Interpreting Quantum Mechanics

This novel text directly addresses common claims and misconceptions around quantum mechanics and presents a fresh and modern understanding of this fundamental and essential physical theory. It begins with a non-mathematical introduction to some of the more controversial topics in the foundations of quantum mechanics. For those more familiar with the theoretical framework of quantum mechanics, the text moves on to a general introduction to quantum field theory, followed by a detailed discussion of cutting-edge topics in this area such as decoherence and spontaneous coherence. Several important philosophical problems in quantum mechanics are considered, and their interpretations are compared, notably the Copenhagen and many-worlds interpretations. The inclusion of frequent real-world examples, such as superconductors and superfluids, ensures the book remains grounded in modern research. This book will be a valuable resource for students and researchers in both physics and the philosophy of science interested in the foundations of quantum mechanics.

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Modern Foundations

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Oh, the depth of the riches and wisdom and knowledge of God!
How unsearchable are his judgments and how inscrutable his ways!
—Romans 11:33

Contents

Preface *page* xii

Part I A Nonmathematical Exposition of Quantum Mechanics and Quantum Field Theory 1

1 It's All Fields and Waves 3
1.1 Fields 3
1.2 Waves 9
1.3 Basic Wave Effects 11
1.4 The Return of the Ether 16

2 How Fields Generate Particles 18
2.1 Field Resonances 18
2.2 Two Types of Quantization 20
2.3 Resonances as Particles 23
2.4 Bosons and Fermions 25
2.5 A Wave Can Be a Very Solid Thing 27
2.6 . . . And a Solid Can Be a Very Wavy Thing 28
2.7 Dirac's Beautiful Theory 30
2.8 Are Particles Real? 32

3 Jumpy Detectors 35
3.1 Atoms and Natural Length Scales 35
3.2 Electron Jumps 37
3.3 The Photoelectric Effect 42
3.4 Avalanche Detectors, Measurement, and Randomness 43
3.5 The Uncertainty Principle 45

4 Nonlocality 48
4.1 Correlation Experiments 48
4.2 Why Physicists Want to Preserve Relativity 51
4.3 One Explanation That Won't Work: The Local Hidden-Variables Hypothesis 52

4.4 The Copenhagen Interpretation 55
4.5 Are Fields Real? 58

5 Alternative Interpretations of Quantum Mechanics 62
5.1 The Many-Worlds Hypothesis 62
5.2 Bohmian Pilot Waves 67
5.3 Variants of Positivism 69
5.4 Spontaneous Collapse 71

6 Decoherence and Collapse 75
6.1 Unitary Theories Will Not Work 75
6.2 Decoherence 77
6.3 Environmentally Induced Selection 80
6.4 Quantum Trajectories and Spontaneous Collapse 82
6.5 Quantifying Spontaneous Collapse 85
6.6 Living with Nonlocality 88

7 Quantum Mechanics and Our View of Reality 93
7.1 The Tao of Copenhagen 93
7.2 Free Will and Quantum Mechanics 98
7.3 Can Quantum Fluctuations Create Something from Nothing? 101
7.4 Spontaneous Symmetry Breaking 104
7.5 Did We Create Ourselves? 108

8 Quantum Mechanics and Technology 111
8.1 Quantum Mechanics in Your Pocket: Computer Chips and Nanotechnology 111
8.2 Tunneling, Radioactivity, and Quantum Biology 115
8.3 Quantum Cryptography 117
8.4 Quantum Information Processing 120
8.5 Lasers, Superfluids, and Superconductors 123

Key Points 128

Part II Basic Results of Quantum Mechanics 131

9 Schrödinger Equation Calculations 133
9.1 Wave Equations 133
9.2 Quantum Confinement Energy: Why Nanometers are Important 136
9.3 Fermi Pressure in Solids: Why are Solids Solid? 137
9.4 Vibration of Atoms: The Simple Harmonic Oscillator Model 139
9.5 Unit Analysis of Atomic States 141
9.6 Universal Conductance in Quantum Wires 144

10 Comparing Classical and Quantum Systems 147
10.1 Derivation of the Planck Spectrum 147
10.1.1 Planck's Derivation in Terms of Particle Statistics 148
10.1.2 Derivation Using Quantum Field Theory 149
10.2 Classical Chaos Theory 150
10.3 Quantum and Classical Entanglement 152

Part III A Short Course in Quantum Field Theory 155

11 Preliminary Mathematics 157
11.1 Dirac Wave Notation 157
11.2 General Properties of Operators 159
11.3 Operators and Measurements 163
11.4 The Schrödinger Equation 165
11.5 The Uncertainty Principle 167
11.5.1 Fourier Analysis 167
11.5.2 Derivation of the Uncertainty Relationship 170

12 Boson Quantization 173
12.1 The Harmonic Oscillator 173
12.1.1 Derivation of Harmonic Oscillator States 173
12.1.2 Basic Rules for Particle Operators 175
12.2 Phonon Quantization 176
12.2.1 Derivation of Phonon Properties 176
12.2.2 Basic Rules for Phonons 179
12.2.3 Spatial Field Operators 180
12.3 The Thermodynamic Limit in Quantum Field Theory 183
12.4 Photon Quantization 185
12.4.1 Derivation of Photon Properties 185
12.4.2 Basic Rules for Photons 187
12.5 Coherent States of Bosons 188
12.5.1 Time Dependence of a Coherent State 188
12.5.2 Number-Phase Uncertainty and Coherent States 190

13 Fermion Quantization 192
13.1 Fermion Field Operators 192
13.1.1 Quantum Field Hamiltonians 192
13.1.2 Visualizing the Fermion Field 193
13.1.3 Fermion Spatial Field Operators 196
13.2 The Dirac Fermion Field 197
13.2.1 Derivation of the Dirac Equation 197
13.2.2 The Dirac Equation and Spin 199

14 Transition Rules 201
14.1 Fermi's Golden Rule 201
14.1.1 Derivation of Fermi's Golden Rule 201
14.1.2 Fermi's Golden Rule and Quantum Statistics 204
14.2 Interaction Terms 205
14.2.1 Electron–Phonon Interactions 205
14.2.2 Electron–Photon Interactions 207
14.2.3 Other Interactions 209
14.3 Optical Transitions 210
14.3.1 Derivation of the Bloch Equations for a Two-Level System 210
14.3.2 The Bloch Vector Representation 212
14.4 Single-Photon Transitions and Fermi's Golden Rule 214
14.5 Nonlinear Optics and Nonunitarity 216

15 Feynman Diagrams 219
15.1 The Expansion of the S-Matrix 219
15.1.1 Justification of Wick's Theorem 221
15.1.2 Green's Functions 222
15.1.3 Example: S-Matrix for a Boson-Mediated Interaction 223
15.2 Diagram Rules for Feynman Theory 226
15.3 How to Interpret Feynman Diagrams 229
15.3.1 Example: Vacuum Energy 229
15.3.2 Example: Self-Energy 230
15.3.3 Example: Nonlinear Optics in Vacuum 232

Part IV Mathematical Considerations of Philosophy of Quantum Mechanics 235

16 Mathematical Considerations of Quantum Interpretations 237
16.1 The Local Hidden-Variables Hypothesis 237
16.1.1 Quantum Wave States of the EPR Experiment 237
16.1.2 Bell's Inequality 240
16.2 The Many-Worlds Hypothesis 242
16.2.1 The Spectral Weight Problem 243
16.2.2 The Many-Worlds Hypothesis and Nonlocality 245
16.2.3 Many-Worlds and Spontaneous Symmetry Breaking 247
16.3 Bohmian Hydrodynamics 248
16.3.1 Derivation of the Bohmian Flow Equations 249
16.3.2 Comparison of Quantum Field Theory and Bohmian Particles in a Standing Wave 250
16.4 The Transactional Interpretation 251
16.4.1 Are There Advanced Waves in Quantum Field Theory? 251
16.4.2 Is There Nonunitarity in Quantum Field Theory? 253

17 Entanglement in a Classical System 255
17.1 An Optical System with Second Quantization 255
17.2 Entangled States of a Resonator 259
17.3 Bell Inequality for the Classical Resonator 260

Part V Decoherence, Spontaneous Coherence, and Spontaneous Collapse 265

18 Irreversibility in Unitary Quantum Field Theory 267
18.1 The Poincaré Recurrence Theorem 267
18.2 The Quantum Boltzmann Equation 269
18.2.1 Derivation of the Quantum Boltzmann Equation for a Many-Particle System 269
18.2.2 Quantum Boltzmann Equation for an Interacting Gas 272
18.3 Experimental Verification of the Quantum Boltzmann Equation 273
18.4 Proof of the Quantum H-Theorem 275

19 Decoherence in Quantum Field Theory 278
19.1 Density Matrix Formalism 278
19.2 Correlation Functions in Quantum Field Theory 280
19.3 Time-Evolution Equations for Correlation Functions of a Many-Particle System 281
19.4 Quantum Trajectories 285
19.4.1 Derivation of the Time-Evolution Equations for the Density Matrix 285
19.4.2 The Quantum Trajectories Recipe 290

20 Proposed Model for Spontaneous Collapse of Fermion States 292
20.1 Hypothesis of Nonunitary Behavior of Quantum Fields 292
20.2 Action on Superposition States 294
20.3 Implementation in Quantum Field Theory 295
20.4 Comparison to Weak Measurement Theory 297
20.5 Relativistic Considerations 299

21 Spontaneous Coherence: Lasers, Superfluids, and Superconductors 303
21.1 Spontaneous Coherence 303
21.2 Why Phase Coherence Leads to “Super” Behavior 306
21.3 Superconductors and Superfluids are the Same Thing 308
21.4 Lasers Also Involve Spontaneous Symmetry Breaking 312

Appendix A Summary of quantum interpretations 317
Index 321

Preface

The overall premise of this book is that, while quantum mechanics is strange in some ways, it is far less strange than you probably think. Most of the intuition you need to understand quantum mechanics can be drawn from your intuition about water waves.

Much of this book is aimed at bringing the discussion of quantum mechanics up to the present day in regard to what quantum physicists know. This will include a fair amount of "debunking" of claims made in the past about quantum mechanics that even many physicists today assume are true. For example, the Planck radiation spectrum and the photoelectric effect have nothing to do with proving that particles exist as localized little objects, as we will see. This book will also include critiques of some widely held interpretations of quantum mechanics.

When the modern understanding is taken into account, much of the strangeness of quantum mechanics disappears, but not all of it. There are some truly strange results, and most of these involve *nonlocality*, the apparent effect that things in one place can affect things far away without any signal (that we know of) traveling from one place to the other. There are also open questions, such as whether the randomness we see is the result of tiny, but real, fluctuations not presently accounted for by the equations of quantum mechanics.

This book can be read at several levels. Part I requires no mathematical knowledge, and gives the overall perspective of this book. I strongly encourage advanced readers not to skip this part, because it includes many new perspectives on what we think we know about quantum mechanics. Part II requires only introductory college math, and works out some basic examples relevant to Part I.

A major contention of this book is that the proper way to start thinking about all philosophy of quantum mechanics is with quantum field theory. But many philosophers and even many physicists never study quantum field theory, because it is assumed to be a very high-level theory understandable only to a few experts. Part III of this book gives an introduction to all of the essential elements of quantum field theory needed to think about the philosophy properly. This section starts at the beginning but will be most suited for people who have already taken at least one upper-level course on quantum mechanics.

While most of the philosophy of quantum mechanics can be discussed without math, there are some arguments that require math. Part IV is a supplement to Part I that gives specific mathematical arguments relevant to the philosophical interpretations under debate.

Finally, Part V presents advanced theory of decoherence, to which I and my coworkers have made original contributions in the literature. This material is appropriate for students who have taken graduate quantum mechanics and quantum field theory or quantum optics classes. Some of the results, however, are accessible to people with less training, if they are willing to skip over the proofs.

I have talked with too many people over the years about quantum philosophy to properly thank them all. Particular discussions that come to mind are those with Harvey Brown, Časlav Brukner, Erica Carlson, Andrew Daley, Steve Girvin, Bob Griffiths, Richard Jones, Andrew Jordan, Ruth Kastner, Tony Leggett, Roger Mong, John Norton, John Sipe, Fernando Sols, David Wallace, Peter Zoller, and Wojciech Zurek. I also thank all of the graduate students at the University of Pittsburgh who endured the philosophical tangents in my classes, and my wife Sandra for her constant support.

Soli Deo Gloria