CAMBRIDGE

Cambridge University Press
978-0-521-89634-4 - Electrical Transport in Nanoscale Systems
Massimiliano Di Ventra
Index
More information

Index

advection, 408
  haronov–Bohm effect, 192, 381
analytic continuation, 304
anharmonic effects, 320
apparatus, measurement, 7, 15, 32, 93
approach
  Landauer, 35
  Langevin, 278
  partition-free, 214, 346
  partitioning, 108, 146, 149, 154, 213
 pproximation
  adiabatic, 53, 213, 282
    in presence of current, 283
  Born, 54, 136, 303
    self-consistent, 303
  conserving, 225
  generalized gradient, 435
  local density, 434
    adiabatic, 357, 358, 392, 437
  loss of memory, 393, 401
  Markov, 28, 429
  mean-field, 60, 65, 70, 73, 89, 107, 137, 166, 230
  non-crossing, 300
  quasi-particle, 229
  relaxation-time, 81, 82, 98, 255, 371, 384
  single-particle, 283
attractor, 367
 verage
  macroscopic, 70
  planar, 70
  vogadro's number, 8

basin of attraction, 367
bath, 7
  phonon, 25, 44, 369
  BGKY hierarchy, 81, 84, 108, 218, 356, 420, 457
bias, 3, 39, 70, 103, 128, 213, 348, 358
  oltzmann constant, 8, 404
  oltzmann equation, 35, 49, 83
   classical, 79, 80
   quantum, 235, 251, 254, 382
Born–Oppenheimer
  approximation, *see* approximation, adiabatic
  surface, 282
bosons, 83, 219, 223, 419
  shot noise for, 263
  time-ordering operator, 287
branch cut, 141
brownian motion, 65
bubble diagram, 304

capacitance, 6, 245, 247, 260, 278, 348
channels, 110, 117
  closed, 177
  incoherent, *see* independent
  independent, 47, 110, 111
  open, 177
characteristic polynomial, 174
charge
  bound, 5, 356
  free, 5, 356
charge neutrality, 369
coherence, 22
  length, 48
  long-range, 62
  orbital, 76
  spin, 76
collision, 77
  elastic, 43
  inelastic, 43
  integral, 80, 255
compressibility, isothermal, 65
conductance, 39
  differential, 130
  four-probe, 181, 375
  heat, 315, 411
  multi-channel, 182
  multi-probe, 185, 348
  quantized, 130, 388
  single-channel, 179
  two-probe, 128, 130
conductivity, 39
  Drude, 42

© Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-0-521-89634-4 - Electrical Transport in Nanoscale Systems
Massimiliano Di Ventra
Index
More information

frequency-dependent, 95
frequency-dependent, 56
sum-rule, 42
tensor, 40
conductor, ohmic, 40
constant of the motion, 363
constriction
adiabatic, 399
non-adiabatic, 400
correlations, 22, 27, 32, 47, 59, 63, 78, 84, 107, 110, 209, 216, 237, 266, 423, 443, 453
Coulomb blockade
non-equilibrium Green's function approach to, 248
othodox picture, 245
coupling
electron-phonon, 285, 290, 291
spin-orbit, 75, 190
cross-correlation, 270
cumulant, 274
current
alternating, 348
chaotic, 398
confined, 14
density, 1, 4, 90, 458
diamagnetic, 55
diffusion, 72
direct, 53, 348, 384, 393
displacement, 276
drift, 72
fluctuations, *see* noise
inelastic, 290
from NEGF, 296
from perturbation theory, 291
localized, 5, 356
magnetization, 5, 356
moments of, 261
non-variational properties of, 199
paramagnetic, 55
persistent, 14
polarization, 5, 356
spontaneously fluctuating, 63
total, 4, 6, 7, 123, 351–356

de Broglie ansatz, 378, 380, 413
decoherence, 22, 44, 46
density
ground-state, 57
number, 4, 89, 458
of states, 66, 123, 205, 226
local, 291, 294, 322
phase, 77, 79
probability, 78, 81, 118, 228
reduced, 26, 78, 84
density-functional theory, 24, 57, 89, 92, 351
stochastic time-dependent current, 5, 57, 351, 356, 444
time-dependent, 57, 351
time-dependent current, 90, 354
dephasing, *see* decoherence
diffusion, 69, 408
coefficient, 65, 66, 73
response coefficient, 73
dilution
energy, 9
geometrical, 181, 390
of degrees of freedom, 112
dimensional analysis, 398, 400
dipole
local resistivity, 114, 333
local resistivity spin, 197
disorder, *see* entropy
distribution
Bernoulli, 274
binomial, 274
gaussian, 275
Lorentzian, 258
Poisson, 264, 265
statistical, 261
distribution function
Bose–Einstein, 31
Fermi–Dirac, 31, 77, 415
local equilibrium, 111, 126, 374
non-equilibrium, 78
dots, quantum, 2, 245
drag
spin Coulomb, 75
viscous, 391, 397
drift, 69
Drude
model, 35, 39
peak, 95
dyadic, 36
dynamics
dissipative, 380
irreversible, 9, 90
non-Markovian, 425

eigenchannel basis, 162, 272
eigendifferential, 14, 119, 336
Einstein relation, 65
electro-migration, *see* force, current-induced
electron-hole pair, 303, 403
electron-pumping effect, 316
electrons
core, 283
independent, *see* approximation, mean-field
left-moving, 112
right-moving, 111
valence, 283
electrostatic potential, 374
energy dissipation, 96, 314, 394, 400
rate of, 396
ensemble, 4, 19, 20, 24, 25, 92, 94, 261
canonical, 30, 63, 87
grand-canonical, 29
micro-canonical, 64
entanglement, *see* correlations
enthalpy, 388
entropy
canonical, *see* entropy, thermodynamic
concavity, 92, 99, 357

© Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-0-521-89634-4 - Electrical Transport in Nanoscale Systems
Massimiliano Di Ventra
Index
More information

flux, 91, 99
local, 71, 407
micro-canonical, 86
production, 99, 367, 406
rate, 91, 99
statistical, 8
classical, 85
Kubo, 91
of measurement, 93
of open systems, 90
of pure states, 87
of stochastic Hamiltonians, 92
quantum, 86
thermodynamic, 68, 87, 98
environment, 7, 423
equation
Bernoulli, 388, 463
Boltzmann, 458
continuity, 6, 62, 75, 225, 361, 378
drift-diffusion, 73
Dyson
interacting, 222
non-interacting, 137
Hartree–Fock, 24, 166
Keldysh, 236
Langevin, 278
Lindblad, 28, 44, 424
Liouville, 97
Liouville–von Neumann, 23, 51, 211, 426
Lippmann–Schwinger
time-dependent, 132
time-independent, 140
Schrödinger, 12, 51, 211
stochastic, 28, 354, 444
stochastic differential, 278, 446
quilibrium
global, 50, 51, 212
local, 49, 71, 80, 83, 101
approach to, 82
quasi-static, 69
thermal, *see* equilibrium, thermodynamic
thermodynamic, 31, 69, 74, 219, 320, 407
ergodicity, 64, 262
uler equations, 387
evolution
non-unitary, 28, 152, 336
unitary, 12, 213, 423, 427
exchange-correlation
field, 392, 440
functional, 433
hole, 433
kernel, 59
pressure, 393
scalar potential, 392, 433, 437
vector potential, 59, 392, 439, 449

ano factor, 273
Fermi
energy, 31, 66, 69, 117
momentum, 66
sea, 403
statistics, *see* distribution function
velocity, 48, 66
wave-vector, 117
ferromagnet, 197
field
electric, 72, 333
inhomogeneous, 35
uniform, 57
magnetic, 109, 156, 190
velocity, 376, 378, 380
field operator, 218, 267, 287, 289, 418
flow
irrotational, 380
laminar, 387, 395, 397
turbulent, 260, 387, 397
fluctuations, 6, 258
spectral density of, 265
spontaneous, 63
thermal, 4
fluid, *see* liquid
Fock
space, 286, 416
states, 416
force
and topology, 341
conservative character, 340
current-induced
elastic, 329
inelastic, 329
direct, 330
from linear response, 332
out of equilibrium, 335
Pulay, 334, 345
sign, 333
wind, 330
formalism
Keldysh, 209
Kubo, 35, 50
linear-response, 35, 50
non-equilibrium Green's function, 209
Fourier transform, 42, 117, 132, 140–142, 222, 223, 225, 239, 240, 253
friction, *see* viscosity
Friedel oscillations, 146, 374
function
autocorrelation, 62, 261
voltage, 279
characteristic, 274
correlation, 97, 224, 278
current-current, 62
distribution, 77
Heaviside, 31, 117
moment generating, 274
sample, 261
spectral, 225, 228
functional, 24, 80, 211, 221, 245, 432
derivative, 433

g-factor, 191
gas
Fermi, 48, 266, 409

© Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-0-521-89634-4 - Electrical Transport in Nanoscale Systems
Massimiliano Di Ventra
Index
More information

degenerate, 31, 66
non-degenerate, 32, 63, 74, 76
ideal, 30, 48, 63, 73, 74, 78
gauge, 52, 56
invariance, 13, 96, 192, 392, 439
Green's function
advanced, 133, 223
anti-time-ordered, 232
contour-ordered, 217, 231
equation of motion, 220
equilibrium, 217
free, 134
greater, 224
lesser, 224
principal-value, 204
relation between retarded and advanced, 134
retarded, 133, 223
series expansion, 136
three-particle, 220
time-ordered, 218
two-particle, 220
group, 423

Hamilton equations, 80, 83
Hamiltonian
electron-ion, 281
Hartree, 108, 231
Kohn–Sham, 355
ground-state, 109
stochastic, 434
random, *see* stochastic
stochastic, 24, 92
transfer, *see* tunneling Hamiltonian
heat dissipation, *see* energy dissipation
heat transfer, 406
heating
local electron, 403, 410
local ionic, 280, 312, 410
vs current-induced forces, 343
Helmholtz, free energy, 68
hypothesis, ergodic, 64, 264

idempotency, 38
information, loss of, 9, 32, 84–86, 94, 357, 390, 394
in Kubo approach, 91
in Landauer approach, 107
with stochastic Hamiltonians, 92
information, maximum, 18, 21
insulator, 67
interaction
electron-electron, 2, 47, 110, 356, 369
electron-ion, *see* interaction, electron-phonon
electron-phonon, 110, 280, 286–288, 290, 365, 369, 410, 451
phonon-phonon, 286
invariance, time-reversal, 83, 122
Itô calculus, 446

jellium model, 338, 341, 358, 401

Kohn–Sham
equations, 57, 432
time-dependent, 437
functional, *see* exchange-correlation functional
orbitals, 58
Kondo effect, 210
Kramers–Krönig relation, 461

leads, 105, 108, 112, 115, 116
lifetime, electron-phonon, 307
Lindbladian, 28
liquid
electron, 376
Fermi, 228
incompressible, 388, 401, 407
Luttinger, 210
viscous, 376
localization length, 175
Lyapunov exponent, 176

Madelung equations, 379
magnetization, 5
magnetoresistance, 194
mass, effective, 41, 95, 299
material
diamagnetic, 5
ferromagnetic, 190
paramagnetic, 5
matrix
T, 157
$\mathcal{S}$, 167
unitarity of, 162, 174, 205
density, 21
N-particle, 89
Kohn–Sham, 59
single-particle, 89
pseudo-unitary, 173, 206
random, 176
reduced density, 103
transfer, 167
mean-free path, 48
inelastic, 48, 290, 294
measurement
complete, 19, 32
continuous, 32
current, 15–17, 19, 93
ideal, 16
outcome of, 32, 94
memory, 27, 28, 83, 171, 368
kernels, 428
mesoscopic, 1, 36
micro-canonical approach, 35, 346
conductance, 374
micro-reversibility, 84
mobility, 74
modes, transverse, *see* channels
molecule, 112
alkanethiol, 323
octanedithiol, 313
moment

© Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-0-521-89634-4 - Electrical Transport in Nanoscale Systems
Massimiliano Di Ventra
Index
More information

dipole, 5
magnetic, 5

nanotube, 2, 112, 118
Navier–Stokes equations, 382, 387
noise, 6
$1/f$, 258
external, 258
input, 445
internal, 258
Johnson–Nyquist, *see* thermal
output, 445
Poisson, 264
shot, 260, 398, 453
spectrum, 265
sub-poissonian, 273
super-poissonian, 273
telegraph, 258
thermal, 260, 263, 275, 277–279, 398
turbulent, 260
normal mode, 285

observables
commuting, 12, 18
compatible, 18
ccupation number, 31, 248, 266, 275, 416
Ohm's law, 39
nsager relation, 196, 206
operator
current, 13, 120
current density, 13
density, *see* operator, statistical
density of states, 143
diamagnetic current density, 13
equilibrium statistical, 29
Kraus, 425
Lindblad, 28, 424
linear, 427
number density, 13
occupation number, 417
paramagnetic current density, 13
Pauli, 75
position, 13
projection, 16
scattering, *see* collision, integral
statistical, 19–21, 93
properties of, 37
reduced, 26, 426
time-evolution, 23
truncation of, 33
super-, 28, 29, 104, 424, 430
time-evolution, 12
series expansion, 217
time-ordering, 12
velocity, 13
optical lattices, 368

particle flux, conservation, 122, 125, 162, 165, 187, 189
articles
indistinguishable, 9, 30, 77, 415
interacting, 77
non-interacting, 30, 79, 415
path
evolutionary, 363
semiclassical, 41
phase, 43
phonon, 25, 29, 44, 83
absorption, 293, 307
dressed, 288
emission, 293, 306
spontaneous, 294
in presence of current, 340
localized, 308, 316
propagator, 288
free, 287, 308
subsystem, 284
picture
Heisenberg, 21
interaction, 53
Schrödinger, 21
polarization, 5, 288
spin, 75, 195, 197
positivity, statistical operator, 21, 54, 355, 424
potential
chemical, 29, 68, 72
electrochemical, 70, 103
local, 179
spin-dependent, 72
electrostatic, *see* Hartree
Hartree, 70, 109, 128, 438
non-local, 193
pressure, 385–387, 407, 413
principal value, 204
principle
exclusion, *see* principle, Pauli
initial-state maximum entropy, 367
maximum entropy, 367
Pauli, 59, 66, 83, 84, 354
Prigogine, 367
probability
inelastic transition, 292
reflection, 121, 267
transmission, 122, 267
probe, 128
capacitative, 128
floating, 188
invasive, 129, 185, 195
local, 313, 403
non-invasive, 128, 173, 179
voltage, 43, 69, 185, 188, 324
process
cascade, 401
dephasing, 43, 110, 171, 186, 187, 189
inelastic, 280, 284, 370
irreversible, 84
normal, 320, 369
stationary, 262
stochastic, 261, 278, 445
δ-correlated, 354
Umklapp, 319, 320, 369
projection method, 426

© Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-0-521-89634-4 - Electrical Transport in Nanoscale Systems
Massimiliano Di Ventra
Index
More information

projector, super-, 427
propagator, *see* Green's function
pseudopotential, 283, 330, 332, 338

quantum master equation, 28, 425, 446
  stochastic unraveling of the, 448
quantum of conductance, 67
quantum point contact, 1, 131

reference frame
  co-moving, *see* reference frame, Lagrangian
  Lagrangian, 383, 458
  non-inertial, 458
reflection amplitude, 158
regime
  ballistic, 67, 178
  hydrodynamic, *see* equilibrium, local
  localization, 176
  ohmic, 67, 177
  quasi-ballistic, 178
relaxation
  energy, 44
  momentum, 43, 50, 369, 370
  spin, 75
renormalization, energy, 28, 105, 148, 151, 229, 299, 427
reservoir, 7, 67, 69, 103, 105, 111, 129, 166, 178, 186, 202
  phonon, 289
resistance, 6, 39, 110, 348
  definition of, 42
  dynamical, *see* resistance, viscous
  quantized, 67
  viscous, 395, 396
resistivity, 39
resolution of the identity, 143
resonance, 128, 148
response, 39, 115
  function, 55
    current-current, 55, 58
  linear, 40, 50, 52, 392
Reynolds number, 398
  critical, 399

scattering
  theory, 132
  boundary conditions, 106
  elastic, 109, 249, 405
  electron-electron, *see* interaction
  electron-phonon, *see* interaction
  inelastic, 283, 290
    selection rules, 296
  rate
    electron-phonon, 291
  solutions, 106
  theory, 102, 106
screening, 129
  length, 114
  magnetic, 5
  partial, 115
Seebeck coefficient, *see* thermopower
self-consistency, 70, 199
self-energy, 136
  electron-phonon
    equilibrium, 301
    non-equilibrium, 307
  greater, 234
  irreducible, 221
  lesser, 234
  operator, 149
semiconductor, 197
  doped, 74, 299
  non-degenerate, 74
semigroup, 423
similarity transformation, 175
single-electron tunneling, *see* Coulomb blockade
Slater determinant, 415
Sommerfeld expansion, 326
specific heat, 404, 407
spectral representation, 142
spectrum
  continuum, 14
  dense, 8, 44, 103
  discrete, 14
spin
  accumulation, 197
  degeneracy, 66, 67
  electron, 75, 190
  flip, 75
  majority, 72, 197
  minority, 72, 197
  nuclear, 75, 190
  polarization, 72
spin valve, 193
spinor, 191
state
  evanescent, 118
  incoherent, 23
  incoming, 138
  lifetime, 137, 148, 151, 229
    elastic, 166
    inelastic, 299
  macro-, 20, 21, 25, 38, 102
  micro-, 17, 19–22, 26, 32–34, 38, 107
  mixed, *see* macro-
  mixing, 47
  outgoing, 139
  pure, *see* micro-
  quasi-steady, 347, 360
    global stability, 364
    variational definition, 360
  square-integrable, 119
  stationary, *see* steady
  steady, 7, 104, 121, 200, 203, 346
    and initial conditions, 364
    approach to, 369
  uncorrelated, 27, 112
statistics, counting, 262, 265, 274
Stosszahlansatz, 84
streamline, 463
subbands, 116

© Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-0-521-89634-4 - Electrical Transport in Nanoscale Systems
Massimiliano Di Ventra
Index
More information

perconductor, 62
perlattice, 398
mmetry breaking, spontaneous, 84
mmetry, time-reversal, *see* invariance, time-reversal
stem
chaotic, 398
closed, 7, 23, 51, 107, 211
finite, 8
homogeneous, 57
infinite, 9, 106
inhomogeneous, 40
isolated, 8
isotropic, 66
Kohn–Sham, 58, 351
macroscopic, 1, 46
mesoscopic, 178
non-interacting, 228
open, 28, 32, 102
strongly correlated, 228
translationally invariant, 369
weakly interacting, 228

temperature
Debye, 319
local electronic, 286, 403
local ionic, 286, 313
nsor, 40, 42
shear stress, 413
stress, 378, 381
Navier–Stokes, 385
eorem
H-, 86, 98
central limit, 275
fluctuation, 88
fluctuation-dissipation, 60, 65, 97, 226, 257
Hellmann–Feynman, 334, 345
Hohenberg–Kohn, 432
Lindblad, 424
Liouville, 79
Migdal, 303
optical, 206
Oseledec, 176
Poincaré recurrence, 8
Runge–Gross, 436
total current, 351–356
variational, 200
Wiener–Khinchin, 265
ermopower, 323
dynamical effects, 327
transient response, 327
me
autocorrelation, 103, 105, 398, 428
and steady state, 262
definition of, 262
coherence, 43
correlation, *see* time, autocorrelation
decoherence, 46
elastic relaxation, 43
inelastic relaxation, 43
momentum relaxation, 49
Poincaré recurrence, 8, 349
relaxation, 41, 81, 90, 95, 230
transit, 2
trace, 20, 36
transition probability, 81
transitions, inelastic, 280, 292, 319
transmission amplitude, 159
transmission coefficient, 124
transport
incoherent, 43
phase coherent, 43, 110
spin-dependent, 75, 190
viewpoints, 35
tunneling
Hamiltonian, 206
resonant, 169, 244
sequential, 171
single-electron, *see* Coulomb blockade
turbulence, 260, 395, 406
eddies, 400
fully developed, 398

ultra-cold gases, 368

variable, extensive, 9
vector potential, 56, 379, 392, 445
longitudinal, 439
velocity
drift, 4, 74
thermal, 4
vertex corrections, 302
virtual process, 304
viscosity, 198
bulk, 386, 441, 461
shear, 376, 386, 441, 461
approximate formulas, 442
voltmeter, *see* probe, voltage

wave-packet, 105, 114, 119, 370
collapse, 16
postulate of reduction, 16
Wiedemann–Franz law, 404
wires, atomic, 2

© Cambridge University Press www.cambridge.org