

Contents

Part I Geometric Mechanics

1 Physics and Geometry	3
1.1 State space and dynamical flows	4
1.2 Coordinate representation of dynamical systems	10
1.3 Coordinate transformation	15
1.4 Uniformly rotating frames	25
1.5 Rigid-body motion	32
1.6 Summary	48
1.7 Bibliography	48
1.8 Homework problems	49
2 Lagrangian Mechanics	53
2.1 Calculus of variations	53
2.2 Lagrangian applications	57
2.3 Dissipation in Lagrangian systems	62
2.4 Lagrange undetermined multipliers	63
2.5 Examples of Lagrangian applications with constraints	64
2.6 Conservation laws	67
2.7 Central force motion	70
2.8 Virial theorem	78
2.9 Summary	79
2.10 Bibliography	80
2.11 Homework problems	80
3 Hamiltonian Dynamics and Phase Space	83
3.1 The Hamiltonian function	84
3.2 Phase space	91
3.3 Integrable systems and action-angle variables	96
3.4 Adiabatic invariants	103
3.5 Summary	105
3.6 Bibliography	106
3.7 Homework problems	106

Part II Nonlinear Dynamics

4 Nonlinear Dynamics and Chaos	111
4.1 One-variable dynamical systems	112
4.2 Two-variable dynamical systems	114
4.3 Limit cycles	125
4.4 Discrete iterative maps	134
4.5 Three-dimensional state space and chaos	136
4.6 Non-autonomous (driven) flows	145
4.7 Summary and glossary	148
4.8 Bibliography	149
4.9 Homework problems	150
5 Hamiltonian Chaos	154
5.1 Perturbed Hamiltonian systems and separatrix chaos	155
5.2 Nonintegrable Hamiltonian systems	160
5.3 The Chirikov Standard Map	164
5.4 KAM theory	168
5.5 Degeneracy and the web map	170
5.6 Quantum chaos [optional]	171
5.7 Summary	174
5.8 Bibliography	174
5.9 Homework problems	175
6 Coupled Oscillators and Synchronization	177
6.1 Coupled linear oscillators	178
6.2 Simple models of synchronization	181
6.3 Rational resonances	186
6.4 External synchronization	192
6.5 Synchronization of chaos	198
6.6 Summary	200
6.7 Bibliography	200
6.8 Homework problems	201

Part III Complex Systems

7 Network Dynamics	207
7.1 Network structures	208
7.2 Random network topologies	212
7.3 Synchronization on networks	216
7.4 Diffusion on networks	226
7.5 Epidemics on networks	231

7.6	Summary	239
7.7	Bibliography	240
7.8	Homework problems	240
8	Evolutionary Dynamics	243
8.1	Population dynamics	244
8.2	Viral infection and acquired resistance	249
8.3	Replicator dynamics	254
8.4	Quasispecies	260
8.5	Game theory and evolutionary stable solutions	267
8.6	Summary	271
8.7	Bibliography	272
8.8	Homework problems	273
9	Neurodynamics and Neural Networks	276
9.1	Neuron structure and function	277
9.2	Neuron dynamics	280
9.3	Network nodes: artificial neurons	286
9.4	Neural network architectures	289
9.5	Hopfield neural network	295
9.6	Content-addressable (associative) memory	298
9.7	Summary	303
9.8	Bibliography	304
9.9	Homework problems	304
10	Economic Dynamics	308
10.1	Microeconomics and equilibrium	309
10.2	Macroeconomics	324
10.3	Business cycles	331
10.4	Random walks and stock prices [optional]	339
10.5	Summary	348
10.6	Bibliography	349
10.7	Homework problems	350

Part IV Relativity and Space-Time

11	Metric Spaces and Geodesic Motion	355
11.1	Manifolds	356
11.2	Derivative of a tensor	360
11.3	Geodesic curves in configuration space	366
11.4	Geodesic motion	377
11.5	Summary	382

11.6	Bibliography	382
11.7	Homework problems	382
12	Relativistic Dynamics	385
12.1	The special theory	386
12.2	Lorentz transformations	388
12.3	Metric structure of Minkowski space	398
12.4	Relativistic trajectories	402
12.5	Relativistic dynamics	406
12.6	Linearly accelerating frames (relativistic)	418
12.7	Summary	423
12.8	Bibliography	424
12.9	Homework problems	424
13	The General Theory of Relativity and Gravitation	426
13.1	The Newtonian correspondence	426
13.2	Riemann curvature tensor	429
13.3	Einstein's field equations	432
13.4	Schwarzschild space-time	436
13.5	Kinematic consequences of gravity	438
13.6	The deflection of light by gravity	439
13.7	Planetary orbits	445
13.8	Black holes	447
13.9	Gravitational waves	452
13.10	Summary	456
13.11	Bibliography	456
13.12	Homework problems	457
Appendix		
A.1	Index notation: rows, columns, and matrices	461
A.2	The complex plane	463
A.3	Solution of linear and linearized ODEs	463
A.4	Runge–Kutta numerical solvers for ODEs	467
A.5	Tangents and normals to a curve in the plane	468
A.6	Elliptic integrals	469
A.7	MATLAB and Python programs for numerical homework	472
Index		473