

Contents

Editors' Preface to the Manchester Physics Series	xii
Author's Preface	xiii

I INTRODUCTORY DYNAMICS	1
1 SPACE, TIME AND MOTION	3
1.1 Defining Space and Time	3
1.1.1 Space and the classical particle	4
1.1.2 Unit vectors	6
1.1.3 Addition and subtraction of vectors	6
1.1.4 Multiplication of vectors	7
1.1.5 Time	8
1.1.6 Absolute space and space-time	10
1.2 Vectors and Co-ordinate Systems	11
1.3 Velocity and Acceleration	14
1.3.1 Frames of reference	16
1.3.2 Relative motion	16
1.3.3 Uniform acceleration	18
1.3.4 Velocity and acceleration in plane-polar co-ordinates: uniform circular motion	20
1.4 Standards and Units	21
2 FORCE, MOMENTUM AND NEWTON'S LAWS	25
2.1 Force and Static Equilibrium	25
2.2 Force and Motion	31
2.2.1 Newton's Third Law	35
2.2.2 Newton's bucket and Mach's principle	39
2.3 Applications of Newton's Laws	41
2.3.1 Free body diagrams	41
2.3.2 Three worked examples	42
2.3.3 Normal forces and friction	46
2.3.4 Momentum conservation	49

2.3.5 Impulse	51
2.3.6 Motion in fluids	51
3 ENERGY	55
3.1 Work, Power and Kinetic Energy	56
3.2 Potential Energy	61
3.2.1 The stability of mechanical systems	64
3.2.2 The harmonic oscillator	65
3.2.3 Motion about a point of stable equilibrium	67
3.3 Collisions	68
3.3.1 Zero-momentum frames	68
3.3.2 Elastic and inelastic collisions	71
3.4 Energy Conservation in Complex Systems	75
4 ANGULAR MOMENTUM	81
4.1 Angular Momentum of a Particle	81
4.2 Conservation of Angular Momentum in Systems of Particles	83
4.3 Angular Momentum and Rotation About a Fixed Axis	86
4.3.1 The parallel-axis theorem	94
4.4 Sliding and Rolling	95
4.5 Angular Impulse and the Centre of Percussion	97
4.6 Kinetic Energy of Rotation	99
II INTRODUCTORY SPECIAL RELATIVITY	103
5 THE NEED FOR A NEW THEORY OF SPACE AND TIME	105
5.1 Space and Time Revisited	105
5.2 Experimental Evidence	108
5.2.1 The Michelson-Morley experiment	108
5.2.2 Stellar aberration	110
5.3 Einstein's Postulates	113
6 RELATIVISTIC KINEMATICS	115
6.1 Time Dilation, Length Contraction and Simultaneity	115
6.1.1 Time dilation and the Doppler effect	116
6.1.2 Length contraction	121
6.1.3 Simultaneity	123
6.2 Lorentz Transformations	124
6.3 Velocity Transformations	129
6.3.1 Addition of velocities	129
6.3.2 Stellar aberration revisited	130
7 RELATIVISTIC ENERGY AND MOMENTUM	135
7.1 Momentum and Energy	135

7.1.1 The equivalence of mass and energy	142
7.1.2 The hint of an underlying symmetry	144
7.2 Applications in Particle Physics	145
7.2.1 When is relativity important?	146
7.2.2 Two useful relations and massless particles	149
7.2.3 Compton scattering	152
III ADVANCED DYNAMICS	157
8 NON-INERTIAL FRAMES	159
8.1 Linearly Accelerating Frames	159
8.2 Rotating Frames	161
8.2.1 Motion on the earth	165
9 GRAVITATION	173
9.1 Newton's Law of Gravity	174
9.2 The Gravitational Potential	177
9.3 Reduced Mass	182
9.4 Motion in a Central Force	184
9.5 Orbits	186
10 RIGID BODY MOTION	197
10.1 The Angular Momentum of a Rigid Body	198
10.2 The Moment of Inertia Tensor	200
10.2.1 Calculating the moment of inertia tensor	203
10.3 Principal Axes	207
10.4 Fixed-axis Rotation in the Lab Frame	212
10.5 Euler's Equations	214
10.6 The Free Rotation of a Symmetric Top	216
10.6.1 The body-fixed frame	216
10.6.2 The lab frame	218
10.6.3 The wobbling earth	223
10.7 The Stability of Free Rotation	224
10.8 Gyroscopes	226
10.8.1 Gyroscopic precession	226
10.8.2 Nutation of a gyroscope	232
IV ADVANCED SPECIAL RELATIVITY	237
11 THE SYMMETRIES OF SPACE AND TIME	239
11.1 Symmetry in Physics	239
11.1.1 Rotations and translations	240
11.1.2 Translational symmetry	245

11.1.3 Galilean symmetry	246
11.2 Lorentz Symmetry	247
12 FOUR-VECTORS AND LORENTZ INVARIANTS	253
12.1 The Velocity Four-vector	254
12.2 The Wave Four-vector	255
12.3 The Energy-momentum Four-vector	258
12.3.1 Further examples in relativistic kinematics	259
12.4 Electric and Magnetic Fields	262
13 SPACE-TIME DIAGRAMS AND CAUSALITY	267
13.1 Relativity Preserves Causality	270
13.2 An Alternative Approach	272
14 ACCELERATION AND GENERAL RELATIVITY	279
14.1 Acceleration in Special Relativity	279
14.1.1 Twins paradox	280
14.1.2 Accelerating frames of reference	282
14.2 A Glimpse of General Relativity	288
14.2.1 Gravitational fields	290
A DERIVING THE GEODESIC EQUATION	295
B SOLUTIONS TO PROBLEMS	297