

Contents: Unit Q

Particles Behave Like Waves

About the Author

Preface

Introduction for Students

Chapter Q1

Wave Models

	Chapter Overview	
Q1.1	What Is a Wave?	
Q1.2	A Sinusoidal Wave Model	
Q1.3	The Phase Speed of a Sinusoidal Wave	
Q1.4	Sound	
Q1.5	Energy in Waves	
Q1.6	The Doppler Effect	
	TWO-MINUTE PROBLEMS	
	HOMEWORK PROBLEMS	
	ANSWERS TO EXERCISES	

Chapter Q2

Standing Waves and Resonance

	Chapter Overview	
Q2.1	The Superposition Principle	
Q2.2	Reflection	
Q2.3	Standing Waves	
Q2.4	Resonance	
	TWO-MINUTE PROBLEMS	
	HOMEWORK PROBLEMS	
	ANSWERS TO EXERCISES	

Chapter Q3

Interference and Diffraction

	Chapter Overview	
Q3.1	Two-Dimensional Waves	

viii	Q3.2	Simple Diffraction	37
	Q3.3	Two-Slit Interference	37
ix	Q3.4	Two-Slit Interference of Light	40
	Q3.5	Diffraction Revisited	44
xvi	Q3.6	Optical Resolution	46
		TWO-MINUTE PROBLEMS	48
		HOMEWORK PROBLEMS	48
		ANSWERS TO EXERCISES	51

2

2

2

4

6

8

11

12

13

15

15

17

18

18

18

20

21

24

26

30

31

33

34

34

34

36

Chapter Q4

The Particle Nature of Light

	Chapter Overview	52
Q4.1	A Short History of Light	54
Q4.2	The Photoelectric Effect	55
Q4.3	Idealized Photoelectric Experiments	55
Q4.4	Predictions of the Wave Model	57
Q4.5	Confronting the Facts	58
Q4.6	The Photon Model of Light	59
Q4.7	Detecting Individual Photons	63
	TWO-MINUTE PROBLEMS	64
	HOMEWORK PROBLEMS	65
	ANSWERS TO EXERCISES	67

Chapter Q5

The Wave Nature of Particles

	Chapter Overview	68
Q5.1	Subatomic Particles as Particles	70
Q5.2	The de Broglie Hypothesis	71
Q5.3	Preparing an Electron Beam	72
Q5.4	The Davisson–Germer Experiment	73
Q5.5	Modern Interference Experiments	75
Q5.6	Interference a Quanton at a Time	78
Q5.7	Implications	80
	TWO-MINUTE PROBLEMS	82
	HOMEWORK PROBLEMS	83
	ANSWERS TO EXERCISES	85

Chapter Q6	86	Q9.3	The Collapse of the Wavefunction	141
Spin	86	Q9.4	The Heisenberg Uncertainty Principle	142
		Q9.5	The Rules Explain Two-Slit Interference	144
			TWO-MINUTE PROBLEMS	146
			HOMEWORK PROBLEMS	147
			ANSWERS TO EXERCISES	149
Chapter Overview	86			
Q6.1 Introduction to Spin	88			
Q6.2 Introduction to the Stern–Gerlach Experiment	89			
Q6.3 Gyroscopic Precession	91			
Q6.4 The Stern–Gerlach Experiment	92			
Q6.5 Spin Experiments	93			
Q6.6 Spin Is Genuine Angular Momentum	96			
TWO-MINUTE PROBLEMS	98			
HOMEWORK PROBLEMS	99			
ANSWERS TO EXERCISES	101			
Chapter Q7	102	Chapter Q10	150	
The Rules of Quantum Mechanics	102	Simple Quantum Models	150	
Chapter Overview	102	Chapter Overview	150	
Q7.1 The Game of Quantum Mechanics	104	Q10.1 An Introduction to Bound Systems	152	
Q7.2 The Playing Pieces and the Goal	105	Q10.2 Energy Eigenfunctions	153	
Q7.3 The Mathematics of Quantum Mechanics	106	Q10.3 A Quanton in a Box	154	
Q7.4 The Rules	107	Q10.4 The Bohr Model of the Hydrogen Atom	156	
Q7.5 Questions and Answers	113	Q10.5 The Simple Harmonic Oscillator	159	
Q7.6 Examples	114	TWO-MINUTE PROBLEMS	162	
TWO-MINUTE PROBLEMS	116	HOMEWORK PROBLEMS	163	
HOMEWORK PROBLEMS	117	ANSWERS TO EXERCISES	165	
ANSWERS TO EXERCISES	119			
Chapter Q8	120	Chapter Q11	166	
Quantum Weirdness	120	Spectra	166	
Chapter Overview	120	Chapter Overview	166	
Q8.1 Introduction	122	Q11.1 Energy-Level Diagrams	168	
Q8.2 The EPR Argument	122	Q11.2 The Spontaneous Emission of Photons	168	
Q8.3 Bell’s Theorem	124	Q11.3 Spectral Lines	169	
Q8.4 Superposition and Schrödinger’s Cat	128	Q11.4 Absorption Lines	170	
Q8.5 The Collapse Problem	129	Q11.5 The Pauli Exclusion Principle	172	
TWO-MINUTE PROBLEMS	132	Q11.6 Conductors and Semiconductors	175	
HOMEWORK PROBLEMS	132	TWO-MINUTE PROBLEMS	178	
ANSWERS TO EXERCISES	133	HOMEWORK PROBLEMS	179	
		ANSWERS TO EXERCISES	181	
Chapter Q9	134	Chapter Q12	182	
The Wavefunction	134	The Schrödinger Equation	182	
Chapter Overview	134	Chapter Overview	182	
Q9.1 Vectors to Wavefunctions	136	Q12.1 Generalizing the de Broglie Relation	184	
Q9.2 Wavefunctions and Position Probability	139	Q12.2 Local Wavelength	185	
		Q12.3 Finding the Schrödinger Equation	186	
		Q12.4 Solving the Equation Numerically	187	
		Q12.5 Using SchroSolver	188	
		Q12.6 Sketching Energy Eigenfunctions	191	
		Q12.7 Tunneling	193	
		TWO-MINUTE PROBLEMS	196	
		HOMEWORK PROBLEMS	197	
		ANSWERS TO EXERCISES	199	

Chapter Q13**Introduction to Nuclei**

	Chapter Overview	200
Q13.1	Introduction to Nuclear Structure	202
Q13.2	The Size of the Nucleus	203
Q13.3	The Strong Interaction	204
Q13.4	Binding Energy and Mass	205
Q13.5	Questions about Nuclear Stability	210
Q13.6	A Historical Overview of Radioactivity	211
	TWO-MINUTE PROBLEMS	213
	HOMEWORK PROBLEMS	213
	ANSWERS TO EXERCISES	215

200**200**

QA.3	The Spin Observable S_y	256
QA.4	The Time Evolution Rule	258
QA.5	An Application: Spins in a Magnetic Field	260
QA.6	Momentum Eigenfunctions	262
	TWO-MINUTE PROBLEMS	264
	HOMEWORK PROBLEMS	264
	ANSWERS TO EXERCISES	267

Index 268

Periodic table 287

Short Answers to Selected Problems 288

Chapter Q14**Nuclear Stability**

	Chapter Overview	216
Q14.1	The Weak Interaction	218
Q14.2	Why $Z \approx N$	219
Q14.3	Why $N > Z$ for Large Nuclei	221
Q14.4	Beta Decay	222
Q14.5	Alpha Decay	223
Q14.6	Gamma Decay	227
	TWO-MINUTE PROBLEMS	228
	HOMEWORK PROBLEMS	229
	ANSWERS TO EXERCISES	231

216**216****Chapter Q15****Nuclear Technology**

	Chapter Overview	232
Q15.1	The Penetrating Ability of Radiation	234
Q15.2	The Biological Effects of Radiation	235
Q15.3	Applications of Radioactive Nuclei	237
Q15.4	Introduction to Nuclear Energy	240
Q15.5	Fission	241
Q15.6	Fusion	245
	TWO-MINUTE PROBLEMS	248
	HOMEWORK PROBLEMS	249
	ANSWERS TO EXERCISES	251

232**232****Appendix QA****Complex Numbers**

	Appendix Overview	252
QA.1	Introduction to Complex Numbers	254
QA.2	The Complex Exponential	255

252**252**