INDEX

Ampere electric circuit law, 19, 21, 106–107, 241
Amplification factor, 127
Anode layer, 10
Attenuation index, 26–27
Boltzmann and Maxwell equation, 239
Boundary conditions for computational electromagnetics
  Farfield condition for computational electromagnetic aerodynamics, 295
  Farfield condition for Maxwell’s equation, 121–123
  Maxwell’s equation, 20, 107, 292–293
  No-reflection condition of null-value incoming flux, 123
  Perfectly match layer, 122
  On electrodes of DCD, 295
  On electrodes of DBD, 295–299
Cathode layer, 10, 289, 331
Cathode fall, 279
Characteristic-based formulation of Maxwell equations
  On rectangular frame, 108–112
  On Curvilinear coordinates, 112–121
  Characteristic rotational excitation temperature, 42
  Characteristic vibrational excitation temperature, 42
  Characteristic variable, 124
  Characteristic electronic excitation temperature, 43
  Charge conservation equation, 19, 72
  Charge separation, 390–392
  Chemical reaction, 47–48, 250–253
    Arrhenius equation, 49, 251, 259
    Condition of equilibrium, 49–50
    Equilibrium constant, 49
    Law of mass action, 47, 50, 250
    Rate of backward reaction, 49, 58, 250
    Rate of forward reaction, 49, 58, 250
  Circular frequency, 12
  Computational electromagnetic-aerodynamics, 58, 242–244
    Bulk recombination, 302–303
    Conservation laws, 58, 87, 242–243
    Conservation of energy, 87, 196, 240
Computational electromagnetic-aerodynamics (Continued)
Conservation of mass (continuity), 58, 87, 195, 239, 242–243, 287, 291, 304
Conservation of momentum, 87, 195, 240
Conservation of vibrational excitation, 58, 243
Conservation of electronic excitation, 58, 243
Effective electric field in transverse magnetic field, 289–290
Electron attachment and detachment, 303
Ion-ion recombination, 303
Motion of charged species, 285–286
Multi-fluid plasma model, 239–242
Three species model, 239
Two species model, 335
Non-equilibrium chemical reaction, 245–248
Quantum chemistry plasma generation and depletion, 65, 304
Concurrent computations, 180–189
Data processing rate (DPR), 183
Floating operation points per second (FLOPS), 189
Message passing interface (MPI), 183, 185, 188, 189
Power FORTRAN (PFA), 193
Scalability, 183–187
Corona discharge, 37, 62, 280
Coulomb’s law, 4
Courant-Friedrichs-Levy (CFL) stability condition, 123
Critical electron number density, 24
Crocco’s theorem, 223–224
Curvilinear coordinate transformation, 198
D’Alembert equation, 148
Debye length, 7–10
Dielectric Barrier discharge (DBD), 63–67, 379–408, 413–414
Electrode gap distance, 386–387
Force field, 392–398
Governing equations of micro jet, 414
Laminar-turbulent transition, 407–408
Leading edge separation, 403–404
Micro jet, 413–414
Periodic electrostatic force, 390–402
Two- and three-species plasma models, 239, 285, 287, 337, 398–402
Voltage-current relationship, 380–385
Von Karman Street, 403
Wall jet, 402–405
Diffusion velocity, 32, 262, 266–268
Direct current discharge (DCD), 61–63, 279–282, 327–333
Bistable state of infinite parallel electrodes, 329
Parallel electrodes configuration, 327–330
Side-by-side electrode configuration, 330–333
Trailing edge of airfoil, 358–362
Hydrodynamic stability, 362–364
Self-oscillation, 363–364
Supersonic diffuser, 365–366
Dispersion relationship of electromagnetic wave, 24
Drift-diffusion theory, 282–289
Drift-diffusion velocity components, 286
Drift-diffusion velocity in transverse magnetic field, 289–292
Drift velocity, 32, 26
Einstein formula, 33, 266, 287
Electric breakdown potential, 21, 62, 388
Electric conductivity, 13–16
Electric current density, 4, 244, 411
Electric field intensity, 4, 24
Electric permittivity, 8, 19, 387–389
Electric potential, 8
Electric wind, 402
Electron number density, 2, 4
Electrostatic force, 3, 4, 390–392
Electromagnetic field
Electrostatic field, 3–4
Magnetic field, 4–6
Electromagnetic waves
Alfven wave, 22, 83
Contact surface wave, 83
Entropy waves, 83
Equation of electromagnetic wave, 23
Fast electromagnetic wave, 22, 83
INDEX

Linearly polarized transverse wave, 127
Plane waves, 147–150
Slow electromagnetic Wave, 22, 83
Transverse electric and magnetic waves, 151
Electromagnetic wave propagation, 150–159
Cut-off frequency, 151
Intrinsic intrinsic impedance, 148
Group velocity, 148
Motion in waveguide, 150–155
Penetration depth, 27, 150
Phase velocity, 148
Propagation (attenuation and phase) constant, 150,155
Reflection and scattering, 168–177
Wave attenuation across plasma sheet, 155–159
Waves in plasma, 20–22
Wave propagation in plasma, 23–27
Energy exchange between electronic and vibrational mode, 246
Energy exchange between electrons and ions mode, 247
Energy exchange between translational and vibrational mode, 246
Energy exchange between vibrational modes, 246
Equation of charge motion, 21
Equation of electromagnetic wave propagation, 23
External electric circuit potential, 295–297
Farady induction law, 19, 71, 76, 106–107, 241
Gauss law for electric field, 19, 107, 241
Gauss law for magnetic field, 19, 107, 241
Gibbs free energy, 48–49, 52
Computational electromagnetic-aerodynamics, 58, 242–244
Bulk recombination, 302–303
Conservation laws, 58, 87, 242–243
Conservation of energy, 87, 196, 240
Conservation of mass (continuity), 58, 87,195, 239, 242–243, 304
Conservation of momentum, 87, 195, 240
Conservation of vibrational excitation, 58, 243
Conservation of electronic excitation, 58, 243
Electron attachment and detachment, 303
Ion-ion recombination, 303
Quantum chemistry plasma generation and depletion, 65, 304
Non-equilibrium chemical reaction
Multi-fluid plasma conservation of mass equations, 287
Multi-fluid plasma conservation of mass equations in transverse magnetic field, 291
Gyro (Larmor, cyclotron) frequency, 6, 347
Hall parameter, 341
Hartman flow, 95–97
Hartman number, 95
Heat flux, 264
Horseshoe vortex, 226–228
Hypersonic similarity parameter, 201–202
Induced magnetic field, 5
Interface condition for ablation, 253
Ionization
Attachment, 54, 65, 259, 303
Detachment, 54, 65, 261
Dissociative attachment, 303
Dissociative recombination, 54, 302–303
Electric impact, 53, 63–67, 258–262
Electron-atom reaction, 259
Electron-molecule reaction, 259
Electronic collision, 53–54
Ion-ion recombination, 303
Ionization potential, 37
Photoionization, 52–53, 54–56
Thermal excitation, 56–60
Valence interaction, 53
Ion number density, 385–386
Joule heating, 27–28, 331
Joule heating actuator, 325–366
Flow control at trailing edge of an airfoil, 358–362
Suppression of cavity self-oscillation, 363–365
Joule heating actuator (Continued)
Thermal bumps on hydrodynamic stability, 362–363
Volumetric heating over side-by-side electrode, 330, 332
Virtual leading edge strake, 333
Electric potential field, 342–344
Governing equations, 336–337
Induced oblique shock, 335–336
Magnetic field amplification, 341, 347–349
Power requirement, 340–341
Relative intensity of electrode and Joule heating, 333, 334
Surface pressure, 338–339
Surface shear, 339
Temperature contours, 334, 335
Virtual Variable geometry cowl, 349–358
Cylindrical inlet, 355–358
Density contours of cylindrical inlet, 356
Density contours of rectangular inlet, 351–353
Pitot pressure distribution of cylindrical inlet, 357
Pitot pressure distributions of rectangular inlet, 353–355
Rectangular inlet, 349–355

Knudsen number, 409

Laminar-turbulent transition, 228–231
Favre-mass-ensemble, 232
Reynolds ensemble, 232
Lorentz force, 6, 346–348, 369
Lorentz-force actuator, 369–379, 405, 408–412
Pulsed microwave discharge, 405
Remote energy deposition, 373–376
Laser energy deposition, 373–375
Microwave, 375–376, 405
Stagnation point heat transfer mitigation, 376–379
Ion thruster
Electrostatic ion thruster, 410–411
Electromagnetic ion thruster, 411–412

Governing equations, 410
Low-pass filter, 139, 232
Magnetic permeability, 19
Magnetic Reynolds number, 70, 79
Magnetic pressure, 78
Magnetic stress tensor, 78
Magnetohydrodynamics (MHD)
Approximated Ampere’s circuit law, 72
Approximated Ohm’s law, 74
Basic assumptions, 71–74
Ideal MHD equations, 74–80
Eigenvalues of Ideal MHD equation, 80–83
Full MHD equation, 86–91
Mass fraction, 263
Master equation for population density distribution, 247
Maxwell’s equations, 19, 105–110.
Characteristic formulation, 108–112
Eigenvalues, 111–116
Finite-difference approximation, 123–131
Finite-volume approximation, 131–137
High resolution algorithm, 137–143
Left-hand inverse similar matrices, 117–118
Maxwell’s equation in integral form, 106–107
Maxwell’s equation on curvilinear coordinates, 112–121
Second-order formulation, 108
Similar matrices, 117–118
Split flux vector, 119–120
Time-dependent Maxwell’s equations, 105–108

Microscopic description of gas, 38–39
Partition functions, 44–47
Quantum number designation for atoms, 39–40
Quantum number designation for molecules, 40
Solutions of Quantum mechanics, 41–43
Electronic mode, 43
Rotational mode, 42
Translational mode, 41
Vibrational mode, 42
Mobility of drift motion, 32, 287
Molar fraction, 263
INDEX

Models of ionization, 50, 65, 250–253, 260
Boeuf-Pitchford, 304
Boeuf-Lagmich-Unfer-Callegari, 304
Bogdanoff-Kudryavtsev-Kuranov-Kozlov-schenko, 261
Ellison-Kogelschatz, 64, 261
Golubovskii-Maiorov-Behnke-Behnke, 261
Olynick-Chen-Tauber high-temperature air mixture, 252
Park’s high-temperature air mixture, 251
Rafatov-Bogdanov-Kudryavtsev, 261
Saha, 50
Shang-Surzhikov, 304
Singh-Roy, 261
Solov’ev-Konchakov-Krivstsoc-Aleksandrov, 261
Surzhikov-Shang, 65
Multi-fluid plasma model, 239–242
Conservation of charged species equation, 239, 241–242, 287
Conservation of energy equation, 240, 242
Conservation of momentum equation, 240, 242
First-order moment of Boltzmann equation, 240
Ionization rate equation, 65
Second-order moment of Boltzmann equation, 240
Zero-order moment of Boltzmann equation, 239
Navier-Stoke equations, 194–196
Flux vector form, 196–197
On curvilinear coordinates, 198–199
Large eddy simulation (LES), 232
Numerical algorithm for solving governing equations, 268–276, 305–322
Alternating direction implicit (ADI) scheme, 126, 272–273
Approximate Riemann problem, 273
Beam-Warming approximated factor scheme, 272
Compact differencing scheme, 138, 141, 319–322
Delta formulation of diminishing residual, 274, 306–311
First-order Roe scheme, 271
Four-stage Runge-Kutta scheme, 126
Fractional steps, 125
Gauss quadrature, 315–316
Minmod limiter/operator, 274, 312
Modified semi-infinite programming (MSIP), 313
Multi-grid algorithm, 312
Multigrid total variation diminishing (MTVD) scheme, 311–314
Newton divided-difference formula, 316
Polynomial refinement, 315–319
Riemann invariant, 273
Semi-infinite programming (SIP), 313
Single-step upwind explicit algorithm, 125
Time division multiple access (TDMA) scheme, 314
Two-stage Runge-Kutta scheme, 126
Total variation diminishing (TVD) scheme, 271–272
Upwind-biasing approximation, 133, 273
Weighted essentially non-oscillatory scheme (WENO), 275–276
Split flux vector, 271
Ohm’s law, 16–18, 74, 244
Partition function, 44–47
Paschen’s law, 21, 62
Perfect shift property, 125
Plasma frequency, 10–12
Plasma sheath, 10
Poisson equation of plasmadynamics, 8, 12–13, 293, 410
Positive column, 289
Poynting vector, 148, 154, 158
Pyramidal horn antenna, 160–168
Radar cross section, 169
Bistaic radar cross section, 170
Scattered far field, 170
Signature reduction, 177–180
Refractive index, 26–27
Saha equation, 50–60
Scattered-field variable, 171

INDEX

Secondary emission, 21
Self-sustain flow oscillation, 209–220, 363–364
   Bifurcation, 216, 220
   Counter-flow jet injection, 216–220, 364
   Long penetration mode, 216
   Rossiter formulation, 211
   Short penetration mode, 216
   Spike-tipped oscillation, 212–215, 364
   Sub- and super-critical state, 217
Shear-layer stability equation, 210
Shock discontinue condition in plasma, 91–92
Shock entropy increment in plasma, 93, 95
Space sheet, 169
Stoichiometric Coefficient, 47, 58

Thermodynamic probability, 43
Transport properties
   Ambipolar diffusion, 32–34
   Collision integral, 264
   Coulomb potential, 265
   Diffusion in transverse magnetic field, 267
   Exponential repulsive potential, 264
   Lenard-Jones potential, 264
   Molecular diffusion, 29, 31
   Molecular viscosity, 29
   Thermal conductivities, 29
   Townsend similarity law, 53, 302
   Viscous-inviscid interaction, 199–209
      Flow separation, 204–206
      Pressure interaction, 199, 202
      Vorticity interaction, 199
   Vortical dynamics, 221–223
      Generalized Crocco equation, 223
      Governing equation for compressible
         vortical motion, 223
      Vortex breakdown, 224–226
      Vortex incident, 226
      Vorticity stretching, 223
   Wilke’s mixing rule, 31
   Zero-order moment of Boltzmann equation, 239