

- Chapter 1 Movement from electricity p. 1
- 1.1 Introduction p. 1
- 1.2 The promise of nanotechnology p. 3
- 1.3 Electrokinetics p. 5
- 1.4 Electrokinetics and nanoparticles p. 9
- 1.5 A note on terminology p. 10
- References p. 12
- Chapter 2 Electrokinetics p. 15
- 2.1 The laws of electrostatics p. 15
- 2.2 Coulomb's law, electric field, and electrostatic potential p. 15
- 2.3 Gauss's, Laplace's, and Poisson's equations p. 19
- 2.4 Conductance and capacitance p. 21
- 2.4.1 Conductance and conductivity p. 21
- 2.4.2 Capacitance p. 23
- 2.4.3 Impedance p. 25
- 2.5 Polarization and dispersion p. 26
- 2.5.1 Dipoles and polarization p. 26
- 2.5.2 Complex permittivity p. 29
- 2.5.3 Dispersion and relaxation processes p. 30
- 2.5.3.1 Debye relaxation p. 30
- 2.5.3.2 The Maxwell-Wagner relaxation p. 33
- 2.6 Dielectric spheres in electric fields p. 35
- 2.7 Forces in field gradients: dielectrophoresis and electrorotation p. 39
- 2.7.1 Dielectrophoresis p. 39
- 2.7.2 Electrorotation p. 42
- 2.7.3 Electro-orientation p. 45
- 2.7.4 Dipole-dipole interactions: pearl chaining p. 46
- 2.7.5 Higher order multipoles p. 48
- Supplementary reading p. 50
- Chapter 3 Colloids and surfaces p. 51
- 3.1 Colloids p. 51
- 3.2 The electrical double layer p. 51
- 3.3 The Gouy-Chapman model p. 52
- 3.4 The Stern layer p. 56
- 3.5 Particles in moving fluids p. 59
- 3.6 Colloids in electric fields p. 60
- 3.7 Electrode polarization and fluid flow p. 63
- 3.8 Other forces affecting colloidal particles p. 69
- 3.8.1 Viscous drag p. 69
- 3.8.2 Buoyancy p. 70
- 3.8.3 Brownian motion and diffusion p. 70
- 3.8.4 Colloidal interaction forces p. 72
- References p. 73
- Supplementary reading p. 74
- Chapter 4 Analysis and manipulation of solid particles p. 75
- 4.1 Dielectrophoresis of homogeneous colloids p. 75

- 4.2 Frequency-dependent behavior and the crossover frequency p. 76
- 4.3 Double layer effects p. 80
 - 4.3.1 Charge movement in the double layer p. 81
 - 4.3.2 Charge movement in the Stern and diffuse double layers p. 82
 - 4.3.3 Stern layer conduction and the effects of bulk medium properties p. 84
 - 4.3.4 Dispersion in the Stern Layer p. 86
- 4.4 Dielectrophoresis versus fluid flow p. 87
- 4.5 Separating spheres p. 89
- 4.6 Trapping single particles p. 93
 - 4.6.1 Theory of dielectrophoretic trapping p. 94
 - 4.6.2 Trapping using positive dielectrophoresis p. 95
 - 4.6.3 Trapping using negative dielectrophoresis p. 96
- 4.7 Limitations on minimum particle trapping size p. 98
- 4.8 Dielectrophoresis and laser trapping p. 102
 - References p. 104
- Chapter 5 Dielectrophoresis of complex bioparticles p. 107
 - 5.1 Manipulating viruses p. 107
 - 5.2 Anatomy of viruses p. 108
 - 5.3 The multishell model p. 109
 - 5.4 Methods of measuring dielectrophoretic response p. 112
 - 5.4.1 Experimental considerations p. 112
 - 5.4.2 Crossover measurements p. 114
 - 5.4.3 Collection rate measurements p. 115
 - 5.4.4 Phase analysis light scattering techniques p. 117
 - 5.4.5 Measurement of levitation height p. 118
 - 5.4.6 Particle velocity measurement p. 120
 - 5.5 Examining virus structure by dielectrophoresis p. 121
 - 5.6 The interpretation of crossover data p. 123
 - 5.6.1 Clarifying assumptions p. 123
 - 5.6.2 Interpretation of results p. 125
 - 5.6.3 The effects of storage p. 128
 - 5.7 Studying nonspherical particles p. 130
 - 5.8 Separating viruses p. 133
 - 5.9 Unexpected charge effects p. 134
 - References p. 136
 - Supplementary reading p. 137
- Chapter 6 Dielectrophoresis, molecules, and materials p. 139
 - 6.1 Manipulation at the molecular scale p. 139
 - 6.2 Manipulating proteins p. 139
 - 6.3 Dielectrophores for protein analysis p. 140
 - 6.3.1 Qualitative description p. 141
 - 6.3.2 Crossover as a function of conductivity p. 142
 - 6.3.3 Crossover as a function of conductivity and pH p. 143
 - 6.4 DNA p. 146
 - 6.5 Dielectrophoretic manipulation of DNA p. 148
 - 6.6 Applications of DNA manipulation p. 150

- 6.6.1 Electrical measurement of single DNA molecules p. 150
- 6.6.2 Stretch-and-positioning of DNA p. 151
- 6.6.3 Molecular laser surgery p. 152
- 6.7 Nanotubes, nanowires, and carbon-60 p. 153
- References p. 156
- Chapter 7 Nanoengineering p. 159
- 7.4 Electrostatic self-assembly p. 162
- 7.1 Toward molecular nanotechnology p. 159
- 7.2 Directed self-assembly p. 160
- 7.3 Device assembly p. 161
- 7.5 Electronics with nanotubes, nanowires, and carbon-60 p. 164
- 7.6 Putting it all together: the potential for dielectrophoretic nanoassembly p. 168
- 7.7 Dielectrophoresis and materials science p. 169
- 7.7.1 Deposition of coatings p. 169
- 7.7.2 Three-dimensional material structuring p. 170
- 7.7.3 Dewatering p. 173
- 7.8 Nanoelectromechanical systems p. 174
- References p. 175
- Chapter 8 Practical dielectrophoretic separation p. 177
- 8.6 Stacked ratcheting mechanisms p. 191
- 8.1 Limitations on dielectrophoretic separation p. 177
- 8.2 Flow separation p. 178
- 8.3 Field flow fractionation p. 182
- 8.4 Thermal ratchets p. 184
- 8.5 Separation strategies using dielectrophoretic ratchets p. 189
- 8.7 Traveling wave dielectrophoresis p. 193
- 8.8 Applications of traveling wave dielectrophoresis p. 200
- 8.8.1 Manipulation p. 200
- 8.8.2 Separation p. 201
- 8.8.3 Fractionation p. 201
- 8.8.4 Concentration p. 202
- References p. 204
- Chapter 9 Electrode structures p. 207
- 9.1 Microengineering p. 207
- 9.2 Electrode fabrication techniques p. 208
- 9.2.1 Photolithography p. 208
- 9.2.2 Wet etching p. 210
- 9.2.3 Dry etching p. 215
- 9.2.4 Laser ablation p. 216
- 9.2.5 Direct-write e-beam structures p. 217
- 9.2.6 Multilayered planar construction p. 218
- 9.2.7 Microfluidics p. 219
- 9.2.8 Other fabrication techniques p. 221
- 9.3 Laboratories on a chip p. 222
- 9.3.1 Steering particles around electrode structures p. 224
- 9.3.2 Particle detection p. 226

- 9.3.3 Integrating electrokinetic subsystems p. 228
- 9.3.4 Contact with the outside world p. 230
- 9.4 A note about patents p. 231
- References p. 233
- Supplementary reading p. 237
- Chapter 10 Computer applications in electromechanics p. 239
- 10.1 The need for simulation p. 239
- 10.2 Principles of electric field simulation p. 239
- 10.3 Analytical methods p. 240
- 10.3.1 Electrode geometries with analytical solutions to their electric fields p. 240
- 10.3.2 Modeling time-dependent behavior using analytical methods p. 244
- 10.4 Numerical methods p. 246
- 10.4.1 The finite difference method p. 247
- 10.4.2 The finite element method p. 248
- 10.4.3 Boundary element methods p. 249
- 10.4.4 The Monte Carlo method p. 249
- 10.4.5 The method of moments p. 250
- 10.5 Finite element analysis p. 251
- 10.5.1 Local elements and the shape function p. 251
- 10.5.2 The Galerkin method p. 253
- 10.5.3 Quadrilateral elements p. 256
- 10.5.4 Assembling the elements p. 258
- 10.5.5 Applying boundary conditions p. 259
- 10.5.6 The solution process p. 261
- 10.6 The method of moments p. 261
- 10.6.1 Calculating charge density p. 262
- 10.6.2 Calculating the potential p. 265
- 10.7 Commercial versus custom software p. 266
- 10.8 Determination of dynamic field effects p. 267
- 10.8.1 The nature of the dynamic field p. 267
- 10.9 Example: simulation of polynomial electrodes p. 269
- 10.9.1 Simulations p. 269
- 10.9.2 Simulation results p. 271
- References p. 275
- Chapter 11 Dielectrophoretic response modeling and MATLAB p. 279
- 11.1 Modeling the dielectrophoretic response p. 279
- 11.2 Programming in MATLAB p. 280
- 11.3 Modeling the Clausius-Mossotti factor p. 280
- 11.4 Determining the crossover spectrum p. 283
- 11.7 Finding the best fit p. 292
- 11.5 Modeling surface conductance effects p. 288
- 11.6 Multishell objects p. 290
- 11.8 MATLAB in time-variant field analysis p. 293
- 11.9 Other MATLAB functions p. 296
- Appendix A A dielectrophoretic rotary nanomotor: a proposal p. 297
- A.1 Electrokinetic nanoelectromechanical systems p. 297

- A.2 Calculation of motor performance p. 298
- A.3 Theoretical limits of motor performance p. 302
- A.4 Digital electronic control of torque generation p. 306
- A.5 Nanomotor applications p. 308
- A.6 The way forward? p. 310
- References p. 311
- Index p. 313