

Contents

<i>Preface</i>	v
1. Physics with Trapped Charged Particles	1
<i>M. Knoop, N. Madsen and R. C. Thompson</i>	
1.1 Introduction	1
1.2 History of Ion Traps	2
1.3 Principles of Ion Traps	3
1.4 Creation, Cooling and Detection of Ions	8
1.5 Applications of Ion Traps	16
1.6 Conclusions and Outlook	22
2. Detection Techniques for Trapped Ions	25
<i>M. Knoop</i>	
2.1 Electronic Techniques	26
2.2 Fluorescence Techniques	35
3. Cooling Techniques for Trapped Ions	43
<i>D. M. Segal and Ch. Wunderlich</i>	
3.1 Introduction	43
3.2 Non-laser Cooling Techniques	45
3.3 Laser Cooling	48
3.4 Laser Cooling Using Electromagnetically Induced Transparency . .	70
3.5 Cavity Cooling	76
3.6 Cooling Scheme Combining Laser Light and RF	77
4. Accumulation, Storage and Manipulation of Large Numbers of Positrons in Traps I – The Basics	83
<i>C. M. Surko</i>	
4.1 Overview	84
4.2 Positron Trapping	86
4.3 Positron Cooling	96

4.4	Confinement and Characterization of Positron Plasmas in Penning–Malmberg Traps	101
4.5	Radial Compression Using Rotating Electric Fields – the "Rotating-wall" (RW) Technique	111
4.6	Concluding Remarks	120
5.	Accumulation, Storage and Manipulation of Large Numbers of Positrons in Traps II – Selected Topics	129
	<i>C. M. Surko, J. R. Danielson and T. R. Weber</i>	
5.1	Overview	130
5.2	Extraction of Beams with Small Transverse Spatial Extent	131
5.3	Multicell Trap for Storage of Large Numbers of Positrons	143
5.4	Electron–Positron Plasmas	156
5.5	Concluding Remarks	166
6.	Waves in Non-neutral Plasma	173
	<i>F. Andereg</i>	
6.1	Diocotron Waves	173
6.2	Plasma Waves	181
6.3	Cyclotron Waves	190
7.	Internal Transport in Non-neutral Plasma	195
	<i>F. Andereg</i>	
7.1	Types of Collisions	195
7.2	Test Particle Transport	196
7.3	Heat Transport	208
7.4	Transport of Angular Momentum	212
7.5	Table of Transport Coefficients	216
8.	Antihydrogen Formation and Trapping	219
	<i>N. Madsen</i>	
8.1	Introduction	219
8.2	Introduction to Antihydrogen Formation and Trapping	220
8.3	Antiproton Catching and Pre-cooling	223
8.4	Trapped Particles and Magnetic Multipoles	224
8.5	The Rotating-wall Technique	225
8.6	Antiproton Preparation	227
8.7	Positron Preparation	229
8.8	Evaporative Cooling of Charged Particles	230
8.9	Merging Antiprotons and Positrons	231
8.10	Trapped Antihydrogen and its Detection	232
8.11	Conclusions and Outlook	235

9.	Quantum Information Processing with Trapped Ions	239
	<i>C. F. Roos</i>	
9.1	Introduction	239
9.2	Storing Quantum Information in Trapped Ions	241
9.3	Preparation, Manipulation and Detection of an Optical Qubit	242
9.4	Entangling Quantum Gates	245
9.5	Quantum State Tomography	251
9.6	Elementary Quantum Protocols and Quantum Simulation	255
10.	Optical Atomic Clocks in Ion Traps	261
	<i>H. S. Margolis</i>	
10.1	Introduction	261
10.2	Principles of Operation	262
10.3	Systems Studied and State-of-the-art Performance	266
10.4	Systematic Frequency Shifts	268
10.5	Conclusions and Perspectives	271
11.	Novel Penning Traps	275
	<i>J. Verdú</i>	
11.1	Introduction	275
11.2	Penning Traps	276
11.3	The CPW Penning Trap	277
11.4	The Real CPW Penning Trap	282
11.5	Compensation of Electric Anharmonicities	284
11.6	Conclusions	285
12.	Trapped Electrons as Electrical (Quantum) Circuits	289
	<i>J. Verdú</i>	
12.1	Introduction	289
12.2	The Induced Charge Density	291
12.3	Detection of the Electron's Motion	292
12.4	Equivalent Electrical Circuit of the Trapped Particle	295
12.5	Coupling the Cyclotron Motion to a Superconducting Cavity	298
12.6	Conclusions	301
13.	Basics of Charged Particle Beam Dynamics and Application to Electrostatic Storage Rings	305
	<i>A. I. Papash and C. P. Welsch</i>	
13.1	Introduction	306
13.2	Relativistic Energy and Momentum	310
13.3	Basic Features of Magnetic and Electrostatic Bends	311

13.4 Betatron Oscillations	316
13.5 Quadrupole Magnets	320
13.6 Strong Focusing	322
13.7 Summary	325
14. Electrostatic Storage Rings – An Ideal Tool for Experiments at Ultralow Energies	327
<i>A. I. Papash, A. V. Smirnov and C. P. Welsch</i>	
14.1 Introduction	328
14.2 Common Features of Electrostatic Storage Rings	329
14.3 Electrostatic Deflectors of Different Shapes	333
14.4 Electric Field Distribution in Electrostatic Deflectors	336
14.5 Equations of Motion in an Electrostatic Deflector	340
14.6 Nonlinear Effects in ESRs	343
14.7 Ion Kinetics and Long-term Beam Dynamics in Electrostatic Storage Rings	344
14.8 Benchmarking of Experiments	353
14.9 Conclusions and Outlook	355
<i>Index</i>	359