

Index

- activity, dissipative, 8
- adiabatic condition, 30, 80
- adiabatic lapse rate, 201
- aerodynamic conductance, 165, 200
- affinity, 35, 228
- albedo, 134
 - clouds, 214
 - surface, 124
- Anthropocene, 291, 321
- Archimedes principle, 156
- arrow of time, 4, 52
- atmospheric electric circuit, 217
- available potential energy, 156, 161
 - convective, 161
 - generation, 162
- barometric formula, 30
- biosphere, 241, 245
- biotic activity, 222, 240
 - evolution by natural selection, 340
- biotic productivity, 223, 244, 247, 279
- blackbody, 125
- boiling temperature, 197
- Boltzmann, Ludwig, 8
- boundary layer, 111
- Bowen ratio, 265
- Budyko classification, 277
- buoyancy, 154, 236
 - and moist convection, 202
- capillary binding energy
 - and evaporation, 198
- Carnot cycle, 78
- Carnot efficiency, 75, 83
- Carnot limit, 9, 73–75, 327
 - and temporal variations, 261
 - dissipative heat engine, 73
 - of a cold heat engine, 267
 - of a dissipative heat engine, 84
- Carnot, Sadi, 9
- Chapman reactions, 233
- chemical disequilibrium
 - and life, 241, 257
 - by interior processes, 237
 - by radiation, 232
 - estimates, 256
 - generation, 220
- chemical potential, 33
 - of water vapor, 195
- chemical reaction, 225
 - activity, 226
 - affinity, 35, 228
 - endothermic, 225, 238
 - equilibrium constant, 227
 - exothermic, 225
 - extent of the reaction, 35, 229
 - hydration, 231
 - oxidation, 231
 - reaction velocity, 227
- chemical weathering, 221, 235, 236
- Clapeyron equation, 196
- Clausius–Clapeyron equation, 196
- climate change, 314
- clouds
 - albedo, 214
 - cloud condensation nuclei, 198, 253
 - optimum cloud cover, 214
- condensation, 195
 - and nucleation, 198
 - cloud condensation nuclei, 198
 - microscopic, 193
- conjugate variables, 24
- conservation laws, 22
 - angular momentum, 174
 - energy, 144
 - momentum, 175

376

convection
 atmospheric, 167
 dry, 167, 261
 moist, 167, 190
 sensitivity to warming, 212
convective boundary layer, 261, 271, 279
convective cooling, 87, 144, 146, 149
convector effect, 285
Coriolis force, 157
Curzon–Ahlborn limit, 96
cycling ratio, 249

degassing, 238
degrees of freedom, 14, 109
dehydration, 239
desalination, 221, 235
desert greening, 305
dew point temperature, 197, 201
dimensionless numbers, 119
disequilibrium, 61
dissipative activity, 8
dissipative heat engine, 73
dissipative structures, 7, 101, 110
dissipative system, 8
drag coefficient, 165, 200, 208
dryness index, 277
dynamics, 61, 63, 99

ecological economics, 294
ecosystem, 247
eddy transport, 172
efficiency, 75
 at maximum power, 88
 Carnot, 75
 dissipative heat engine, 85
 of the large-scale circulation, 170
Einstein, Albert, 3
energy, 19
 binding energy, 33
 chemical energy, 34
 gravitational energy, 30
 internal energy, 48, 62
 kinetic energy, 32, 154, 164
 osmotic energy, 33, 221
 potential energy, 30, 154
 radiative energy, 24, 126
 surface energy, 33
 thermal energy, 26
 total energy, 48
 total potential energy, 31
 turbulent kinetic energy, 165
 uncompensated heat, 28
energy balance
 atmospheric, 144
 kinetic, 164
 planetary, 138
 surface, 138, 264
 surface energy balance and diurnal variations, 266

Index

energy conversion
 overview of planetary estimates, 328
energy return on investment, 305, 318
enthalpy, 30, 62
entropy, 3, 19, 36
 and disorder, 36
 and mass conversions, 55
 as energy dispersal, 3, 36
 definition by Clausius, 26
 maximum, 3, 38
 molar, 37, 42
 radiative, 37, 41, 127
 scaling to macroscopic scale, 20
 thermal, 26, 37, 43
entropy exchange, 4, 54
entropy of an ideal gas, 29
entropy production, 54
 by a chemical reaction, 230
 by absorption, 136
 by evaporation, 199
 by frictional dissipation, 172, 203
 by heat conduction, 59
 by scattering, 132
 maximum, 94
 minimum, 96
environment (thermodynamic), 21
equilibrium
 and saturation, 189
 chemical, 220
 global, 161
 hydrostatic, 68
 local, 161
 radiative, 125, 170
 soil hydraulic, 273
 thermodynamic, 40, 52
evaporation, 195, 199
 and temperature, 275
 bulk formula, 200
 contribution by plants, 273
 energy limitation, 278
 equilibrium rate, 265
 evaporative fraction, 278
 evaporative index, 277
 microscopic, 193
 potential rate, 265
 relative sensitivity, 210
 simple model, 192
 water limitation, 278
evaporative cooling, 275
evolutionary dynamics, 14, 99, 106
exergy, 61

feedback, 101
 convective feedback to a chemical reaction, 251
 feedback factor, 105
 gradient-depletion, 101, 105
 power-enhancing, 101, 104
food webs, 223

- force
 - Coriolis, 175
 - drag, 165
 - pressure gradient, 161
- fossil fuel consumption, impacts, 315
- fractal networks, 12, 119
- free energy, 19, 61
 - exergy, 61
 - Gibbs, 61, 63
 - Helmholtz, 61, 63
 - minimum, 66
- frictional dissipation, 110, 165
- frictional heating, 68
- fusion energy, 307
- Gaia hypothesis, 2, 7, 219, 325
 - thermodynamic interpretation, 340
- geochemical cycling, 16, 219
- geopotential, 30
- geostrophic flow, 157, 175
- geothermal heat flux, 239
- Gibbs–Duhem relationship, 196
- Gibbs free energy, 61
 - and soil water, 273
 - and thermodynamic equilibrium, 69
 - in geochemistry, 220
 - in phase transitions, 195
- global warming, 315
- greenhouse effect, 138, 140, 149
- grey atmosphere approximation, 138
- ground heat flux, 268
- habitability, 325, 332
 - and chemical disequilibrium, 250, 257
 - and mass exchange, 257, 332
 - thermodynamic signature, 336
- habitable zone, 333
- heat, 30
- heat capacity, 26
- heat engine, 10, 72
 - atmospheric, 10, 83, 123
 - convective, 144
 - dissipative, 85
 - dry, 261
 - endoreversible, 97
 - moist, 202
- heating
 - by condensation, 190
 - by dissipation, 50
 - by friction, 165
 - by interior processes, 178
 - by radiation, 121
- human activity, 16, 291
 - and brain size, 297
 - and feedbacks, 298
 - and land use, 303
 - basal metabolic rate, 293
 - carrying capacity, 295, 300, 304
 - encephalization, 297
 - externalized, 292, 299
 - food acquisition, 300
 - future scenarios, 317
 - impacts, 314
 - limits to growth, 295
 - thermodynamic view, 291
 - within the Earth system, 320
- human appropriation of net primary productivity, 300, 303, 315
- human evolution, 297
- hurricanes, 208, 211
- hydration, 239
- hydrologic cycling, 16, 188
- hydrologic sensitivity, 209
- hydrostatic balance, 31
- hydrostatic equilibrium, 156
- hydrothermal vents, 252
- hydroxyl radical, 233
- ice albedo, 215
- ideal gas law, 28
- industrial metabolism, 299
- irreversibility, 54
- isentropic expansion, 78
- jet stream, 157, 176
 - paradox, 177, 335
- Kleiber's law, 295
- land cover change, impacts of, 315
- large-scale circulation, 157, 167
- latent heat flux, 199, 264, 274
- latent heat of vaporization, 34, 196
- law of mass action, 227
- Le Châtelier, Henry Louis, 230
- Le Châtelier's principle, 230, 231
- life, 6, 222, 240, 324
 - and chemical disequilibrium, 241
 - chemotrophic, 222, 240
 - heterotrophic, 241
 - intelligence, 295
 - phototrophic, 222, 240
 - transport limitation, 241, 333
- lightning, 211, 217, 221, 234
- limits to growth, 347
- Lorenz energy cycle, 163
- Lotka, Alfred, 11, 247
- Lovelock, James, 7, 325
- magnetic field, 182
- Magnus formula, 197
- mantle convection, 178
- mass exchange, 172, 208, 276
 - and heat storage changes, 276
 - and large-scale circulation, 172
 - and water limitation, 277

- mass exchange (cont.)
 - of dry convection, 276
 - of moist convection, 208
- maximum efficiency
 - of converting radiative heating, 145
 - of converting solar radiation, 143
 - of photosynthesis, 243
- maximum entropy, 3, 37, 40, 56
 - of phase transitions, 195
- maximum entropy production (MEP), 12, 74, 94, 349
 - and vegetation, 289
- maximum power limit, 12, 87, 108
 - and diurnal variations, 266
 - and dry convection, 264
 - and heat storage changes, 268
 - and kinetic energy conversion, 92
 - and large-scale circulation, 169
 - and seasonal variations, 171
 - associated transport characteristics, 166
 - mantle convection, 181
 - moist convection, 206
 - of an electric circuit, 90
 - of other energy forms, 90
- maximum power principle, 12
- maximum power transfer theorem, 90
- mechanical work, 28
- metabolic activity, 240
 - and fractal networks, 296
- metabolic rate, 295, 296
- minimum entropy production (MinEP), 12, 96
- Morse equation, 34

- Navier–Stokes equation, 154
- net ecosystem exchange, 263, 279
- net primary productivity, 247, 300
- nitrous oxides, 221

- ocean tides, 308
- OH radical, 233
- optical depth, 139
- optimum grazing hypothesis, 249
- order through fluctuations, 13
- organizing principle
 - maximum entropy production, 12, 94, 349
 - maximum gross bedform-normal transport, 116
 - maximum power, 120
 - minimum energy expenditure, 117
 - minimum entropy production, 12, 96
- origin of life, 242, 335
- osmotic pressure, 235
- ozone, 220, 233

- phase transitions, 193
- photodissociation, 233
- photolysis, 233
- photon gas, 124
- photons, 41, 125

- photosynthesis, 123, 133, 223, 242
 - and mass exchange, 244
 - fertilization effect, 283
 - light use efficiency, 281
 - maximum efficiency, 282
 - of terrestrial vegetation, 279
 - thermodynamic limit, 243
 - transport limitation, 282
 - water use efficiency, 282
- photovoltaics, 123, 309
- planetary boundary concept, 347
- planetary evolution
 - thermodynamic baseline scenario, 341
- planetary habitability, 325, 332
- planetary regulation, 340
- poleward heat transport, 171
- potential
 - chemical potential, 33, 195
 - chemical potential of water vapor, 199
 - matric potential, 273
 - soil water, 273
 - osmotic potential, 33, 221
- potential energy, 30
 - available, 156, 161
- potential temperature, 80
- power, 49, 72
- precipitation, 195
- Prigogine, Ilya, 7
- primary energy consumption, 292, 306
- psychrometric constant, 201, 264

- radiation
 - absorption, 133
 - diffuse, 133
 - diluted, 131
 - dilution factor, 131
 - direct, 133, 309
 - emission, 125
 - photodissociation, 133
 - photoionization, 133
 - photosynthetically active, 243, 282
 - radiation pressure, 127
 - reflection, 123
 - solar, 41, 129
 - terrestrial, 41, 137
- radiative engine, 123
- radiative temperature, 125, 138
 - effective, 185
 - from entropy balance, 185
- relative humidity, 199
- renewable energy, 293, 307
 - comparison of impacts, 316
 - direct concentrated solar, 307
 - Earth system overview, 307
 - estimates, 312
 - estimation biases, 313
 - global estimates, 312
 - impacts, 316

- ocean thermal energy conversion, 309
- photovoltaics, 143
- solar updraft towers, 310
- wind power, 178, 310
- wind power from jet streams, 313
- residence time, 26, 28
- respiration, 247
- river networks, 117
- rotation rate, 178
- sand dunes, 116
- saturation of water vapor, 189, 194
- saturation vapor pressure
 - numerical approximation, 197
 - pressure dependence, 197
 - slope, 196
- scattering of radiation, 131, 132
- Schrödinger, Erwin, 6
- shear stress, 165
- Snowball Earth, 215, 342
- socioeconomic metabolism, 299
- soil water budget, 272
- solar constant, 130
- solar luminosity, 130
- solar radiation, 41, 121, 130
 - diurnal variations, 261
 - maximum conversion, 143
- solid angle, 127
- specific humidity, 200
- state variables, 22
- steady state, 5
- stomata, 281
- structures, 112
 - and organization, 110
 - dissipative structures, 7
 - networks, 117
 - sand dunes, 116
 - vegetation patterns, 116
 - wave-like, 114
- superorganism, Earth as a, 7
- supersaturation, 194, 198
- sustainability, 319
- system
 - boundary, 21
 - dissipative, 8
 - thermodynamic, 21
 - types of, 23
- temperature
 - radiative, 125, 138, 185
 - surface, 138, 265, 268
- terrestrial radiation, 41, 122, 137
- thermalization, 44
- thermodynamic cycle, 78
- thermodynamic disequilibrium, 4, 56
 - and geochemical cycling, 219
 - and human activity, 314
 - and hydrologic cycling, 216
 - and life, 240
 - and potential energy, 156
 - and radiation, 130
 - and solar radiation, 130
 - different forms of, 64
 - distance to equilibrium, 61
 - enhanced depletion by motion, 185
 - maintenance of, 53, 60
- thermodynamic equilibrium, 3, 40, 56
 - and geochemical cycling, 220
 - and hydrologic cycling, 195
 - and phases of water, 189
 - and radiation, 125
 - and water vapor, 194
 - evolution towards equilibrium, 52
 - free energy minimum, 66
- thermodynamic limits, 2
 - Carnot limit, 74
 - Carnot limit of a dissipative heat engine, 84
 - Curzon–Ahlborn limit, 96
 - maximum entropy production, 94, 349
 - maximum power limit, 86, 90
- thermodynamics
 - and sustainability, 319
 - finite time, 96
 - first law, 3, 47, 48
 - illustration of the laws, 4
 - laws of, 3, 46
 - second law, 3, 47, 51, 66
 - thermodynamic flows, 65
 - thermodynamic forces, 65
 - thermodynamic potential, 62
 - third law, 48
 - zeroth law, 46
- thermohaline circulation, 236
- thunderstorms, 211
- tidal forcing, 171, 308
- tipping points, 346
- turbulence, 165
- van’t Hoff equation, 235
- vascular networks, 118
- vegetation–atmosphere interactions, 284
- viscous friction, 165
- waste-heat flux, 72
- waves, 114, 171
- Wien’s law, 41
- wildfires, 252
- wind power
 - effects on wind speed, 312
 - maximum conversion, 92, 310
 - of jet streams, 313
- wind speed
 - from energetics, 208
 - from geostrophic balance, 176