5	Coherent States for Symplectic Groups	323
D.5.1	$Sp(2, \mathbf{R})$ Coherent States	323
D.5.2	Linear Dynamical Systems	324
E	Trap Design and Electronics	327
F	Charged Microparticle Trapping	331
	References	335
	Index	349

Charged Particle Traps

Physics and Techniques of Charged Particle Field
Confinement

Major, F.G.; Gheorghe, V.N.; Werth, G.

2005, XII, 356 p., Hardcover

ISBN: 978-3-540-22043-5