

SUBJECT INDEX

absorption, 117, 140, 141, 142, 154 AC circuits, 137, 138 accurate measurement, 136 adiabatic process, 83 reversible, 83 adiabatic theorem, 113, 114 alpha particle, 139, 140 Ampère's law, 45-47 Amperian loop, 46, 47 angular momentum, in classical mechanics, 12-14, 18, 20 angular momentum, in quantum mechanics addition of, 110, 112 commutation relations, 105 operator, 93, 105-106 orbital, 105-106, 108 angular velocity, 7, 9, 13, 14 annihilation operator, see lowering operator areal velocity, 21 atomic number, 116, 140, 141, 148 azimuthal quantum number, 106

bandpass filter, 138 baryon, 148 baryon number, 146, 148 BCS theory, 152, 155 beta decay, see decay, beta binding energy, 139, 140, 163 Biot-Savart law, 46, 47 blackbody, 117 blackbody spectrum, 117, 118, 152, 155 block problems, 1-4, 29-30 blueshift, 129 Bohr radius, 107 Boltzmann statistics, 78 Boolean logic, 138, 139 boost, 125, 126 Bose condensation, 88 Bose-Einstein statistics, 88, 118 boson, 88, 111-112, 118, 146 boundary conditions, 35 electromagnetic waves, 55 electrostatics, 38, 40, 44, 48, 159 Laplace's equation, 42

magnetostatics, 48

sound waves, 73 wavefunction, 101–103 Bravais lattice, 150 bremsstrahlung, 140, 143 Brewster's angle, 66 Brillouin zone, 150 bulk modulus, 87

calorimeter, 141
canonical ensemble, 78, 80
capacitance, 27, 43, 44, 57
with dielectrics, 54
capacitor, 43, 44, 57, 136, 137
charging, 58
discharging, 58
energy in, 44
parallel-plate, 44, 54
Carnot cycle, 85–86
center of mass, 8, 14, 15, 15–81
charge density, 36
line, 38
point charge, 36, 52
surface, 40, 48

volume, 39 charge, induced, 40-42 chemical potential, 88 circular orbit, 20-21 Bohr model, 115 clipping, 138 coefficient of friction, 1, 4 commutation relation canonical, 97, 105 harmonic oscillator, 99, 100 product identities, 97 uncertainty principle and, 97 with Hamiltonian, 98 complex notation, 55, 64 Compton scattering, 140, 141 Compton wavelength, 140, 163 conductor, 40-43, 55, 159

conservation, 148 angular momentum, 20, 21, 105, 117 baryon number, 148 charge, 57, 148, 149

conjugate momentum, 18-20, 148

energy, 7–11, 27, 81, 159 fluid, 28, 29 Kepler's laws, 21 lepton number, 148, 149 momentum, 12–14, 159 relativistic, 127, 128 Cooper pair, 152

cosmic microwave background, 152, 155, 163

Coulomb's law, 37, 39 counting statistics, 136 covariant vector, 126 CPT theorem, 149

creation operator, *see* raising operator critical damping, 25

crystal, 70, 142, 149–151 current, 49–52, 57, 58 alternating, 136 density, 126 displacement, 50 induced, 50 surface, 48 cyclic coordinate, 18

damping, 24-26 dark matter, 153 de Broglie relation, 64, 102 de Broglie wavelength, 140 De Morgan's laws, 139 decay, 97, 136, 141, 147-149 alpha, 148 beta, 147-149, 153, 154 excited state, 142 relativistic kinematics of, 127, 128 degeneracy, 88 delta-function potential, 102-104 density of states, 88, 151 deriving formulas, 159-160 dielectric constant, 54 dielectric materials, 54 dimensional analysis, 134, 160-161 diode, 138 diode laser, 142 dipole, 110, 115 electric, 38, 52

electric potential of, 52

magnetic, 52	total, 126, 127	Gaussian surface, 36, 38-40
moment, 52	energy-momentum 4-vector, 126	gluon, 147, 154
radiation from, 56	entropy, 79-80, 82, 83, 85	good quantum numbers, 116
Dirac notation, 94-95, 109	of mixing, 87	graphene, 155
dispersion relation, 65, 102, 151, 155	equation of state, 82	graviton, 147, 154
light in medium, 65	equipartition theorem, 80, 81, 85, 86	ground, 40
doping, 141, 151, 154	error propagation, see propagation of error	ground state, 96, 114, 141, 142
Doppler effect	Euler–Lagrange equations, 17–18, 20	energy of helium, 107, 163
nonrelativistic, 72–73	exclusion principle, see Pauli exclusion	energy of hydrogen, 107, 116, 163
relativistic, 129, 152	principle	energy of positronium, 107
transverse, 129	expectation value, 79	finite square well, 103
driven oscillations, 24–25, 27	energy, 79, 114	harmonic oscillator, 99, 100, 161
	observable, 92, 94, 96, 97, 99, 100, 109	hydrogen atom, 107, 115, 117
dual lattice, 150	perturbation theory, 113	infinite square well, 101, 102
m 1 00 01 105	perturbation theory, 113	group velocity, 65
effective potential, 20, 21, 105	Faraday's law, 50	
eigenfunctions, 92–93, 95, 102	Fermi energy, 151, 152	gyromagnetic ratio, 115, 116
free particle Hamiltonian, 96, 102		L-If I:f- 07 141
properties of, 93-96, 102	Fermi surface, 150, 151	half-life, 97, 141
simultaneous, 106	Fermi-Dirac statistics, 88	Hamilton's equations, 18
three dimensions, 100	fermion, 87, 88, 111, 112, 147, 148, 150, 152	Hamiltonian
eigenvalues, 92-94, 98	Feynman, Richard, 159	classical mechanics, 16, 18–19
angular momentum, 106, 111, 115	fine structure	quantum mechanics, 95, 96, 98–103, 105,
energy, 95, 101, 114	constant, 107	106, 110, 113–117, 154
spin, 108–109	hydrogen, 115, 117	statistical mechanics, 80, 81, 86
eigenvectors, 109, 114	fission, 139, 148	harmonic oscillator
Einstein relation, 64, 141	flux	classical mechanics, 22-25, 27, 64
elastic collision, 12, 140, 159	electric, 36	quantum mechanics, 81, 99-101, 161
	magnetic, 45, 50, 51, 152	statistical mechanics, 81
electric dipole, see dipole, electric	force	heat, 81, 83, 84
electric field, 35, 36	centrifugal, 14	heat capacity, see specific heat
boundaries, 38	centripetal, 5–7, 159	heat engine, 85
capacitors, 43	conservative, 7, 8, 11	Heisenberg uncertainty principle, see
changing, 50	Coriolis, 14	uncertainty principle
conductors, 40	electric, 35	Hermite polynomial, 99
infinite line, 38	between point charges, 37	Hermitian
infinity, 38	electromagnetic (in particle physics), 139,	conjugate, 94, 99, 100
matter, 53	140, 146, 147	matrix, 109
point charge, 37	frictional, 1, 4, 11	operator, 92–94, 106, 109
spherical surfaces, 38	gravitational, 1, 5, 8, 21, 147, 162	Higgs boson, 149, 154
electromotive force, 50	•	
electron	Lorentz, 45, 46, 48	high-pass filter, 137
configuration, 116	normal, 1, 4, 11	Hilbert space, 94, 108, 109, 111
in metals, 150	strong nuclear, 147	hole, 142, 151, 154
mass of, 163	weak nuclear, 147, 153, 154	Hooke's law, 22, 23
elliptical orbit, 21	free particle, 18, 81, 86, 96, 101–103	Hubble's law, 152, 155
energy, 7–11, 31	free-body diagram, 1–4, 30	hydrogen atom, 106, 107, 160, 163
	frequency, 64	perturbations, 115–117
capacitor, 44, 57	AC circuit, 137	spectrum, 107
charge configuration, 42	angular, 64	wavefunctions, 107
electric dipole, 52	cyclotron motion, 49	hydrogenic atom, 107, 116
electric field, 43	harmonic oscillator, 22, 25, 99	hyperbolic orbit, 21
electromagnetic waves, 55	friction, 1, 3, 7, 10	hyperfine structure, 115
Hamiltonian mechanics, 18	fundamental thermodynamic identity, 84	
inductor, 51, 57	fusion, 148, 154	ideal gas, 83, 84
Lagrangian mechanics, 16, 17		diatomic, 81-82
magnetic dipole, 53	Galilean transformation, 123	entropy, 80, 85, 87
magnetic field, 48	gauge symmetry, 149	equation of state, see ideal gas law
orbit, 20–21	Gauss's law, 36–42, 44	internal energy, 86
rotational kinetic, 7, 9–10, 17, 268	for magnetism, 45, 53	monoatomic, 80, 85–87
energy, relativistic	polarized materials, 54	specific heat, 85
kinetic, 126	Gaussian integral, 80	ideal gas law, 82, 83
rest, 126, 130, 159	Gaussian probability, 135	identical particles, 111–112
1601, 120, 130, 137	Gaussian probability, 133	racinical particies, 111-112

statistical mechanics, 80, 86-88	Lorentz transformation, 123-126, 130	parabolic orbit, 21
images	low-pass filter, 137	parallel axis theorem, 14, 160
method of, 42	lowering operator, 99, 109, 111	parity violation, 149
real, 71	luminosity, 139	partition function, 79, 80, 86
virtual, 71		Pauli exclusion principle, 87, 88, 112, 148, 150,
impedance, 136-138	magnetic dipole, see dipole, magnetic	151
index of refraction, 65–66, 68, 69	magnetic field, 45	Pauli matrices, 108, 109
inductance, 50, 57	boundaries, 48	pendulum, 5, 19, 25–26
mutual, 50	induced, 50	perfect conductor, 55
self, 50, 51	matter, 53	period, 64
solenoid, 51	motion in constant field, 48	period (orbital), 21
inductor, 57	solenoid, 47, 51	periodic table, 151, 163
inertial reference frame, 123, 125–127	time-varying, 49, 50	phase, 64, 148
inner product, 94–95, 100, 109	toroid, 47	current, 137
insulator, 54, 151	wire, 46, 47	difference in interference, 67
intensity, 55, 64, 66	work due to, 48	harmonic oscillator, 22
•		
dipole radiation, 56 interference	magnetization, 70	shift at boundary, 69–70
	magnetization, 79 Maxwell relations, 84	wavefunction, 93, 112, 154
constructive, 67		waves, 64, 142
destructive, 67	Maxwell's equations, 35, 36, 38, 40, 45, 49, 65,	phase velocity, 65
interferometer, 143–144	66, 69, 159	photoelectric effect, 54, 140, 141
invariant dot product, see relativistic dot	measurement	photon, 117, 118, 140–142, 146–148, 152–155
product	error, 135–136	plane wave, 64, 104
invariant interval, 126, 127	in quantum mechanics, 92–94, 97–98	Poisson distribution, 136
invariant, relativistic, 127, 128, 130	Meissner effect, 151	Poisson waiting time, 136
irreversible process, 83, 84	meson, 147–149	Poisson's equation, 36, 42
isentropic process, 83	minimum-ionizing particle, 140	polarization (of a medium), 54
isobaric process, 83	mirror, 71–72, 143	polarization (of a wave), 55, 66-67, 73
isochoric process, 83	moment of inertia, 8, 9, 13–14, 18, 26, 81	population inversion, 142
isothermal process, 83, 85, 86	momentum, 12–15	positronium, 107
	operator, 93, 105	potential
Kepler's laws, 21–22	quantum particle, 64, 102	central, 19, 21, 105
kinematics, 5–7	relativistic, 126, 127	chemical, see chemical potential
relativistic, 127	multipole expansion, 53	Coulomb, 37, 106, 107
kinetic/potential problems, 8-10	muon, 147–149	effective, see effective potential
Kirchoff's rules, 57, 58		electric, 35, 36
	neutrino, 147-149, 153-154	gravitational, 8, 21
Lagrangian, 16-19, 148	node (in circuits), 57	ground, 40
Lamb shift, 115	node (of a function), 73, 96	point charge, 37, 38
Laplace's equation, 36, 42	Noether's theorem, 148	scalar, 35, 36
Laplacian, 105, 106	normal mode, 23-24, 159	uniqueness of, 42
Larmor formula, 56	normalizable, 96, 102-103	vector, 45
laser, 141-143	normalization, see wavefunction, normalization	potential energy, 7–9
LC circuits, 137, 138	nucleus, 139-141, 147-148	point charges, 42
Legendre polynomials, 53, 106	,	Poynting vector, 55, 64
length contraction, see Lorentz contraction	observable, 92-94, 109	precise measurement, 136
lens, 71–72	occupation number, 87, 88	principal quantum number, 107
lensmaker's equation, 71	Ohm's law, 136	probability
Lenz's law, 50	op-amp, 138	quantum mechanics, 92–94
lifetime, 97, 141, 147, 148	operator, 93–94	reflection, 103–104
light, speed of, 55, 65, 66, 71, 123	optical path length, 68–69, 143	
light-emitting diode (LED), 154	orbit, 19–22	statistical mechanics, 78–79
lightlike interval, 127	orbital, 116, 117	transmission, 103–104
limiting cases, 161–162, 164	orbital angular momentum, see angular	propagation of error, 135–136
line charge, 38	momentum, orbital	propagation vector, see wavevector
		quantum statistical most: 07 00
line integral, 8, 40	orbital quantum number, 106	quantum statistical mechanics, 87–88
log plot, 134–135	orthogonal functions, 93–95	quark, 147–149, 154, 155
logic gates, 138–139	orthonormal, 92, 94, 106	no dial avaryation 105
longitudinal wave, 66, 73	overdamping, 25	radial wavefunction, 105
Lorentz contraction, 124, 130		radiation
Lorentz force law, see force, Lorentz	pair production, 141	blackbody, 117–118

cosmic microwave background, see cosmic	sound wave, 65, /1-/5, 85, 8/	transmission coefficient, see probability,
microwave background	spacelike interval, 127, 152	transmission
detection, 139-141	specific heat, 84-85	transpose, 95
dipole, 56, 72	speed	transverse wave, 55, 66
gamma, 148	light, 55, 65, 66, 71, 123	triplet state, 111, 112, 115
point charge, 56	sound, 65, 87	truth table, 138
recombination, 143	spherical harmonic, 106-107	tunneling, 104, 148
raising operator, 99, 109	spin, 108–112	
Rayleigh criterion, 70	addition of, 110-111, 148	unbound orbit, 20
Rayleigh scattering, 72	one-half, 108-109	uncertainty principle, 96-98, 102, 160
RC circuits, 58, 137, 138	spin–orbit coupling, 115	underdamping, 25
reciprocal lattice, see dual lattice	spin-spin coupling, 115	uniform circular motion, 5-6, 11, 48, 159, 160
reciprocal lattice vector, 150	square well potential	uniqueness of potential, 42
redshift, 153	finite, 101, 103	unit cell, 150
cosmological, 152-153, 155	infinite, 96, 101, 102, 107	conventional, 150
reflection, 70–71	three-dimensional, 102, 105	primitive, 150
by thin films, 69	standard deviation, 135, 136	
reflection coefficient, see probability, reflection	standing wave, 63, 64, 73	van der Waals equation, 82
refraction, 70-71	Stark effect, 116	variance, 79, 97, 135-136
relativistic dot product, 126-127, 127, 128-130	stationary state, 95, 96	variational principle, 114, 163
resistance, 57	Stefan–Boltzmann law, 118	vector potential, see potential, vector
resistivity, 57, 151	Stern-Gerlach experiment, 117	vector space, 94, 95
resonant frequency	stimulated emission, 141, 142	velocity addition (relativistic), 125
electrical circuits, 58, 137	Stirling's formula, 80	vibrating string, 65
mechanical systems, 25	strong nuclear force, see force, strong nuclear	virial theorem, 100, 153
reversible process, 83, 86	superconductor, 151–152	
adiabatic, 83	superposition	W boson, 146, 154
rigid rotor, 81	energy eigenstates, 96, 100, 102, 154	wave, 102
RL circuits, 58	oscillations, 23	electromagnetic, 54
RLC circuits, 58, 137, 138	waves, 55, 63, 64, 67, 102	interference and diffraction, 67-70
rotating reference frame, 14	surface charge, 38, 48	properties of, 63-67
Rydberg formula, 107, 115	symmetry, 35, 148	wave equation, 63-65
	cylindrical, 36, 38, 47	electromagnetic, 55
sample variance, see variance	discrete, 149	wavefunction, 92–94
scalar potential, see potential, scalar	planar, 36	antisymmetric, 111, 112, 148
scattering	spherical, 20, 36	normalization, 92–93, 99–100, 105, 109–111
classical mechanics, 12	•	symmetric, 111, 112, 148
cross section, 139	temperature, 83, 84	wavelength, 64-66, 73, 118, 129, 152
quantum mechanics, 102-104	blackbody, 117-118, 152	wavenumber, 64
Schrödinger equation, 95, 103, 154	laws of thermodynamics, 81-82	wavevector, 55, 64, 66, 126, 150, 274
secular equation, 23, 24	statistical ensembles, 78	weak nuclear force, see force, weak nuclear
selection rules, 117	thermodynamic definition, 84	work
semiconductor, 138, 142, 151, 154	thermodynamic equilibrium, 82, 83	moving continuous charge distributions, 43
semimajor axis, 21	thermodynamics, laws of, 81-82	moving image charges, 42
separation of variables, 105	time dilation, 124, 130	moving point charges, 42
shell model, 115–116	time-independent perturbation theory,	performed by magnetic fields, 48
simultaneity, 124, 127	113-114	work function, 140
singlet	timelike interval, 127	work–energy theorem, 5, 11
color, 147, 148	toroid, 47, 48	
spin, 111, 115	torque, 13, 117, 162	x-ray, 70, 140, 163
sky, blueness of, 72	electric dipole, 52	·
Snell's law, 55, 70–71	magnetic dipole, 53	Z boson, 146, 154
solenoid, 47, 51	transient effects, 58	Zeeman effect, 116-117