

# QUANTUM PHYSICS: AN INTRODUCTION

<b>Introduction</b>	<b>6</b>
<b>Chapter 1 The origins of quantum physics</b>	<b>7</b>
1 The Compton effect — a strange dichotomy in the nature of electromagnetic radiation	7
2 Five problems for classical physics	7
2.1 Problem 1: Understanding atoms	8
2.2 Problem 2: Understanding spectroscopy	8
2.3 Problem 3: Understanding blackbody radiation	11
2.4 Problem 4: Understanding the photoelectric effect	14
2.5 Problem 5: Understanding heat capacities of solids	15
3 Physics saved by the quantum	16
3.1 The ultraviolet catastrophe tamed	16
3.2 Einstein's theory of the photoelectric effect	18
3.3 Einstein's theory of specific heats	21
3.4 Summary of Section 3	23
4 First insights into atomic structure	23
4.1 Introduction	23
4.2 J. J. Thomson's 'plum-pudding' model	23
4.3 $\alpha$ -particle scattering	25
4.4 Rutherford's classical model of the atom	28
4.5 Summary of Section 4	30
5 Bohr's semi-classical atomic model	31
5.1 Bohr's model of the hydrogen atom	31
5.2 Bohr's model extended to heavy atoms	38
6 Towards a quantum model of the atom	39
6.1 Introduction	39
6.2 Wave-particle duality	39
6.3 The de Broglie formula and its verification	40
7 Closing items	43
<b>Chapter 2 Schrödinger's wave mechanics</b>	<b>46</b>
1 Quantum mechanics — a new approach to describing atomic matter	46
2 Towards quantum mechanics	47
2.1 Electron diffraction experiments	47
2.2 The scope of quantum mechanics	50
2.3 Probability waves	50
2.4 Summary of Section 2	52
3 Heisenberg's uncertainty principle	53
3.1 A wave packet description of the electron	53
3.2 Some more properties of wave packets	54
3.3 Wave packets and Heisenberg's uncertainty principle	55
3.4 Some examples of the uncertainty principle	57

	3.5	Another form of the uncertainty principle	60
	3.6	Summary of Section 3	61
4		The Schrödinger equation	61
	4.1	Introduction	61
	4.2	Free and confined particles	64
	4.3	The time-dependent Schrödinger equation	66
	4.4	Schrödinger's time-independent equation	67
	4.5	The Schrödinger equation for a particle in a one-dimensional infinite square well	68
	4.6	Interpretation of the wavefunction	72
	4.7	The Schrödinger equation for a particle in a one-dimensional finite square well	77
	4.8	Barrier penetration	78
	4.9	A particle confined in three dimensions — degeneracy	80
	4.10	The correspondence principle	84
	4.11	Summary of Section 4	86
5		Closing items	87
		<b>Chapter 3 Quantum mechanics in atoms</b>	<b>91</b>
	1	Lasers — a modern tool	91
	2	Hydrogen — the simplest atom	93
	2.1	Introduction	93
	2.2	Using the Schrödinger equation to study the electron in the hydrogen atom	93
	2.3	The energy of the electron in the hydrogen atom	96
	2.4	The quantum numbers that specify the wavefunctions of the electron in the hydrogen atom	98
	2.5	The effect of a magnetic field on the energy levels of the electron in a hydrogen atom	102
	2.6	Spectroscopic notation	105
	2.7	Summary of Section 2	106
	3	Wavefunctions and transitions in hydrogen	107
	3.1	Electron distribution patterns in hydrogen — the shape of the hydrogen atom	107
	3.2	Atomic electrons in transition — atomic spectra	111
	3.3	Summary of Section 3	114
	4	Electron spin	115
	4.1	Introduction	115
	4.2	An explanation — electron spin	115
	4.3	Quantum numbers for electron spin	116
	4.4	A pattern in the degeneracy of the quantum states of the electron in the hydrogen atom	117
	4.5	Summary of Section 4	118
	5	The structure of heavy atoms	119
	5.1	Introduction	119
	5.2	The constituents of heavy atoms	119
	5.3	Schrödinger's equation applied to electrons in heavy atoms	120
	5.4	Pauli's exclusion principle and the electronic structures of heavy atoms	123
	5.5	The Periodic Table	129
	5.6	Summary of Section 5	131

6	Light from atoms and lasers	131
6.1	Introduction	131
6.2	Line spectra of sodium	132
6.3	Line spectra of helium	135
6.4	Light from lasers	137
6.5	Absorption and emission of light	137
7	Closing items	142
<b>Chapter 4 The interpretation of quantum mechanics</b>		<b>146</b>
1	Formalism vs. interpretation	146
2	Description and prediction in quantum mechanics	147
2.1	Quantum systems	147
2.2	States and observables	148
2.3	Eigenstates and eigenvalues	153
2.4	Superposition states	155
2.5	A first look at interpretation	158
2.6	Summary of Section 2	161
3	Measurement in quantum mechanics	161
3.1	The nature and effect of a measurement	162
3.2	Measurement and time evolution	164
3.3	Schrödinger's cat and Wigner's friend	165
3.4	A second look at interpretation	168
4	Non-locality and realism in quantum mechanics	169
4.1	The Bohr–Einstein debate	170
4.2	The Einstein–Podolsky–Rosen argument	172
4.3	Bell's theorem	175
4.4	A third look at interpretation	177
5	Closing items	180
<b>Chapter 5 Consolidation and skills development</b>		<b>183</b>
1	Introduction	183
2	Overview of Chapters 1 to 4	183
3	How to find out more physics	188
3.1	Different notations and conventions	188
3.2	Printed media	189
3.3	Libraries	190
3.4	The Internet	191
3.5	What sources do you believe? The authority problem	192
4	Basic skills and knowledge test	193
5	Interactive questions	195
6	<i>Physica</i> problems	196
<b>Answers and comments</b>		<b>197</b>
<b>Suggestions for further reading</b>		<b>216</b>
<b>Acknowledgements</b>		<b>217</b>
<b>Index</b>		<b>218</b>