Cambridge University Press & Assessment 978-1-009-63377-2 — The Origin and Nature of Life on Earth Eric Smith , Harold J. Morowitz Index More Information

Index

 \wedge , defined, 303 acetogen, 47, 51 active data, 601 λ -calculus formulation, 602 allometric scaling of genomes, 604 of metabolic rate, 604 α -ketoacids introduced, 183 reductive amination, 212, 387 amino acids biosynthesis and genetic code, 281, 285 branched-chain, 212 decision tree, 312 from α -ketoacids, 212 in Aquifex, 212 using dinucleotides, 312 using GTP, 313 using uracil, 313 biosynthetic homologies, 298 early steps, 299 complex as cofactors, 261, 322 code assignments, 292 introduced, 291 hydrophobicity and protein folding, 317 ranking, 298 organosynthesis energetics of, 153 simple code assignments, 292, 303 introduced, 291 sulfur introduced, 291 three classes, 291 A-minor interaction, 415 anabolism, 50, 54 pillars of, 184

anaplerotic pathway defined, 185 in rTCA, 237 antagonistic pleiotropy, 577 anthropic principle, 429, 571 Aquificales, 47, 144 Aquifex aeolicus, 179 sulfur metabolism, 181 Hydrogenobacter thermophilus, 216, 242 rTCA cycle in, 186 asthenosphere, 84 convection in, 111 depth of, 111 atmosphere CO accumulation, 105, 360 ratio to CO2, 166, 362, 364 runaway, 361 CO_2 Archean, 82, 163, 165, 360 on Mars, 104 on Venus, 104 removal processes, 82, 97, 357 composition Archean, 159 feedbacks with tectonics, 104 signatures of, 159 electrolysis of N₂, 105 escape, 97 parameters controlling, 99 processes, 102 velocity and energy, 98 exobase, 99 defined, 101 exosphere, 99 defined, 101 fo_2 Ärchean, 164 determinants of, 98 formation

Cambridge University Press & Assessment 978-1-009-63377-2 — The Origin and Nature of Life on Earth Eric Smith , Harold J. Morowitz Index

More Information

as retention, 97 from cometary infall, 97 from magma outgassing, 97 greenhouse Archean, 80, 165 decline over time, 81 HCN, 166 homopause defined, 102 hydrogen escape, 98, 357 in Hadean, 157 photochemistry, 76, 357 photolysis of CO2, 105, 166, 357 of SO₂, 163, 358, 362 of water, 104, 105, 357 redox disequilibria, 357 scale height, 99 defined, 100 stellar defined, 80 temperature, 80 sulfur exit channels, 160, 362 fractionation, 362 atoms formation of, 475 autocatalysis network, 185, 511 fragility of, 237 in core metabolism, 183 in glyoxylate shunt, 211 in long loops, 268 in short loops, 268 need for, 236 redundancy in, 239 phase transition, 511 autotrophy, 48 chemoautotrophy, 54 lower complexity of, 189 awaruite, 135 Bacon, Francis and empiricism, 342, 427, 557 and induction, 427, 557 barriers in stellar fusion Coulomb repulsion, 78 weak interactions, 78 to relaxation, 75 in planets, 83 basalt mid-ocean ridge (MORB), 94, 116 pillow, 97, 112, 118 Bayes model selection, 547, 556, 564

Index

661

and optimal induction, 563 defined, 556 theorem, 556 defined, 557 likelihood, 557, 564 posterior, 557, 565 prior, 557, 564, 599 Belousov-Zhabotinsky reaction, 474, 522, 593 biochemical databases **KEGG**, 57 MetaCyc, 57 Uniprot, 57 biochemistry activation/temperature scales, 76 and vent chemistry, 10 modules, 150 recapitulated, 176, 274, 276 overlap with geochemistry, 156, 175 roles of elements, 60 scales of molecules, 62 separation of timescales, 151 bioenergetics electron bifurcation acetogens versus methanogens, 376 in minerals, 265, 379 emergence of, 275 geochemical context, 330 energy carriers electrons, protons, phosphates, 323 non-interchangeability, 324 fuel cell models, 378 Na⁺-mediated, 413 need for, 188 proton-mediated, 368 redox 368 subsystems, 71, 275 cellular triangle of, 328 interconnections among, 323 introduced, 277 oxidation/reduction, 326 phosphoryl group transfer, 326 proton transfer, 327 trans-membrane potential in acetogens and methanogens, 375 biogeochemical cycles carbon, 50 biosphere and living state, 11 as a channel, 28, 188, 541, 592 as a geosphere, 10 defining characteristics, 541 emergence, 28 as a planetary subsystem, 106 as network autocatalyst, 239 as particular system, 589 abstractions of, 589 boundary exchanges, 11

Cambridge University Press & Assessment 978-1-009-63377-2 — The Origin and Nature of Life on Earth Eric Smith , Harold J. Morowitz Index

More Information

662

chemotrophic basal. 141 model for early life, 155 parallel, 140 deep hot, 142 processes, 11 subsurface, 146, 157 systems, 11 Boltzmann, Ludwig entropy function, 438 "bowtie" topology anabolism in, 180 catabolism in, 180 Brusselator, 474, 522 C1 metabolism central superhighway, 195 in Wood-Ljungdahl, 206 C₁ reduction acetogens versus methanogen, 235 catalysts magnetite, 372 sulfides, 372 centrality of, 192 free energies of, 374 geochemical, 372 Heinen and Lauwers, 372 in acetogens and methanogens, 373 in Wood-Ljungdahl, 206 introduced, 192 microbial models, 373 reconstruction of, 229 relation to mixotrophy, 229 under mild conditions, 373, 377 universality, 219, 227 ramifications of, 229 variant THF pathway, 227 Ca^{2+} and CO2 removal, 165, 357 role of oceans, 104 exchange for Mg²⁺, 134 precipitation of phosphate, 152, 365 precipitation of sulfate, 129 canalization and error buffering, 308, 318 carbon fixation partial oxidation in, 190 productivity versus selectivity, 191 carbon fixation pathways 3-hydroxypropionate, 204 and alkalinity, 234 3-hydroxypropionate/4-hydroxybutyrate, 205 acetyl-CoA, 379 split arcs, 233 autocatalytic loops, 201 Calvin-Benson-Bassham, 208 distribution, 209

Index

pentose phosphate in, 208 RubisCO, 208, 234 common reactions, 216, 218, 383 dicarboxylate/4-hydroxybutyrate, 203 distribution, 204 distinguishing reactions, 216, 218 historical reconstruction, 219 history of, 219 redundancy across, 214, 216 rTCA, 201, 379 biosynthetic precursors, 201 discovery, 201 distribution, 203 seven building blocks, 211 Wood-Ljungdahl, 192, 206, 372 distribution, 206, 207 carbonate in Archean basalts, 165 in Archean sediments, 165 carbonyl insertion at thioesters, 380 in rTCA, 202 at thiols Huber and Wächtershäuser, 239, 372 catabolism, 50, 55 reverse of anabolism, 180 catalysis ladder of, 410 network, 185 non-specific, 178, 218 phase transfer, 510 promiscuity, 177, 178 through time, 178 tweezers and hands, 277 cells as unit of life, 331 functions control by genomes, 332 energy system integration, 331 homeostasis, 332 partitioning of, 333 integration of, 278 cellular life age, 58 geological record, 58 central limit theorem, 438 chance and necessity, 22, 38, 66, 86 and selection of TCA cycle, 248 criteria of 69 degrees of, 68 chemical potential, defined, 444 chemistry as digital system, 594 combinatorial state space, 593 separation of scales, 594 chirality of sugars and amino acids, 402

Cambridge University Press & Assessment 978-1-009-63377-2 — The Origin and Nature of Life on Earth Eric Smith , Harold J. Morowitz Index

More Information

selection for, 309, 400 chromosome as unit of selection, 575 Church-Turing thesis, 602 classification bioenergetic, 42, 45 five kingdoms, 44 Mayr and prokaryotes, 44 phylogenetic, 43, 45 Linnaean, 44 molecular, 44, 45 trophic, 42, 46, 48 typological, 43, 45 phenetic, 45 Clausius, Rudolf and Darwin, Charles, 502 statement of second law, 502 clinopyroxene hydrolysis reactions, 133 temperature dependence of, 131, 137 clostridia, 48 Cl. kluvveri, 204 CODH/ACS enzyme homology of, 235 introduced, 206 codon as instruction word, 302, 312 capture causes for. 296 defined, 296 coenzyme-A acetyl in rTCA, 201 in Wood-Ljungdahl, 206 cofactors, 62 alkyl-thiol, 260 acyl-carrier protein, 261 convergent evolution in, 260 lipoic acid, 261 S-adenosyl-methionine, 262 as targets of selection, 252 biosynthesis cvclohvdrolase enzymes, 396 in relation to RNA, 253, 263, 389 biotin in 3HP/4HB cycle, 205 in rTCA, 202 feedback and control, 64, 263, 269, 389 flavins, 258 folates biosynthesis, 255 variations among, 255 function as monomers, 389 histidine as, 259 lipoic acid

Index

663

and rise of oxygen, 248 molecular characteristics, 250 pterins, 254 C1 free energies, 207, 233, 377 in Wood-Ljungdahl, 206 introduced, 192 quinones, 262 and rise of oxygen, 245, 248 in γ -proteobacteria, 245 roles in metabolism, 249 amino group transfer, 253 C1 group transfer, 253 membrane electron transport, 253 metals and electron transfer, 253 oxidation/reduction, 253 phosphoryl group transfer, 253 thioester formation, 253 roles in networks, 251 roles of elements, 264 in C1 group transfer, 264 metals and electron bifurcation, 265 metals and radical intermediates, 265 nitrogen in heterocycles, 266 sulfur in redox cycling, 267 stages of emergence, 389 alkyl thiols, 399 biotin, 399 C-N heterocycles, 391 nicotinamide, 391 nucleobases, 392 relative to metabolism, 251, 263, 391 relative to RNA, 397 thiamin, 398 THE at root of autotrophy, 235 introduced, 194 thiamin biosynthesis, 258 in rTCA, 202 combinatorial explosion, 386, 561, 566 compartmentalization emergence of, 275 sequence, 336 partial autonomy of genomes, 337 pre-cellular, 332 competitive exclusion in chemical kinetics, 236 complexity effective, 289 frontier of, 422 compositional inheritance, 20 computation and erasure, 497 reversible, 497 computing analogue limitations of, 594

Cambridge University Press & Assessment 978-1-009-63377-2 — The Origin and Nature of Life on Earth Eric Smith , Harold J. Morowitz Index

More Information

664

digital role of error correction, 594 constraint propagation direction of, 276 from metabolism, 540 satisfiability problem, 308, 604 frustration in, 604 relation to glasses, 605 continents accretion at convergent margins, 112, 113 and CO2 removal, 104, 165 cratons Archean, 113, 158 formation of, 113 orogens, defined, 113 shields, defined, 113 supercontinents age of first formation, 82 continuity hypothesis, 176, 218, 220, 236, 409 control concept of, 548, 566 distributed in ecosystems, 586 localized in organisms, 585 role of models in, 567, 575 control first, 350 control systems buffering, 548 and Simon modularity argument, 567 feedback Darwinian selection, 355 feedforward allosteric regulation, 354 Central Dogma, 354 hierarchical, 548, 567 open-loop reaction networks, 354 controller variety of, 548 convection mantle, 95 Rayleigh-Bénard and spherical topology, 108 as analogy to emergence of life, 96 as non-equilibrium phase transition, 96 shear localization 110 Crick, F. H. C. Central Dogma, 178, 279, 352 wobble-base, 292 crust continental, 107 differentiation of, 113 preservation, 114 oceanic, 107

Index

recycling, 114 porosity, 143 thickness and spreading rates, 158 Archean, 158 Curie, Pierre Curie temperature, 454 Curie-Weiss model conditional independence of fluctuations, 468, 469 domain flips in, 463, 600 order parameter, 460 partition function, 457 cyanobacteria 2-methylhopanoids, 58 anoxic and C1 reduction, 235 phylogenetic dating, 58, 82 D" layer, defined, 114 Darwin, Charles endless forms, 569 warm little pond, 345 Darwinian Threshold, 419 as phase transition, 583 defined, 309 development regulation, 44 de Duve, Christian thioester world, 320, 382 as source of phosphate, 330 Diels-Alder reaction, 510 dike formation, 118 and biota, 120 and salinity, 119 and volatiles, 119 sheeted, 118 disequilibria hierarchy of, 75 hydrothermal vents chemical, 120 pH, 359, 366 phosphoanhydrides, 367 redox potential (E_h) , 359, 366 thermal, 120 thioesters, 367 long-lived species, 360 oxidation/reduction from planet formation, 95 planetary scale, 356 disequilibrium planetary arc of, 74, 171, 341, 366 DNA as "queen bee", 347 Doi-Peliti construction, 528 Downward causation, 470

Cambridge University Press & Assessment 978-1-009-63377-2 — The Origin and Nature of Life on Earth Eric Smith , Harold J. Morowitz Index

More Information

Earth core separation from mantle, 84 temperature, 83 restless, chemical, 106 ecosystem, 38 architecture stability of, 605 as community, 585 as decoder through coevolution, 602 through physiological regulation, 602 through trophic balance, 602 as entity, 585 as super-organism, 41 coevolution within, 18, 552 community assembly, 15, 56 first-class citizen, 40 meta-metabolome, 52 metabolic universality, 15, 40, 51, 180 relative to organism, 14 Ehrenfest, Paul classification of phase transitions, 464 electron bifurcation flavins in, 267 in early organosynthesis, 266 introduced, 265 mechanism, 266 on organic cofactors, 266 emergence and reductionism, 26, 434, 466 role of gateways, 342 energy conservation, 444 and heat, 461 Noether's theorem, 324 entities durable versus ephemeral, 606 entropy and energy conservation, 442, 444, 461 and fluctuations, 436, 440, 463 and inference, 436 and information, 447 combinatorial basis of, 487 convexity of, 445 equilibrium in living systems, 502 in open systems, 504 functional. 505 from Legendre transform, 530 in classical thermodynamics, 436, 442, 443 Kolmogorov-Sinai, 509 maximization, 440 as maximum ignorance, 447 in least-biased inference, 447 in relation to living matter, 504 role of constraints, 441, 449

Index

665

negative, 448, 505 non-equilibrium, 505, 511 and rates, 506 as action, 509 maximization, 434 of histories, 27, 506, 509 of states, 27 production, 507 relative, 285 defined, 450, 564 epibiont, 145 error correction across scales, 64 analogue from large oligomers, 595 and phase transition, 32, 500 argument for autocatalysis, 384 at multiple scales, 546 biological role of unique solutions, 559, 568 sources of, 546 buffering, 31, 548 by genetic code, 281 in hierarchical control, 579 closure, 22 conditions for, 547, 572 of biosphere, 591, 597 codes block encoding, 490 correlation length, 490, 598 degeneracy of, 605 ecological analogy, 559 rate, 491 digital advantages of, 594 free energy cost of, 595 from quantum state space, 595 from small molecules, 595 in living systems, 595 reason for core metabolism, 596 distributed over biological order, 572 sufficient conditions for, 544 finite-rate and creep, 605 and glasses, 600, 605 in biological systems challenges of, 544 in hierarchies, 22, 501, 544, 546, 578, 597 large-deviations scaling, 492 molecular recognition as, 497 first-order phase transition, 498, 601 optimal, 434, 486, 494, 558, 597 relations to thermodynamics, 489, 500, 558, 598 Schneider relaxation model, 496, 497, 601 signal/noise ratio in, 492 trade-offs, 597

Cambridge University Press & Assessment 978-1-009-63377-2 — The Origin and Nature of Life on Earth Eric Smith , Harold J. Morowitz Index

More Information

666

decoding time, 489, 499, 558 message rate, 489, 499, 598 zero-rate many phases, 599 one phase, 599 error threshold, Eigen, 18, 178, 316, 578 escape charge transfer mechanisms, 102 hydrodynamic, 102 Jeans, 102, 357 criterion, 101 parameter, 99, 100 photochemical, 103 through impact ejection, 103 through polar wind, 103 through sputtering, 103 evolution and induction, 33, 563 and order parameters, 32 constraints in evolved, 546 physical, 546 Darwinian adaptive, 552 and individuality, 20 and phase transition, 571 as derived process, 18 as mechanism, 590 as paradigm, 16 basis for defining life, 572, 589 churn, 66, 605 context for, 16 distinguishing features of, 572 emergence, 19, 550, 590 in embryogenesis, 17 in immunogenesis, 17 limitations, 16, 541, 550, 571, 578 opportunities for, 579 reliance of life on, 549 requirements, 20, 570 sufficiency, 18 directionality in, 221, 242 historical contingency, 67 pathway serendipity, 177 innovation partitioning in time, 65 light of, 219 long-term and convergence, 200, 276 major transitions, 65 biogeochemical, 420 in carbon fixation, 420 phototrophy, 421 rise of oxygen, 421 neutral, 574 open-ended, 19, 20, 33, 68, 601 retrograde, 178

Index

short-term and variation 200 exaptation, 307 faint young Sun paradox, 80, 165 faulting, transform from spherical geometry, 110, 117 feedback in metabolism, 175 fermentation, 48, 55 links to autotrophy, 231 ferromagnetism, 453 field theory effective and renormalization, 473, 478 quantum condensed matter, 473 vacuum, 473 Fischer-Tropsch reaction, 238, 361, 371 Fisher, R. A. fundamental theorem, 570 fitness Fisher-Price formulation, 41 flavins in relation to RNA, 396 fluctuations and entropy maximization, 440 conditional independence, 448, 451 defined, 468 in Curie-Weiss model, 468, 469 non-equilibrium Gaussian order, 534 perturbing pervasiveness of, 542 problem of containing, 542 sources of, 542 scale, 437, 450 structure, 437 fo_2 **b**uffer fayalite/magnetite/quartz (FMQ), 93 iron/wüstite (IW), 93 of mantle, 84 FO-F1 ATPase antiquity of, 330 complexity of, 330 folates in relation to RNA, 312, 396 force electro-weak, 475 electromagnetic, 475 strong, 475 weak, 475 formose reaction and borate, 389 autocatalysis, 388 with phosphorylation, 389

Cambridge University Press & Assessment 978-1-009-63377-2 — The Origin and Nature of Life on Earth Eric Smith , Harold J. Morowitz Index

More Information

free energy Gibbs 445 and effective potential, 465 Helmholtz, 444, 449, 457 Landau "grand potential", 445 free lunch no such thing, 187 paid to eat, 188 freezing generalized usage, 452 hierarchy of matter, 474 fugacity of oxygen (f_{O_2}) , defined, 84 futile cycle, 55, 180 Gaia theory, 41 gene granularity of, 582 horizontal transfer, 241, 574 aminoacyl-tRNA synthetases, 282, 310 form of modularization, 582 in evolution of translation, 582 linkage disequilibrium, 581 material definition, 581 origin in physiology, 582 selfish, 581 generating function cumulant, 445 duality, 527 from Laplace transform, 526 moment, 527 ordinary power series, 527 generating functional cumulant, 530 genes first, 349 genetic code as firewall, 286 as window on translation, 284 assignments, 278 permutations of, 284 defined, 278 description length compression, 289 establishment of, 275 formation of complex amino acids, 321 cysteine and metalloproteins, 321 cysteine and protein folding, 321 methionine and reading frame, 321 simple amino acids, 319 sulfur amino acids, 321 "frozen accident" interpretation, 68 introduced, 277 regularities, 71 A-second, ATP, and histidine, 301 and amino acid biosynthesis, 281 compatibility of explanations, 319

Index

667

confounds of explanations, 318 construction rules 289 empirical account of, 280 error buffering, 281, 288, 306, 315 exceptions, 296, 300 explanations for, 281, 306 first base and CHO backbones, 294, 303 functional criteria, 288 G-first and amination, 294 G-second and GTP cofactors, 300 histidine as outlier, 301 interpretation of, 280 of metabolic origin, 275 probabilistic, 290 second base and hydrophobicity, 297, 303 similarities versus rules, 298 third-base redundancy, 289, 292, 303 UTP and pyruvate, 305 rule combinations intersections, 302, 303 property similarities, 302, 306 redundancies, 302, 305 universality of and innovation-sharing, 574, 577 and statistical proteins, 308 before modern aaRS, 310 geodynamo, 84 geosphere abiotic partitioning role, 356 as coarse partition, 6 atmosphere, 7 biosphere, 10 Vernadsky, 10 concept. 6 hydrosphere, 7 interfaces biota, 9 complexity, 8 lithosphere/hydrosphere, 8, 158 lithosphere, 7 Gibbs equilibrium as null hypothesis, 431, 503, 543 gluconeogenesis, 181, 183 glycine biosynthesis from C1 pathway, 193, 300 gene alternations in, 224, 228 oxidative, via serine, 195 pathway distributions, 225 problem of, 193, 219, 224 reconstruction of, 224 reductive, from C1-THF, 195 three pathways, 194 transamination, via glyoxylate, 196 cleavage system, 195, 228 glycolysis, 181

Cambridge University Press & Assessment 978-1-009-63377-2 — The Origin and Nature of Life on Earth Eric Smith , Harold J. Morowitz Index

More Information

668

glyoxylate from photorespiration, 196, 209 shunt, 196, 209 aldol reactions in, 209 and 3-hydroxypropionate bicycle, 210 Goldstone's theorem, 537 Gompertz, Benjamin mortality distribution, 577 Gould, Stephen Jay historical contingency, 467 punctuated equilibrium, 605 granularity and jamming, 576 characteristics of, 576 consequences of compared to fluids, 576 for standing variation, 577 examples of, 576 in time, 577 graph bipartite, defined, 270 great oxidation event, 358 Hadean eon, 2 dating, 58 hydrothermal systems, 53 rock record, 38, 58 "the unseen", 2 halophiles phylogeny of, 157 HCN and rTCA intermediates, 394 polymerization, 393 computational modeling, 395 heat, definition, 444 Hertzsprung-Russell diagram, 77 heterosis Lewontin model, 581 heterotrophy, 48 hierarchy, 3, 39 and error correction, 64 recapitulation of patterns, 70, 276 stability of, 31, 33, 343 hydrogen sequestration in the ocean, 104 in the troposphere, 104 hydrosphere hydrothermal fluids, 358 ocean, 358 oxides in, 358 hydrothermal vents, 53 acidic, 368 AHV model, 368, 373, 412 alkaline, 359, 368 mineral membranes, 369 alteration fluids

Index

dissolved metals, 120 H₂ activity, 120 ion exchanges in, 127 $Mg \rightarrow 0, 134$ pH, 120, 122 phosphorus, 152 rules of thumb for, 139 temperature, 120 animals ecology, 145 endosymbiotic bacteria, 145 Riftia pachyptila, 146 antiquity of, 155 as conservative environments, 155, 156 as focusing centers, 366 as redox conduits, 120, 126 at/near spreading centers, 142 bacteria endosymbiotic, 145 mat-forming, 145, 147 bacterial energy systems, 152 basalt-hosted, 120, 126, 368 chimney formation, 126 CO2 reduction in, 153 depth, 127 diffuse flows in, 130 dissolved metals, 129 lifetimes, 126, 369 oxygen fugacity, 129 pH. 129 precipitates, 126 volatiles, 129 black smokers, 121 pH, 125 carbon fixation at, 141 chimneys anhydrite, 129 chemical environments, 143 colonizing clades, 144, 154 formation, 143 growth rates, 129 sulfide, 130 diking/eruptive events, 119 and subsurface biosphere, 146 release of brines, 157 discovery, 140 diversity, 148 anoxia, 149 dissolved metals, 149 sulfides versus carbonates, 149 temperature, 149 East Pacific Rise, 121, 151, 153 ecosystems in, 140 event plumes brines, 147 energy, 146 volatiles, 146

Cambridge University Press & Assessment 978-1-009-63377-2 — The Origin and Nature of Life on Earth Eric Smith , Harold J. Morowitz Index

More Information

floc and Beggiatoa spp., 148 from diking/eruptive events, 148 fluid mixing at, 125, 152 Guaymas basin, 388 hot springs colonizing clades, 154 Juan de Fuca ridge, 144, 152, 388 Kremlin, 130 Logatchev, 121, 131, 369 Lost City, 121, 131, 132, 134, 359 and Fischer-Tropsch reaction, 135, 372 chimney formation, 135 H₂, 134 models of, 135 pH. 134 precipitates, 135 temperature, 134 volatiles, 134 magma-hosted chimneys, 129 precipitation at, 129 recharge zone, 127 thermal gradient, 127 Main Endeavor Field, 149, 152, 388 map of locations, 126 Menez Hom, 131 microbial communities in chimneys, 143 in/on animals, 143 morphology, 121 Mothra Field, 144 nitrogen sources in, 145 organosynthesis in, 151 and metabolism, 156 peridotite-hosted, 120, 368 CO₂ reduction in, 153 diversity, 131 H₂, 132, 369 high-temperature, 132 lifetimes, 369 low-temperature, 132, 134 pH, 369 рĤ Ca²⁺, H⁺, SiO₂ exchange, 122 control variables, 122 in basalt-hosted vents, 124 in peridotite-hosted vents, 123 referenced to 25 °C, 125 silicate buffers, 123 plumes cells in, 144 clades found in, 144 primary production, 145, 154 Rainbow, 121, 131, 369 chimney formation, 137 H₂, 137

Index

669

kinetic factors, 136 pH, 137 precipitates, 137 temperature, 137 redox couples in, 151 Saldanha, 131 stockwork, 143 Trans-Atlantic Geotraverse, 121, 130 variations among, 120 white smokers, 121 pH, 125 hypergraph introduced, 270 individuality, 20, 42 compartments, 31 concept, 551 complexity of, 570 granularity, 21, 576 shared fate, 21, 577 created by life, 590 defining characteristics, 575 emergence of, 21, 541, 551, 569 and historical contingency, 551 and origin of evolution, 571 changes in autonomy, 580 complexity, 580 examples of kinds, 570, 576 genomes, 31 in development, 580 individuals parallelism of, 551, 573 variation among, 551 induction optimal and Bayesian model selection, 563 in complex systems, 562 problem of, 562 inference and standardization, 63 information criterion Akaike, 281 Bayes, 281 defined relative to distributions, 282, 287 from entropy, 287, 447 informal, 282 mutual, 288 syntactic versus semantic, 287 information flow direction of, 176 bottom up, 540 downward, 279 information theory, 282 and thermodynamics, 487 entropy in, 487

Cambridge University Press & Assessment 978-1-009-63377-2 — The Origin and Nature of Life on Earth Eric Smith , Harold J. Morowitz Index

More Information

670

innovation in carbon fixation pathways, 216 conserved enzymes, 216 metal centers, 216, 218 rise of oxygen, 244 mechanisms of, 177 enzymatic promiscuity, 177 pathway serendipity, 177 interstellar medium (ISM), 75 iron abundance of, 85 oxidation/reduction of, 85 iron/magnesium ratio to silicon, 86 Jaynes, E. T. caliber, 509 Jeans, Sir James, 102 Knallgas reaction, 151 Kolmogorov, A. N. entropy, 509 komatiites composition, 115 temperature, 115 viscosity, 115 Kullback-Leibler divergence, 285, 564 Lagrange multipliers, 449 large-deviations definition of entropy, 433, 438, 507 rate function, 438 scaling, 433, 437, 487 and universality, 439 in population processes, 572, 594 of central limit theorem, 438 of error rate, 492, 495, 597, 603 of escape probability, 518 thermodynamic limit, 438 theory, 20, 450 of chemical reactions, 594 late heavy bombardment relative to stellar age, 80 laws of large numbers, 432, 437, 597 Legendre transform, 441, 444 Leibniz, G. W. F. first question, 428 life as a confederacy, 274, 338 defined category error in, 590 in terms of biosphere, 541, 553 in terms of chemistry, 553, 593, 596 in terms of order parameters, 592 not as attribute, 541 specificity of metabolism, 591 definitions of, 588

Index

essential features, 587 of viruses, 590 temperature range, 142 lightning analogy to life, 28, 520 Liouville equation, 527 operator, 529 lipid availability, 411 encapsulation, 409 and Darwinian Threshold, 409 and macromolecules, 411 in bacteria and archaea, 409 relative to genetics, 412 relative to metabolism, 412 lipid phase transition liquid/gel/liquid crystal, 481, 483 and sterols, 486 in bacteria, 485 Landau theory, 485 order parameter, 485 van der Waals bonds, 482 phase separation, 481 and protein folding, 486 hydrogen bonds, 482 micell, 482 vesicle, 482 liquids formation of, 476 lithosphere as redox buffer, 155 structure at spreading centers, 118 pillow basalts, 118 plutonic foundation, 118 sheeted dike sequence, 118 weathering of, 116 living as predicate, 590 living state and biosphere, 11, 590 defined by participation, 591 architecture, 31 dynamical order, 13 emergence of Darwinian evolution, 19 nature of, 541, 552, 587 and Darwinian evolution, 571 as property of components, 589 confederacy, 338 origin in chemistry, 13, 107, 593 origination gradual accretion, 353 through evolving replicators, 354 preservation of pattern, 19 robustness, 5 living systems

as catalysts, 151

Cambridge University Press & Assessment 978-1-009-63377-2 — The Origin and Nature of Life on Earth Eric Smith , Harold J. Morowitz Index

More Information

magmas composition at spreading centers, 112 at subduction zones, 112 komatiites 115 extrusive, defined, 118 intrusive, defined, 118 origins plume, 108, 114 rifting, 108, 111 subduction, 108, 112 viscosity at spreading centers, 112 at subduction zones, 113 komatiites, 115 magnetization, 453 defined, 456 magnetotaxis, 454 Malthus, Thomas, 50 mantle convection, 9 and redox delivery, 95, 96 as relaxation channel, 95 beneath spreading centers, 117 plate tectonics, 97 rigid lid, 96 $f_{O_2}, 84, 91$ depth profile, 92 mineral buffers, 92 of lower mantle, 93 of transition zone, 93 of upper mantle, 93 hydration of Archean, 159 iron early oxidation of, 157 oxidation/reduction capacity, 85, 91 siderophiles veneer, 157 temperature in Archean, 158 transition zone, 90 wedge, defined, 112 Markov process, 20, 574 generator of, 579 state complexity of, 575 Mars atmosphere escape, 104 master equation, 515, 526 matter concept of, 477 hierarchy, 471

Index

building blocks, 476 origin of, 471 Mayr, Ernst and prokaryotes, 44 "bean-bag" genetics, 222 melting decompression, 112 flux, 112 and continent formation, 112 melts and partitioning of crust, 107 Archean komatiites, 115 lavas, defined, 107 magmas, defined, 107 partial, 112 beneath spreading centers, 117 memory emergence of, 407 meta-metabolome, 180 metabolism architecture of, 170, 173, 352 as ecosystem property, 15, 56, 180, 541, 552, 584 as foundation, 4 as oldest fossil, 58, 59, 554, 606 as order parameter, 559, 592, 599 falsifiability, 560 fluctuations about, 559, 600 selectivity around, 561 statistical interpretation, 560 as palimpsest, 174, 348 as Platonic form, 59 as source of information, 171 as summary statistic, 592 autocatalysis, 30 autotrophic in ecosystems, 179, 222, 586 in organisms, 179, 585 comparative analysis of, 172, 175 core as constraint, 182 autocatalysis in, 183 CHO core of, 183, 197 composition, 178 diversity in, 183 gateway for error correction, 596 network topology, 199 size, 4, 179 variations in 4, 171 hierarchical context for, 273, 545 intermediary defined, 179 layers, 156, 174, 370 sequence in biogenesis, 569 models of Aquifex, 179, 222, 241 flux balance, 179, 221, 222

Cambridge University Press & Assessment 978-1-009-63377-2 — The Origin and Nature of Life on Earth Eric Smith , Harold J. Morowitz Index

More Information

672

modes, 49 modules, 173 error-correcting role of, 560 network topology "bowtie", 180, 182, 186 ladder, 214 radial fan, 181, 186 Nicholson chart, 4 oxidative, 46, 47 reductive, 46, 47, 54 energetics of, 188 syntrophic regulation of, 586, 602 universality, 4, 56, 585 and ecological assembly, 585 covering network, 197 variation within, 172, 196 metabolism first, 350, 428 metabolites monomers, 62 three classes, 171, 179, 285 oligomers defined, 179 meteorology theorem, 335 methanogen, 47, 51 bioenergetic efficiency, 234 methanotroph denitrifying, 377 methylotrophy C1 reduction in, 245 reticulated history of, 245, 573 serine cycle in, 245 microbial mats, 51 mid-ocean ridge and crust formation, 142 basalt composition, 116 extraction, 116 hydrothermal systems, 142 melting and spreading rate, 117 depths, 116 fractions, 116 geometry, 117 magma chamber, 117 spreading rates Archean, 158 stress on bending, 118 hydration, 118 tension, 117 thermal, 118 Miller-Urey synthesis, 344, 430 mineral buffer coexistence curve, 84, 92 complexity, 85

Index

diversity, 85 evolution of, 167 in Hadean, 168 felsic, defined, 107 mafic, defined, 107 metasomatism, defined, 116 nomenclature glossary, 87 oxide decomposition, 86 polymorph, defined, 90 substitution effects, 91 mixotrophy, 48 introduced, 230 modularity and mutual prediction, 562 in cellular architecture, 274 in dynamical settings, 558 in evolutionary innovation, 333 need of for control, 555 for emergence of complexity, 547 for error correction, 555 for evolvability, 547 for stability, 547, 554 Herbert Simon argument, 554 provision of and phase transition, 548 modules autonomy of in cellularization, 332 in hierarchies, 547 molecules formation of, 476 Moon-forming event, 84, 157 Muller's ratchet, 18 Mycobacteria M. smegmatis, 245 M. tuberculosis, 48, 245 negentropy, 448 Nernst equation, 366 nitrogen fixation, 387 in hydrothermal vents, 145 in catalysis, 60, 183 N1 interconversions, 387 by tube-worm endosymbionts, 146 N_2 and electric discharge, 105, 387 and shock heating, 387 oxidation, 387 reduction. 388 reduced incorporation, 387 nuclei formation of, 475 nucleobases

Cambridge University Press & Assessment 978-1-009-63377-2 — The Origin and Nature of Life on Earth Eric Smith , Harold J. Morowitz Index

More Information

non-Watson-Crick, 286 nucleons formation of, 475 nucleosynthesis cosmic, 77 stellar, 79 ocean liquid persistence of, 80, 158 retention of, 357 oligomers, 63 as a disequilibrium system, 404 emergence of, 403 olivine hydrolysis reactions, 132 temperature dependence of, 131, 137 Oparin-Haldane conjecture, 176, 344, 430 ophiolite, 142 organosynthesis constraints on thermodynamic, 152, 187 dependence on f_{O_2} , 153 facility of, 153, 187, 430 in meteorites, 430 origin of life and organization of the biosphere, 31 as "collapse", 26 as a planetary process, 2 as phase transitions, 24, 559 autotrophic, 176 dating, 2 "happy accident", 5, 150 orthopyroxene hydrolysis temperature dependence of, 137 oxygen as energy source, 233 as poison, 231 rise of, 421 clades spanning, 245 pathway reversal, 244 parsimony interpretation and geochemical niches, 240 and levels of selection, 223 when violated 240 phylogenetic criterion, 222, 223 partition function defined, 449 of Curie-Weiss model, 457 patterns abiotic versus biotic, 606 information in, 287 amount, 288

Index

and description length, 289, 296 kind 288 persistence of, 571 causes, 607 realization of, 606 relation to entities, 554, 606 pentose phosphate pathway, 208 peridotite residual, 94 composition, 116 phase transition and error correction, 427, 544 in hierarchies, 544 and fluctuations, 432 and laws of large numbers, 432 and robustness, 426 and unpredictability, 432 as mathematical concept, 431 as rare occurrence, 426, 432 binary, 434, 452, 455 ceilings and floors, 25, 477 chance and necessity in, 22, 466 collective effects, 468 confinement, 524 contingency, 434, 467, 568 cooperative effects, 24, 426, 543 Curie-Weiss, 452, 599 Ehrenfest classification, 464 emergence, 434 equilibrium, 24, 434, 452 first-order, 451, 516 and molecular recognition, 498 coexistence regime, 466, 533 duality to second-order, 498 in biogenesis accreting complexity in, 586 cascade of, 587 in glasses, 600 creep, 600 in non-hierarchical systems and evolution, 545 roles in the biosphere, 545 single scales in, 544 lipid-water, 481, 599 long-range order, 307, 434, 468 infrastructure for complexity, 586 non-equilibrium, 25, 434, 501, 516 Bénard convection, 96 in complex systems, 542 order parameter and inference, 470 as control parameter, 567 biological design from, 568 low dimensionality of, 561 of Curie-Weiss model, 460 of lipid phases, 485 predictability, 467, 569

Cambridge University Press & Assessment 978-1-009-63377-2 — The Origin and Nature of Life on Earth Eric Smith , Harold J. Morowitz Index

More Information

674

robustness of, 432 threshold for, 543 unpredictability, 467, 559 use in induction, 563 paradigm, 431, 542 second-order, 451 and symmetry, 454, 543 simple versus complex, 598 theory of biological order, 480 theory of matter, 25, 434, 471 accreting complexity in, 586 phosphorus, 61 phosphate availability, 152, 365 in polymerization, 405 polyphosphates, 365 roles in biochemistry, 364 reduced from Schreibersite, 365 in organic reactions, 365 solubility, 365 phosphorylation from hypophosphite, 365 oxidative, 329 proton-driven Mitchell hypothesis, 382 prebiotic models, 382 substrate-level as bottleneck, 382 as connection, 328 in a thioester world, 330 in rTCA, 201 thioesters in, 329 photosynthesis, 55 oxygenic, 47 phylogeny Aquificales, 186 Galton's problem, 220 of autotrophs, 180, 219 causes along arcs, 221, 231 reconstructed tree, 230, 573 root node, 236 versus standard phylogenies, 235 phylotypic stage, 248 planet core/mantle separation, 84 formation of, 479 plants quasi-autotrophs, 145 polymerization and surfaces, 405 by template-directed ligation, 320, 418 in clays, 406 in lipid bilayer stacks, 406 Popper, Karl and falsification, 557 potential

Index

effective, 458 and free energy, 464 for escapes, 516, 531 pressure, defined, 444 Price, George Price equation, 307, 570, 583 primordial soup, 430 progenote, defined, 309 protein fold as Platonic form, 59 purines from HCN, 393 Oró synthesis, 393 pyrimidines from cyanoacetylene, 395 radioactivity and planetary heating, 83 redox disproportionation, 48 reductionism and emergence, 26 in Curie-Weiss model, 563 source of error-correcting codes, 598 refrigerators parable of, 508 regulation allosteric, 65 genomic, 65, 67 replicator, 20 as non-chemical abstraction, 593 respiration, 55 Reynolds number, 44 ribosome domains and A-minor interactions, 415 core, 415 large subunit layered structure, 415 peptidyl transferase center, 414 origin of, 284, 413 as translation system, 321 as triplicase, 320, 418 peptides core, 308, 322, 416, 574 early roles, 309, 322 reading frame origin of, 417 small subunit origin in RNA replicase, 417 ring of fire, 108 Rissanen, Jorma minimum description length, 281 RNA as Darwinian individual, 345, 575 catalysis, 345 and iron, 320, 416

Cambridge University Press & Assessment 978-1-009-63377-2 — The Origin and Nature of Life on Earth Eric Smith , Harold J. Morowitz Index

More Information

by dimers, 312 by monomers, 311 by short sequences, 311, 409 small-molecule organocatalysis, 312 functions, 344, 349 non-standard base pairing, 293 purine cofactors derived from, 253, 396 pyrimidine abiotic synthesis, 348, 396 regioselectivity, 309 from double helices, 418 self-replicase, 348 systems chemistry, 344, 349 RNA first, 347, 428 source of fitness, 408 RNA World, 344 and continuity hypothesis, 348 and Darwinian evolution, 345 as paradigm, 348 proposed, 345 second, 347 strong, 347, 572 weak, 347 rTCA cycle antiquity of, 186 as first metabolism, 201 as order parameter fluctuations about, 470 autocatalysis, 185 and phase transition, 386 C1 reduction and robustness, 239 minimal model, 237 plausibility of, 384 threshold, 239, 384, 386 universality of intermediates, 384 carbon-addition reactions β -carboxylation, 381 carbonyl insertion at thioesters, 380 in geochemistry, 380 introduced, 185 network context, 385 synergy with Wood-Ljungdahl, 237 RubisCO photorespiration by, 209 scaling implicational, 229, 255 scenario limitations of, 422 Schreibersite, 365 seawater oxidants in, 152 selection and sparseness, 4

enantiomeric in core metabolism, 400

Index

in geochemistry, 400 group, 17 Hamilton's rule for, 583 levels of, 570 and non-tree phylogenies, 223 distribution of sequences, 307 gene selection, 41 individual sequences, 308 kin selection, 583 organism selection, 40 sources of, 188, 352, 407 for genetic code, 309 geochemical kinetics, 360, 383, 559 independent of memory, 408 network autocatalysis, 236, 239, 268, 384 over metabolic rules, 173 stabilizing, 68, 552 and metabolic rate, 604 toward core metabolism, 572 stereoselectivity at minerals, 401 in small-molecule catalysis, 401 thermodynamic cost, 506 units of chromosome, 575, 581 debate over, 581 developmental kernels, 582 genome, 585 relation to individuality, 570, 580 selfish gene, 581 Selkov model, 511 senescence evolution of, 577 serine biosynthesis, 193 oxidative, 301 reductive, 301 serpentinization, 53, 131, 369 from enstatite, 133 from forsterite, 133 from olivine, 133 Shannon, Claude asymptotic rate theorem, 488 channel capacity, 489, 491, 494 Gaussian channel, 494 entropy function, 285, 438 information theory, 434, 487 signal/noise ratio, 492 Simon Herbert argument for modularity, 554 example of Alexandrian empire, 555, 569 parable of watchmakers, 555 Sinai, Yakov entropy, 509 SO₂ photodissociation mechanisms of, 163

Cambridge University Press & Assessment 978-1-009-63377-2 — The Origin and Nature of Life on Earth Eric Smith , Harold J. Morowitz Index

More Information

676

solar flux actinic, 163 solids formation of, 476 solidus dry melting, defined, 111 wet melting, defined, 112 speciation allopatric, 241 species as message, 603 maintenance of, 603 number of, 585 origin of, 586 spin, 453 stability perspective, 432, 549 statistic descriptive defined, 446 sufficient, 446 and inference, 562, 563 as central tendency, 560 defined, 447 sample estimators of, 560, 563 summary, 221, 439 defined, 446 stereochemical hypothesis introduced, 283 stochastic effective action, 509 Onsager-Machlup form, 519, 534 zero eigenvalues, 536 stochastic process, 515 Markov property, 20, 562 stoichiometry defined, 270 ecological, 42 mineral oxide components, 86 string chemistry defined, 182 struggle for existence, 50 as paradigm, 150 sugars from formose reaction, 388 phosphorylated, 388 sulfur, 61 compounds gases, 159 minerals, 160 solubility, 160 isotope fractionation and atmospheric screening, 364 and rise of oxygen, 164 causes, 160 correlations in, 164 Δ -notation, 161

Index

 δ -notation, 161 in Archean, 159, 163, 362, 363 in sulfates, 363 in sulfides, 363 introduced, 160 mass-dependent, 160, 161 mass-independent, 161, 162, 362, 363 reference for, 161 oxidation states, 152, 159 in metabolism, 160 stable isotopes, 160 Sun convection in, 110 young, 77 luminosity, 79 magnetic activity, 81 rotation, 81 UV flux, 80, 81 X-ray flux, 80 superconductivity, 476 symmetry breaking limits of applicability, 470 spontaneous, 460, 464, 563 internal, 473 Lie group, 474 TCA cycle as Krebs cycle (oxidative), 185, 186 as rTCA cycle (reductive), 185, 186 centrality of, 184 energetics of, 186 in split pathways (fermentative), 203 introduced, 183 oxidation states in, 189 redundancy in enzymes, 214, 216, 242 substrate molecules, 185, 214 universality of, 184 tectonics consequences of, 97, 158 origination of relative to life, 158 temperature, defined, 444 theory role of, 341, 423 thermodynamics ensemble, 457 non-equilibrium, 505 roles of energy and entropy, 324 state variables, 440, 443 and inference, 446 as sufficient statistics, 446 conserved quantities as, 440 extensive, 441 from Lagrange multipliers, 449 intensive, 441, 444

Cambridge University Press & Assessment 978-1-009-63377-2 — The Origin and Nature of Life on Earth Eric Smith , Harold J. Morowitz Index

More Information

non-equilibrium, 505 scaling with system size, 441 thermophiles phylogeny of, 156, 220 thiamin in relation to RNA, 396 thioesters and non-ribosomal peptides, 331 and trans-phosphorylation, 382 from thioacids, 382 in gramicidin synthesis, 372 in polymerization, 405 in protometabolism, 382 Thompson, D'Arcy, 44 transfer matrix, 515, 526 transition metals, 61 translation emergence of, 275 from an RNA World, 279 error rate, 307 errors in and codon adjacency, 316 and genetic code, 286 conditional independence, 318 empirical rates, 316 origin of, 417 and amino acid groups, 321 reliable and Darwinian Threshold, 419, 582 robustness of, 318 system components of, 278 transmission channel, 489 capacity, 491, 598 Gaussian model, 492 block encoding, 493 sphere packing, 494, 600 repeaters in, 500, 603 transversality, 409 in natural selection, 334 introduced, 333 troilite Canyon Diablo meteorite, 161 tropopause, defined, 104 tube worms, 146 universe age of, 78

Index

aging, 75 variation facilitated, 174, 547, 580 metabolic related to fluctuations, 200 variety defined, 548 requisite as rate, 579 effect of phase transition on, 567 for bacterial cell, 578 in organism selection, 578 law of, 567 of genome selection, 604 Venus hydrogen escape, 104 volcanism arc, 112 Wächtershäuser, Günter pyrite-pulled metabolism, 239 Wöhler, Friedrich synthesis of urea, 430 water-gas shift reaction, 361, 373 Weiss, Pierre-Ernest mean-field approximation, 453 Wilson, J. Tuzo proposal of "hot spots", 114 Woese, Carl canonical (16S rRNA) tree, 310 polar requirement buffered by genetic code, 317 defined, 298 original context, 316 progenote, 308 statistical proteins, 308, 583 stereochemical hypothesis, 297, 309, 316 Wong, Tze-Fei coevolutionary hypothesis, 294, 310 Wood-Ljungdahl pathway acetogens versus methanogens, 207, 220, 235, 374 and Fischer-Tropsch, 207, 371 as first metabolism, 207 bioenergetics, 374 selectivity from, 379