

Contents

Part I Introduction to Kinetics and Many-Body Theory

1. Boltzmann Equation	3
1.1 Heuristic Derivation	
of the Semiclassical Boltzmann Equation	3
1.2 Approach to Equilibrium, H-Theorem	5
1.3 Linearization, Eigenfunction Expansion	8
2. Numerical Solutions of the Boltzmann Equation	11
2.1 Linearized Coulomb Boltzmann Kinetics	
of a 2D Electron Gas	12
2.2 Ensemble Monte Carlo Simulation	20
2.2.1 General Theory	20
2.2.2 Simulation of the Relaxation Kinetics	
of a 2D Electron Gas	23
2.3 $N^+N^-N^+$ -Structure: Boltzmann Equation Analysis	30
3. Equilibrium Green Function Theory	35
3.1 Second Quantization	35
3.2 Green Functions	38
3.2.1 Examples of Measurable Quantities	39
3.3 Fluctuation-Dissipation Theorem	41
3.4 Perturbation Expansion of the Green Function	44
3.5 Examples of Simple Solvable Models	46
3.5.1 Free-Particle Green Function	46
3.5.2 Resonant-Level Model	47
3.6 Self-Energy	49
3.6.1 Electron-Phonon Interaction	49
3.6.2 Elastic Impurity System; Impurity Averaging	51
3.7 Finite Temperatures	55

Part II Nonequilibrium Many-Body Theory

4. Contour Ordered Green Functions	59
4.1 General Remarks	59
4.2 Two Transformations	60
4.3 Analytic Continuation	65
5. Basic Quantum Kinetic Equations	71
5.1 The Kadanoff-Baym Formulation	71
5.2 The Keldysh Formulation	73
6. Boltzmann Limit	75
6.1 Gradient Expansion	75
6.2 Quasiparticle Approximation	77
6.3 Recovery of the Boltzmann Equation	78
7. Gauge Invariance	79
7.1 Choice of Variables	79
7.2 Gauge Invariant Quantum Kinetic Equation	81
7.2.1 Driving Term	81
7.2.2 Collision Term	83
7.3 Retarded Green Function	85
8. Quantum Distribution Functions	87
8.1 Relation to Observables, and the Wigner Function	87
8.2 Generalized Kadanoff-Baym Ansatz	88
8.3 Summary of the Main Formal Results	91

Part III Quantum Transport in Semiconductors

9. Linear Transport	95
9.1 Quantum Boltzmann Equation	95
9.2 Linear Conductivity of Electron-Elastic Impurity Systems	98
9.2.1 Kubo Formula	98
9.2.2 Quantum Kinetic Formulation	102
9.3 Weak Localization Corrections to Electric Conductivity	104
10. A Model for Dynamical Disorder:	
The Gaussian White Noise Model	109
10.1 Introduction	109
10.2 Determination of the Retarded Green Function	109

10.3 Kinetic Equation for the GWN	111
10.4 Other Transport Properties	115
11. Quantum High-Field Transport in Semiconductors	119
11.1 Introduction	119
11.2 Free Green Functions and Spectral Functions in an Electric Field	120
11.3 Resonant-Level Model in High Electric Fields	130
11.3.1 Introduction	130
11.3.2 Retarded Green Function: Single Impurity Problem ..	131
11.3.3 Retarded Green Function: Dilute Concentration of Impurities	133
11.3.4 Analytic Continuation	140
11.3.5 Quantum Kinetic Equation	141
11.4 Quantum Kinetic Equation for Electron-Phonon Systems ..	144
11.5 An Application: Collision Broadening for a Model Semiconductor	148
11.5.1 Analytical Considerations	148
11.5.2 A Simple Model: Optical Phonon Emission at $T = 0$	150
11.6 Spatially Inhomogeneous Systems	152
12. Transport in Mesoscopic Semiconductor Structures	157
12.1 Introduction	157
12.2 Nonequilibrium Techniques in Mesoscopic Tunneling Structures	160
12.3 Model Hamiltonian	160
12.4 General Expression for the Current	162
12.5 Non-Interacting Resonant-Level Model	165
12.6 Resonant Tunneling with Electron-Phonon Interactions	168
12.7 Transport Through a Coulomb Island	170
13. Time-Dependent Phenomena	179
13.1 Introduction	179
13.2 Applicability to Experiments	180
13.3 Mathematical Formulation	181
13.4 Average Current	183
13.5 Time-Dependent Resonant-Level Model	184
13.5.1 Response to Harmonic Modulation	187
13.5.2 Response to Step-Like Modulation	190
13.6 Linear-Response	193
13.7 Fluctuating Energy Levels	195

**Part IV Theory of Ultrafast Kinetics
in Laser-Excited Semiconductors**

14. Optical Free-Carrier Interband Kinetics in Semiconductors	199
14.1 Interband Transitions in Direct-Gap Semiconductors	199
14.2 Free-Carrier Kinetics Under Laser-Pulse Excitation	202
14.3 The Optical Free-Carrier Bloch Equations	205
15. Interband Quantum Kinetics with LO-Phonon Scattering	209
15.1 Derivation of the Interband Quantum Kinetic Equations	209
15.2 Approximations for the Green Functions $G_{\mu\nu}^r$ and $G_{\mu\nu}^a$	213
15.3 Intraband Quantum Kinetics	216
15.4 Linear Polarization Kinetics, Phonon Sidebands	218
15.5 Coupled Interband Kinetic Equations in Diagonal Approximation	219
15.6 Numerical Studies	221
16. Exciton Quantum Kinetics in Polar Semiconductors	227
16.1 Interband Quantum Kinetic Equations with Excitonic Effects	227
16.2 Quantum Beats and Urbach Tail	229
16.2.1 LO-Phonon Quantum Beats	229
16.2.2 Urbach Tail Absorption	236
16.3 Excitonic Optical Stark Effect	238
16.4 Coupled Quantum Kinetics of Electrons and Phonons	241
16.5 Quantum Coherence of the Green Functions	244
17. Two-Pulse Excitation	253
17.1 Calculation of the Photon Echo	253
17.2 Calculation of the Four-Wave Mixing Signal	255
17.3 Comparison with Four-Wave Mixing Experiments	258
18. Coulomb Quantum Kinetics in a Dense Electron Gas	261
18.1 Introduction	261
18.2 Derivation of a Closed Quantum Kinetic Description	263
18.3 Simplifying Approximations	268
18.3.1 Initial Time Regime Without Screening and Energy Conservation	268
18.3.2 Time-Dependent Plasmon Pole Approximation	269
18.3.3 Instantaneous Static Potential Approximation	272

19. Interband Coulomb Quantum Kinetics, Optical Dephasing	277
19.1 Interband Quantum Kinetic Equations with Coulomb Interaction	277
19.2 Early Stage of the Coulomb Quantum Kinetics	280
19.3 Quasi-Classical Theory of the Polarization Decay	288
20. The Build-Up of Screening After Ultra-Short Pulse Excitation	293
20.1 The Model	293
20.2 Numerical Results	295
References	301
Subject Index	309