Subject Index

a

action integral 31
adiabatic compression heating 288
adiabatic compression scaling 290
adiabatic gas law 93, 94, 288
adiabatic invariant 31
advanced tokamak 514
Alfven
– shear Alfven wave 137
– speed 138
– toroidal Alfven (TAE) instabilities 299
– transit time 95
– wave 160, 164
alpha particles
– distribution 298
– energy transfer 293
– toroidal Alfven instabilities 299
Ampere's law 17
anisotropic pressure tensor model 96
anomalous transport 267
anomalous transport coefficients *see* turbulent transport coefficients
atomic physics processes 319

b

ballooning mode transformation 281
ballooning modes 179, 496
banana orbit 58
banana regime 61
β, beta 23, 104, 123
β_{p}, beta poloidal 110, 122, 124
beta limit 495
beta normal 497
Bickley function 440
binding energy 1
Boltzmann equation 66, 85
Boltzmann neutral atom transport equation 413
Boltzmann or Maxwell–Boltzmann distribution 6, 133, 315
bootstrap current 242
bounce time or frequency for trapped particles 57, 61
bremsstrahlung 470
burning plasma dynamics 475

c

canonical angular momentum 34
characteristics, method of 143
charge-exchange neutral "scattering" model 415
Chew–Goldberger–Low theory 160
Christoffel symbols 251
classical transport
– ambipolarity 214
– central impurity peaking 215
– fluid theory 212
– friction force 210, 213
– heat conductivities 229
– heat fluxes and transport coefficients 207
– momentum fluxes and transport coefficients 208
– particle fluxes and transport coefficients 205
– rate-of-strain tensor 226, 230
– thermal conductivity 237
– thermal force 210
– transport parameters 228
– viscosity coefficients 230
collision regime 61
collisional friction models
– Ignitkhanov 344
– Lorentz 213, 260
– Rutherford 217
compound nucleus 1
conductivity tensor 137
confinement scaling *see* energy confinement scaling, particle confinement
conservation of angular momentum
– constraint on particle motion 35
constants of the motion 31, 34

constraints on fusion reactor design
– beta limit 503
– blanket and shield 507
– bootstrap current 506
– confinement 502
– density limit 503
– fatigue limit 509
– heat flux limits 507
– inductive current drive 504
– kink stability limit 504
– noninductive current drive 505
– radiation damage limits 510
– stress limits 508
Coulomb potential 6, 12
Coulomb scattering
– 90° deflection cross section 15
– 90° deflection characteristic time 12
– 90° deflection cross section 12
– collisional friction 260
– energy transfer characteristic time 14, 79, 80, 294
– impact parameter 70
– Krook scattering operators 82
– Rutherford scattering cross section 11
current density 14
current drive
– electron cyclotron 307
– fast wave 306, 307
– inductive 285
– lower hybrid 305
– neutral beam 292
current induction in a tokamak 285
curvature drift 28
curvilinear coordinates 529
cyclotron radiation 471

d

Debye length 6
Debye sphere 6
density asymmetries 260
density limits
– confinement deterioration-electromagnetic instabilities 491
– confinement deterioration-thermal instabilities 492
– disruption 481, 485, 489
– divertor collapse or detachment 495
– empirical Greenwald limit 495
– empirical Murakami/Hugill limit 487
– Hugill diagram 482
– MARFE 490
diamagnetic current 38
diamagnetic field 37
diamagnetism 36, 109
dielectric tensor 301
diffusion coefficient
– Kadomtsev mixing length 273
– magnetic fluctuation 275
– weak turbulence 273
diffusion coefficients
– Bohm 272, 335
– classical 62
– edge 402
– electrostatic drift waves 272
– gyro-Bohm 272
– neoclassical 60
– Pfirsch–Schlüter 61
dispersion relation
– Chew–Goldberger–Low theory 161
– cold plasma 302
– collisionless drift waves 195
– dielectric tensor form 297
– divertor MARFE thermal instability 347
– drift-cone waves 200
– electromagnetic waves 136
– electrostatic drift waves 185
– electrostatic waves 149, 193
– guiding center hydrodynamic 164
– ion acoustic wave 153, 269
– ion cyclotron waves 151
– ion temperature gradient 197, 270
– kinetic instabilities 193
– Langmuir waves 140
– loss-cone waves 200
– lower hybrid wave 150, 152
– MARFE thermal instability 394
– MHD hydrodynamic 160
– mixed longitudinal and transverse 136
– radiative collapse thermal instability 484
– shear Alfven waves 138
– thermal instability with short k_r^{-1} 377
– upper hybrid wave 150
– Vlasov theory 146

disruption
– causes 481
– current decay 480
– current in vacuum vessel 481
– current limit 481
– density limit 481, 485, 489
– forces in vacuum vessel 480
– magnetic island 480
– magnetic reconnection 480
– mode locking 480
– neutral density limit 489
– physics 479
– pressure on vacuum vessel 481
– radiative collapse 481
– radiative collapse thermal instability 483, 487
– tearing mode 480
distribution function
– guiding center 67, 231
– joint statistical 65
– single-particle 65
divertor
– bundle 332
– currents and drifts 351
– detached regime 341, 358
– divertor MARFE 346
– double null 33
– high recycling regime 341
– impurity retention 343
– parameter scaling 342
– poloidal 332
– private flux region 332
– separatrix 331
– sheath-limit regime 340
– single null 332
– target plate 331
– toroidal 332
– two-point model 338
– X-point 331
double-adiabatic model 98
Dreicer velocity 14
drift kinetic equation 66, 68, 69
drift velocities
– $\boldsymbol{E} \times \boldsymbol{B}$ 24, 199, 268
– curvature 28, 32
– diamagnetic 91, 184
– divertor 351
– electron diamagnetic 194
– electron drift 269
– grad-$\boldsymbol{B}$ 25, 32, 38
– ion diamagnetic 92, 197
– polarization 27, 199, 268
– poloidal 69
– radial 69
drift waves 185, 267, 276, 280

e
$\boldsymbol{E} \times \boldsymbol{B}$ drift 24
$\boldsymbol{E} \times \boldsymbol{B}$ shear stabilization of turbulence
– comparison with experiment 374, 389
– criterion for turbulence suppression 374
– linear stabilization 372
– nonlinear turbulence decorrelation 372, 374
– physics 372
– radial electric field shear 372
– shearing rate for flute-like modes 372
edge operation boundary 398
edge pedestal or transport barrier
– s–α stability boundary 367
– ballooning modes 365
– ELMs 364
– gradients 362
– neutral penetration constraint on width 371
– peeling modes 365
– pressure constraint on width 369
– pressure gradient constraint 368
– short k_r^{-1} thermal instabilities 376
– spontaneous edge transport barrier formation 384
– spontaneous formation 376
– threshold edge temperature gradient 379
edge physics 331, 361
elastic scattering (neutral) from Maxwellian ions 416
elastic scattering (neutral) model 416
electric field
– radial 262, 403
– toroidal 264
electromagnetic energy density 18

electromagnetic instabilities
– axisymmetric, rigid body displacement 115
– bad curvature 178
– ballooning 179, 496
– collisionless drift waves 193
– drift cone 197
– drift waves 183
– electron temperature gradient 195
– energy principle 165, 169
– firehose 162, 164
– flute interchange modes 44, 173
– free energy sources & constraints 155
– growth rates *see* growth rates, instabilities
– interchange mode stability condition 175, 177
– internal kink modes 173, 179, 498
– ion temperature gradient 196
– Kruskal–Shafranov surface kink criterion 173
– loss cone 45, 157, 197
– Mercier interchange mode stability condition 179
– MHD instabilities *see* MHD instabilities
– microinstabilities *see* microinstabilities
– mirror 164
– peeling modes 365
– pinch 169
– resistive tearing 186
– sawtooth oscillations 201
– surface kink modes 498
– Suydam interchange mode stability condition 179
– tearing mode 480
– toroidal Alfven eigenmode (TAE) 300
– vertical displacement 114
electromagnetic stress 18, 19
electromagnetic theory 15
electromagnetic wave heating and current drive
– dispersion relation *see* dispersion relation
– electron cyclotron resonance heating 310
– evanescent region 302
– fast wave electron cyclotron resonance current drive 313
– fast wave ion cyclotron resonance current drive 312
– ion cyclotron resonance heating 308
– lower hybrid current drive 311
– lower hybrid resonance heating 309
– physics 304
– refractive index 301
– resonance frequencies 305
energy confinement scaling
– Alcator 287
– definitions 463
– Goldston 466
– IOC ASDEX 466
– ITER89-P 467
– ITERH93-P 467
– ITERPB93(ym2) 468
– Ohmic 465
energy principle 165
energy transfer characteristic time 79, 80, 294
equilibria
– anisotropic pressure 128
– axisymmetric toroidal plasma 105
– cylindrical plasma 104
– force balance 103
– tokamak large aspect ratio plasma 111
equipartition of energy 87
evanescent region 302
exponential integral function 421

f

Faraday's law 16
finite gyroradius corrections 91
fluid theory
– anisotropic pressure tensor model 96
– anisotropic shear 87
– charge continuity equation 89
– charge density 89
– collisional friction 86, 260
– continuity or particle balance equation 86
– current density 89
– double-adiabatic model 98
– energy balance equation 86, 88
– energy flow 86, 88
– energy flux equation 86

– energy flux tensor 86
– equilibrium condition 100
– external source moment 86
– finite gyroradius corrections 91
– force balance 91
– heat conduction 88
– isotropic pressure 87
– mass continuity equation 89
– mass density 89
– mass source 89
– mass velocity 89
– MHD model 93
– moments equations 85
– momentum balance equation 86, 89, 103
– momentum stress tensor 86
– Ohm's law 91
– one-fluid model 89
– plasma resistivity 90
– pressure tensor 87, 96
– rate-of-strain tensor 251
– strong field, transport ordering 98
– temperature 88
flux surface
– average over 107
– definition 35, 53, 105
– evolution 125
– Grad–Shafranov equation 108
Fokker–Planck
– equation 69, 72
– Lorentz model 73, 77
– Rosenbluth potentials 72
– theory of collisions 69
– velocity-space diffusion 74
force-free current 103
free energy sources 155
further reading 539
fusion
– break-even condition 4
– cross section 15
– energy release 3
– process 1
– reaction rates 3
– reactions 4

g
Gauss' law 15
Grad–Shafranov equation 108, 120
grad-$\boldsymbol{B}$ drift 25
growth/damping rates, instabilities
– collisionless drift waves 195
– divertor MARFE 348
– drift waves 185
– guiding center 22
– ion temperature gradient 196
– MARFE 394
– radiative collapse 484, 486, 489
– resistive tearing modes 190
– thermal instabilities with short 383, 385
– thermal instabilities with short k_r^{-1} 378
gyrofluid model 282
gyrokinetic model 282, 283
gyromotion 21
– finite gyroradius corrections or effects 90
– guiding center 55
– gyrofrequency 22
– gyroperiod average 30
– gyroradius or Larmor radius 22

h
hydromagnetic instabilities
– Alfven wave 160
– Chew–Goldberger–Low theory 160
– firehose 162
– guiding center theory 162
– ion sound waves 133
– magnetosonic wave 161
– MHD theory 159
– mirror 164

i
ignorable coordinate 31, 34
impact parameter 10
impurity production 324
impurity radiation 326, 473
incompressibility 94
index of refraction 138
inertial confinement 4
instabilities
– electromagnetic *see* electromagnetic instabilities
– free energy sources 155

– hydromagnetic 158
– inhibiting constraints 155
– thermal 376
international tokamak program 511
isobaric surface 91, 103, 105
ITER 513

k
kinetic instabilities 192
kink modes 170, 173, 498

l
L–H mode transition
– comparison with experiment 374, 389
– power threshold 361, 388, 391
– trigger mechanisms 374
Landau damping of waves 139
last closed flux surface LCFS 331
Legendre polynomials 414, 420
limiter 332
Liouville's equation 65
lithium resources 5
Lorentz force 65
loss cone 43

m
magnetic
– diffusion time 95
– field diffusion 95, 125
– field index 114
– flux conservation 126
– flux requirements 285
– flux, poloidal 105
– flux, toroidal 110
– island 190, 480
– moment 23, 25, 31, 67
– pressure 20
– reconnection 201, 480
– Reynolds number 95
– viscosity 95
– well 41, 44, 56
magnetic confinement
– closed field lines 49
– goals 4
– open field lines 41
– principles 41
– progress and status 5
magnetization 38
magnetization current 36
magnetohydrodynamic (MHD) theory 93, 159, 165
MARFEs
– edge density limit 394, 396
– linear stability analysis 392
– radiative condensation 395
MHD ordering 94
mass defect 1
Maxwell's equations 93, 103, 131
Maxwellian distribution 3, 141, 142, 148, 163, 258, 289
minimum-B stabilization 45, 156, 169
mirror confinement
– central solenoid of tandem mirror 48
– confinement time 44
– loss cone 43
– loss cone instabilities 45
– loss fraction 43
– minimum-B 45
– mirror ratio 43
– simple mirror 41
– tandem 46
mode locking 480
molecular processes 319
momentum confinement time 264

n
neoclassical transport
– banana-plateau 237
– bootstrap current 242
– Chang–Hinton thermal conductivity 237
– closure 224
– drift-kinetic derivation 231
– extended neoclassical theory 238
– multifluid formalism 221
– orbit distortion 244
– orbit squeezing 246
– parallel collisional friction 217
– parallel viscous force 257
– Pfirsch–Schlüter 215, 217, 219
– poloidal rotation 260
– potato orbits 245
– radial electric field 262
– rate-of-strain tensor 251

– toroidal rotation 262
– toroidal viscous force 253, 405
– viscosity 251
– viscosity coefficients 258
– ware pinch 244
neutral beam heating and current drive
– critical fast ion energy 296
– cross sections 291
– current drive 298
– deposition in the plasma 290
– energy transfer to plasma 293
– fast ion distribution 296
– fast ion energy loss 293
– neutralization efficiency 293
– penetration 293
– production of neutral beams 292
neutral particle streaming operators 430
neutral particle transport methods
– collision probability 442
– discrete ordinates 453
– extended diffusion theory 424
– integral transport 432
– interface current balance 445
– Monte Carlo 456
– Navier–Stokes 460
– spherical harmonics P_N 421
neutral particle transport modeling
– charge-exchange 415
– collision probabilities 442
– elastic scattering 416
– escape probability 437, 445, 450
– first collision source 419
– Marshak boundary conditions 425, 426
– rational approximation for escape probability 451
– reciprocity 442
– recombination 419
– transmission probability 437, 442, 445, 447
neutral particle transport theory 428
neutron source 515

o
Ohm's law 15, 91, 350
ohmic heating of the plasma 287
orbit turning point 56

p
paramagnetism 109
particle confinement times
– simple mirror 44
– tandem mirror 48
– tokamak neoclassical 62
particle transport in edge pedestal
– density gradient scale length 402
– diffusion coefficient 402
– pinch velocity 402
– pinch-diffusion relation 402
– pressure gradient scale length 403
physical constants 521
pitch angle 42, 56
plasma
– definitions 1, 6
– formulas 537
– frequency 8, 132, 148
– inductance 285
– internal inductance 113, 122, 498
– resistance 285
– resistivity 14, 78, 90
Poisson's equation 6, 17, 140, 149, 152, 315
polarization drift 27
polarization of waves 135, 305
poloidal magnetic flux 105
poloidal rotation 260, 406
Poynting vector 19
pressure 87
pressure gradient, normalized parameter α 182
pressure tensor 87, 96
private flux region 332

q
quasilinear transport analysis 270
quasineutrality 90, 151, 268

r
radiation
– bremsstrahlung 470
– cyclotron 471
– impurity 326, 473
radiative mantle 397
radius of field line curvature 29

rate-of-strain tensor 251
recycling
– coefficient 319
– energy reflection coefficient 318
– hydrogen retention 319
– particle reflection coefficient 318
– re-emission 319
resonance absorbtion wave heating
– electron cyclotron 305
resonance absorption wave heating
– ion cyclotron 303
– lower hybrid 303
rotation
– poloidal 260
– toroidal 262
rotational transform of magnetic field 52
runaway electrons 14, 479

s
safety factor 110, 116
sawtooth oscillations 201
scrape-off layer SOL
– definition 331
– length 334
– width 334
second adiabatic invariant 32
second stability regime 365, 498, 499
separatrix 331
Shafranov shift 120
shear of the magnetic field 53
shear parameter S 182
sheath
– potential 315
– power transmission coefficient 317, 337
solenoidal law 16
Sonine polynomials 226
sputtering 324
stagnation (flow) point 334
stellarator 50
strong field, transport ordering 98

t
temperature 74
thermal diffusivity
– chaotic magnetic island overlap 277
– dissipative trapped electron mode 276
– electron temperature gradient mode 277
– ion temperature gradient mode 276
– resistive ballooning mode 277
– trapped ion mode 276
thermal instabilities
– confinement deterioration 491
– divertor MARFE 346
– MARFE 392
– power threshold for L–H transition 388
– radiative collapse 483
– short radial wavelength 376
– spontaneous edge transport barrier formation 384
thermonuclear temperature 3
tokamak 50
toroidal coordinates 531
toroidal magnetic flux 110
toroidal rotation 240, 262
transmutation of spent nuclear fuel 516
transport in partially ionized gas 247
transport ordering 98
trapped particle bounce time 57
trapped particles 42, 56
Troyon beta limit 497
turbulent transport coefficients
– chaotic magnetic island overlap 277
– electron temperature gradient modes 277
– ion temperature gradient modes 276
– resistive ballooning modes 277
– trapped electron modes 276
– trapped ion modes 276

u
units 523

v
vector calculus 527
vector potential 16, 17
viscosity
– gyroviscosity 253
– neoclassical viscosity 258, 260
– parallel viscosity 253, 257
– perpendicular viscosity 253
– toroidal viscous force 253
– viscous stress tensor 252
Vlasov equation 66, 139

w
Ware pinch 59
waves in plasmas
– Bernstein 301
– circularly polarized 135
– current drive *see* above
– cut-off 302, 307, 309, 310
– dielectric tensor 301
– direct interaction approximation 279
– drift waves *see* drift waves
– electromagnetic 131, 134, 295
– electron cyclotron 305
– electrostatic 136, 148
– evanescence region 302
– group velocity of wave packet 303
– Hasegawa–Mima equation 280
– index of refraction 138, 295
– ion acoustic 133, 162, 268
– ion cyclotron 150, 305
– Landau damping 139
– Langmuir 139
– lower hybrid 137, 150, 305
– mode coupling 278
– ordinary (O) and extraordinary (X) 307
– penetration condition, parallel waves 136
– phase velocity 138
– polarization 135, 305
– propagation 302, 306
– ray tracing 303
– reflection 302
– resonance absorption wave heating *see* above
– resonance frequencies *see* electromagnetic wave heating
– shear Alfven 137, 188
– upper hybrid 137, 150, 305
– Vlasov theory of 142, 155
– wave packets 303
– wave–particle collisionless dissipation 307

x
X-point 331