

Contents

Principal Mathematical Symbols Used in This Work	V
Some Universal Constants (SI-units)	XIII

Introductory Remarks	1
-----------------------------	----------

1.	Storing Matter and Dissipating Matter	1
2.	Some Phenomenological Considerations to the Reactions of Matter	2

I Matter as a Conglomeration of Charged Mass Points in the Electromagnetic Field

1.	The Hamiltonian of Charged Particles in the External Field	7
2.	Analysis of the Hamiltonian	9
2.1.	Field Analysis	10
2.2.	The Interaction Terms	12
3.	Multipole Moments	15
3.1.	Dipole, Quadrupole, Octopole Moments	16
3.2.	Permanent and Induced Moments	18
3.3.	Tentative Illustrative and Conceptual Interpretation of the Individual Moments	19

II Microscopic Models, Characteristic Curves, Processes

1.	Models of Matter	22
2.	The Equation of Motion of Charged Particles in the Electromagnetic Field	24
2.1.	Derivation from the Hamiltonian	24
2.2.	Equation of Motion with Purely Electric Fields	25
2.3.	Equation of Motion with Purely Magnetic Fields	26
2.3.1.	The Larmor-Bloch Equation	27
2.3.2.	Modification of the Larmor-Bloch Equation	29
3.	Characteristic Curves	31
3.1.	Electric Characteristic Curves	31
3.1.1.	Dipole Characteristics	31
3.1.1.1.	Oscillator Types	31
3.1.1.2.	Central-field Types	35
3.1.2.	The Quadrupole Characteristic Curve in a Linear System of Matter	38
3.2.	Magnetic Characteristic Curves	39
3.2.1.	Dipole Characteristics	39
3.2.2.	Remarks Concerning Quadrupole Characteristics	41
3.3.	The Derivatives of the Characteristic Curves, Their Frequency Dependence	41
3.4.	Comparison with Well-known and Proven Storage Characteristics; Microscopic and Quasimacroscopic Bonds	45
4.	Survey of the Interaction Processes	46
4.1.	The Calculation of the Mixing	46
4.2.	The Processes	49
4.2.1.	Linear Processes	49
4.2.2.	Quadratic Processes	50
4.2.3.	Cubic Processes	55
5.	Transition to the Discussion in Terms of Quantum Mechanics	61
5.1.	Transfer, with the Help of the Correspondence Principle, of Fourier Coefficients into Matrix Elements	62
5.2.	Conclusions from the Matrices	65

III The Quantum-mechanical Treatment of the Interactions

1.	The General Solution Scheme	68
1.1.	The expectation Values as Theoretical Predictions of Observable Quantities	68

XIV

Contents

1.1.1.	Expectation Values, State Vectors, Operators	68
1.1.2.	The Description of the State	71
1.2.	Determination of the Expectation Values	72
1.2.1.	The Unperturbed Particle System	72
1.2.1.1.	Considerations with the Temporal Variation Neglected	72
1.2.1.2.	The Temporal Variation	76
1.2.2.	Types of Representation	78
1.2.2.1.	Representations of State Vectors, Operators, Expectation Values	78
1.2.2.2.	Transformations	81
1.2.3.	The Perturbed Particle System	83
1.2.3.1.	Perturbed State Vectors and Expectation Values	83
1.2.3.2.	Formulation with Density Matrices	88
1.2.3.3.	Summary and Comparison of the Results	90
2.	Special Steady-state Formulations	95
2.1.	The Perturbed Hamiltonian	95
2.1.1.	Derivation from the Classical Hamiltonian	95
2.1.2.	The Operator of the Perturbation Energy and the Operators of the Moments	96
2.1.3.	The Dynamics of the Perturbation Operator	100
2.2.	Steady-state Expectation Values	102

IV Special Processes I: Static and Quasistatic (off-resonance) Interactions

1.	The Static Expansion Coefficients	106
1.1.	General Considerations Concerning the Solution of the Set of Equations of the Static Expansion Coefficients	106
1.1.1.	Nondegenerate and Degenerate States	107
1.1.2.	Expansion Coefficients of a Two-state System	109
1.1.2.1.	Exact Solution for Nondegenerate and Degenerate States	109
1.1.2.2.	Approximate Solution for Nondegenerate States	113
1.2.	Determination of the General Expansion Coefficients	117
2.	The Static Characteristic Curve	118
2.1.	The Single-field Characteristic Curve and Its Special Form in a Two-state System	118
2.2.	Generalizations and Specializations	125
2.2.1.	The Characteristic Curve with a Number of Single Fields	125
2.2.1.1.	The Two-field Characteristic Curve as a Typical Multifield Characteristic	125
2.2.1.2.	The Tensor Representation	127
2.2.2.	The Quadrupole Characteristic	132
2.3.	Some Interaction Processes	135
3.	Considerations Concerning the Operating Point of Matter	137

V Special Processes II: Dynamic Processes, in Particular Resonance Processes

1.	Single-field Processes	141
1.1.	The Expansion Coefficients and Expectation Values of the Moments	141
1.2.	Linear Processes	143
1.2.1.	Moments and Polarizations	144
1.2.2.	The Linear Process between Two Energy States	144
1.2.2.1.	Polarization and Susceptibility	144
1.2.2.2.	The Power Conversion	148
1.3.	Nonlinear Single-field Processes	158
1.3.1.	Single-field Rectifying Effects	158
1.3.2.	Stimulated Single-field Multiquantum Processes (Transition Processes)	161
1.3.2.1.	Two-quantum Processes	162
1.3.2.2.	Three-quantum Processes	164
1.3.2.3.	Stimulated Single-field Processes for the Generation of Electromagnetic Fields	166
2.	Multifield Processes	167
2.1.	Controllable Processes	167

2.2.	Harmonic Processes	170
2.2.1.	The Second Harmonic	170
2.2.1.1.	Expansion Coefficients	170
2.2.1.2.	The Resonance Moments	171
2.2.2.	The Third Harmonic	174
2.2.2.1.	Expansion Coefficients	174
2.2.2.2.	The Resonance Moments	175
2.2.3.	Special Resonance Polarizations of Harmonic Processes	178
2.2.3.1.	The Resonant Frequency Doubling	179
2.2.3.2.	The Resonant Frequency Tripling	180
2.3.	Mixing Processes	181
2.3.1.	Expansion Coefficients and Expectation Values of the Moments in General	182
2.3.2.	The Resonance Moments of Special Mixing Processes	185
2.3.2.1.	Phase-sensitive Mixing Processes	185
2.3.2.2.	Phase-insensitive Mixing Processes	188
2.3.3.	Special Resonance Polarizations	193
3.	Power Relations of Nonlinear Resonance Processes	197
3.1.	The Process Power Values with Resonant Frequency Doubling and Mixing	197
3.1.1.	The Process Power Values in Frequency Doubling	197
3.1.1.1.	The Power Conversion in the Phase-sensitive Process	197
3.1.1.2.	The Power Conversion in the Related Phase-insensitive Process, the Overall Power Balance	202
3.1.2.	The Process Power Values in Frequency Mixing	203
3.1.2.1.	The Power Conversion in the Phase-sensitive Process at the Lower Side Frequency	203
3.1.2.2.	The Power Conversion in the Phase-insensitive Process at the Lower Side Frequency, the Overall Power Balance	206
3.1.2.3.	The Power Conversion in Mixing Processes at the Upper Side Frequency	206
3.1.3.	Comments on the Results	207
3.2.	General Power Relations of Phase-insensitive Resonance Processes and Determination of Their Transition Probabilities by Way of Phase-sensitive Interactions	208
3.2.1.	The Interpretation of the Phase-insensitive Resonance Processes by Phase-sensitive Interactions	208
3.2.2.	The Power Relations and Transition Probabilities	209
3.2.3.	Some Examples	211
4.	On the Presentation of the Resonance Processes	215

VI Macroscopic Structures

1.	The Generalized Field Equation	218
2.	Structures with Reactions due to the Linear Process	221
2.1.	The Solution of the Elementary Case	221
2.1.1.	The Plane Wave without Aperture Limitations	221
2.1.2.	Wave Propagation in the Absence of Boundary Effects	222
2.1.3.	Wave Propagation in the Presence of Boundary Effects	223
2.1.3.1.	General Description of the Three-layer Structure	223
2.1.3.2.	Amplifiers and Oscillators	230
2.2.	The Solution with Consideration of the Tensor Properties of the Susceptibility	236
2.2.1.	The Simplest Solution	236
2.2.2.	A Special Case	238
3.	Structures with Reactions via Nonlinear Single-field Processes	242
3.1.	The Field Equation	242
3.2.	The Solution	242
3.3.	Discussion of the Solution	244
3.3.1.	Self-focusing Effects	244

3.3.2.	Amplification and Oscillation via Two-quantum Transition Processes	245
4.	Frequency Doubling in Macroscopic Structures	248
4.1.	The Field Equations	248
4.2.	The Solution	249
4.2.1.	The Solution in General and its One-dimensional Specialization	249
4.2.2.	Wave Propagation in the Absence of Boundary Effects	252
4.2.3.	Wave Propagation in the Presence of Boundary Effects	255
4.2.3.1.	The Three-layer Structure and Surface Effects	255
4.2.3.2.	The Reflection Type of the Doubler as an Example	258
5.	Frequency Mixing in Macroscopic Structures	261
5.1.	The Field Equations	261
5.2.	The Solution	263
5.2.1.	The General Solution and a Few Special Cases	263
5.2.2.	Wave Propagation in the Absence of Boundary Effects	269
5.2.2.1.	Loss-free Media	270
5.2.2.2.	Lossy Media	273
5.2.3.	Wave Propagation in the Presence of Boundary Effects	278
5.2.3.1.	The Three-layer Structure	278
5.2.3.2.	Amplifier Arrangements	281
5.3.	Comparison of the Amplification Principles	287

Appendix

1.	The Anharmonic Oscillator as an Example of Electric Dipole Interactions in the Range of Infrared Frequencies	292
1.1.	The Parameters	292
1.1.1.	The Parameters of the Harmonic Oscillator	292
1.1.2.	The Parameters of the Anharmonic Oscillator	293
1.2.	Some Interaction Processes	296
1.2.1.	The Characteristic Curves of the Oscillator Models	296
1.2.1.1.	The Characteristic Curve of the Harmonic Oscillator	297
1.2.1.2.	The Characteristic Curve of the Anharmonic Oscillator	297
1.2.2.	Processes in Numerical Values	298
1.2.2.1.	The Adaptation of the Data	298
1.2.2.2.	The Hydrogen Characteristic Curve	300
1.2.2.3.	Frequency Doubling in Hydrogen	300
2.	The Single Spin as an Example of Magnetic Dipole Interactions in the Microwave Range	302
2.1.	The Parameters	302
2.1.1.	The Parameters in the Presence of Degeneracy	302
2.1.2.	The Parameters with Cancellation of the Degeneracy	303
2.1.3.	The Parameters with Cancellation of the Degeneracy and an Additional Field $H_0 \rightarrow$	303
2.2.	Some Interaction Processes	305
2.2.1.	The Spin Characteristic Curve	306
2.2.2.	Comparison of Static and Dynamic Spin Tensors	307
2.2.3.	Orientation Dependence of Individual Processes	310
2.2.4.	Processes in Numerical Values	312
2.2.4.1.	The Static Characteristic Curve	312
2.2.4.2.	Frequency Doubling in Paramagnetic Media	313
2.2.4.3.	Influence of Resonance Coincidences	315
	Survey of the Historical Evolution	317
	Bibliography	324
	Subject Index	345