Contents

Preface xiii

Acknowledgments xiv

Introduction xv

1 Acceleration principles 1
1.1 The electron 1
1.1.1 Basic properties 1
1.1.2 Attributes of motion 2
1.2 Acceleration 3
1.2.1 What is an accelerator? 4
1.2.2 Acceleration by kinematic collision 5
1.2.3 Acceleration by electric fields 9
1.2.4 Acceleration by magnetic fields 16
1.2.5 Acceleration in combined electric and magnetic fields 19
1.2.6 Summary 21
1.3 Assemblies of particles 21
1.3.1 Velocity distributions 22
1.4 Generation of velocity distributions 24
1.4.1 Entropy 25
1.4.2 Level or flat distributions 26
1.4.3 The Landau plateau 27
1.4.4 The Maxwell–Boltzmann distribution 28
1.4.5 The power law 31
1.4.6 The kappa distribution 33
1.4.7 Composites 35
1.5 Metamorphosis 36
1.5.1 Liouville's theorem 36
1.5.2 Some consequences 39
1.5.3 Loopholes in phase space? 48
1.6 Measurement and display 51
1.6.1 Platform 51
1.6.2 Detectors 52

1.6.3 Derivation of velocity distribution from measurements 57
1.6.4 Methods of presentation 59
1.7 Conclusion 64

2 The arena 65
2.1 The nature of the medium 65
2.1.1 The plasma state 65
2.1.2 Magnetic lines of force 68
2.2 Interplanetary space 69
2.2.1 Protons and other ions 69
2.2.2 Magnetic field 70
2.2.3 Electric field 72
2.2.4 Electrons 74
2.3 The solar wind in the vicinity of planets and other bodies 75
2.3.1 Magnetised bodies 75
2.3.2 Unmagnetised bodies 78
2.3.3 Electrons of the Earth's magnetosheath 78
2.4 Magnetosphere formation 79
2.4.1 Magnetic field 79
2.4.2 Cosmic rays 80
2.4.3 Trapped particles 81
2.4.4 Planetary rotation 85
2.4.5 Magnetosheath plasma 86
2.4.6 Magnetosheath magnetic field 89
2.5 The Earth's magnetosphere 91
2.5.1 Configuration 91
2.5.2 Temporal variations 94
2.5.3 Electron populations 95
2.6 Panorama 98

3 Electron acceleration in the aurora 99
3.1 The aurora 99
3.1.1 As a spectacle 100
3.1.2 As a geophysical phenomenon 102
3.1.3 As a plasma physics laboratory 103
3.2 Observations of auroral electrons 104
3.2.1 A demonstration 104
3.2.2 At low altitude 106
3.2.3 At 'mid'-altitude 115
3.2.4 At 'high' altitude 118
3.3 The potential-difference theory 120
3.3.1 Beginnings 120
3.3.2 Further impetus 122
3.3.3 The paradigm 122
3.3.4 Predictions 124

3.3.5 Tests 131
3.3.6 Search for parallel-to-B electric fields 133
3.4 The wave theory 138
3.4.1 Beginnings 138
3.4.2 Lower-hybrid waves 139
3.4.3 A wave model 143
3.4.4 Predictions 152
3.4.5 Wave fields 156
3.4.6 The 'chicken-and-egg' question 160
3.4.7 Power source and energy budget 160
3.5 Summary 163
3.6 A loose end 163
3.7 Conclusions 163

4 Electron acceleration at the Earth's bow shock 164
4.1 The archetypal electron transition 164
4.2 A case study 167
4.2.1 Orientation 167
4.2.2 Electrons 167
4.2.3 Taking stock 171
4.3 Potential-difference theories 174
4.3.1 Cross-shock potential difference 174
4.3.2 Interplanetary electric field 176
4.3.3 Cross-shock potential difference and interplanetary electric field combined 177
4.3.4 Summary 178
4.4 Wave theories 178
4.4.1 Advent 179
4.4.2 Lower-hybrid waves 179
4.4.3 A wave model 180
4.5 Conclusions 182

5 Electron acceleration in the neighbourhood of 'artificial comets' 184
5.1 'Artificial comets' 184
5.1.1 Creation 184
5.1.2 Magnetic cavities 185
5.1.3 'Pick-up' 186
5.2 The AMPTE lithium experiments 188
5.3 The AMPTE barium experiments 189
5.4 Interpretation 193
5.4.1 Potential difference 193
5.4.2 Adiabatic compression 193
5.4.3 Waves 194
5.5 Conclusion 195

6 Electron acceleration in solar-wind events **196**
6.1 Observations 196
6.1.1 Particles and fields 196
6.1.2 Locations 197
6.2 A case study 198
6.2.1 Electrons 198
6.2.2 Interpretation 200
6.3 Conclusions 203

7 Electron acceleration at the Earth's magnetopause **205**
7.1 The magnetopause 205
7.2 A case study 205
7.2.1 'Perpendicular' electrons 206
7.2.2 'Parallel' electrons 209
7.3 'Depletion layer' 213
7.4 Flux-transfer events 213
7.5 Conclusions 214

8 Electron acceleration in the Earth's magnetosphere **216**
8.1 Electron content 216
8.1.1 Sources 216
8.1.2 Tail lobes 218
8.1.3 Plasma sheet 219
8.1.4 Radiation belts 220
8.2 Acceleration theories 221
8.2.1 Conservative fields 221
8.2.2 Resonant accelerators 223
8.2.3 Non-resonant accelerators 225
8.3 Conclusions 227

9 Electron acceleration at the Sun **228**
9.1 Regions of the Sun 228
9.1.1 Interior 228
9.1.2 Photosphere 228
9.1.3 Chromosphere 229
9.1.4 Transition region 229
9.1.5 Corona 229
9.1.6 Solar flares 229
9.2 Solar-wind electrons 230
9.2.1 Observations 230
9.2.2 Acceleration theories 231
9.3 Solar-flare electrons 235
9.3.1 A case study 235
9.3.2 Acceleration theories 241
9.4 Conclusions 244

10 Electron acceleration in the Cosmos **245**
10.1 Electron observations 245
10.1.1 Direct 245
10.1.2 Indirect 246
10.2 Acceleration theories 247
10.2.1 Fermi's first theory 248
10.2.2 Fermi's second theory 252
10.2.3 Random walk in energy 252
10.3 Conclusions 254

11 Reflections **255**

Appendices 1–3. QBasic program listings **258**

Appendix 4. Key formulae **276**

References **285**

Questions and exercises **294**

Symbols, abbreviations and units **298**

Answers to questions **303**

Index **307**