

# PREDICTING MOTION

<b>Introduction</b>	<b>6</b>
<b>Chapter 1 Forces and Newton's laws</b>	<b>7</b>
1 Voyager's odyssey — an example of Newton's laws	7
2 Newton's laws and the definition of force	8
2.1 Underlying concepts: frames of reference and observers	8
2.2 Newton's first law: inertia and inertial frames of reference	10
2.3 Newton's second law: force, mass and acceleration	13
2.4 Newton's third law: action and reaction	17
2.5 Newton's laws and vectors: resultant force, resolution and redirection	18
2.6 Newton's laws and rigid bodies: centre of mass	22
3 Some familiar forces	26
3.1 Weight and terrestrial gravitation	26
3.2 Universal gravitation	27
3.3 Contact forces and normal reactions	30
3.4 Friction, viscosity and air resistance	31
3.5 Forces arising from tension and compression	35
3.6 Forces in action	38
4 Forces and motion	42
4.1 Rates of change: gradients and derivatives — a reminder	42
4.2 Some familiar forms of motion	44
4.3 Derivatives and Newton's laws: equations of motion	53
4.4 Stepping through Newton's laws	59
5 Closing items	62
<b>Chapter 2 Work, energy and power</b>	<b>66</b>
1 Escaping the Earth — an application of energy	66
2 Work and kinetic energy	67
2.1 Kinetic energy — energy due to motion	67
2.2 Work and changes in kinetic energy	69
2.3 The work done by a constant aligned force	70
2.4 The work done by a constant non-aligned force	71
2.5 Work and the scalar product of vectors	73
3 Work and potential energy	74
3.1 Conservative and non-conservative forces	75
3.2 Potential energy — energy due to configuration	77
3.3 Strain potential energy	80
3.4 The work done by a varying force	83
3.5 Gravitational potential energy	86
3.6 Force as the negative gradient of potential energy	89
3.7 The conservation of mechanical energy	90
3.8 The role of energy in predicting motion	92
4 Power	93
4.1 Power — the rate of energy transfer	93
4.2 Power and vectors	95



5	Energy in oscillating systems	95
5.1	The energy of a simple harmonic oscillator	96
5.2	The energy of a damped harmonic oscillator	99
5.3	The energy of a driven damped harmonic oscillator	107
5.4	A note on exponential functions	112
6	Closing items	114
<b>Chapter 3 Linear momentum and collisions</b>		<b>118</b>
1	Discovering the atomic nucleus — an example	118
2	Linear momentum	119
2.1	The linear momentum of a body	119
2.2	Momentum and Newton's second law	121
2.3	Impulse and impulsive forces	122
2.4	The momentum of a system of bodies	124
2.5	Conservation of momentum	125
2.6	The role of momentum in predicting motion	127
3	Collisions and conservation laws	130
3.1	Elastic and inelastic collisions	130
3.2	Elastic collisions in one dimension	131
3.3	Elastic collisions in two or three dimensions	134
3.4	Inelastic collisions	136
3.5	Collisions all around us	137
3.6	Relativistic collisions	139
4	Closing items	142
<b>Chapter 4 Torque and angular momentum</b>		<b>145</b>
1	Precession — an example of rotational dynamics	145
2	Torque	147
2.1	The turning effect of a force	147
2.2	Torque and levers	151
2.3	A vector definition of torque	152
2.4	Torque and angular motion	155
2.5	A note on vector and scalar products	158
3	Equilibrium and statics	160
3.1	Equilibrium conditions	160
3.2	Static equilibrium conditions	161
3.3	The stability of equilibrium	163
3.4	Static structures	164
4	Rotational energy and moments of inertia	165
4.1	Rotational energy of particles	165
4.2	Rotational energy of rigid bodies	167
4.3	Torque, moment of inertia and angular acceleration	169
4.4	The role of rotational energy in the prediction of motion	170
4.5	Flywheels and energy storage	172
5	Angular momentum	173
5.1	Angular momentum of particles	173
5.2	Angular momentum of rigid bodies	175
5.3	Torque and the rate of change of angular momentum	176
5.4	Conservation of angular momentum	177
5.5	Tops, gyroscopes and precession	182
6	Closing items	185



<b>Chapter 5</b>	<b>Chaotic motion</b>	<b>188</b>
1	Is motion always predictable?	188
2	What is chaos?	190
2.1	A linear map	190
2.2	The logistic map	192
2.3	Some features of chaos	197
2.4	Fractals	200
2.5	State spaces and trajectories	202
2.6	Strange attractors	204
3	Examples of chaos	207
3.1	Dripping taps and beating hearts	207
3.2	Chaos in the Solar System	208
3.3	Chaos in galaxies	211
4	Closing items	212
<b>Chapter 6</b>	<b>Consolidation and skills development</b>	<b>214</b>
1	Introduction	214
2	Overview of Chapters 1 to 5	214
3	Problem-solving skills	217
4	Basic skills and knowledge test	223
5	Interactive questions	225
6	<i>Physica</i> problems	225
	<b>Answers to questions</b>	<b>226</b>
	<b>Acknowledgements</b>	<b>251</b>
	<b>Index</b>	<b>253</b>



Figure 1.1. Voyager 2.