Contents

Preface vii

Chapter 1. Special Relativity 1

1.1 Coordinatizations of spacetime 1

1.2 Lorentz coordinatizations 3

1.3 Minkowski space 4

1.4 Lorentz transformations 6

1.5 Orientations 10

1.6 Spacetime diagrams and the metric tensor 12

1.7 Proper time and four-velocity 14

1.8 Mass and relativistic momentum 18

Exercises 1 24

Chapter 2. Mathematical Tools 32

2.1 Multilinear algebra 32

2.2 Alternating forms 38

2.3 Manifolds 43

2.4 Tangent spaces and vector fields 45

2.5 Covariant derivatives 48

2.6 Stokes' Theorem 53

2.7 The metric tensor 58

2.8 The covariant divergence 59

2.9 The equations $d\beta = \gamma$ and $\delta\beta = \alpha$ 69

Exercises 2 86

Chapter 3. The Electrodynamics of Infinitesimal Charges **93**

3.1 Introduction 93

3.2 The Lorentz force law 94

3.3 The electromagnetic field tensor 97

3.4 The electric and magnetic fields 98

3.5 The first Maxwell equation 99

3.6 The second Maxwell equation 100

3.7 Potentials 102

3.8 The energy-momentum tensor 104

Exercises 3 119

Chapter 4. The Electrodynamics of Point Charges **126**

4.1 Introduction 126

4.2 The retarded potentials and fields of a point particle 128

4.3 Radiation reaction and the Lorentz-Dirac equation 136

4.4 Calculation of the energy-momentum radiated by a point particle 145

4.5 Summary of the logical structure of electrodynamics 161

Exercises 4 163

Chapter 5. Further Difficulties and Alternate Approaches **172**

5.1 The Cauchy problem for the Maxwell-Lorentz system 172

5.2 Spherically symmetric solutions of the Maxwell-Lorentz system 176

5.3 Nonexistence of global solutions of the Maxwell-Lorentz system 187

5.4 An alternate fluid model 190

5.5 Peculiar solutions of the Lorentz-Dirac equation 195

5.6 Evidence for the usual energy-momentum tensor 204

5.7 Alternate energy-momentum tensors and equations of motion 211

Appendix on Units **238**

Solutions to Exercises 245

Appendix 2 292

Bibliography 296

Table of Notations 300

Index 303