

# Contents

**Preface — VII**

**Foreword — XV**

## **1 Introduction — 1**

- 1.1 The 7 basic rules of quantum mechanics — 1
- 1.2 Interpretations of quantum mechanics — 3
- 1.3 Quantum magic — 5
- 1.4 Coherent quantum physics — 8
- 1.5 Overview to Part I — 10
- 1.6 Overview to Part II — 11
- 1.7 Overview to Part III — 12

## **Part I: Mathematical concepts for quantum physics**

### **2 Basic quantum physics — 17**

- 2.1 Axioms for the formal core of quantum physics — 17
- 2.2 The Ehrenfest picture of quantum mechanics — 19
- 2.3 The classical approximation — 23
- 2.4 The Rydberg–Ritz combination principle — 25
- 2.5 The pure state idealization — 27
- 2.6 Schrödinger equation and formal Born rule — 28

### **3 Uncertainty, statistics, probability — 31**

- 3.1 Uncertainty — 31
- 3.2 Expectations as properties of anonymous events — 34
- 3.3 Classical probability via expectation — 35
- 3.4 Description dependence of probabilities — 39
- 3.5 The stochastic description of a deterministic system — 41
- 3.6 Deterministic and stochastic aspects of q-expectations — 42
- 3.7 What is probability? — 45

### **4 Euclidean spaces — 47**

- 4.1 Euclidean spaces and their antidual — 47
- 4.2 Norm and completion of a Euclidean space — 50
- 4.3 Linear mappings between Euclidean spaces — 53

4.4	Functions of positive type —	54
4.5	Constructing functions of positive type —	56
4.6	The Moore–Aronszajn theorem —	59
4.7	Reproducing kernel Hilbert spaces and Mercer’s theorem —	61
4.8	Theorems by Bochner and Kreĭn —	62
4.9	Theorems by Schoenberg and Menger —	64
4.10	The Berezin–Wallach set —	66
<b>5</b>	<b>Coherent spaces —</b>	<b>69</b>
5.1	Motivation for coherent spaces —	69
5.2	Coherent spaces —	70
5.3	Quantum spaces —	72
5.4	Length, angle, distance —	75
5.5	Vectors in the augmented quantum space —	77
5.6	New states from old ones —	78
5.7	Some examples —	79
5.8	Normal, projective, and nondegenerate coherent spaces —	83
5.9	Symmetries —	88
5.10	Uses of coherent spaces —	90
<b>6</b>	<b>Coherent quantum physics —</b>	<b>93</b>
6.1	The coherent action principle —	93
6.2	Systems with classical and quantum view —	94
6.3	Quantization and the dynamics of q-observables —	97
6.4	Relations to geometric quantization —	100
6.5	Lie $\ast$ -algebras —	102
6.6	Quantities, states, uncertainty —	103
6.7	Examples —	106
6.8	Coherent chaos —	107
6.9	Dynamical Lie algebras —	109
<b>7</b>	<b>Quantum field theory and quantum statistical mechanics —</b>	<b>113</b>
7.1	Fields and their dynamics —	114
7.2	Coherent spaces for quantum field theory —	116
7.3	Observability in quantum field theory —	119
7.4	Currents —	121
7.5	Coarse-graining —	123
7.6	Gibbs states —	124
7.7	Nonequilibrium statistical mechanics —	126
7.8	Conservative mixed quantum-classical dynamics —	129
7.9	Important examples of quantum-classical dynamics —	131
7.10	Koopman’s representation of classical statistical mechanics —	132

## Part II: The interpretation of quantum physics

<b>8</b>	<b>Requirements for good foundations — 135</b>
8.1	Interpreting the formal core — 135
8.2	The interpretation of mature theories — 137
8.3	Is quantum physics a mature theory? — 141
8.4	Objective properties — 144
8.5	The universe as a quantum system — 146
8.6	A classical view of the qubit — 147
<b>9</b>	<b>The thermal interpretation of quantum physics — 151</b>
9.1	A reinterpretation of the tradition — 151
9.2	The thermal interpretation — 153
9.3	The interpretation of quantum-classical systems — 160
9.4	Advantages of the thermal interpretation — 161
9.5	Open problems — 163
<b>10</b>	<b>Measurement — 165</b>
10.1	Objective properties and their measurement — 165
10.2	Physical systems and their states — 167
10.3	A single qubit as a subsystem of the universe — 168
10.4	The emergence of Born's rule — 170
10.5	Relations to decoherence — 174
10.6	Measurement errors — 175
10.7	What should be the true value? — 178
<b>11</b>	<b>Measurement devices — 181</b>
11.1	Measurement protocols — 182
11.2	Statistical and deterministic measurements — 184
11.3	Macroscopic systems and deterministic instruments — 187
11.4	Statistical instruments — 189
11.5	Probability measurements — 190
11.6	Chaos, randomness, and quantum measurement — 193
11.7	The statistical mechanics of definite, discrete events — 195
11.8	Dissipation, bistability, and Born's rule — 198
<b>12</b>	<b>Particles — 201</b>
12.1	The photoelectric effect — 202
12.2	Particle tracks — 204
12.3	How real are particles? — 206
12.4	Particles from quantum fields — 208
12.5	Fock space and particle description — 209

- 12.6      Physical particles in interacting field theories — **210**
- 12.7      Semiclassical approximation and geometric optics — **211**
  
- 13      Some quantum experiments — 215**
- 13.1      Quantum buckets and time-resolved events on a screen — **215**
- 13.2      Particle decay — **216**
- 13.3      The Stern–Gerlach experiment in terms of currents — **218**
- 13.4      The Stern–Gerlach experiment in terms of particles — **220**
- 13.5      Relativistic causality — **222**
- 13.6      Nonlocal correlations and conditional information — **223**

### **Part III: Appendix: Critique of the tradition**

- 14      A critique of Born’s rule — 229**
- 14.1      Early, measurement-free formulations of Born’s rule — **230**
- 14.2      Formulations of Born’s rule in terms of measurement — **232**
- 14.3      Limitations of Born’s rule — **235**
  
- 15      Pure states and mixed states — 239**
- 15.1      What is a state? — **239**
- 15.2      The nature of mixed state? — **241**
- 15.3      What is an ensemble? — **243**
- 15.4      Pure states in quantum field theory — **244**
  
- 16      Traditional interpretations — 247**
- 16.1      A classification of interpretations — **248**
- 16.2      The Copenhagen interpretation — **249**
- 16.3      The minimal statistical interpretation — **253**

**Bibliography — 257**

**Authors — 271**

**Index — 275**