

Contents

<i>Preface</i>	xi
1 Newtonian mechanics of a single particle	1
1 The algebra and calculus of vectors	3
1.1 Vectors and vector quantities	3
1.2 Linear operations: $a + b$ and λa	5
1.3 The scalar product $a \cdot b$	10
1.4 The vector product $a \times b$	13
1.5 Triple products	15
1.6 Vector functions of a scalar variable	16
1.7 Tangent and normal vectors to a curve	18
Problems	22
2 Velocity, acceleration and scalar angular velocity	25
2.1 Straight line motion of a particle	25
2.2 General motion of a particle	28
2.3 Particle motion in polar co-ordinates	32
2.4 Rigid body rotating about a fixed axis	36
2.5 Rigid body in planar motion	38
2.6 Reference frames in relative motion	40
Problems	43
3 Newton's laws of motion and the law of gravitation	50
3.1 Newton's laws of motion	50
3.2 Inertial frames and the law of inertia	52
3.3 The law of mutual interaction; mass and force	54
3.4 The law of multiple interactions	57
3.5 Centre of mass	58

3.6	The law of gravitation.	59
3.7	Gravitation by a distribution of mass.	60
3.8	The principle of equivalence and g	67
	Problems.	71
4	Problems in particle dynamics	73
4.1	Rectilinear motion in a force field.	74
4.2	Constrained rectilinear motion.	78
4.3	Motion through a resisting medium.	82
4.4	Projectiles.	88
4.5	Circular motion.	92
	Problems.	98
5	Linear oscillations	105
5.1	Body on a spring.	105
5.2	Classical simple harmonic motion.	107
5.3	Damped simple harmonic motion.	109
5.4	Driven (forced) motion.	112
5.5	A simple seismograph.	120
5.6	Coupled oscillations and normal modes.	121
	Problems.	126
6	Energy conservation	131
6.1	The energy principle.	131
6.2	Energy conservation in rectilinear motion.	133
6.3	General features of rectilinear motion.	136
6.4	Energy conservation in a conservative field.	140
6.5	Energy conservation in constrained motion.	145
	Problems.	151
7	Orbits in a central field	155
7.1	The one-body problem - Newton's equations.	157
7.2	General nature of orbital motion.	159
7.3	The path equation.	164
7.4	Nearly circular orbits.	167
7.5	The attractive inverse square field.	170
7.6	Space travel - Hohmann transfer orbits.	177
7.7	The repulsive inverse square field.	179
7.8	Rutherford scattering.	179
	Appendix A The geometry of conics.	184
	Appendix B The Hohmann orbit is optimal.	186
	Problems.	188

8	Non-linear oscillations and phase space	194
8.1	Periodic non-linear oscillations.	194
8.2	The phase plane ((x ₁ , x ₂)-plane)	199
8.3	The phase plane in dynamics ((x, u)-plane).	202
8.4	Poincare-Bendixson theorem: limit cycles.	205
8.5	Driven non-linear oscillations.	211
	Problems	214
2	Multi-particle systems	219
9	The energy principle	221
9.1	Configurations and degrees of freedom.	221
9.2	The energy principle for a system.	223
9.3	Energy conservation for a system.	225
9.4	Kinetic energy of a rigid body.	233
	Problems	241
10	The linear momentum principle	245
10.1	Linear momentum.	245
10.2	The linear momentum principle.	246
10.3	Motion of the centre of mass.	247
10.4	Conservation of linear momentum.	250
10.5	Rocket motion.	251
10.6	Collision theory.	255
10.7	Collision processes in the zero-momentum frame.	259
10.8	The two-body problem.	264
10.9	Two-body scattering.	269
10.10	Integrable mechanical systems.	273
	Appendix A Modelling bodies by particles.	277
	Problems	279
11	The angular momentum principle	286
11.1	The moment of a force.	286
11.2	Angular momentum.	289
11.3	Angular momentum of a rigid body.	292
11.4	The angular momentum principle.	294
11.5	Conservation of angular momentum.	298
11.6	Planar rigid body motion.	306
11.7	Rigid body statics in three dimensions.	313
	Problems	317

3	Analytical mechanics	321
12	Lagrange's equations and conservation principles	323
12.1	Constraints and constraint forces	323
12.2	Generalised coordinates.	325
12.3	Configuration space (q-space).....	330
12.4	D'Alembert's principle.	333
12.5	Lagrange's equations.	335
12.6	Systems with moving constraints.	344
12.7	The Lagrangian.	348
12.8	The energy function h	351
12.9	Generalised momenta.	354
12.10	Symmetry and conservation principles.	356
	Problems	361
13	The calculus of variations and Hamilton's principle	366
13.1	Some typical minimisation problems.	367
13.2	The Euler-Lagrange equation.	369
13.3	Variational principles.	380
13.4	Hamilton's principle.	383
	Problems	388
14	Hamilton's equations and phase space	393
14.1	Systems of first order ODEs.	393
14.2	Legendre transforms.	396
14.3	Hamilton's equations.	400
14.4	Hamiltonian phase space ((q,p)-space).....	406
14.5	Liouville's theorem and recurrence.	408
	Problems	413
4	Further topics	419
15	The general theory of small oscillations	421
15.1	Stable equilibrium and small oscillations.	421
15.2	The approximate forms of T and V	425
15.3	The general theory of normal modes.	429
15.4	Existence theory for normal modes	433
15.5	Some typical normal mode problems.	436
15.6	Orthogonality of normal modes	444
15.7	General small oscillations.	447
15.8	Normal coordinates.	448
	Problems	452

16 Vector angular velocity and rigid body kinematics	457
16.1 Rotation about a fixed axis	457
16.2 General rigid body kinematics.	460
Problems.	467
17 Rotating reference frames	469
17.1 Transformation formulae.	469
17.2 Particle dynamics in a non-inertial frame.	476
17.3 Motion relative to the Earth.	478
17.4 Multi-particle system in a non-inertial frame.	485
Problems.	489
18 Tensor algebra and the inertia tensor	492
18.1 Orthogonal transformations.	493
18.2 Rotated and reflected coordinate systems.	495
18.3 Scalars, vectors and tensors.	499
18.4 Tensor algebra.	505
18.5 The inertia tensor.	508
18.6 Principal axes of a symmetric tensor.	514
18.7 Dynamical symmetry.	516
Problems.	519
19 Problems in rigid body dynamics	522
19.1 Equations of rigid body dynamics.	522
19.2 Motion of 'spheres'.	524
19.3 The snooker ball.	525
19.4 Free motion of bodies with axial symmetry.	527
19.5 The spinning top.	531
19.6 Lagrangian dynamics of the top.	535
19.7 The gyrocompass.	541
19.8 Euler's equations.	544
19.9 Free motion of an unsymmetrical body.	549
19.10 The rolling wheel.	556
Problems.	560
Appendix Centres of mass and moments of inertia	564
A.1 Centre of mass.	564
A.2 Moment of inertia.	567
A.3 Parallel and perpendicular axes	571
Answers to the problems	576
<i>Bibliography.</i>	589
<i>Index.</i>	591