

Contents

Preface	xi
1 High-energy ion microprobes	1
1.1 Introduction	1
1.2 Proton-induced x-ray emission (PIXE)	2
1.3 Particle-induced nuclear reactions	8
1.4 Elastic or Rutherford backscattering (RBS)	12
1.5 High resolution scanning ion microscopy	17
1.6 Beam energy requirements for PIXE, PRA and RBS	18
1.7 Ion sources and related beam-optical parameters	19
1.8 Probe formation	22
1.9 Brief description of the quadrupole lens	23
1.10 Introduction to beam optics terminology	25
1.11 Review of present microprobe systems using magnetic quadrupole focusing	27
1.12 Brief review of theoretical work carried out relevant to the beam optics of quadrupole probe-forming systems	30
2 Description of the quadrupole field	34
2.1 The quadrupole magnetic field (cross section)	34
2.2 The quadrupole magnetic field (longitudinal profile)	39
2.3 The quadrupole field (three-dimensional)	42
2.4 Determination of the field profile for practical lenses	42
2.5 Electrostatic quadrupoles	43
3 Calculation of the imaging properties of quadrupole systems: matrix methods	44
3.1 Introduction	44
3.2 Matrix methods in beam optics	45

3.3	Paraxial imaging properties derived from the first-order matrix elements	47
3.4	First-order matrix elements of a quadrupole lens	49
3.5	The chromatic aberration of a quadrupole lens	52
3.6	Higher-order aberrations in quadrupoles	52
3.7	Limitations of matrix methods	53
4	Calculation of the imaging properties of quadrupole systems: numerical raytracing	55
4.1	The numerical solution of ordinary differential equations	56
4.2	Solving the differential equations of motion	57
4.3	Calculating the electrostatic and magnetic fields	59
4.3.1	<i>Field distributions of cylindrical harmonics</i>	59
4.3.2	<i>Misalignments</i>	61
4.3.3	<i>Numerical values</i>	62
4.3.4	<i>Electrostatic fields</i>	62
4.4	Practical aspects of numerical raytracing	62
4.4.1	<i>Data handling</i>	63
4.4.2	<i>Locating the image planes</i>	63
4.4.3	<i>Calculating the aberration coefficients</i>	64
4.4.4	<i>Generating image intensity maps</i>	67
4.5	Assessment of accuracy	71
5	The imaging properties of quadrupole probe-forming systems	73
5.1	Introduction	73
5.2	The choice of system parameters	74
5.3	Interpretation of the results in Appendix 1	75
5.4	Calculation of the image size using Appendix 1: worked example	76
5.5	The dependence of imaging properties on object distance	78
6	Parasitic aberrations in quadrupole probe-forming systems	81
6.1	Fringing fields	83
6.2	Quadrupole translational misalignment	86
6.3	Quadrupole tilt misalignment	92
6.4	Quadrupole rotation misalignment	99
6.5	Harmonic contamination	103
6.6	Power supply stability	109
6.7	Quadrupole system alignment procedures	110
6.8	Beam scanning	111

7	Alternative approaches to the production of ion microbeams	114
7.1	The plasma lens	114
7.2	The electrostatic coaxial lens and associated developments	115
7.3	Superconducting solenoids	117
7.4	The electrostatic quadrupole triplet	120
7.5	Achromatic quadrupole lenses	120
7.6	Spherical aberration correction using octupoles	122
7.7	Ion source development	123
Appendix 1	First-, second- and third-order imaging properties of quadrupole probe-forming systems	126
Appendix 2	A table of x-ray energies	247
References		251
Index		259