

Contents

<i>Preface</i>	page ix
<i>Acknowledgements</i>	xi
1 Introduction	1
1.1 Nanostructures: The impact	2
1.1.1 Progressing technology	2
1.1.2 Some physical considerations	4
1.2 Mesoscopic observables in nanostructures	8
1.2.1 Ballistic transport	8
1.2.2 Phase interference	11
1.2.3 Universal conductance fluctuations	13
1.2.4 Weak localization	14
1.2.5 Carrier heating in nanostructures	16
1.3 Space and time scales	18
1.4 An introduction to the subsequent chapters	19
1.5 What is omitted	21
2 Quantum confined systems	23
2.1 Nanostructure materials	24
2.2 Quantization in heterojunction system	26
2.2.1 Quantum wells and quasi-two-dimensional systems	27
2.2.2 Coupled wells and superlattices	31
2.2.3 Doped heterojunction systems and self-consistent solutions	34
2.3 Lateral confinement: Quantum wires and quantum dots	39
2.3.1 Nanolithography	39
2.3.2 Quantum wire and quantum dot structures	41
2.4 Electronic states in quantum wires and quantum dots	44
2.5 Magnetic field effects in quantum confined systems	46
2.5.1 Magnetic field in a 2DEG	47
2.5.2 Magnetic field and 1D waveguides: Edge states	51
2.6 Screening and collective excitations in low-dimensional systems	54
2.6.1 Dielectric function in quasi-2D systems	56
2.6.2 Dielectric function in quasi-1D systems	62
2.7 Homogeneous transport in low-dimensional systems	63
2.7.1 Semiclassical transport	64
2.7.2 Relaxation time approximations	66

2.7.3	Elastic scattering mechanisms	68
2.7.4	Lattice scattering	75
2.7.5	Experimental mobility in 2DEG heterostructures	81
2.7.6	Magnetotransport in quantum confined structures	84
3	Transmission in nanostructures	91
3.1	Tunneling in planar barrier structures	92
3.2	Wavefunction treatment of tunneling	96
3.2.1	Single rectangular barrier	97
3.2.2	The double barrier case	104
3.2.3	Tunneling time	111
3.3	Current in resonant tunneling diodes	113
3.3.1	Coherent tunneling	114
3.3.2	Incoherent or sequential tunneling	118
3.3.3	Space charge effects and self-consistent solutions	121
3.4	Landauer formula	124
3.5	The multi-channel case	128
3.6	Quantized conductance in nanostructures	131
3.6.1	Experimental results in quantum point contacts	131
3.6.2	Adiabatic transport model	134
3.6.3	Temperature effects	137
3.6.4	Inhomogeneous effects	138
3.6.5	Nonlinear transport	141
3.7	Transport in quantum waveguide structures	145
3.7.1	Mode-matching analysis	146
3.7.2	Transport through bends	151
3.7.3	Lateral resonant tunneling	153
3.7.4	Coupled waveguides	155
3.8	Lattice Green's function method	156
3.8.1	Single-particle Green's functions	159
3.8.2	Tight-binding Hamiltonian	161
3.8.3	Lattice Green's functions	162
3.8.4	Analytic forms of lattice Green's functions	166
3.8.5	Relation between Green's functions and S-matrix	173
3.8.6	Recursive Green's function method	174
3.8.7	Application to specific geometries	178
3.9	Multi-probe formula	181
3.9.1	Specific examples	185
3.9.2	Experimental multi-probe measurements ($B = 0$)	191
3.10	Magnetic fields and quantum waveguides	194
3.10.1	Quantized conductance in a perpendicular field	195
3.10.2	Edge states and the quantum Hall effect	198
3.10.3	Selective population of edge states	201
4	Quantum dots and single electron phenomena	209
4.1	Electronic states in quantum dot structures	209
4.1.1	Noninteracting electrons in a parabolic potential	209
4.1.2	Dot states in a magnetic field	213

4.1.3	Multi-electron quantum dots	215
4.1.4	Quantum dot statistics	219
4.1.5	Spectroscopy of quantum dots	220
4.2	Single electron tunneling and Coulomb blockade	226
4.2.1	Introduction to Coulomb blockade and experimental studies	226
4.2.2	Orthodox theory of single electron tunneling	249
4.2.3	Co-tunneling of electrons	262
4.2.4	Coulomb blockade in semiconductor quantum dots	264
4.3	Coupled dots and quantum molecules	264
4.4	Transport in anti-dot systems	267
4.4.1	The low-magnetic field regime	268
4.4.2	The high-magnetic field regime	272
5	Interference in diffusive transport	280
5.1	Weak localization	282
5.1.1	Semiclassical treatment of the conductance	283
5.1.2	Effect of a magnetic field	286
5.1.3	Size effects in quantum wires	291
5.1.4	The magnetic decay “time”	294
5.1.5	Extension to short wires	297
5.2	Universal conductance fluctuations	299
5.3	The Green’s function in transport	305
5.3.1	Interaction and self-energies	308
5.3.2	Impurity scattering	309
5.3.3	Beyond the Drude result	314
5.4	Weak-localization correction to the conductance	317
5.4.1	The cooperon correction	319
5.4.2	Role of a magnetic field	323
5.4.3	Periodic eigenvalues for the magnetic effects	325
5.5	Quantum treatment of the fluctuations	328
5.5.1	The correlation function in energy	330
5.5.2	Correlation function in a magnetic field	334
5.6	Summary of universality	336
5.6.1	The width dependence of the fluctuations	336
5.6.2	Size variation of the correlation magnetic field	338
5.6.3	Breakdown of the universality in a magnetic field	340
5.7	Fluctuations in quantum dots	346
6	Temperature decay of fluctuations	361
6.1	Temperature decay of coherence	362
6.1.1	Decay of the coherence length	363
6.1.2	Decay of the coherence time	368
6.1.3	Summary	371
6.2	The role of temperature on the fluctuations	372
6.2.1	Fluctuation amplitudes	375
6.2.2	Dimensional crossover	376
6.2.3	Correlation ranges	377

6.3	Electron-electron interaction effects	379
6.3.1	Electron energy loss in scattering	381
6.3.2	Screening and plasmons	382
6.3.3	Temperature Green's functions	386
6.3.4	One-particle density of states	391
6.3.5	The effective interaction potential	392
6.3.6	Electron-electron interactions in disordered systems—The self-energy	403
6.4	Conductivity	408
6.5	The phase-breaking time	414
6.5.1	Interactions coupled to background fields	415
6.5.2	Modifications of the self-energy	419
7	Nonequilibrium transport and nanodevices	423
7.1	Nonequilibrium transport in mesoscopic devices	425
7.1.1	Nonequilibrium effects in tunnel barriers	426
7.1.2	Ballistic transport in vertical and planar structures	429
7.1.3	Thermopower in nanostructures	431
7.1.4	Measuring the hot electron temperature	436
7.1.5	Hot carriers in quantum dots	437
7.1.6	Breakdown of the Landauer-Büttiker formula	442
7.2	Real-time Green's functions	445
7.2.1	Equations of motion for the Green's functions	447
7.2.2	The Langreth theorem	449
7.2.3	The Green-Kubo formula	450
7.3	Transport in an inversion layer	453
7.3.1	Coulomb scattering	454
7.3.2	Surface-roughness scattering	455
7.3.3	The retarded function	458
7.3.4	The "less-than" function	463
7.4	Considerations of mesoscopic devices	465
7.4.1	A model device	465
7.4.2	Proportional coupling in the leads	469
7.4.3	A noninteracting resonant-level model	471
7.4.4	Another approach to the phonon-assisted tunneling	473
7.5	Nonequilibrium transport in high electric fields	476
7.5.1	The retarded function	477
7.5.2	The "less-than" function	482
7.5.3	Gauge-invariant formulations	484
7.6	Screening with the Airy-transformed Green's function	487
7.7	Other approaches to quantum transport in nonequilibrium systems	490
7.7.1	The density matrix	492
7.7.2	The Wigner distribution	494
		507