

Contents

Preface

page ix

1 Newtonian mechanics	1
1.1 Introduction	1
1.2 Newton's laws of motion	2
1.3 Newton's first law of motion	2
1.4 Newton's second law of motion	5
1.5 Newton's third law of motion	7
1.6 Nonisolated systems	10
1.7 Motion in one-dimensional potential	12
1.8 Simple harmonic motion	15
1.9 Two-body problem	17
Exercises	18
2 Newtonian gravity	22
2.1 Introduction	22
2.2 Gravitational potential	22
2.3 Gravitational potential energy	24
2.4 Axially symmetric mass distributions	25
2.5 Potential due to a uniform sphere	28
2.6 Potential outside a uniform spheroid	29
2.7 Potential due to a uniform ring	33
Exercises	34
3 Keplerian orbits	38
3.1 Introduction	38
3.2 Kepler's laws	38
3.3 Conservation laws	39
3.4 Plane polar coordinates	39
3.5 Kepler's second law	41
3.6 Kepler's first law	42
3.7 Kepler's third law	43
3.8 Orbital parameters	43
3.9 Orbital energies	44
3.10 Transfer orbits	45
3.11 Elliptical orbits	46
3.12 Orbital elements	49

3.13 Planetary orbits	52
3.14 Parabolic orbits	54
3.15 Hyperbolic orbits	55
3.16 Binary star systems	56
Exercises	58
4 Orbits in central force fields	63
4.1 Introduction	63
4.2 Motion in a general central force field	63
4.3 Motion in a nearly circular orbit	64
4.4 Perihelion precession of planets	66
4.5 Perihelion precession of Mercury	67
Exercises	69
5 Rotating reference frames	72
5.1 Introduction	72
5.2 Rotating reference frames	72
5.3 Centrifugal acceleration	73
5.4 Coriolis force	76
5.5 Rotational flattening	78
5.6 Tidal elongation	83
5.7 Tidal torques	89
5.8 Roche radius	92
Exercises	94
6 Lagrangian mechanics	97
6.1 Introduction	97
6.2 Generalized coordinates	97
6.3 Generalized forces	98
6.4 Lagrange's equation	99
6.5 Generalized momenta	101
Exercises	102
7 Rigid body rotation	105
7.1 Introduction	105
7.2 Fundamental equations	105
7.3 Moment of inertia tensor	106
7.4 Rotational kinetic energy	107
7.5 Principal axes of rotation	108
7.6 Euler's equations	109
7.7 Euler angles	111
7.8 Free precession of the Earth	114
7.9 MacCullagh's formula	115
7.10 Forced precession and nutation of the Earth	118

7.11 Spin-orbit coupling	127
7.12 Cassini's laws	138
Exercises	145
8 Three-body problem	147
8.1 Introduction	147
8.2 Circular restricted three-body problem	147
8.3 Jacobi integral	149
8.4 Tisserand criterion	149
8.5 Co-rotating frame	152
8.6 Lagrange points	155
8.7 Zero-velocity surfaces	158
8.8 Stability of Lagrange points	162
Exercises	167
9 Secular perturbation theory	172
9.1 Introduction	172
9.2 Evolution equations for a two-planet solar system	172
9.3 Secular evolution of planetary orbits	176
9.4 Secular evolution of asteroid orbits	187
9.5 Secular evolution of artificial satellite orbits	190
Exercises	194
10 Lunar motion	197
10.1 Introduction	197
10.2 Preliminary analysis	198
10.3 Lunar equations of motion	200
10.4 Unperturbed lunar motion	202
10.5 Perturbed lunar motion	204
10.6 Description of lunar motion	209
Exercises	213
Appendix A Useful mathematics	217
A.1 Calculus	217
A.2 Series expansions	218
A.3 Trigonometric identities	218
A.4 Vector identities	220
A.5 Conservative fields	221
A.6 Rotational coordinate transformations	221
A.7 Precession	223
A.8 Curvilinear coordinates	223
A.9 Conic sections	225
A.10 Elliptic expansions	229
A.11 Matrix eigenvalue theory	231

Appendix B Derivation of Lagrange planetary equations	234
B.1 Introduction	234
B.2 Preliminary analysis	235
B.3 Lagrange brackets	236
B.4 Transformation of Lagrange brackets	238
B.5 Lagrange planetary equations	242
B.6 Alternative forms of Lagrange planetary equations	244
 Appendix C Expansion of orbital evolution equations	 247
C.1 Introduction	247
C.2 Expansion of Lagrange planetary equations	247
C.3 Expansion of planetary disturbing functions	251
 <i>Bibliography</i>	 259
<i>Index</i>	263