

Index

- ^3He , p -wave superfluidity in, 621
 r_s , of electron gas, 384
 2DEG, *see* two-dimensional electron gas
- Abrikosov vortex lattice, 569, 577
 activation energy, 202
 adiabatic
 theorem, 332, 447
 transport, 336
 Affleck–Kennedy–Lieb–Tasaki (AKLT) model, 507
 Aharonov–Bohm
 effect, 103, 222, 273, 336
 phase, 275, 326, 337
 Ambegaokar–Baratoff relation, 604
 Anderson
 –Higgs mechanism, 578
 localization, 198, 236, 253, 304
 in QHE, 305
 length, 255
 length, exponent, 321
 scaling theory, 283
 strong, 276
 suppression by spin–orbit coupling, 343
 weak, 254, 273
 weak anti-, 344
 theorem, 619
 anomaly, chiral, 373
 antiferromagnet, 4, 23, 481
 anyon, 455
 Arrhenius law, *see* activation energy
 autocorrelation function, 666
- backscattering, 317
 “glory” effect, 270
 quantum enhancement of, 270
 band
 “twisted”, 367
- Chern, 351
 conduction, 104
 crossing, 352
 gamma point, 201
 index, 108
 inversion, 200
 Möbius, 365
 magnetic, 329, 349
 parity of, 367
 rubber, 365
 \mathbb{Z}_2 topological classification of, 366
 valence, 104
 valley, 201
 velocity
 anomalous, 358
 width, 148
- Bardeen–Cooper–Schrieffer (BCS), *see* BCS
- BCS
 coherence factors, 597
 coherence length, 610
 reduced Hamiltonian, 594
 theory, 592
- Berry
 connection, 333, 336, 457
 gauge choice for, 338, 340
 curvature, 166, 334, 346, 348, 648
 “radiated” by degeneracy, 341
 Dirac monopole, 341
 pseudovector nature of, 334, 348
 flux, 335
 phase, 274, 332, 334, 500
 geometric gates in quantum information processing, 341
 spin- s , 340
 spin-1/2, 339, 340
 spin–orbit coupling, 343
- Bijl–Feynman formula (SMA), *see* Feynman
- Bloch
 band
 magnetic, 344
 velocity, anomalous, 166, 346, 347
 oscillations, 168
 theorem, 105, 107, 164
- Bogoliubov
 –de Gennes (BdG) Hamiltonian, 613
 –de Gennes (BdG) equation, 611
 modes, 548
 quasiparticle, 600, 604, 605, 627
 theory, 541, 542
 transformation, 496, 498, 540, 600
- Bohr
 –Sommerfeld quantization, 176
 –van Leeuwen theorem, 481, 485
 magneton, 151, 482
 radius, 79
- Boltzmann equation, 183, 265
 collision term, 183
 relaxation time approximation, 183, 185
 Drude conductivity, 190
 linearized, 187
 transport lifetime, 188
- bond
 resonating, 122
 valence, 504
 solid (VBS), 505
- Born approximation, 10, 16, 34, 47, 49, 98, 184, 254
- Born–Oppenheimer approximation, 68, 70
- Bose–Einstein
 condensation (BEC), 158, 209, 531, 545, 609

- factor, 80, 90, 638
 Bose–Einstein condensation (BEC), 532
 bosonization, 83, 420, 465
 boundary conditions
 periodic
 generalized, 327
 Bragg
 diffraction, 44
 distributed reflector (DBR), 158, 546
 peaks, 36, 42, 89, 92
 reflection, 167
 Brillouin zone, 31, 81
 boundary, 37, 74, 76, 109, 110, 128, 129, 167, 201, 499
 causality, 59, 637
 centrosymmetric, 29, 156, 619
 charge, fractional, 430
 Chern
 insulator, 355, 364
 number, 304, 349, 352, 362, 648
 circuit QED, 588, 672
 Clausius–Clapeyron equation, 551
 Clifford group operation, 526
 coherent state, 434, 532
 cohesive energy, 131, 390
 completeness relation, 47, 207
 composite fermions, 469
 composition, of loops, 650
 compressibility, 66, 441, 487, 540, 645
 Gibbs–Duhem relation, 410
 isothermal, 252
 sum rule, 462
 Compton effect, 11
 condensation energy,
 superconductor, 579, 598
 conductance, mesoscopic, 222–224, 233, 254, 284, 287
 conductivity
 Drude, *see* Drude
 tensor, 103, 301
 continuity equation, 257, 360, 398, 484, 554
 Cooper pair, 417, 418, 429, 479, 530, 531, 563, 592, 604, 610, 619
 box, 588
 density wave states, 621
 coordination number, 25, 120, 410, 491
 core hole, 422
 Coriolis force, 576
 correlation function
 retarded, 59, 636
 creation operator
 electron, 487
 fermion, 613, 681
 phonon, 84
 photon, 14
 critical exponent, 321
 dynamical, 93, 289, 291
 cross section
 absorption, 423
 differential, 259
 scattering, 11
 crystal
 field, 131
 liquid, 1, 19, 41
 Curie
 law, 423, 486
 temperature, 481
 current, persistent, *see* persistent current
 curvature, Berry, *see* Berry
 curvature, Gaussian, 341, 349, 651, 656
 cyclotron
 frequency, 176, 307
 motion, circular, 307
 resonance, 176, 180, 210
 de Haas–van Alphen oscillations, 178, 485
 Debye
 –Waller factor, 40, 53, 88, 91, 95, 419, 493, 499
 screening, 440, 441
 temperature, 80–82, 103, 594
 degeneracy
 Landau level, *see* Landau
 valley, 201
 density
 N -representable, 387
 V -representable, 387
 density functional theory, 378, 385, 544
 density matrix, reduced, 250, 534, 659
 density of states, 112, 115, 148
 in wave-vector space, 48, 227
 thermodynamic, 150, 645
 tunneling, 290, 645
 pseudogap in, 290
 dephasing, *see* phase coherence
 detailed balance, 186, 638
 diamagnet, 4, 480
 diamagnetism, perfect, 549
 dielectric function, 278, 593
 Lindhard, 394
 optical, 401
 static, 393
 diffusion
 as random walk, 257, 258
 constant, 190, 252
 equation, 257
 quantum, 254, 265
 corrections, 268
 Dirac
 electrons
 Hall effect for, 322
 Landau levels, 323
 equation, 125, 321, 368, 486
 fermion, 136, 177
 chirality, 353, 356
 mass, 362
 Hamiltonian, 343, 353, 362, 368
 four-component, 373
 massless surface states of, 370
 Weyl representation, 368
 mass, 137, 353
 monopole, 341
 negative energy solutions, 137
 point, 135, 136, 356, 369
 sea, 138
 string, 342
 disorder
 annealed, 262
 quenched, 262
 displacement field, elastic
 continuum, 64
 distributed Bragg reflector (DBR), *see* Bragg
 distribution
 Fermi–Dirac, 149, 247
 function
 pair, 17, 444
 radial, 17
 two-point, 17
 Poisson, 104, 245
 drift velocity, 99
 $c\vec{E} \times \vec{B}/B^2$, 314
 Drude
 conductivity, 100
 ac, 100
 model, 99, 190
 semiclassical, 164
 edge mode
 chiral, 354, 365
 counter-propagating, 320
 gapless, chiral, 355
 helical, 363
 edge states
 topological, 146
 effective mass approximation, 120, 166
 Ehrenfest theorem, 165, 167
 Einstein
 A, B coefficients, 186
 relation, 190, 192, 252
 elasticity, 64
 tensor, 70, 390

- electric polarization, 360
 electrochemical potential, 192, 228
 electromagnetic field, quantization of, 13
 electron
 classical radius of, 11
 tunneling spectroscopy, 600
 electronic structure calculations, *ab initio*, 390
 energy functional, 142, 386
 elastic, 66
 entanglement, 588
 entropy, 251, 662
 area law of, 662
 Hamiltonian, 663
 monogamy, 515, 662
 with environment, 248, 250
 envelope function, 125
 evaporative cooling, 536
 exchange
 -correlation hole, 445
 direct, 490
 energy, 380, 384
 hole, 384
 non-local, 380
 operator, 452
- Fabry–Pérot cavity, 158, 234
 Fermi
 arc, 372
 Golden Rule, 637
 wavelength, 225
 fermionization, 83
 ferrimagnet, 481
 ferromagnet, 4, 480
 Feshbach resonance, 537
 Feynman
 Bijl–Feynman formula (SMA), 52, 461
 Hellman–Feynman theorem, 116
 path integral, 236, 266, 337
 Fick’s law, 257
 fine-structure constant, 100, 303
 Floquet theorem, 113
 fluctuation–dissipation theorem, 638, 668
 fluctuations
 rare, 242
 flux
 -flow resistance, 451, 587
 quantum, 223, 304, 309, 311, 327, 337, 342, 440
 tube, magnetic, 336, 447, 455
 variable, in electrical circuits, 670
 form factor, 16
 atomic, 12
 crystal, 16
 multi-atom, 37
- four-terminal impedance
 measurement, 233
 fractional
 charge, 244, 447
 quantum Hall effect (FQHE), 301
 quantum Hall liquid, 420
 quantum number, 303
 statistics, 303, 452, 455, 456
 Friedel
 oscillations, 395
 sum rule, 421
 frog, levitation of, 481
 Fu–Kane formula, 367
 Fulde–Ferrell–Larkin–Ovchinnikov (FFLO) states, 620
 functional derivative, 673
 fundamental group, 174, 453, 650
- Galilean invariance, 305, 413, 414
 gamma point, *see* band
 gate charge, *see* offset charge
 gauge
 field, synthetic, 577
 Landau, 309
 symmetric, 309, 433
 transformation
 singular, 447
 transformation, large, 359, 361
 Gauss–Bonnet theorem, 349, 651
 Gaussian
 correlators, *see* Wick’s theorem
 curvature, *see* curvature
 genus, 349, 647
 geometric phase, *see* Berry phase
 geometry
 of Hilbert space, 331
 plane, 331
 Gibbs potential, 563
 Ginzburg–Landau
 coherence length, 567
 theory, 544, 559, 568
 Girvin–MacDonald–Platzman
 algebra, 472
 Goldstone
 mode, 7, 76, 541, 578
 theorem, 7, 71
 graphene, 27, 134
 band structure, 362
 Green’s function, 262
 guiding center, 310, 313, 432
- Haldane
 gap, 500, 507, 509
 model, 356, 363
 mass, 357, 362
 pseudopotential, 436
 Hall
 state, quantum anomalous, 370
- Hall effect
 Anderson localization in, 318
 anomalous in ferromagnets, 348
 coefficient, 103, 173, 179, 181
 edge
 currents, 315
 states, chiral, 317
 fractional quantum (FQHE), 303, 433
 integer quantum (IQHE), 303, 364
 Landauer transport picture, 315
 longitudinal resistance, 303
 percolation
 fractal dimension, 321
 picture, 318
 transition, 320
 plateau, 302
 quantum spin, 363
 resistance, 302
 resistivity, classical, 301
 handle, *see* genus
 harmonic approximation, 40, 69
 Hartree
 approximation, 377
 Hartree–Fock
 approximation, 378
 equations, 380
 self-energy, 383
 heat capacity, *see* specific heat
 Heisenberg spin model, 490
 Hellman–Feynman theorem, *see* Feynman
 HEMT, 219
 hierarchy states, 469
 homeomorphism, 648
 homotopy, 649
 class, 453, 649
 fundamental group, *see*
 fundamental group
 group, second, 655
 Hubbard model, 163, 486
- independent-electron approximation, 376
 index theorem
 Atiyah–Singer, 144
 insulator
 Anderson, 252
 band, 252
 Mott, 4, 252, 487
 interband transitions, 168, 169
- jellium model, 382, 419, 439
 Josephson
 effect, 604
 (ac), 583
 energy, 581, 588, 605
 junction, 581, 672

- π junction, 626
 - critical current, 582, 604
 - relation (first), 582
 - relation (second), 582, 672
 - relations, 584
- Kane–Mele
 - model, 363
- kinetic inductance, 100, 586
- Kitaev
 - model, 614
 - toric code, 521, 525
- Kohn’s theorem, 461
- Kohn–Sham equations, 388, 389
- Kondo problem, 423, 675
- Koopmans’ theorem, 382
- Kramers degeneracy, 154, 363, 369
- Kramers–Kronig relations, 402, 637
- Kubo formula, 632
- Lagrangian
 - vector potential in, 337
- Lamé coefficient, 65
- Landau
 - diamagnetism, 528, 558, 608
 - Fermi liquid
 - instabilities of, 412, 618
 - nematic, 413
 - Pomeranchuk instability of, 413
 - Fermi liquid theory, 376, 385, 402
 - gauge, *see* gauge
 - level, 176, 177, 311
 - degeneracy of, 327, 374, 435, 472, 528
 - filling factor, 304
 - tilted, 314
- Landau–Ginzburg–Wilson theory, 562
- Landauer–Büttiker
 - “noise is the signal”, 242
 - formula, 229
 - multi-terminal formula, 231
 - multichannel transport, 276
 - transmission eigenvalues, 239
 - transport, 317
 - voltage probe, 232
- laser speckle, 233, 238, 267
- lattice
 - Bravais, 24
 - optical, 159, 359
 - reciprocal, 24, 30
 - vector, 24
 - primitive, 24
- Laue diffraction, 36
- Laughlin
 - quasielectron state, 446
 - quasihole state, 446
 - wave function, 442
- Lieb–Schultz–Mattis theorem, 501
- Lindhard function, 395
- linear response, 59, 632
- Liouville’s theorem, 182
- local moment, 423
- local-density approximation (LDA), 389
- localization
 - Anderson, *see* Anderson
 - many-body (MBL), 663
- London
 - equation, 553, 554
 - gauge, 554
 - penetration length, 550, 554
- long-range order, 4, 19, 493, 502
- off-diagonal (ODLRO), 534, 535
- positional, 18
- Lorentz
 - covariance, 306
 - force, 10, 301, 336
 - number, 98
 - transformation, 306
- Lorentz force, 10
- low-depth circuit, 519
- lower critical dimension, 493
- Luttinger liquid, 419
 - chiral, 466
- Luttinger’s theorem, 408
- Mössbauer effect, 15, 93
- magnetic
 - length, 309
 - monopole, 342, 371
 - pressure, 482
 - susceptibility, 141, 480
- magnetism, role of exchange in, 380
- magnetization, 152
 - definition of, 480
 - staggered, 500
- magnetophonon mode, 462
- magnetoresistance, 103, 181
 - negative, due to weak localization, 273
 - Sharvin–Sharvin experiment, 275
 - weak localization, 344
- magnetoroton, 462
- magnon, 45
- Majorana
 - fermion, 614, 615, 683
 - zero-mode, 616
- Majumdar–Ghosh model, 504
- many-body localization (MBL), 297
- mass action, law of, 202
- matrix product state (MPS), 511
- Matthiessen’s rule, 99
- Meissner
 - effect, 530, 549, 606
 - kernel, 556
- phase, 550
- mesoscopic
 - conductance, non-self-averaging of, 233
 - devices, 223
- mid-gap state, 144
- Miller indices, 32
- mobility, 203
- modulation doping, 219, 430
- modulus
 - bulk, 66
 - shear, 66
- momentum
 - canonical, 307, 308, 431
 - mechanical, 307, 308, 431
- monopole, *see* Dirac, 353
- MOSFET, 217
- Mott insulator, *see* insulator, Mott
- Néel
 - order, 488
 - state, 495
 - temperature, 623
- Nagaoka theorem, 488
- noise
 - 1/ f , 240, 243
 - autocorrelation time, 243
 - current, 242
 - Johnson–Nyquist, 243
 - nonequilibrium, 244
 - partition, 246
 - maximal, 246
 - random telegraph, 245
 - shot, 238, 239, 244
 - fractional charge, 244, 467
 - quantum, 245
 - spectrum, 242
 - white, 666
- offset charge, 589
- Onsager relation, 195, 635
- orbit
 - closed, 174
 - electron, 174
 - hole, 174
 - open, 174
- order parameter, 5, 22
 - superconducting, 559
- orthogonality catastrophe, 422, 466
- oscillator strength, 50
 - projected, 461
 - sum rule, 52, 96
- over screening, 630
 - by phonons, 593
- pair distribution function, *see* distribution function
- paramagnet, 4, 480

- participation ratio, inverse, 255
 Pauli paramagnetic susceptibility, 529
 Peierls instability, 140
 persistent current, in mesoscopic rings, 224, 282
 perturbation theory
 degenerate, 110
 phase coherence, 223, 224, 235
 dephasing, 224
 inelastic scattering, 224, 248
 rate, 249
 role of entanglement, 248
 length, 224, 233, 287
 phase transition
 continuous, 277
 metal–insulator, 253, 277
 phonon, 45
 acoustic, 73, 76, 594
 mode of superfluid, 541
 optical, 67, 73
 photoemission
 angle-resolved (ARPES), 210, 211, 362, 372, 625
 Pippard coherence length, 611
 plasma frequency, 396
 Poisson
 distribution, *see* distribution, Poisson
 summation formula, 641
 polariton, 86
 exciton, 86, 209
 phonon, 86
 upper, lower, 547
 polarizability, 159
 atomic, 160
 polarization
 electric, 360
 function, electron gas, 393
 spin, 152
 polyacetylene, 141
 power spectrum
 see spectral density, 666
 projected entangled pair states (PEPS), 512
 projective sphere, 453, 650
 proximity effect, 631
 pseudospin, 156, 298, 322, 343, 344, 352, 595, 630
 pump, electron, 359
 quantum
 bit (qubit), 525, 587
 logical, 525
 physical, 525
 transmon, 589
 critical point, 256, 288
 disordered, 499
 dot, 221, 359
 error correction, 526
 point contact, 221, 467
 well, 189, 218
 wire, open channels of, 227
 quasicrystal, 19, 41
 random phase approximation (RPA), 396
 random walk, *see* diffusion
 renormalization group, 7, 277, 415, 417, 423, 562, 679
 flow, 425, 427, 595
 resistance
 quantum of, 231
 resistivity tensor, 102
 resolvent, 295
 operator, 261
 resonating valence bond (RVB)
 states, 516
 Rydberg, 2, 79, 205, 208, 572
 S-matrix, 230, 657
 scanning tunneling microscope (STM), 43, 570, 642
 spectroscopy mode, 646
 surface topography mode, 645
 scattering
 amplitude, 12, 184
 angle, 12
 cross section, 49, 101, 259
 differential, 48, 183, 260
 elastic, 12
 length, 49
 partial wave expansion, 189
 phase shift, 260
 Thomson, 10
 X-ray, 10
 Schmidt decomposition, 661
 semiconductor
 p–n junction, 212
 acceptor, 206
 band bending, 213
 depletion layer, 213
 diode, 212
 direct gap, 200
 donor, 204
 doped, 204
 heterostructure, 217
 indirect gap, 201
 inhomogeneous, 212
 intrinsic vs. extrinsic, 204
 inversion layer, 217
 electric subbands, 217
 quantum well, *see* quantum well
 semimetal, 112
 graphene, 114, 136
 Weyl, *see* Weyl
 shot noise, *see* noise
 Shubnikov–de Haas oscillations, 178
 single-mode approximation (SMA), 60, 399, 463
 Bijl–Feynman formula, *see* Feynman
 singular-value decomposition (SVD), 238, 661
 soliton, 141
 sound, speed of, 66, 72, 81, 208
 of light, 548
 specific heat
 classical, 79
 Debye model, 81
 Einstein model, 79
 electronic, 83, 150
 spectral density, 637
 one-sided, 638, 668
 two-sided, 668
 spin
 density wave (SDW), 481
 rotation symmetry, 154
 susceptibility, *see* susceptibility waves, 491
 spin–charge separation, 148
 spin–liquid state, 518
 spin–orbit coupling, 151
 synthetic, 577
 spinon, 502
 SQUID, superconducting quantum interference device, 585
 statistics
 angle, 455
 Fermi–Dirac, 103
 Laughlin quasiparticle, 457
 non-Abelian, 479
 Stokes theorem, 334, 570
 strain tensor, 65
 string order, 508
 structure factor
 dynamical, 48, 50, 89
 simple harmonic oscillator, 57
 projected, 461
 static, 16
 Su–Schrieffer–Heeger (SSH) model, 140, 503, 517, 621
 subband index, 219, 226, 229
 superconducting gap- T_c ratio, 603
 superconductor
 heavy fermion, 627
 high-temperature, 622
 copper-oxide (CuO₂) planes in, 622
 topological, 614
 Type-I, 550
 Type-II, 552
 mixed state of, 567
 unconventional, 617

- superexchange, 490
 superfluid, 609
 superlattice, 158
 semiconductor, 219
 superposition principle, 587
 supersolid, 535
 surface reconstruction, 43
 susceptibility
 dissipative part of, 638
 reactive part of, 638
 spin, 152, 411, 424
 symmetry
 chiral, 145
 inversion, 21, 348, 366
 particle–hole, 145, 196
 point, 26, 618
 rotation, 29
 spontaneously broken, 7
 time-reversal, 348, 363, 635
 translation, 5, 64, 85, 106, 171,
 254, 310, 383, 611, 633
 magnetic, 344
 spontaneously broken, 18, 20,
 22, 493
 synchrotron radiation, 10

 tensor, conductivity, *see* conductivity
 thermal conductivity
 classical, 101
 of electrons, 195
 thermoelectric effect
 Mott formula, 196
 phonon drag, 196
 thermopower, 196
 Thomas–Fermi screening, 278, 394
 Thouless
 charge pump, 358
 energy, 280
 tight-binding model, 118
 topological
 charge, 654
 defect, 654
 insulator, 200, 343, 364, 365, 616
 \mathbb{Z}_2 classification, 365
 massless surface states of, 370
 strong, 3D, 368
 weak, 3D, 368
 invariant, 331, 647
 order, 303
 phase, 352
 phase, symmetry-protected (SPT),
 370
 protection, 331
 superconductor, 616
 topology, 331
 toric code, *see* Kitaev
 transistor
 bipolar, 214
 field effect (FET), 217
 translation
 magnetic, 326, 327, 329
 operator, 106
 transport
 lifetime, *see* Boltzmann equation
 non-local, 224
 quantum, 222
 scattering theory of, 223
 tunnel junction, 466, 581, 643
 tunneling Hamiltonian, 642
 turnstile, electron, 359
 two-dimensional electron gas
 (2DEG), 217, 225, 301
 two-level fluctuators, 240

 umklapp process, 90, 595
 unit cell
 conventional, 28
 magnetic, 327, 329
 primitive, 25
 Wigner–Seitz, 25
 universal conductance fluctuations
 (UCF), 224, 233

 vacuum state, 595, 680
 valence bond solid (VBS), *see* bond
 van Hove singularity, 115, 176
 Vandermonde polynomial, 438

 voltage, *see* electrochemical potential
 vortex, 654
 lines, persistence length of, 572
 superconductor, 602

 Wannier function, 123, 486
 non-local in topological bands,
 123, 351
 wave packet
 Gaussian, 164
 Weyl
 fermions, 371
 Hamiltonian, 371
 point, 371
 semimetal, 371
 which path
 detector, 249
 information erasure, 250
 Wick’s theorem, 237
 Wiedemann–Franz law, 98, 195
 Wiener–Khinchin theorem, 243, 666
 Wigner crystal, 419, 430
 Wigner–Seitz cell, *see* unit cell,
 primitive
 Wilson ratio, 152
 winding number, 275, 336, 337, 574,
 649
 wrapping (or engulfing) number, 655

 X-ray
 edge problem, 423
 photoemission, 422

 Zeeman energy, 151
 zero mode, 144, 369
 boundary, 148
 zero-point
 energy, 87
 fluctuations, 92, 94
 zero-sound mode, ^3He , 412
 zone scheme, 167
 extended, 74
 reduced, 74