

# Contents

## 1. Evolution of Quantum Theory

By W. Schommers .....	1
1.1 Classical Pictures of Reality .....	1
1.1.1 Mythological and Intellectual Pictures .....	1
1.1.2 Mechanistic View of the World .....	2
1.2 From Classical to Quantum Mechanics .....	6
1.2.1 Planck's Constant .....	7
1.2.2 Einstein's Picture of Light .....	11
1.2.3 The Structure of Atoms .....	12
1.2.4 Matter Waves, Schrödinger's Wave Equation, and Matrix Mechanics .....	17
1.2.5 Born's Probability Interpretation .....	25
1.2.6 Uncertainty .....	28
1.2.7 The Principle of Complementarity .....	30
1.3 Theories of Measurement: Brief Remarks .....	31
1.3.1 Objectivity .....	31
1.3.2 The Measurement Problem .....	32
1.3.3 Theories of Measurement: Final Comments .....	38
1.4 Summary .....	39
Appendix 1.A. Classical Mechanics: Some Basic Remarks .....	41
1.A.1 The Principle of Least Action and Lagrange's Equations ..	41
1.A.2 Newton's Equations .....	42
1.A.3 Hamilton's Equations .....	43
1.A.4 The Hamilton-Jacobi Equations .....	44
Appendix 1.B. The Relation Between Schrödinger's Equations and Classical Mechanics .....	46
References .....	47

## 2. The EPR Paradox. Roots and Ramifications

By P. H. Eberhard (With 4 Figures) .....	49
2.1 A Debate Lasting More Than Fifty Years .....	49
2.1.1 Are There Faster-Than-Light Effects in Quantum Phenomena?	49
2.1.2 Einstein's Point of View .....	51
2.1.3 Dissenting Voices .....	54
2.1.4 The Verdict of Experiment .....	56
2.2 A Far-Reaching Argument .....	58

2.2.1	Example of an EPR-Bohm Experiment .....	58
2.2.2	How to Compute the Predictions in Quantum Theory ....	62
2.2.3	Reality and Lorentz Invariance .....	65
2.2.4	Bell's Theorem .....	68
2.2.5	Analogy with a Spy Story .....	71
2.3	A Sample of Possible Solutions .....	74
2.3.1	Experimental Loopholes .....	74
2.3.2	Giving up on Conventional Concepts of Reality .....	76
2.3.3	Fundamental Space-Time Restframes .....	78
2.3.4	How a Model with Rudimentary Locality Can Work .....	80
2.3.5	Conclusions .....	85
	References .....	87

**3. Nonseparability and the Tentative Descriptions of Reality**

	By B. d'Espagnat (With 6 Figures) .....	89
3.1	Introduction .....	89
3.2	Realism and Separability .....	90
3.2.1	Realism .....	90
3.2.2	The Principle of Separability .....	92
3.2.3	Separable "Conception of the World" .....	95
3.3	Separability and Quantum Physics .....	96
3.3.1	Separability and Quantum State .....	96
3.3.2	The Usefulness and Scope of the Statistical Operator Description of States .....	98
3.3.3	How to Prove Nonseparability .....	101
3.3.4	A Few Words of Caution .....	103
3.3.5	Quantum Mechanics Does Not Allow Superluminal Signalling	104
3.4	Disproof of the Principle of Separability .....	105
3.4.1	Derivation of the Bell-CHSH Inequalities .....	106
3.4.2	Relativity and the Bell-CHSH Inequalities .....	111
3.4.3	Other Assumptions Leading to the Bell-CHSH Inequalities	114
3.4.4	The Special Case of Strict Correlations .....	119
3.4.5	The "Principle of Inductive Causality", its Motivation and Function .....	120
3.4.6	The Generality of the Bell Inequalities .....	124
3.5	Counterfactuals and Influences-at-a-Distance .....	126
3.5.1	Strict Implication and Counterfactuals .....	127
3.5.2	A Few Applications for These Concepts .....	129
3.5.3	An Application to the Everett "Relative State" Theory ...	132
3.5.4	In What Sense Can We Speak of Superluminal Propagation of Influences? .....	134
3.5.5	A Nonrelativistic Approach .....	135
3.5.6	What About the Relativistic Case? .....	140
3.6	Some Problems Bearing on Causality .....	142
3.6.1	A Remark on Delayed Choice Experiments .....	142

3.6.2	Remarks on Relativistic Covariance and its Meaning . . . . .	144
3.6.3	On Measurement Time Asymmetry and the Nonexistence of Superluminal Signals . . . . .	145
3.7	Tentative Descriptions of an "Independent Reality" . . . . .	150
3.7.1	Assumption Q Made . . . . .	151
3.7.2	Assumption Q Not Made . . . . .	158
3.8	Conclusion . . . . .	159
	Appendix 3.I. Some Disproved Objections to the Bell Theorem . . . . .	160
	Added Note . . . . .	164
	Appendix 3.II. . . . .	165
	References . . . . .	166
<b>4.</b>	<b>A Realistic Model for Quantum Theory With a Locality Property</b>	
	By P.H. Eberhard (With 4 Figures) . . . . .	169
4.1	Introduction . . . . .	169
4.1.1	Background and Scope . . . . .	169
4.1.2	Basic Features of the Model . . . . .	171
4.1.3	Possible Experimental Evidence . . . . .	172
4.2	Field Theory and Translation-Invariant Operators . . . . .	172
4.2.1	The Density Matrices for the Universe and for an Isolated Quantum System . . . . .	173
4.2.2	Measurement Probabilities and Collapses . . . . .	174
4.2.3	Translation Invariant Operators . . . . .	175
4.2.4	The Translation-Invariant Formalism . . . . .	177
4.2.5	Lorentz Invariance . . . . .	178
4.3	The Model and its Predictions . . . . .	179
4.3.1	Probabilities of Measurement Results . . . . .	180
4.3.2	Equations for Time Evolution . . . . .	181
4.3.3	Collapses of the Quantum Matrix . . . . .	183
4.3.4	Role of the Spatial-Compatibility Condition in Collapses . . . . .	184
4.3.5	Collapses Without Observers . . . . .	186
4.4	Properties Related to Locality . . . . .	187
4.4.1	Invariances and Locality of the Model . . . . .	187
4.4.2	Evolution When $V$ is Not Infinite . . . . .	189
4.4.3	Measurements Well Spaced in Time . . . . .	190
4.4.4	Measurements Closely Spaced in Time . . . . .	192
4.4.5	Isolated Systems . . . . .	194
4.4.6	Superluminous Communication . . . . .	196
4.5	Impact on Measurement Theory . . . . .	199
4.5.1	Locality of Measurement Processes . . . . .	199
4.5.2	Measurements Equated to Acts of Consciousness . . . . .	201
4.5.3	The Spontaneous Measurements Approach . . . . .	203
4.6	Conclusion . . . . .	204
	Appendix 4.A. A Partial Derivative Equation for $\zeta(x, t)$ . . . . .	205
	Appendix 4.B. Conservation of the Spatial-Compatibility Condition . . . . .	207

Appendix 4.C. Generating the Spatial-Compatibility Condition .....	209
Appendix 4.D. Collapses Due to Two Measurements Closely Spaced in Time .....	211
References .....	214
<b>5. Space-Time and Quantum Phenomena</b>	
By W. Schommers (With 1 Figure) .....	217
5.1 Introduction .....	217
5.2 Time-Operator Within Usual Quantum Theory .....	219
5.3 Superoperator Formalism .....	222
5.3.1 Being and Becoming: General Remarks .....	222
5.3.2 Liouvillian Formulation of Quantum Mechanics .....	223
5.3.3 Extension of the Formalism of Classical and Quantum Mechanics .....	225
5.3.4 Superoperator for the Time .....	227
5.3.5 "Picture of Reality" Within the Superoperator Formalism	229
5.4 Space-Time and Quantum Theory: A Formulation in Accordance With Mach's Principle .....	232
5.4.1 Space-Time and Mach's Principle .....	232
5.4.2 Other Spaces .....	233
5.4.3 The Influence of Planck's Constant .....	234
5.4.4 Operators .....	236
5.4.5 Intermediate Spaces .....	239
5.4.6 A New Complementarity .....	240
5.4.7 Determination of $\psi(r, t)$ and $\psi(p, E)$ .....	241
5.4.8 Meaning of the Wave Functions .....	246
5.4.9 Eigenvalues .....	246
5.4.10 The Role of Time .....	247
5.4.11 Being and Becoming .....	251
5.4.12 Particles and Waves .....	255
5.4.13 Wave Function and Measurement .....	256
5.4.14 Remarks Concerning the Superposition Principle .....	258
5.4.15 Reality and Basic Reality .....	261
5.5 Summary and Final Remarks .....	263
Appendix 5.A. On the Second Law of Thermodynamics .....	264
Appendix 5.B. A Non-absolute Space-Time .....	266
Appendix 5.C. On the Uncertainty Relation for Energy and Time ...	273
Appendix 5.D. On the Definition of Being and Becoming .....	275
References .....	276
<b>6. Wave-Particle Duality: Recent Proposals for the Detection of Empty Waves.</b> By F. Selleri (With 16 Figures) .....	279
6.1 Introduction .....	279
6.2 The Einstein-De Broglie Formulation .....	280
6.3 The Copenhagen-Göttingen Formulation of Duality .....	289

6.4 Delayed-Choice Experiments .....	294
6.5 Noteworthy Experimental Facts .....	298
6.6 Empty-Wave Stimulation of Photon Emission .....	303
6.7 Theories of Stimulated Emission .....	308
6.8 Experimental Discriminations .....	316
6.9 Further Experiments for the Detection of Empty Waves .....	320
Note Added in Proof .....	329
References .....	330
Additional References .....	331
<b>Subject Index</b> .....	<b>333</b>