# Contents

**Preface**

**1. What Is Quantum Mechanics?** **1**
1.1. Introduction . . . . . 1
1.2. Spooky Action at a Distance . . . . . 2
1.3. The Double-Slit Experiment . . . . . 3
1.4. Heisenberg's Uncertainty Principle . . . . . 6
1.5. Schrödinger's Cat . . . . . 7
1.6. Interpreting Quantum Mechanics . . . . . 8
1.7. Quantum Horizons . . . . . 9
1.8. What Makes Quantum Mechanics Hard? . . . . . 10
1.9. Summary . . . . . 11

**2. Planck's Act of Desperation** **13**
2.1. Introduction . . . . . 13
2.2. Classical Physics . . . . . 13
2.3. Blackbody Radiation . . . . . 14
2.4. Planck's Inspired Guesswork . . . . . 16
2.5. Counting Standing Waves . . . . . 17
2.6. The Ultraviolet Catastrophe . . . . . 19
2.7. The Boltzmann Distribution . . . . . 22
2.8. An Act of Desperation . . . . . 22
2.9. Summary . . . . . 28

**3. Einstein's Unreasonable Reality** **29**
3.1. Introduction . . . . . 29
3.2. Quantum Filters . . . . . 30
3.3. Single Photons . . . . . 32
3.4. The Inverse Quantum Zeno Effect . . . . . 36
3.5. The Short Version . . . . . 38
3.6. Counting Photon Pairs: Bell's Inequality . . . . . 38
3.7. The Hidden-Variable Hypothesis . . . . . 42
3.8. Summary . . . . . 48

**4. Waves of Light and Matter** **49**
4.1. Introduction . . . . . 49
4.2. Matter Waves . . . . . 49
4.3. Heisenberg's Uncertainty Principle . . . . . 51
4.4. Diffraction . . . . . 52
4.5. Diffraction and Uncertainty . . . . . 55
4.6. Atomic Models . . . . . 60
4.7. Bohr's Model . . . . . 62
4.8. Quantised Matter Waves . . . . . 67
4.9. Summary . . . . . 68

**5. The Double-Slit Experiment** **69**
5.1. Introduction . . . . . 69
5.2. Interference in Light and Water . . . . . 71
5.3. Flying Clocks and Oscillators . . . . . 73
5.4. The Travelling Wave . . . . . 75
5.5. Real Interference . . . . . 77
5.6. Complex Interference . . . . . 80
5.7. What Is Seen in Light and Water . . . . . 84
5.8. Which Slit for Which Photon? . . . . . 84
5.9. Wheeler's Delayed-Choice Experiment . . . . . 85
5.10. Summary . . . . . 88

**6. Schrödinger's Wave Equation** **89**
6.1. Introduction . . . . . 89
6.2. Quantum Guitar Strings . . . . . 89
6.3. The Classical Wave Equation . . . . . 91
6.4. Stationary Classical Waves . . . . . 92
6.5. Schrödinger's Wave Equation . . . . . 95
6.6. Wavefunctions in a Box . . . . . 99
6.7. Wavefunctions in a Hydrogen Atom . . . . . 102
6.8. Summary . . . . . 104

**7. Quantum Interpretations** **105**
7.1. Introduction . . . . . 105
7.2. The Copenhagen Interpretation . . . . . 105
7.3. Objective Collapse Theories . . . . . 107
7.4. Bohmian Mechanics . . . . . 107
7.5. The Many-Worlds Interpretation . . . . . 108
7.6. The von Neumann–Wigner Interpretation . . . . . 108
7.7. Summary . . . . . 108

**8. A History of Quantum Mechanics** **109**

**Further Reading** **115**

**A. Glossary** **117**

**B. Mathematical Symbols** **121**

**C. The Boltzmann Distribution** **123**

**D. Complex Numbers** **129**

**E. Pioneers of Quantum Mechanics** **131**

**F. Fourier Optics and Heisenberg** **133**

**G. Wavefunctions and PDEs** **139**

**H. Key Equations** **141**

**References** **143**

**Index** **145**