

Index

- Absolute zero, 284
- Absorptivity, 65, 73
- Adiabatic, 9, 22–3, 30, 187, 194
- Adiabatic demagnetization refrigerator (ADR), 297–9
- AIAA Thermophysics TC YouTube channel, 186
- Alloy, 288
- Aluminum
 - 1100, 54, 111
 - 2024-T6, 24
 - 6061-T6, 19, 24
- Analysis methodologies
 - Onboard thermal dissipations, 131
 - Environmental thermal loads, 123–5
 - Max/Min, 131
- Anomalous skin effect (ASE) theory, 294
- Apiezon L, 19
- Apiezon N, 19, 302
- Arc length, 41–2
- Argon, 287, 317
- Assembly level
 - Instrument, 10, 114–16, 216, 335–8
 - Spacecraft, 1, 42, 114–16, 119, 334–8
 - Subsystem, 114, 335
- Astrodynamics
 - Beta angle, 119
 - Ecliptic plane, 119
 - Equatorial plane, 119–20
 - Inclination angle, 119, 133
 - Orbit period (OP), 119, 121
 - Solstice, 119
 - Universal gravitational constant, 121
- Avogadro’s number, 275
- Bernoulli’s equation, 166
- Beryllium-copper, 289
- Blackbody
 - Surface, 65, 69–74, 84–5
 - Temperature, 68, 69
- Boiling heat transfer, 181–7
 - Critical heat flux (CHF), 182–3
 - Dry-out, 194, 208
 - Film, 184–6
 - Leidenfrost point, 182–3
 - Minimum heat flux (MHF), 184
 - Natural convection, 182–4
 - Nucleate, 182–4
 - Onset of nucleate boiling (ONB), 182–3
 - Superheat, 182–4
 - Transition, 182–4, 209
- Bolometers, 267
- Boltzmann’s constant, 8, 68, 275
- Bond number, 185
- Boundary conditions, 14, 38, 174, 210, 219–20, 235
- Cadmium, 116, 297
- Calorimeters, 267–8
 - Micro-kinetic inductance detectors (MKIDs), 268
- Capillary pressure rise, 191, 204
- Ceramic, 223, 288
- Cernox™ thermometers, 266
- Chelyabinsk, 3
- Cho-therm, 19
- Coefficient of performance
 - Carnot, 171, 316
 - Thermodynamic, 316
- Coefficient of thermal expansion (CTE), 285
- Concentric cylinder, 37–9, 200
- Conduction, 1, 5, 6, 13
- Conductor, 88, 152, 177–81
- Coordinate system
 - Cartesian, 13
 - Cylindrical, 37–42
 - Spherical, 37, 42, 66
- Coupling ring, 308–9
- Crossover pressure, 272
- Cross-sectional area, 5, 15, 17
- Cryocoolers, 311
 - % Carnot, 316
 - Cooling load performance plot, 323
 - Joule–Thomson, 313–14, 316
 - Pulse tube, 313
 - Reverse-Brayton, 315, 320
 - Specific power, 316
 - Stirling, 312–13
- Cryogenics, 284
- CVD diamond, 24
- Darcy–Weisbach equation, 166
- Detectors, 263, 266–8, 276
- Dewar, 186, 303–4

- Differential
 - Element, 13
 - Solid angle, 65–7, 70, 77–8
 - Surface area, 65–7, 70
- Drude single electron theory, 292
- Duty cycle, 230–2
- Eclipse, 116
- Effective emittance, 98, 100–1
- Electrical
 - Resistance, 218, 220–1, 264, 293, 295–6
 - Resistivity, 6–7, 219, 283, 293, 302
- Electromagnetic waves, 64
 - Infrared, 64, 69, 306
 - Theory, 64
 - Ultraviolet, 64
 - Visible, 64, 69, 76, 263
 - Wave particle duality, 64
- Electron number density, 292
- Element temperature
 - Finite difference, 25–7
 - Finite element, 25–7
- Emissive power
 - Blackbody, 65, 67–70
 - Directional, 65, 67
 - Hemispherical, 67–8
 - Spectral, 64–5, 67–70
 - Total, 70
- Emissivity, 72–3
- Energy balance, 9
 - Steady-state, 9, 26, 74, 131
 - Transient, 9, 13–14, 131, 136–8, 236, 239, 242
- Energy equation, 13, 26, 37–8, 47
- Enthalpy of vaporization, 194, 197
- Entropy, 172, 284–5, 295
 - Disordered systems, 298–9
 - Magnetic disorder, 298
 - Ordered systems, 298
- Environmental heating, 115–16, 118, 129, 137
 - Albedo, 123–5, 133–4
 - Earth-IR, 123–5, 133
 - Orbit average, 131
 - Solar, 116–19, 123
- Error analysis, 276–8
 - Independent variables, 276
 - Measurement quantities, 276
 - Root sum square (RSS), 277
- Extension wire, 264–6
- Finite difference, 25–7
- Finite element, 25–7
- Flow resistance, 167
- Flow regimes, 273–4
 - Continuum, 8, 273
 - Molecular, 7–8, 101, 273–4, 284
- Food supply, 2
- Fourier–Biot equation, 301
- Fluid types
 - Cryogenic, 285–7
 - Inert, 196, 286, 336
 - Newtonian, 293, 295
 - Quantum, 295
 - Superfluid helium, 24, 287, 293–4, 306
- Fluorine, 286–7
- Friction factor, 166
 - G-10, 20, 291
 - Galvanometer, 267
 - Glenn Research Center microgravity two-phase flow video library, 186
 - Gravitational effects, 186
 - Gray body surfaces, 76–7, 88–96
- Hardware
 - Flight, 209, 333–4
 - Test support, 263
- Heat exchangers
 - Liquid line suction line (LLSL), 173–7
 - Recuperative, 173, 177, 312–15
 - Regenerative, 312
- Heat flow assumption
 - Adiabatic, 22–3, 30
 - Isothermal, 22–3, 30
- Heat leak, 101, 204, 290
- Heat loss, 99, 126, 145
- Heat Pipes, 165, 167, 181, 186–201
 - Adiabatic section, 187, 194–6
 - Boiling limit, 192–4
 - Capillary limit, 191–3, 197
 - Condenser section, 187, 194, 196, 201
 - Entrainment limit, 192–4
 - Evaporator section, 187, 200–1
 - Gravity effects, 195
 - Liquid flow, 187, 189–90, 194, 196
 - Liquid transport factor, 197
 - On/Off conductance, 188
 - Radiators, 201
 - Sonic limit, 192
 - Total pressure drop, 188–9, 193
 - Vapor flow, 187, 195–6, 198, 201
 - Variable conductance, 196
 - Viscous limit, 194
 - Wick, 187–93, 195–7, 199–200
 - Wicking height, 197
- Heat pumps, 152, 165, 167–77, 221–2
 - Carnot efficiency, 171, 316
 - Coefficient of performance, 173, 316
 - Compressor efficiency (η_{comp}), 176
 - Condenser, 168–77
 - Evaporator, 168–77
 - Heat exchanger effectiveness, 175, 315
 - Inversion temperature, 169–70
 - Isenthalpic expansion, 169, 174–8
 - Joule–Thomson coefficient, 168–9

- LLSL heat exchanger, 173–7
- P-h diagram, 170
- Temperature lift, 167, 171, 223, 314
- Vapor dome, 170
- Heat transfer
 - Coefficient, 8, 21
 - Fourier's Law, 5–6, 15–16, 26, 34, 38, 40, 42, 99, 181, 277
 - Newton's Law of Cooling, 7–8, 16, 210, 216
 - Stefan–Boltzmann Law, 8–9, 64, 70, 124
- Heat transfer mechanisms, 4–5, 13, 98, 202, 334
 - Conduction, 5–7, 13
 - Convection, 5, 7–8, 15, 96, 181–95
 - Radiation, 5, 8, 64
- Heaters, 268
 - Cartridge, 268–9
 - Flexible, 198, 268–70
 - Wirewound power resistor, 268–9
- Helium, 18, 24, 287, 293–5
- Honeycomb panel, 44–5, 152
 - Cell, 45–6
 - Configuration thickness, 45–6
 - Directions (L,W,T), 45–6
 - Extension factor, 45
 - Ribbon thickness, 45
 - Structure, 45–6, 152, 243
- Hydrogen, 286–7, 307
- Inconel 718, 289
- Indium, 19, 302
- Institute For Space Nuclear Power Studies, University of New Mexico, 184
- Invar, 288–9
- Irradiation, 70–1, 76
 - Hemispherical, 70–1
 - Spectral, 71
 - Total, 74, 86
- Isentropic, 171–2, 174, 176
- Isothermal, 13, 22–3, 30, 75, 216–17, 314
- Joule heating, 216, 218–20, 285, 295–303
- Joules, 4–5
- Kinetic energy, 4, 194, 295
- Kirchhoff's Law, 74–5
- Krypton, 287
- L-bracket, 31, 81, 89
- Lagrange points, 121–3
 - Space missions, 122
 - Sun–Earth system, 122
- Lead, 297
- Leak checking, 276
 - Sniffer mode, 276
 - Housing unit mode, 276
- Liquid viscosity, 189
- Linear expansion, 287–8
- Loop heat pipes (LHPs), 201–16
 - Boiling limit, 209
 - Capillary pressure rise, 204
 - Compensation chamber (CC), 202–3, 205–6, 212
 - Condenser, 202, 204–11
 - Constant conductance regime, 206–7
 - Elevation, 208–9
 - Evaporator, 202–12
 - Liquid return line, 204–6, 210–12
 - Primary wick, 203–4, 210–12
 - Secondary wick, 203–8, 210–12
 - Shutdown, 202, 204–5, 207
 - Start-up, 202, 204–6
 - Steady-state operation, 205–6
 - Tilt, 208
 - Total pressure drop, 204
 - Vapor line, 204–7, 210–11
 - Variable conductance regime, 206–9
 - Wicking height, 209
- Low temperature, 284–5
 - Detectors, 114, 263, 266, 268, 299, 308
 - Physics, 285
- Lumped capacitance, 46, 133
- Magnetism, 296–7
 - Diamagnetic, 297
 - Ferromagnetic, 297–8
 - Paramagnetic, 297–9
- Magnetocaloric effect, 285, 297–9
- Measurement
 - Accuracy, 266
 - Base, 263
 - Resistance, 265
- Mechanical strength, 288
 - Fracture, 285, 290
 - Modulus of elasticity, 291
 - Plastic deformation, 285, 290
 - Yield strength, 290–1
- Meissner effect, 296–7
- Meniscus, 190–1
- Mercury, 297
- Metals, 288–9
- Meteor, 3
- Methane, 192, 287
- Microscale heater array, 266–7
- MIL-STD 1540 Rev E, 334–5
- Mission types
 - Deep space, 116–18, 216
 - Earth-based, 116–18
- More Than Honey*, 3
- Multi-layer insulation (MLI), 96–101
 - Construction, 98–101
 - Gas conduction, 101, 334
 - Ideal assumption, 129, 140, 146, 148
 - Layer conduction, 101
- Lockheed Equation, 101–2

- Multi-layer insulation (MLI) (cont.)
 - Non-ideal assumption, 102, 145–6, 148
 - Performance degradation, 101
- Nadir, 132, 134, 138–9
- National Bureau of Standards, 284
- Near-earth asteroids (NEAs), 3
- Neon, 169, 192, 204, 287, 304
- Nickel, 24, 188
- Ni-steel Fe 2.25 Ni, 288–9
- Niobium, 297
- Nitrogen, 286–7
- Non-condensable gas (NCG), 196, 210
- Nylon, 98–9, 288–9
- Nuclear power systems, 118
- NuSil™, 19
- Ohm’s Law, 166, 295
- Ohmic, 166, 218, 295–6, 301
- One-dimensional analysis
 - Composite wall, 15–18, 21–2
 - Plane wall, 13–15
- Orbits, 120–1
 - Apogee, 120–1
 - Geosynchronous Earth orbit (GEO), 121
 - High Earth orbit (HEO), 120–1
 - Low Earth orbit (LEO), 120–1
 - Medium Earth orbit (MEO), 120–1
 - Molniya, 121
 - Perigee, 120–1
 - Semi-major axis, 120–1
- Overall heat transfer coefficient, 21
- Oxygen, 286–7
- Oxygen-free high thermal conductivity copper (OFHC), 19, 24
- Parker and Abbott relation, 292
- Path length, 42, 213
- Periodic table, 286
- Phase-change materials, 226–43
 - Duty cycle, 231–4
 - Enthalpy of fusion, 228, 230, 232–3
 - Full melt/solidification, 232, 238
 - Hold time, 303
 - Melt temperature, 228, 230, 242–3
 - Melt-to-solidification ratio, 227, 232–5, 239, 241–4
 - Paraffin waxes, 229
 - Pulse heating, 231–3, 235, 242
 - Total mass change, 230
 - Total melt energy, 232
- Phase diagram, 293–4
- Phonons, 6, 292–4
- Photon absorber material, 267–8
- Photovoltaic (PV), 116
- Physics
 - Classical, 64, 295
 - Quantum, 64, 295
- Planck, 68
 - Constant, 68, 292
 - Distribution Law, 68–9
- Platinum, 264, 267, 302
- Platinum resistance thermometers (PRTs), 264
- Poiseuille flow, 166, 274
- Polystyrene, 288–9
- Polytetrafluoroethylene (PTFE), 20, 144–5, 288–9
- Pressure-sensitive adhesive (PSA), 269
- Pressure vessels, 272
 - Above atmospheric, 272
 - Sub-atmospheric, 272, 276
- Project life-cycle phases, 335
- Projection, 30, 55, 65, 78, 129
- Radiation intensity, 65–7
 - Diffuse, 67
 - Directional, 67
 - Hemispherical, 67
 - Spectral, 67
- Radiation shields, 96–7
 - Large separation distance, 96–7
 - Small separation distance, 96–7
- Radiative energy exchange, 84
 - Blackbody, 84–6
 - \hat{F} Technique, 93–6
 - Gebhart technique, 92–3
 - Gray body, 86–96
 - Reflection, 86, 91–3, 153
 - Scaling factor, 92–3
- Radiative thermal resistance
 - Geometric, 87
 - Net heat transfer, 87–90
 - Surface, 87
- Radiosity, 71–2
 - Directional, 71
 - Hemispherical, 72
 - Spectral, 71–2
 - Total, 72
- Real surface, 71–7
- Reflectivity, 73–4
- Refrigeration, 165, 168–77, 221
- Relevant test environments, 272, 333
- Requirements, 114
 - Heat flux, 115
 - Heat rejection capability, 115
 - Hold time, 303–6
 - Spatial gradients, 115
 - Stability, 115
 - Temperature, 4, 115
- Residual resistivity ratio (RRR), 289, 293
- Resistance-based temperature calibration curve, 264–7
- Roughing pump, 272
- S-glass, 288–9
- Saddle bracket, 198–9

- Saturated conditions
 - Liquid, 170–1, 182, 227
 - Vapor, 170–1, 227
- Second Law of thermodynamics, 284
- Sensible heating, 46–8, 198, 212
- Sensors, 263
 - Fluid flow, 263
 - Human, 263
 - Photon detection, 267–8
 - Pressure, 308
 - Temperature, 263–6
- Shape factors, 42–4
 - Hollow sphere w/uniform wall thickness, 43
 - Hollow square, 43
 - Square extrusion w/centered hole, 43
 - Square extrusion w/centered square hole, 43
- Silicon diode thermometers, 265–6
- Solar arrays, 152–4
 - Anti-reflective (AR) coatings, 153
 - K1100, 153
 - M55J, 153
 - PV cells, 118, 152–3
 - Thermal-to-electrical conversion efficiency (η_{PV}), 118, 153
- Solar constant, 116, 125
- Solar loading, 127–30
 - Flat plate, 123, 125–7
 - Projected surface, 129–30
 - Spinning plate, 130–1
- Solid angle, 65–6, 77–8
- SpaceCube analysis, 139
- Spherical wave, 117
- Stainless steel, 19, 24, 288–9, 290–1
- State of health (SOH), 116, 263
- Steinhart–Hart equation, 264
- Stefan–Boltzmann
 - constant, 8, 70, 86, 125
 - Law, 8–9, 64, 70, 124
- Stored cryogens, 303, 306
 - Heat intercept, 307
 - Hold time, 305–8
 - Reduced boil-off (RBO) systems, 307
 - Spaceflight missions, 306
 - Vapor-cooled shield (VCS), 308–10
 - Zero boil-off (ZBO) systems, 307
- Strength-to-thermal conductivity ratio, 290
- Subsystems, 114–16, 336
 - Cryogenic, 284, 300
 - Detectors, 115–16
 - Electrical, 115–16
 - Guidance, navigation and control, 115–16
 - Lasers, 115–16
 - Mechanical, 115–16
 - Optical, 115–16
 - Thermal, 115–16
- Superconducting, 268, 295–7
- Superconductivity, 268, 285, 295–7
 - Cooper pairs, 295
 - Critical current, 296
 - Critical magnetic field, 296
 - Critical temperature, 296
 - Quenching, 296
- Superconductors
 - Type I, 296
 - Type II, 296
- Superfluid helium (SHe), 24, 293–4
- Support structures, 290
- Surface area
 - Projection, 129
- Surface tension, 185–7, 190–1, 193
- T300, 288–9, 291
- Temperature
 - Cycling, 336–9
 - Function, 14–15, 25–6, 38, 246
 - Lift, 167, 171, 223, 314
 - Operational, 114, 165, 209, 228, 263, 268, 270, 285, 290, 300, 302–3, 339
 - Sink, 165, 267–8
 - Source, 165, 177
 - Staging, 300
 - Superheat, *See Boiling Heat Transfer:superheat*
 - Survival, 114
- Temperature control, 270
 - Deadband, 270–1
 - On/Off, 270–1
 - PID, 223, 270
- Testing
 - Acceptance, 336–7
 - Developmental, 333, 336
 - Environmental, 333
 - Philosophy, 333–4
 - Qualification, 336–9
 - Thermal vacuum (T-Vac), 272–4, 334, 337–8
- Thermal circuit, 9, 15, 88, 91
- Thermal conductance
 - Interface, 19
- Thermal conductivity, 5
 - Electronic, 6–7
 - Lattice, 6–7
 - Total, 6–7
- Thermal energy, 168–9, 216, 226–35, 313
 - Balance, 9–10
 - Storage, 198
- Thermal interface material (TIM), 18, 19
- Thermal resistance
 - Contact, 18–19
 - Interface, 18
 - Limiting, 18–21, 300
 - Parallel, 21–2
 - Series, 15–18
 - Total, 18, 23, 28–30, 220–1
- Thermal storage capacity, 13, 239, 242, 268

- Thermal straps, 177–81
- Braided wires, 180–1
- Endpoint efficiency (η_E), 178
- Foils, 177–80
- Footer, 177–9
- Header, 177–9
- Packing efficiency (η_P), 178–9
- Shape efficiency (η_S), 178–9
- Sink, 177
- Source, 177
- Thermal vacuum chamber, 272–334
- Thermistors (TMs), 264–6
- Thermocouples (TCs), 265–6
- Thermodynamic vent system (TVS), 307
- Thermoelectrics, 216
 - Coolers (TECs), 216–26
 - Couple, 219
 - Current density, 217, 219
 - Electrostatic potential, 218
 - Energy balance, 220–5
 - Figure of merit (FOM), 222
 - Generators (TEGs), 216
 - Module, 221–2
 - Multistage, 224
 - N-Type, 218–19, 223
 - P-type, 218–19, 223
 - Peltier coefficient, 217
 - Peltier effect, 216–17, 264
 - Power-cycle efficiency, 222
 - Refrigeration COP, 221
 - Resistivity, 220–2
 - Seebeck coefficient, 217–19
 - Seebeck effect, 216–18
 - Semiconductors, 218–19, 223
 - Thomson effect, 216, 218–19
- Thermostat, 270
- Torlon, 20, 289
- TPLI™ 200, 19
- Transfer processes, 165–7, 187, 293–9
- Transmissivity, 73–4, 86
- Triple point, 285, 287, 293–4, 303
- Turbopump, 272
- Ultem, 20
- Vacuum line, 274–6
 - Aperture, 274
 - Conductance, 274–5
 - Particle velocity, 274, 292
 - Transmission Probability, 275–6
- Vacuum pump systems, 272
 - Desorption, 273
 - Diffusion, 273
- Leak rate, 273, 276
- Permeation, 273
- Pump inlet, 273–4
- Pumpdown time, 273, 275
- Sump port, 273–4, 276
- Throughput, 273–5
- Volume flow rate, 273
- Vespel, 20, 144–5, 288–9
- Vessel construction
 - Inner shield, 304, 309–11
 - Outer shield, 309–11
- View factors, 77–84
 - Enclosure, 79–80
 - Hottel's string method, 83–4
 - Reciprocity, 78–9
 - Separation distance, *See* Radiation Shields:finite separation distance
 - Subdivision, 80–1
 - Summation, 79
- Virtual hemisphere, 65
- Watts, 4–5
- Wavelength, 64
- Weber number, 193–4
- Wheatstone bridge circuit, 267
- Wick structures
 - Axial grooves, 188–9
 - Darcy equation, 189
 - Effective thermal conductivity, 199–200, 213
 - Permeability, 188–9, 193
 - Porosity, 193, 199–200, 212
 - Screens, 188–9
 - Sintered pores, 188–9
 - Wetting/non-wetting conditions, 188, 190–1, 208
 - Young–Laplace equation, 190–1
- Wiedemann Franz Law, 6, 293
- Wien's Displacement Law, 69
- Wiring
 - Brass, 302
 - Conductance, 303
 - Copper, 302
 - Cryogenic, 285, 301–2
 - Nichrome, 302
 - Phosphor bronze, 302
 - Platinum, 302
 - Stainless steel, 302
 - Superconducting, 295
 - Tungsten, 302
- Workmanship, 148, 179, 302, 335
- Zero-point energy (ZPE), 295
- Zinc, 297