

Author index

Albert Einstein, 13, 158, 164, 274	Günter Wächtershäuser, 100, 102	Nikolai Kardashev, 327
Alexander Oparin, 100, 102	Harold Morowitz, 97, 100, 102, 257	Olaf Stapledon, 331
Alfonso Herrera, 102	Ivan Wallin, 127	Oskar Baudisch, 10, 102
Anaxagoras, 170	J. D. Bernal, 347	Otto Struve, 272, 274
Anaximander, 8	J. B. S. Haldane, 102, 251	Paul Portier, 127
Aristotle, 7, 9	James Lovelock, 122	Peter Mitchell, 153
Bertrand Russell, 323	James Watson, 94	Robin Hanson, 327
Carl Sagan, 257	Jill Tarter, 317	Rosalind Franklin, 94
Carl Woese, xiii	Joan Oró, 108	Sara Seager, 305
Cecilia Payne-Gaposchkin, 19	John Maynard Smith, 133	Sidney Altman, 99
Charles Darwin, 101, 123	John von Neumann, 322	Sir Arthur C. Clarke, 332
Constantin Mereschowsky, 127	Joshua Lederberg, 5	Sir Fred Hoyle, 148
David Belorizky, 272, 274	Konstantin Tsiolkovsky, 345, 347	Sir Isaac Newton, 10, 173
Didier Queloz, 266	Lady Murasaki Shikibu, xiii	Sir James Jeans, 10, 37, 305
Enrico Fermi, 322	Liu Cixin, 325	Stanley Miller, 102
Epicurus, 8	Louis Pasteur, 300	Stephen Jay Gould, 122
Eörs Szathmáry, 133	Lynn Margulis, 122, 127	Steven Benner, 116
Fakhr al-Dīn al-Rāzī, 9	Maurice Wilkins, 94	Stuart Kauffman, 101
Frances Westall, 114	Michael Russell, 100	Syukuro Manabe, 178
Francis Crick, 94	Michel Mayor, 266	Thomas Cech, 99
Frank Drake, 317, 328	Muhammad al-Bāqir, 9	Vladimir Artsikhovski, 10, 309
Freeman Dyson, 101, 331		Walther Löb, 10, 102
Gerard K. O'Neill, 347		
Giordano Bruno, 9		

Subject index

<i>D</i> -amino acids, 315	<i>Animalia</i> , 129	<i>Mahābhārata</i> , 9
<i>D</i> -sugars, 92, 95, 300	<i>Apollo</i> missions, 85, 345	<i>Mariner 4</i> , 203
<i>L</i> -amino acids, 91, 300, 315	<i>Artemis</i> mission, 345	<i>Mars 2020</i> mission, 219
α -amino acids, 91, 119, 300	<i>Asgard</i> archaea, 127	<i>Mars Express</i> mission, 208
α -carbon, 91, 300	<i>Aspergillus penicillioides</i> , 167	<i>Mars Science Laboratory</i> mission, 219
β Pictoris planetary system, 224	<i>Bilateria</i> , 131	<i>Methanopyrus kandleri</i> , 166
β -amino acids, 91, 119, 300	<i>Breakthrough Listen</i> project, 334, 337	<i>Methanothermococcus okinawensis</i> , 157
β -carbon, 91	<i>Breakthrough Starshot</i> initiative, 350	<i>Micrococcus</i> , 127
δ -amino acids, 91, 119, 300	<i>CHEOPS</i> mission, 266	<i>NIROSETI</i> survey, 334
δ -carbon, 91	<i>Cassini–Huygens</i> mission, 157	<i>Nanohaloarchaea</i> , 168
γ -amino acids, 91, 119, 300	<i>Cassini–Huygens</i> mission, 226, 229, 237	<i>Nautilus Array</i> telescope, 287
γ -carbon, 91	<i>Charophyceae</i> , 130	<i>New Horizons</i> spacecraft, 348
<i>‘Oumuamua</i> , 324	<i>Curiosity</i> rover, 206, 208, 209, 219	<i>PLATO</i> telescope, 266
(per)chlorate reduction, 155	<i>DAVINCI</i> mission, 258	<i>Pan-STARRS1</i> survey, 223
<i>Acetobacterium woodii</i> , 155	<i>Dawn</i> mission, 232	<i>Panoramic SETI</i> survey, 334, 336
<i>Acidithiobacillus ferrooxidans</i> , 156	<i>Deinococcus geothermalis</i> , 165	<i>Perseverance</i> rover, 219
<i>Arecibo Observatory</i> , 335	<i>Deinococcus radiodurans</i> , 169, 186, 210	<i>Picrophilus oshimae</i> , 168
<i>Candidatus Brocadia</i> , 156	<i>Dragonfly</i> mission, 231, 263	<i>Picrophilus torridus</i> , 168
<i>Cassini–Huygens</i> mission, 226	<i>Embryophyta</i> , 129	<i>Pioneer 10</i> spacecraft, 348
<i>Chloracidobacterium</i> , 159	<i>Enceladus Orbilander</i> mission, 244	<i>Pioneer 11</i> spacecraft, 348
<i>Chlorobi</i> , 159	<i>Escherichia coli</i> , 90, 97, 120, 166, 186, 250	<i>Project Daedalus</i> concept, 348
<i>Chloroflexus</i> , 159	<i>Europa Clipper</i> mission, 229	<i>Project Icarus</i> concept, 348
<i>Curiosity</i> rover, 205	<i>ExoMars</i> mission, 220, 316	<i>Project Orion</i> concept, 349
<i>Dechloromonas hortensis</i> , 155	<i>Gaia</i> mission, 277	<i>Project Ozma</i> , 328
<i>Dehalococcoides</i> , 155	<i>Geogemma barossii</i> , 165	<i>Roman Space Telescope</i> , 266
<i>Desulfobacterales</i> , 155	<i>Green Bank Observatory</i> , 317, 328	<i>Rosalind Franklin</i> rover, 220
<i>Desulfobacterium autotrophicum</i> , 156	<i>Halarsenatibacter silvermanii</i> , 167	<i>SOFIA</i> telescope, 28
<i>Desulfotignum phosphitoxidans</i> , 156	<i>Haloarchaea</i> , 310	<i>Serpentinomonas</i> , 168
<i>Gemmatimonas</i> , 159	<i>Henneguya salminicola</i> , 154	<i>Spitzer</i> telescope, 28, 47, 334
<i>Geobacter</i> , 155	<i>Herschel Space Observatory</i> , 28	<i>Square Kilometre Array</i> telescope, 337, 338
<i>Heliobacteria</i> , 159	<i>Homo sapiens</i> , 133	<i>TESS</i> mission, 266
<i>Mars Global Surveyor</i> mission, 205	<i>Hubble Space Telescope</i> , 231	<i>Thermococcus gammatolerans</i> , 169
<i>Methanopyrus kandleri</i> , 156	<i>IKAROS</i> probe, 349	<i>Thermococcus piezophilus</i> , 166
<i>Methanosarcina</i> , 155	<i>IRAS</i> telescope, 334, 337	<i>Thiomargarita magnifica</i> , 127
<i>Methylococcus capsulatus</i> , 156	<i>InSight</i> mission, 214	<i>Thiomicrospira crunogena</i> , 155
<i>Nitrosomonas</i> , 156	<i>JWST</i> , 266, 281, 284, 286, 287, 332	<i>Tianwen-1</i> mission, 220
<i>Oscillochloris</i> , 159	<i>Jupiter Icy Moons Explorer</i> (JUICE) mission, 229, 231, 232	<i>VERITAS</i> mission, 258
<i>Pseudomonas</i> , 155	<i>Keck Observatory</i> , 334	<i>Viking</i> mission, 203, 217–219, 303, 316
<i>Shewanella oneidensis</i> , 155	<i>Kepler</i> telescope, 266, 331, 335	<i>Voyager 1</i> spacecraft, 348
<i>Sporomusa ovata</i> , 156	<i>Lick Observatory</i> , 334	<i>Voyager 2</i> spacecraft, 232, 348
<i>Thiobacillus</i> , 156	<i>MAVEN</i> mission, 212	<i>WISE</i> mission, 334
<i>Wolinella succinogenes</i> , 155		<i>Zhurong</i> rover, 220
<i>ALMA</i> observatory, 28		2-amino-oxazole, 108
<i>ARIEL</i> mission, 266, 287		
<i>Alphaproteobacteria</i> , 128		

394 Subject index

- 3-hydroxypropionate bicycle, 159
 51 Pegasi b, 266, 271
- pre-main-sequence star, 40
- abelsonite, 303
 abiogenesis zone, 182
 absorption spectroscopy, 279
 Acasta Gneiss Complex, 79
 accretion tail scenario, 85
 accretional heat, 75, 76, 225
 acetaldehyde, 154
 acetoclastic methanogens, 308
 acetogenesis, 154–156, 208
 acetylene, 47, 261, 264
 acidophiles, 168
 acrylonitrile, 262
 action spectrum, 182
 activating agent, 108, 111
 activation energy, 32, 91, 164, 254, 264
 active phase, 196, 197, 199
 acute radiation syndrome, 346
 adenine, 93, 108, 109, 114, 152
 adenosine, 93
 adenosine diphosphate (ADP), 152, 153
 adenosine triphosphate (ATP), 93, 152, 154, 158, 161, 165
 aerobic respiration, 95, 138, 153, 193, 239, 240
 aerosols, 116, 141, 257, 261
 alanine, 106, 217
 aldehyde, 105, 254
 alkaline hydrothermal vents, 100, 107, 109, 113
 alkaline hydrothermal vents: definition, 113
 alkaliphiles, 168
 Allan Hills (Antarctica), 218
 Allan Hills 84001 (ALH84001), 97, 120, 203, 218, 219, 299
 Amazonian, 205
 amino acid synthesis, 105
 amino group, 91, 300
 ammonia: solvent, 148, 251, 256, 264
 amphiphilic, 96, 103, 262
 anaerobic ammonium oxidation, 156
 anaerobic respiration, 138, 154, 155
 angular momentum problem, 40
 animals: evolution, 130
 anomalous expansion of water, 250
 anoxia, 141
 Anthropocene, 133
 Anthropocene extinction, 142
- anthropogenic climate change, xi, 11, 311, 344
 anti-biosignature, 308
 antimatter propulsion, 349
 apatites, 240
 aptamers, 303
 arabinose, 110
 Archean Earth, 83, 88, 105, 123, 312
 Argyre crater, 205
 Ariel, 232
 aromatic compounds: general, 255
 Arrhenius equation, 91, 164, 171
 Arrhenius factor, 164
 artificial intelligence, xi, xii, 8, 325, 344
 aspartic acid, 168
 assembly theory, 302
 asteroid belt, 65, 81, 223, 324
 asteroids, 31, 77, 141, 334, 343
 astrobiology definition, 3
 atmospheric scale height, 280
 ATP synthase, 152, 153
 autocatalysis, 90, 101–103, 107, 134
 autotrophic origin of life, 102
 autotrophs, 101, 149
 azotosomes, 262
- bacteriochlorophyll *b*, 161, 309
 bacteriochlorophylls, 161, 309
 bacteriorhodopsin, 161, 310
 banded iron formations (BIFs), 136
 Bayes' theorem, 313
 Bayesian analysis, 313, 323, 334
 beaches, 116, 235
 benzene, 255, 256
 Big Bang, 13, 15, 19
 Big Five extinctions, 125, 140, 142
 bio-technosignature, 311, 316
 biodiversity loss, xi, 344
 bioessential elements: definition, 90
 biological productivity, 125, 130, 137, 139, 240, 309
 biologically effective irradiance (BEI), 182, 186, 210
 biomolecules: definition, 90
 biomorphs, 298
 biosignature: definition, 293
 biospace, 162, 261
 birds, 132, 243
 blackbody radiation, 15, 16, 78, 244, 278
 blueshift, 269, 271
 bolide, 141, 143
 Bond albedo, 174, 197, 264
 bond angle, 255, 263
- bond dissociation energy, 247, 254, 255
 borazine, 256
 Boring Billion, 130
 boron, 108, 116, 256
 Bracewell probe, 325
 brines, 167, 207, 210, 217, 229, 232
 brown algae, 130
- calcium carbonate, 188
 calcium–aluminum-rich inclusions, 79
 Callisto, 229, 231
 Calvin–Benson–Bassham (CBB) cycle, 159
 Cambrian, 125, 131, 132
 Cambrian explosion, 131, 132
 cap carbonates, 127, 131
 Capitanian mass extinction, 141
 carbohydrate functions, 95
 carbon dioxide: spectral features, 281, 283, 285
 carbon fixation, 158, 159, 161, 193, 256, 296
 carbon monoxide, 29, 46, 193, 209, 261, 308
 carbon-13, 48, 212, 296, 297, 316
 carbonaceous chondrites, 81, 83, 109
 carbonate precipitation, 188
 carbonate–silicate cycle, 176, 179, 187–189, 198
 carbonic acid, 187
 Carboniferous, 125, 132
 carbonyl, 251, 252, 261
 carbonyl sulfide, 111
 carboxyl group, 91, 96, 300
 carboxylic acid, 96, 105, 107, 209, 254
 carotenoid, 167
 catastrophic outgassing, 80, 82
 cell–cell adhesion, 129
 cellular differentiation, 129
 cellulose, 95
 Cenozoic, 125
 Central Atlantic Magmatic Province, 141
 central dogma, 94, 119
 centre-of-mass (COM), 268–271, 277
 Ceres, 86, 232
 cetaceans, 243
 Changcheng Group (China), 129
 chaotropic, 167, 210
 Chappuis absorption bands, 281, 285, 308
 chemical disequilibrium, 308, 312
 chemical gardens, 298, 299
 chemiosmosis, 98, 153, 154, 161

- chemoautotrophs: definition, 149
 chemoheterotrophs: definition, 149
 chemoton, 90
 Chicxulub impact, 141, 142
 chiral selectors, 300
 chiral: definition, 91
 chitin, 95
 chlorofluorocarbons (CFCs), 332
 chlorophyll *a* (Chl *a*), 158, 310
 chlorophylls, 10, 158, 161, 182, 309
 CHNOPS, 90, 119, 147, 148, 209, 227
 chromophore, 161
 cinnabar, 309
 circular polarisation, 310
 Clarke exobelt, 332
 clays, 110, 111, 206
 climate sensitivity, 177, 178
 cloud condensation nuclei, 258
 co-crystals, 260
 coagulation equation, 55
 coenzyme world, 103, 120
 coenzymes, 103
 cold Haber worlds, 308
 combustion, 139, 332
 comets, 31, 81, 109, 223, 251, 343
 compatible solutes, 167
 complex multicellularity, 127, 129, 138, 162, 193
 condensation reaction, 92
 conduction, 77, 232
 Confidence of Life Detection (CoLD) scale, 315
 continental weathering, 137, 139, 188, 240, 342
 continuously habitable zone, 180
 convection, 78, 84, 231, 232, 258
 Copernican principle, 14, 18, 326
 core accretion, 57, 58
 coronal mass ejections (CMEs), 186
 coronagraph, 285
 corotation resonance, 62
 Cosmic Dust Analyser (CDA), 226, 227
 cosmic microwave background, 16, 17
 cosmic rays, 31, 191, 210, 236, 261, 346
 cosmological redshift, 35
 covalent bonds, 30, 260
 COVID-19 pandemic, 344
 crater lakes, 206
 Cretaceous, 125, 132
 Cretaceous–Paleogene mass extinction, 132, 140–142
 critical radiation threshold, 186
 Cryogenian, 131
 cryovolcanism, 232, 261
 cyanoacetylene, 29, 108
 cyanobacteria, 126, 127, 264
 cyanosulfidic protometabolism, 106
 cyclic nucleotides, 111
 cysteine, 106, 248
 cytochromes, 152
 cytoplasm: definition, 168
 cytosine, 94, 250
 cytoskeleton, 128
 Dallol hot springs (Ethiopia), 168
 dark dune streaks, 207
 dark forest hypothesis, 325
 dark reactions, 158, 159
 Darwinian evolution, 7, 12, 101, 122, 301, 313
 dayside, 191, 284
 debris discs, 223
 Deccan Traps, 142
 deep subsurface, 153, 156, 157, 172, 216, 219
 deforestation, 142, 344
 dehydration reaction, 92, 95, 110, 251
 dendritic valley networks, 205, 206
 dendrolites, 299
 denitrification, 297, 308, 332
 deoxyribose, 93–95
 desert planet, 120
 desiccation, 166, 210, 216, 258
 detrital minerals, 136
 deuterium-to-hydrogen ratio, 48, 67, 81
 Devonian, 125, 132
 dextrorotatory, 92, 300
 diatoms, 256
 dielectric constant, 208, 248, 251
 diffraction limit, 278
 dinosaurs, 132
 Dione, 232
 dissipative structure, 17
 dissolved phosphorus, 124, 148, 258
 division of labour, 130, 134, 242
 DNA functions, 93
 DNA polymerases, 99
 dolphins, 243
 Doppler effect, 269–271
 Drake equation: definition, 317
 Drake equation: limitations, 319
 Drake equation: settling factor, 320
 Drook Formation (Canada), 130
 Dyson sphere, 331, 334, 337
 Earth analogue, 174, 176, 178, 180, 186
 Eberswalde Crater, 205
 eccentric orbits, 60, 65, 192, 228
 ecospace, 134
 ecosystem engineers, 130, 142
 ectothermy, 242
 Eddington limit, 199
 Ediacaran, 125, 131, 242
 effective atmospheric thickness, 280, 282
 effective viscosity, 44
 Einstein ring, 275, 276, 288
 electric dipole moment, 47, 92, 96, 247, 251, 253
 electric sails, 349
 electrochemistry, 151, 152, 161
 electromotive force (EMF), 227
 electron cyclotron maser instability (ECMI), 190
 electron tower, 151
 electron transport chain (ETC), 152–154, 158, 161
 electronegative atoms, 247
 electrostatic potential, 152, 170
 emission spectroscopy, 279
 enantiomeric excess, 300, 305, 315
 enantiomers, 91, 300
 endergonic, 150, 152
 endoplasmic reticulum, 127, 128
 endosymbionts, 127, 128
 endosymbiosis, 127
 endothermic, 150
 endothermy, 242
 enstatite chondrites, 81
 enthalpy, 149, 247
 enthalpy of fusion, 247, 252
 enthalpy of vaporisation, 87, 247, 248, 251, 252
 entropy, 117, 119, 150, 248, 330
 enzyme, 91, 99, 103, 159, 165, 263
 equilibrium temperature, 78, 175, 176, 192, 197, 215
 equivalent isotropically radiated power (EIRP), 329, 334, 335, 338
 escape velocity, 53, 54, 184, 187, 212
 ester linkages, 165
 ether linkages, 165, 262
 eukaryogenesis, 128, 129, 133, 134, 142
 eukaryotes: advantages, 128
 eukaryotes: definitions, 127
 eukaryotes: general, 127, 130, 133, 138, 169
 Europa: chaos terrain, 228

396 Subject index

- eusociality, 134, 242
 eutectic freezing, 237
 evolutionary arms race, 131
 evolutionary singularities, 135
 exergonic, 150
 exhaust velocity, 348
 exobase, 184
 exobiology, 5
 exocomets, 223
 exogenous delivery, 109, 111
 exomoons, 289
 exothermic, 32, 150
 Extrasolar Planets Encyclopaedia, 267
 Extremely Large Telescopes, 287, 289
 extremophiles, 97, 209, 217, 258, 342
 extremophiles: astrobiology benefits, 162
 extremophiles: definition, 162
 extremotolerant, 162, 169

 faint young Sun paradox, 84
 false negative: definition, 293
 false negatives, 293, 294, 300, 306
 false positive: definition, 293
 false positive: oxygen, 305
 false positives: general, 294, 298, 308, 310, 311, 313
 far-UV radiation, 184
 fatty acids, 95, 96, 109, 110, 165, 302
 fayalite, 157
 fermentation, 154, 155, 209
 Fermi paradox: definition, 322
 ferredoxins, 161
 ferric iron, 136, 155, 156
 ferrous iron, 136, 155–157, 208
 figure-of-merit, 334
 first eukaryotic common ancestor (FECA), 127, 129
 Fischer–Tropsch-type synthesis, 107–109, 239
 fish, 132, 240, 243
 flavoproteins, 152
 flowering plants, 132
 fluorescence, 310
 follow the water strategy, 147, 222
 formaldehyde, 29, 32, 107, 193, 252
 formamide, 29, 108, 251, 252
 formic acid, 109
 formose reaction, 107
 fougurite, 110, 113
 Fourier's law, 233
 free-floating worlds, 224, 233, 244, 320
 freeze-thaw cycles, 237
 fumarate, 155
 fumarate respiration, 155
 functional group, 91, 254–256

 Gaia hypothesis, 122
 Galactic Club, 325
 Galactic habitable zone (GHZ), 194, 197, 319
 Gale Crater, 205, 206, 209, 219
 Gamma Cephei Ab, 266
 gamma ray burst, 141, 195, 319, 343
 Ganymede, 229, 231, 232
 gas chromatography, 300, 303, 305
 gene, 93
 general circulation models, 178
 genetic code, 134
 geodynamo, 78, 84, 190, 204
 geometric albedo, 285, 289
 geothermal gradient, 171, 265
 germanium, 256, 257
 Giant Impact hypothesis, 79, 80, 82
 Gibbs free energy, 150–152, 154, 248, 261
 glacial deposits, 127, 131
 global equivalent layer, 207
 global warming, 141, 142, 332
 glucose, 95, 154, 159
 glutamic acid, 168
 glyceraldehyde 3-phosphate (G3P), 159
 glycine, 29, 91, 105, 217, 237, 302
 Goldilocks zone, 173
 Gorka Lake (Poland), 168
 Grand Tack model, 65, 66, 68, 220
 graphite, 297
 gravitational instability, 52, 58
 gravitational microlensing, 224, 268, 274
 gravitational waves, 333
 Great Ordovician Biodiversification Event, 132
 Great Oxidation Event (GOE), 126, 129, 136, 138, 143
 green algae, 130
 greenhouse effect: definition, 175
 greenhouse gases, 82, 84, 123, 175, 193, 215
 group III elements, 256
 group IV elements, 255–257
 guanine, 93, 108, 109

 Haber–Bosch process, 332
 habitability definition, 5
 habitable zone: complex life, 193
 habitable zone: general, 147, 173, 222, 280, 336
 habitable zone: history, 10
 habitable zone: lifetime, 180, 342
 habitable zone: limits, 178
 Hadean Earth, 75, 79, 88, 89, 105
 halides, 155
 halocarbons, 155, 209
 halophiles, 167
 Hart–Tipler argument, 322
 Hartley–Huggins bands, 308
 HD114762, 266
 heat islands, 333
 Hellas crater, 205
 hematite, 136
 hemiacetal group, 95
 Hesperian, 205, 206
 heterotrophic origin of life, 101
 heterotrophs, 101, 149
 Hill radius, 55, 63, 64
 hominins, 133
 homochirality, 91, 107, 109, 300, 301, 310
 horizontal gene transfer, 161
 Hot Jupiters, 60, 65, 194, 267, 271, 280
 human language, 134
 Hycean worlds, 180, 308
 hydrodynamic escape, 184, 196, 212, 213
 hydrofluoric acid, 252
 hydrogen bond: definition, 247
 hydrogen bond: general, 94, 247, 248, 260
 hydrogen cyanide, 29, 32, 47, 106, 108, 252
 hydrogen escape, 137, 178, 184, 342
 hydrogen line, 328–330
 hydrogen peroxide, 138, 229, 239
 hydrogen phosphate, 156, 167
 hydrogen sulfide, 100, 105, 157, 159, 161, 227, 309
 hydrogenases, 152
 hydrological cycle, 130, 206, 260
 hydrolysis, 100, 105, 152, 165, 250, 261
 hydronium ion, 152
 hydrophilic, 96, 262
 hydrophobic, 92, 96, 256, 262
 hydrophobic effect, 248, 262
 hydrostatic equilibrium, 22, 25, 42, 58, 226
 hydrothermal fields, 100, 114–116, 235
 hydrothermal vents: definition, 100
 hydroxyl line, 329, 330
 hyperthermophiles, 165, 169

- ice line, 46, 223
ice mantle, 31, 33
Ice VI, 230
ice-albedo feedback, 139, 176
ichnoscale, 335, 336
icy worlds: definition, 222
imine, 251, 261
immunoassays, 305
impact parameter, 60, 61, 274
impact-generated hydrothermal systems, 86
impulse approximation, 60, 61
in situ biosignatures: definition, 294
inclusions, 82, 84
industrial revolution, 133
inorganic phosphate, 152, 153, 159
insects, 132
integration time, 329, 332
interdict hypothesis, 325
internal energy, 149
interstellar medium, 28, 30–34, 48
interstellar objects, 294, 324
invertebrates, 343
Ion and Neutral Mass Spectrometer (INMS), 226, 227
ion pumps, 161, 168, 310
ionising radiation, 32, 45, 195, 196, 210, 346
ionising radiation: definition, 194
iron oxidation, 156, 209
iron reduction, 155
iron–sulfur world, 100
iron–sulfur proteins, 152, 161
isolation mass, 55, 57, 58
isotope: definition, 296
isotopic fractionation, 48, 66, 125, 136, 212, 296
isotopologues, 48
Isua supracrustal belt (Greenland), 297, 299

Jack Hills zircons, 82, 84, 297
Jeans escape, 183, 184
Jeans escape parameter, 184
Jeans radius, 22, 59
Jezero crater, 219
Jurassic, 125, 132

Kardashev scale: definition, 327
Kardashev scale: extensions, 328, 338
Kardashev scale: Type I, 327, 335, 338
Kardashev scale: Type II, 327, 331, 333
Kardashev scale: Type III, 327
Kelvin–Helmholtz mechanism, 35, 58

Kepler's Third Law, 270, 288
Kepler-186f, 71
Kepler-61b, 71
Kepler-62e, 71
Keplerian angular velocity, 42
kerogen, 297, 298
KIC 8462852, 331
kosmotropic, 167, 210
Kromberg Formation (South Africa), 299
Kuiper Belt, 65, 223

lactic acid, 155
lactic acid bacteria, 155
Ladder of Life Detection, 313, 314, 316
Lake Vostok (Antarctica), 240
Lamarckian evolution, 8
land plants: evolution, 130
large igneous province (LIP), 141, 142, 343
last eukaryotic common ancestor (LECA), 127–130
last universal common ancestor (LUCA), 102, 128, 134, 135
Late Devonian mass extinction, 132, 140, 141
Late Heavy Bombardment (LHB), 65, 85
Late Ordovician mass extinction, 132, 140, 141
late veneer, 80, 83
LAWKI, 252, 254, 261, 263
LAWKI: definition, 246
leiolites, 299
levorotatory, 91, 300
LHS 3844b, 284
libration, 226
light curve, 272, 275–277, 331
light reactions, 158–160
light sails, 330, 349, 350, 352
Lindblad resonances, 62
linear polarisation, 310
lipid bilayer, 96, 103, 262
lipid functions, 95
lipid monolayer, 165
lipid world, 103
liquid chromatography, 305
liquid propane, 262
lithosphere, 78, 84, 189
Little's Law, 318
Lomagundi–Jatuli Excursion, 126, 143
Low Earth Orbit (LEO), 166
lunar cataclysm, 85
Lunar Gateway, 345

lysosomes, 128
lyxose, 110

M-dwarfs: habitability, 181, 183, 185–187, 191, 193
M-dwarfs: properties, 181, 280
magma ocean, 76, 79, 80, 82, 83, 86
magnetic sails, 349
magnetite, 157, 218
magnetosphere, 190, 191, 196, 213, 346
magnetotactic bacteria, 218
main sequence, 20, 266
major evolutionary events, 133
major evolutionary transitions, 133
mammals, 132, 169, 243, 343
manganese oxidation, 156
mantle plumes, 84
Marinoan glaciation, 131
Mars Advanced Radar for Subsurface and Ionosphere Sounding (MARSIS), 208
Mars: Special Regions, 210
Martian crustal dichotomy, 204, 205
Martian gullies, 207
mass dependent fractionation (MDF), 136
mass extinction: definition, 139
mass extinctions, 125, 138, 139, 195, 343
mass independent fractionation (MIF), 136
mass spectra: definition, 303
mass spectrometry, 229, 300, 301, 303, 305
maximum greenhouse, 179–181, 193
McMurdo valleys, 216
megastructures, 328, 331, 334
megatrajectories, 134, 135, 143
messenger RNA, 134
metabolism–first origin of life, 99–103
metabolism: definition, 99, 149
metallicity: definition, 194
metallicity: habitability, 194, 197
metals (astronomy), 38
metamorphism, 137, 188, 297
methane: spectral features, 281, 283, 285, 308
methanogenesis, 125, 154, 155, 208, 238, 261
methanotrophy, 154, 156, 193, 239, 254
methylated halogens, 308
metre barrier, 51–53
microbialites: definition, 299

398 Subject index

- microbially induced sedimentary structures, 298
microdroplets, 108, 117
microenvironment, 112, 117, 121
microfossils, 97, 120, 219, 297–299
micrometeorite, 110, 120, 237
microstate, 117
Milankovitch cycles, 192, 204
Miller–Urey experiments, 102, 105, 106, 109, 120
milliarcsecond: definition, 275
Mimas, 231
Miranda, 232
mirror self-recognition test, 243
mitochondria, 127, 128, 133
mixotrophs, 149
moist greenhouse, 178–180, 342
molar concentration, 98, 148, 240, 250
molecular assembly number, 302
molecular clock, 90, 103, 125, 127, 130
molecular clouds, 22, 23, 30, 31, 34, 45
molecular oxygen: spectral features, 281, 285, 305
molybdenum, 36, 116, 125, 136, 241
monosaccharides, 94, 95
Moon formation, 79
motility, 126, 130, 138, 193, 303
Murchison meteorite, 254
- N-glycosidic bond, 93
nanofossils, 219
nanopore sequencing, 305
nanotechnology, 344
NASA Astrobiology Institute, 3, 5, 11
NASA definition of life, 7
NASA Exoplanet Archive, 267, 287
natural selection, 7, 8, 100, 101, 115, 122, 192
near-UV radiation, 184
nebular hypothesis, 37
negative climate feedbacks, 176, 178, 187, 189
Neogene, 125, 133
Neoproterozoic, 130, 131, 136, 139
Neoproterozoic Oxidation Event (NOE), 131, 136
neutrinos, 18, 333
neutron stars, 16, 26, 266
Nice model, 65
niche construction, 130, 142
nicotinamide adenine dinucleotide phosphate (NADP⁺), 159, 161, 165
nightside, 192, 284
nitrate reduction, 155, 258
nitrates, 138, 209, 297
nitric acid, 312
nitric oxide, 208
nitrification, 156, 332
nitriles, 29, 261
nitrite, 157
nitrogen fixation, 125
nitrogen-15, 48, 125, 212, 297
nitrous oxide, 84, 175, 281, 283, 308, 332
Noachian, 205, 206, 209, 212, 215, 216
non-terrestrial artefacts (NTAs), 323–325
non-thermal escape, 185, 212, 213, 220
nuclear annihilation, 344
nuclear fission, 324, 349
nuclear propulsion, 348
nuclear pulse propulsion, 349
nucleic acids: function, 93
nucleoside, 93, 108, 111, 116, 117
nucleotide structure, 93
nucleotide synthesis, 108, 117, 237
Nuvvuagittuq belt (Canada), 299
- O₂–A band, 281, 285, 305
O₂–O₂ dimer, 306
O-glycosidic bond, 95
obliquity, 192, 193, 198, 204, 230
ocean acidification, 141, 142, 344
ocean planet, 120, 143, 242, 283
octopuses, 243
oligarchic growth, 57
oligonucleotides, 110, 111, 115, 120
olivine, 157
Oort cloud, 223, 243
optical activity, 300
optical depth, 176, 197, 220
orbital circularisation, 191
orbital plane, 192, 268, 273
orderly growth, 54, 56
Ordovician, 125, 132
organelles, 96, 127, 128, 133
organohalide respiration, 155
organosilicon chemistry, 255
osmotic stress, 167, 248
oxalic acid, 109
oxammite, 303
oxidation: definition, 151
oxidising agent: definition, 151
oxygen-18, 48, 49, 82, 212
oxygen-evolving complex (OEC), 158
ozone: spectral features, 281, 283, 285, 308
ozone: UV shielding, 136, 137, 182, 186, 193, 195
- P680 (Chl *a* dimer), 158
P700 (Chl *a* dimer), 158
Péclet number (Pe), 129
Paleocene–Eocene thermal maximum, 133
Paleogene, 125, 132
Paleoproterozoic, 136
paleosols, 136
pandemics, 344
Pangaea, 132, 141
panspermia, 170, 221, 300, 320
Paraná Valles, 205
pebble accretion, 58
pentose, 95, 108, 116
peptide bond, 92, 93, 110, 251
peptide synthesis, 103, 110, 117
peptide world, 103
perchlorate, 155, 167, 208, 209, 213
perchlorate brines, 208
Permian, 125, 132
Permian–Triassic mass extinction, 132, 140, 141
pH: definition, 152
phagocytosing archaeon model, 142
phagocytosis, 128, 130
Phanerozoic, 125, 131, 140, 198, 312, 343
phosphine, 257, 308
phosphite oxidation, 156
phosphodiester bond, 93, 111
phospholipids, 95, 96, 240
phosphorylation, 108, 111, 152
photoautotrophs: definition, 149
photodissociation, 30, 45, 48, 178, 342
photoelectric effect, 158
photoheterotrophs: definition, 149
photolysis, 136, 185, 256, 306
photometry: definition, 279
photon spectral flux density, 170
photosynthetically active radiation (PAR), 157, 169, 182, 238
photosystem I, 158, 160
photosystem II, 158, 160, 169
phototrophy: definition, 157
phylogenetics, 127, 129, 130, 132
PICERAS: definition, 8
piezophiles, 166, 171, 172
Pilbara Craton (Australia), 299
Planck function, 40, 198, 281
Planet Nine, 243
planetary embryo, 49, 57, 67

- planetary radar, 329, 335, 338
 planetary-scale origin of life, 75, 117, 118
 plastids, 127, 134
 plate tectonics, 78, 84, 188, 189, 214, 229
 plurality of worlds, 8, 9, 12, 266
 Pluto, 174, 232
 polarisation spectroscopy, 310, 311
 polycyclic aromatic hydrocarbons, 29, 32, 47, 218
 polyextremophiles, 166, 170
 polysaccharides, 94, 95, 110
 porpoises, 243
 positive climate feedbacks, 139, 176, 178
 pre-main-sequence star, 23, 41, 306
 pre-Noachian, 205, 212, 216, 218
 pre-RNA worlds, 99, 103
 predation, 126, 128, 242
 present atmospheric level (PAL), 123, 126, 131
 primates, 132
 primordial soup, 101
 principle of mediocrity, 122, 322, 327
 prokaryotes: definition, 96
 protein functions, 91
 proteinogenic amino acid, 91, 92, 106, 109, 254, 300
 Proterozoic, 125, 126, 312
 protocells, 90, 103, 109, 112, 115, 134
 protometabolism, 100, 101, 113, 114, 156
 proton motive force (PMF), 113, 152, 158, 161, 170
 Proxima b, 71, 186, 267, 271, 284, 285
 Proxima c, 71
 psychrophiles, 165, 166, 215, 254
 punctuated habitability, 216
 purine nucleobases, 93
 Purple Earth, 310
 Purple non-sulfur bacteria, 159
 Purple sulfur bacteria, 159
 pyrimidine nucleobases, 94, 108
 pyrite, 100, 136
 pyruvate, 154, 155
 Quaternary, 133
 racemic, 91
 radial velocity semi-amplitude, 271
 radiation belts, 228, 236
 radiation pressure, 330, 349, 352
 radiation-resistant organisms, 169, 186, 195, 210
 radiative forcing, 177
 radio auroral emission, 190
 radiogenic heat, 76, 78, 233
 radiolysis, 156, 208, 229, 239
 Rayleigh instability criterion, 45, 71
 Rayleigh number, 78, 84, 232
 Rayleigh–Jeans limit, 289
 reactive oxygen species, 138, 169
 recurring slope lineae, 207, 208
 red algae, 130
 red beds, 136
 red giant, 25, 26, 29, 341
 redox couples, 151
 redox potential, 151, 154, 158, 160
 redox reactions: definition, 149
 redshift, 15, 269, 271
 reducing agent: definition, 151
 reduction: definition, 151
 remote-sensing biosignatures: definition, 294
 replication–first origin of life, 99, 107
 reptiles, 132
 retinal, 161
 reverse gyrase, 165
 reverse Krebs cycle, 100–102, 159
 rhodopsins, 161, 310
 ribonucleotides, 108, 109
 ribose, 93–95, 107, 108, 110, 117, 152
 ribozymes, 99, 121, 237
 ribulose 1,5-bisphosphate carboxylase/oxygenase (RuBisCO), 159
 Richmond Mine (USA), 168
 RNA functions, 93
 RNA world, 99, 103, 107, 116, 165
 RNA-peptide world, 103
 RNA/DNA nucleobase, 93, 103, 108, 117
 rocket equation, 348, 351
 runaway greenhouse, 178, 181, 187
 runaway growth, 54–57
 salinity, 116, 166, 167, 209, 226, 228
 Salpeter time, 199
 salt-in approach, 167
 salt-induced peptide formation, 110
 salt-out approach, 167
 sea spray, 116
 second law of thermodynamics, 118, 119
 self-replicating probes, 322, 326, 337
 semi-arid aquifers, 116
 serine, 106, 248
 serpentinisation, 137, 156, 157, 208, 226, 238
 SETI: definition, 317
 sexual reproduction, 128, 134
 Sgr A*, 196, 197, 199
 shadow biosphere, 90, 263, 265
 Shark Bay (Australia), 243
 shock waves: prebiotic chemistry, 106, 109, 111
 Siberian Traps, 141
 siderites, 297
 sievert: definition, 346
 signal-to-noise ratio (SNR), 309, 329, 330
 signalling molecules, 91, 129
 silanes, 255, 256
 silicon dioxide, 85, 157, 226, 256, 298, 347
 silicones, 256
 Silurian, 125, 132
 simple multicellularity, 126, 129, 142
 SNC meteorites, 218
 snow line, 46, 67, 223
 Snowball Earth, 126, 131, 139
 Soanesville Group, 125
 social learning, 243
 soda lakes, 166
 sodium chloride, 110, 167, 228
 solar constant, 178
 Space Age, 345
 space weather, 173, 186, 305
 SpaceX, 346
 spark discharge, 102, 105, 120
 species richness, 119
 specific heat capacity, 76, 87, 204, 247, 248
 spectral energy distribution, 20, 40
 spectral radiance, 170, 198, 281
 Sputnik Planitia, 232
 sputtering, 212
 stagnant-lid tectonics, 84, 189, 214
 standard state, 150, 151
 starch, 95
 starshade, 285
 stellar energetic particles (SEPs), 186, 191, 306
 stellar flares: definition, 185
 stellar flares: general, 173, 195, 310
 stellar flares: habitability, 186, 198
 stellar proton events (SPEs), 186, 187, 196
 stellar winds: definition, 185

400 Subject index

- stellar winds: general, 29, 173, 190, 349
 stellar winds: habitability, 185, 190
 stereoisomers, 95
 sterols, 95, 96
 Strecker synthesis, 105
 Strelley Pool Formation (Australia), 299
 stromatolites: definition, 299
 stromatolites: general, 298, 299
 structural isomers, 111, 300
 Sturtian glaciation, 131
 subduction, 84, 188, 189, 214
 submarine hydrothermal vents, 107, 108, 111, 113, 226, 236
 succinate, 155
 sugar synthesis, 107
 sulfate reduction, 155, 156, 170, 239
 sulfates, 138, 167, 210, 229, 239
 sulfur cycle, 170, 209
 sulfur mass independent fractionation (S-MIF), 136
 sulfur oxidation, 155, 156, 170, 209, 258
 sulfuric acid: solvent, 148, 252, 256, 258
 supercritical fluid, 249, 253
 superflares, 185–187
 superintelligence, 344
 supermassive black hole (SMBH), 6, 196, 197, 199, 249, 333, 343
 supernova, 26, 29, 141, 194, 319, 343
 supervolcano, 343
 surface tension, 248, 251, 252
 synapsids, 132
 synchronous rotation, 191, 283
 syntrophy, 155
 system equivalent flux density, 329

 tape of life, 122, 123
 tardigrades, 164
 technological intelligence, 135, 139
 technosignatures: definition, 317
 temperate zone, 173
 termites, 242
 terraforming, 347
 tertiary structure, 93
 Tethys, 232
 tetrapods, 132
 tetrapyrroles, 309
 Tharsis bulge, 205
 Theia, 79
 thermal buffering, 204, 247, 248, 252
 thermal escape, 183, 184, 212, 220
 thermal phase curve, 284
 thermodynamic disequilibrium, 17, 88, 118
 thermophiles, 165, 168
 thiocyanate, 167
 thrombolites, 299
 thymine, 94
 tidal disruption events (TDEs), 197
 tidal force, 85, 191, 192, 225
 tidal heating, 225, 228, 229, 233, 234, 244
 tidal height, 121
 tidal locking, 191, 192
 tides, 116, 121
 Titania, 232
 transit depth, 273, 280, 282, 288
 transit probability, 273
 transit: definition, 273
 transmission spectroscopy: definition, 280
 transmission spectrum: definition, 280
 transmitter rate, 334, 335
 TRAPPIST-1, 183, 198, 267, 283, 285
 TRAPPIST-1b, 284
 TRAPPIST-1c, 71, 284
 TRAPPIST-1e, 283, 286
 TRAPPIST-1f, 71
 TRAPPIST-1h, 71
 Tree of Life, 128
 Triassic, 125, 132
 Triassic–Jurassic mass extinction, 132, 140, 141
 triglycerides, 95, 96
 Triton, 232
 Type I migration, 62
 Type I reaction centre, 159–161
 Type Ia supernovae, 194
 Type II migration, 63, 65
 Type II reaction centre, 159–161
 Type II supernovae, 194

 Ultraviolet radiation: prebiotic chemistry, 236
 uracil, 94, 109
 uraninite, 136
 uranium reduction, 155
 urea, 29, 108
 Utopia Planitia plain, 220
 UV radiation: damage, 116, 138, 168, 182, 186, 210
 UV radiation: prebiotic chemistry, 34, 106, 109, 114, 181
 UV-B radiation, 137, 193
 UV-C radiation, 182

 valence electron, 255, 256
 Van Maanen 2, 266
 vascular plants, 132, 242, 343
 vegetation red edge, 285, 309–311, 333
 vertebrates, 132, 242, 343
 Vesta, 85, 87
 Viking: Gas chromatograph/mass spectrometer (GCMS), 217, 218
 Viking: Gas exchange (GEX), 217, 218
 Viking: Labelled release (LR), 217, 218
 Viking: Pyrolytic release (PR), 218
 virus, 8, 12, 93, 103, 120
 virus world, 103, 120
 vitrification, 164

 warm little pond, 101, 114
 warp drives, 347
 waste heat, 330, 333
 water activity, 167, 210, 258
 water hole, 329, 330
 water problem, 116, 250
 water world, 82, 120, 124, 242
 water–rock reactions, 107, 156, 226, 231, 235, 238
 water: spectral features, 281, 285
 waterbelt state, 127, 131
 Watson–Crick–Franklin base pairs, 165, 169, 248, 251
 Watson–Crick–Franklin base pairs, 94
 wet–dry cycles, 109, 111, 112, 115, 116
 wet-dry cycles, 110
 whales, 243
 white dwarf, 21, 26, 195, 266
 Wien's displacement law, 278, 281, 288
 wollastonite, 188
 Wood–Ljungdahl pathway, 101, 102, 113
 world ship, 350, 352

 X-rays, 47, 168, 212, 237, 305
 xanthine, 109, 254
 xerophiles, 167
 XUV radiation: definition, 184

 yeast, 97, 155
 young stellar object, 40
 Young–Laplace equation, 248

 zirconium(IV) silicate (zircons), 79
 zoo hypothesis, 325
 zoonosis, 344
 zwitterions, 91