

Contents

1	Statics	I-1
1.1	Balancing forces	I-1
1.2	Balancing torques	I-5
1.3	Exercises	I-9
1.4	Problems	I-12
1.5	Solutions	I-17
2	Using $F = ma$	II-1
2.1	Newton's Laws	II-1
2.2	Free-body diagrams	II-4
2.3	Solving differential equations	II-8
2.4	Projectile motion	II-12
2.5	Motion in a plane, polar coordinates	II-15
2.6	Exercises	II-18
2.7	Problems	II-24
2.8	Solutions	II-28
3	Oscillations	III-1
3.1	Linear differential equations	III-1
3.2	Simple harmonic motion	III-4
3.3	Damped harmonic motion	III-6
3.4	Driven (and damped) harmonic motion	III-8
3.5	Coupled oscillators	III-13
3.6	Exercises	III-18
3.7	Problems	III-22
3.8	Solutions	III-24
4	Conservation of Energy and Momentum	IV-1
4.1	Conservation of energy in 1-D	IV-1
4.2	Small Oscillations	IV-6
4.3	Conservation of energy in 3-D	IV-8
4.3.1	Conservative forces in 3-D	IV-9
4.4	Gravity	IV-12
4.4.1	Gravity due to a sphere	IV-12
4.4.2	Tides	IV-14

4.5	Momentum	IV-17
4.5.1	Conservation of momentum	IV-17
4.5.2	Rocket motion	IV-19
4.6	The CM frame	IV-20
4.6.1	Definition	IV-20
4.6.2	Kinetic energy	IV-22
4.7	Collisions	IV-23
4.7.1	1-D motion	IV-23
4.7.2	2-D motion	IV-25
4.8	Inherently inelastic processes	IV-26
4.9	Exercises	IV-30
4.10	Problems	IV-41
4.11	Solutions	IV-47
5	The Lagrangian Method	V-1
5.1	The Euler-Lagrange equations	V-1
5.2	The principle of stationary action	V-4
5.3	Forces of constraint	V-10
5.4	Change of coordinates	V-12
5.5	Conservation Laws	V-15
5.5.1	Cyclic coordinates	V-15
5.5.2	Energy conservation	V-16
5.6	Noether's Theorem	V-18
5.7	Small oscillations	V-21
5.8	Other applications	V-24
5.9	Exercises	V-27
5.10	Problems	V-29
5.11	Solutions	V-34
6	Central Forces	VI-1
6.1	Conservation of angular momentum	VI-1
6.2	The effective potential	VI-3
6.3	Solving the equations of motion	VI-5
6.3.1	Finding $r(t)$ and $\theta(t)$	VI-5
6.3.2	Finding $r(\theta)$	VI-6
6.4	Gravity, Kepler's Laws	VI-6
6.4.1	Calculation of $r(\theta)$	VI-6
6.4.2	The orbits	VI-8
6.4.3	Proof of conic orbits	VI-10
6.4.4	Kepler's Laws	VI-11
6.4.5	Reduced mass	VI-13
6.5	Exercises	VI-16
6.6	Problems	VI-18
6.7	Solutions	VI-20

7	Angular Momentum, Part I (Constant \hat{L})	VII-1
7.1	Pancake object in x - y plane	VII-2
7.1.1	Rotation about the z -axis	VII-3
7.1.2	General motion in x - y plane	VII-4
7.1.3	The parallel-axis theorem	VII-5
7.1.4	The perpendicular-axis theorem	VII-6
7.2	Non-planar objects	VII-7
7.3	Calculating moments of inertia	VII-9
7.3.1	Lots of examples	VII-9
7.3.2	A neat trick	VII-11
7.4	Torque	VII-12
7.4.1	Point mass, fixed origin	VII-13
7.4.2	Extended mass, fixed origin	VII-13
7.4.3	Extended mass, non-fixed origin	VII-14
7.5	Collisions	VII-17
7.6	Angular impulse	VII-19
7.7	Exercises	VII-21
7.8	Problems	VII-28
7.9	Solutions	VII-34
8	Angular Momentum, Part II (General \hat{L})	VIII-1
8.1	Preliminaries concerning rotations	VIII-1
8.1.1	The form of general motion	VIII-1
8.1.2	The angular velocity vector	VIII-2
8.2	The inertia tensor	VIII-5
8.2.1	Rotation about an axis through the origin	VIII-5
8.2.2	General motion	VIII-9
8.2.3	The parallel-axis theorem	VIII-10
8.3	Principal axes	VIII-11
8.4	Two basic types of problems	VIII-15
8.4.1	Motion after an impulsive blow	VIII-15
8.4.2	Frequency of motion due to a torque	VIII-18
8.5	Euler's equations	VIII-20
8.6	Free symmetric top	VIII-22
8.6.1	View from body frame	VIII-22
8.6.2	View from fixed frame	VIII-24
8.7	Heavy symmetric top	VIII-25
8.7.1	Euler angles	VIII-25
8.7.2	Digression on the components of $\vec{\omega}$	VIII-26
8.7.3	Torque method	VIII-29
8.7.4	Lagrangian method	VIII-30
8.7.5	Gyroscope with $\dot{\theta} = 0$	VIII-31
8.7.6	Nutation	VIII-33
8.8	Exercises	VIII-36
8.9	Problems	VIII-38

8.10 Solutions	VIII-44
9 Accelerated Frames of Reference	IX-1
9.1 Relating the coordinates	IX-2
9.2 The fictitious forces	IX-4
9.2.1 Translation force: $-md^2\mathbf{R}/dt^2$	IX-5
9.2.2 Centrifugal force: $-m\vec{\omega} \times (\vec{\omega} \times \mathbf{r})$	IX-5
9.2.3 Coriolis force: $-2m\vec{\omega} \times \mathbf{v}$	IX-7
9.2.4 Azimuthal force: $-m(d\vec{\omega}/dt) \times \mathbf{r}$	IX-11
9.3 Exercises	IX-13
9.4 Problems	IX-15
9.5 Solutions	IX-17
10 Relativity (Kinematics)	X-1
10.1 The postulates	X-2
10.2 The fundamental effects	X-4
10.2.1 Loss of Simultaneity	X-4
10.2.2 Time dilation	X-7
10.2.3 Length contraction	X-10
10.3 The Lorentz transformations	X-14
10.3.1 The derivation	X-14
10.3.2 The fundamental effects	X-18
10.3.3 Velocity addition	X-20
10.4 The invariant interval	X-23
10.5 Minkowski diagrams	X-26
10.6 The Doppler effect	X-29
10.6.1 Longitudinal Doppler effect	X-29
10.6.2 Transverse Doppler effect	X-30
10.7 Rapidity	X-32
10.8 Relativity without c	X-35
10.9 Exercises	X-39
10.10 Problems	X-46
10.11 Solutions	X-52
11 Relativity (Dynamics)	XI-1
11.1 Energy and momentum	XI-1
11.1.1 Momentum	XI-2
11.1.2 Energy	XI-3
11.2 Transformations of E and \vec{p}	XI-7
11.3 Collisions and decays	XI-10
11.4 Particle-physics units	XI-13
11.5 Force	XI-14
11.5.1 Force in one dimension	XI-14
11.5.2 Force in two dimensions	XI-16
11.5.3 Transformation of forces	XI-17

11.6	Rocket motion	XI-19
11.7	Relativistic strings	XI-22
11.8	Mass	XI-24
11.9	Exercises	XI-26
11.10	Problems	XI-30
11.11	Solutions	XI-34
12	4-vectors	XII-1
12.1	Definition of 4-vectors	XII-1
12.2	Examples of 4-vectors	XII-2
12.3	Properties of 4-vectors	XII-4
12.4	Energy, momentum	XII-6
12.4.1	Norm	XII-6
12.4.2	Transformation of E, p	XII-6
12.5	Force and acceleration	XII-7
12.5.1	Transformation of forces	XII-7
12.5.2	Transformation of accelerations	XII-8
12.6	The form of physical laws	XII-10
12.7	Exercises	XII-12
12.8	Problems	XII-13
12.9	Solutions	XII-14
13	General Relativity	XIII-1
13.1	The Equivalence Principle	XIII-1
13.2	Time dilation	XIII-2
13.3	Uniformly accelerated frame	XIII-4
13.3.1	Uniformly accelerated point particle	XIII-5
13.3.2	Uniformly accelerated frame	XIII-6
13.4	Maximal-proper-time principle	XIII-8
13.5	Twin paradox revisited	XIII-9
13.6	Exercises	XIII-12
13.7	Problems	XIII-15
13.8	Solutions	XIII-18
14	Appendices	XIV-1
14.1	Appendix A: Useful formulas	XIV-1
14.1.1	Taylor series	XIV-1
14.1.2	Nice formulas	XIV-2
14.1.3	Integrals	XIV-2
14.2	Appendix B: Units, dimensional analysis	XIV-4
14.2.1	Exercises	XIV-6
14.2.2	Problems	XIV-7
14.2.3	Solutions	XIV-8
14.3	Appendix C: Approximations, limiting cases	XIV-11
14.3.1	Exercise	XIV-13

14.4	Appendix D: Solving differential equations numerically	XIV-15
14.5	Appendix E: $F = ma$ vs. $F = dp/dt$	XIV-17
14.6	Appendix F: Existence of principal axes	XIV-19
14.7	Appendix G: Diagonalizing matrices	XIV-22
14.8	Appendix H: Qualitative relativity questions	XIV-24
14.9	Appendix I: Lorentz transformations	XIV-29
14.10	Appendix J: Resolutions to the twin paradox	XIV-32
14.11	Appendix K: Physical constants and data	XIV-34