

Index of names

- Adair, Gilbert S. 206, 256
 Alpher, Ralph 351
 Alzheimer, Alois 314
 Anaximenes 1
 Anfinson, Christian Boehmer 185
 Anson, Mortimer L. 185
 Archimedes 265
 Aristotle 8, 133, 345
 Arrhenius, Svante A. 88
 Avogadro, Amadeo Q. 219
- Bernal, John D. 334
 Berzelius, J.J. 74, 300
 Bethe, Hans 1, 351
 Black, James W. 167
 Black, Joseph 28, 47
 Bohr, Christian 272
 Bohr, Niels xv, 272
 Boltzmann, Ludwig 219
 Bonhoeffer, Klaus xv
 Boyle, Robert 13
 Bragg, J.K. 240–2
 Brahe, T. 133
 Briggs, George E. 301
 Brønsted, J.N. 115
 Brown, Adrian J. 300
 Buffon, George L.L. de 352
- Carnot, N.L.S. 61, 219–23
 Changeaux, Jean-Pierre 272
 Clausius, R.J.E. 38, 219
 Copernicus, Nicolaus 25
 Coulomb, Charles A. de 175
 Crick, Francis H. 174, 185, 336, 351
- Dalton, John 170, 208
 Debye, Petrus J.W. 107, 175
 Delbrück, Max xv
 Democritus 208
 Descartes, René 351
 Donder, Théophile de 45
 Donnan, Frederick G. 158
- Eddington, Sir Arthur S. xii
 Edison, Thomas Alva 207
- Einstein, Albert 26, 133, 214, 327,
 329–32, xii
 Euclid 28
 Euler, Leonard 207
 Eyring, Henry 36, 185, 294
- Faraday, Michael 121
 Feynman, Richard P. 208, 252, xv
 Filmer, D. 271
 Fischer, Hermann E. 300
 Fourier, Baron Jean B.J. 368
- Galilei, Galileo 25, 133
 Gamow, Georgy A. 351
 Gauss, Carl F. 265, 268
 Gibbs, J. Willard 86–7, 110
 Gibson, George E. 35
 Gilbert, Walter 336
 Gulberg, Cato M. 88
- Haldane, John B. S. 301
 Haller, Albrecht von 352
 Hanson, Emmeline J. 318
 Heisenberg, Werner K. 75
 Helmholtz, Hermann von 35–6
 Henseleit, K. 57
 Hess, Germain Henry 39
 Hill, Archibald Vivian 262
 Hopkins, Johns 36
 Hückel, Erich 107, 175
 Huxley, Hugh E. 318
- Jefferson, Thomas 26
 Joule, James Prescott 2, 36
- Kalckar, Hermann 142
 Kendrew, John C. 252
 Kepler, Johannes 26, 27, 133
 Kirchhoff, Gustav Robert 49
 Koshland, Daniel E. 271
 Krebs, Hans A. 57, 138
- Langmuir, Irving 253
 Laplace, Pierre S. de 13, 51
 Lavoisier, Antoine L. 13, 51, 210
- Le Châtelier, Henri L. 109–10
 Lehninger, Lester 140
 Leibniz, Gottfried Wilhelm 36
 Lewis, Gilbert N. 99
 Liebig, Justus xv
 Lifson, Shneior 242
 Linderstrøm-Lang, K.U. 74, 240, 308
 Lipmann, Fritz A. 138, 142
 Lowry, Thomas M. 115
 Lummer, O.H. R. 36
 Lumry, Rufus W. 36, 185
- Marcus, Rudolph A. 297
 Maupertuis, Pierre L. 352
 Mayer, Julius R. von 36
 Maxwell, James C. 77, 86, 121
 McCartney, Paul 301
 Mendele'ev, Dmitri I. 208
 Menten, Maud L. 302
 Michaelis, Leonor 302
 Mirsky, Alfred E. 185
 Mitchell, Peter D. 140
 Monod, Jacques L. 272
 Müller, Johannes P. 36
 Mullis, Kary R. 178
- Nasir al-Din al-Tusi 233
 Némethy, G. 271
 Nernst, Walther H. 122
 Neumann, John von 343
 Newton, Isaac 26, 27, 133, 265, 331
 Nobel, Alfred 284
 Northrop, John H. 300
- Pascal, Blaise 47, 233
 Pauli, Wolfgang xv
 Pauling, Linus C. 185
 Penn, William 35
 Perutz, Max F. 252
 Pfeffer, Wilhelm F.P. 149
 Phillips, David C. 306
 Planck, Max K.E.L. 3, xiv
 Plato 8, 345
 Prigogine, Ilya 336
 Pythagoras 28

- | | | |
|-----------------------------------|---|--------------------------------|
| Ramachandran, Narayana I. 242 | Sutherland, Earl 144 | Virchow, Rudolf C. 314 |
| Roig, A. 242 | Szent-Györgi, Albert 3, 318 | Virgil 206 |
| Rubner, Max 51 | | Volkenstein, M. V. xii |
| | Thales 21, 98 | Volta, Alessandro G. A. A. 120 |
| Scatchard, George 166 | Thompson, Benjamin (Count
Rumford) 210 | Waage, Peter 88 |
| Schrödinger, Erwin 77 | Thomson, William, Lord Kelvin 326 | Watson, James D. 174, 185 |
| Schwann, Theodor 136 | Torricelli, Evangelista 262 | Watt, James 24, 38 |
| Shakespeare, William 244, 348 | | Wigner, Eugene P. 224 |
| Shannon, Claude Elwood 343 | van der Waals, Johannes D. 42 | Wyman, Jeffries 272 |
| Snow, Baron Sir Charles
P. xii | van't Hoff, Jacobus H. 151 | |
| Sørensen, S. P. L. 74, 115 | Venn, John 330 | Zimm, Bruno H. 240–2 |

Subject index

Page entries for headings with subheadings refer to general aspects of that topic.
 Page entries for figures/tables appear in **bold** type.

- abiotic synthesis 333–4, 400
 absolute temperature 33
 acidity constant 400
 acids 115–17, 116, 210, 400
 actin 32
 binding proteins 315
 critical concentration 317
 filaments 314, 315, 316, 316–17
 polymerization 314
 treadmilling 316
 action potential 161
 activated complex 294, 400
 activation barrier 295, 400
 activation energy 282–3, 400, 405; *see also* energy
 active site 284, 400
 active transport 159, 400
 activity 98, 99, 400
 coefficient 400
 ionic 107
 actomyosin ATPase reaction cycle 318
 Adair equation 256, 400
 adenosine triphosphate 5–6, 32, 400, xiii
 hydrolysis *see* oxidative phosphorylation
 synthesis 161, 162
 aging 77, 352, 354; *see also* death
 allosteric inhibition 304
 allosteric regulation/allostery 169, 269–, 400, 270, 272
 heteroallostery 404
 homoallostery 271
 reaction kinetics 281
 Alzheimer's disease 314
 amino acids 334–5
 chirality 334–5
 composition 183
 extremization 342
 in meteorites 334–5
 physical properties 379–80
 sequencing optimization 340–2
 thermodynamic stability 341
 transfer energetics 180–2, 182
 amplification 270
 amyloid
 fibrils 314
 plaques 314
 amyloidogenic lysozyme 314
 animals; *see also* fish
 ATP hydrolysis 145
 body temperature and longevity 145–6
 consumption, energy and food 13–17, 75
 energy transformations 2, 4
 antibodies 172–3
 binding 375
 anti-freeze proteins 104
 antigens 172–3
 arc repressors 341
 archaea 337–9
 aromatic compounds 60, 65, 149, 206
 Arrhenius equation 291
 Arum maculatum scent example of entropy 65, 206
 aspartate transcarbamoylase (ATCase)
 allosteric regulation 271
 reaction kinetics 281
 association constant 253, 400
 ATCase *see* aspartate transcarbamoylase
 atmosphere 3
 atomic
 fluctuations, protein dynamics 192
 hypothesis 208
 ATP *see* adenosine triphosphate
 ATPase reaction cycle 318
 autotrophism 338
 bacteria 1, 337–9
 cell walls 153–4
 baseline values 226, 226
 bases 115–17, 210, 401, 401
 bell-shaped curve 268
 Big Bang 1, 327, 351
 binding capacity 166, 401
 binding energy 224
 binding equilibria 250–3; *see also* Scatchard/Hill plots
 allosteric regulation 269–72, 270, 272
 isothermal titration calorimetry (ITC) 45, 46, 257, 259
 multiple independent sites 255–60, 258, 260
 oxygen transport 261–5; *see also* hemoglobin
 proton binding 272–5
 single-site model 253–5, 254
 study exercises 277–80
 binding interactions 165–9, 166
 allostery 169
 information and energy 169
 insulin binding 169
 ligands 165–9, 168
 phosphotyrosine-mediated binding 167–9
 Scatchard plot 166, 166
 biocalorimetry 372–3
 biological techniques 376
 differential scanning calorimetry (DSC) 373–4
 enthalpy–entropy compensation 374
 pharmaceutical drug development 375
 protein folding reversibility 373
 site-directed mutagenesis 376
 bioenergetics 139, 401
 biofuels 17–18
 biological information *see* information theory

- biopolymers, abiotic synthesis 333–4
 blood cells *see* red blood cells
 blue-green algae 2
 body plan 401
 Bohr effect 272, 273, 401
 Boltzmann
 distribution 215–22, 329–30, 401
 equation of statistical mechanics 216, 219
 factor 219, 233, 401
 law 293
 bomb calorimeter 13, 14
 boundary
 phenomena 31–2
 systems 11, 401
 breathing motions 192, 261, 309, 401
 Brønsted–Lowry definitions 115, 401;
 see also acids; bases
 brown adipose tissue 146; *see also*
 thermogenesis
 Brownian motion 27, 292
 Brussels school of thermodynamics 45
 buffer ionization constants 382
 buffering capacity 116, 401

Caenorhabditis elegans (nematode worm) 358
 calories xiv
 calorimetry 13–14, 401; *see also*
 isothermal titration calorimetry
 bomb 13, 14
 differential scanning (DSC) 49, 50, 235–4, 373–4
 nanocalorimetry 49–50
 cAMP 144, 145, 348
 cancer 283
 carbon 18–19, 401
 carbon dioxide 2
 animal production 51, 338
 atmospheric 17
 blood transport/circulation 170, 319
 citric acid cycle 138
 and glycolysis 137
 and photosynthesis 3–4, 339
 carbon monoxide 171
 catalysis, enzyme 215, 333
 CD (circular dichroism spectroscopy) 312, 312
 cells, living; *see also* membranes;
 mitochondria; red blood cells
 component biosynthesis/origins 333
 energy distribution 10
 osmosis 153–4
 cellulose 2, 4
 chaperones 313
 charge; *see also* Donnan equilibrium
 and dialysis 155–6
 and membrane transport 159–60, 162, 162
 chemical coupling 117–19, 118
 chemical denaturation 188–9
 chemical equilibrium 88–93, 89, 90, 91
 diffusion 90–2, 91
 dynamic equilibria 92
 features of equilibrium state 93
 law of mass action 88
 and living organisms 89
 models of reality 89
 proteins 93
 reaction kinetics 281–2
 stable/unstable equilibria 90
 chemical potential 98–102, 401
 activity of substance 98
 and osmosis 148, 150
 peptide hormone binding example 100–1
 standard free energy change 98
 thermodynamics of solutions 98–102
 two-component solution example 101–2
 water 86, 98
 chemiosmotic theory 140
 chemolithotrophs 135
 chemosynthesis 1, 337, 338, 401
 chirality/handedness, protein 300, 334–, 402
 chlorophyll 3, 3, 22, 135, 183, 402
 cholesterol 96
 cilia 315
 circular dichroism spectroscopy 312, 312
 citric acid cycle 118, 138, 139, 402
 reaction energetics 383–4
 classical thermodynamics 208, 209, 223
 clay adsorption, biopolymers 334
 closed systems 11, 11, 402
 CMP (Cytidine monophosphate) 46
 cold denaturation 188, 402
 collisions 33, 64, 65, 210, 212–15
 collision theory 291–3, 294, 402
 combustion 283
 competitive inhibition 304–6, 402
 complexity 349–55
 death/aging 352, 354
 ecosystems 354
 and evolution 355
 expressed/potential 357
 far-from-equilibrium open systems 351, 352
 immune system, vertebrate 350
 machine analogy 351–2
 order in non-living systems 352–3
 physicochemical basis of order 351
 protein turnover/renewal 352
 repair mechanisms 351
 and survival 353–4
 universe 329–30
 concerted model, allosteric regulation 271, 272, 272
 configuration 75, 217–19, 402
 conformation 219
 convection 2, 29, 60, 92
 cells 353
 cooperativity 236–7, 237, 402
 cosmology 327
 counterions 158, 175
 coupling, chemical 117–19, 118
 covalent bonds 305
 creatine 133
 critical concentration 317, 402
 CTP (cytidine triphosphate) 178, 271, 281, 300
 currency, energy 5, 6, 7–9
 cyclic AMP 144, 145, 348
 cytidine monophosphate (CMP) 46
 cytidine triphosphate (CTP) 178, 271, 281, 300
 cytochrome *c* 120, 130, 135, 140
 cytoskeleton 46, 255, 315, 316

 Dalton's Law 170, 402
 damping 270
 data analysis 223–8
 baseline values 226, 226
 binding energy 224
 ergodic hypothesis 224
 fluorimetry 224
 lysozyme denaturation 224
 NMR methodology 224
 two-state approximation 224
 death 352, 354; *see also* aging
 programmed 191
 degeneracy 219, 402

- denaturation, protein *see* protein denaturation
- deoxyribonucleic acid (DNA)
 binding 250, 251
 Donnan equilibrium 157–8
 linking number 177
 melting 44, 72, 176
 polymerase 331–2
 replication 178
 thermodynamics 331–2
 thermostability 174–8, 174, 175
- dialysis 154–6, 154
 charge 155–6
 equilibrium 156, 156
 ligand example 156
 non-equilibrium 155–6
 urea example 155
- dielectric constant 105, 108, 317
- differential scanning calorimetry (DSC) 49, 50, 235–6, 373–4, 402
- diffusion 2, 90–2, 91, 292, 402
 dynamics of equilibrium 211
 and entropy 62, 63
 enzyme catalysis 215
 facilitated 215
 glucose molecule behavior, mathematical expression 212–14, 213
 perfume molecule example 60, 65, 149, 206
 randomness 214, 214
 reaction kinetics 282
 statistical thermodynamics 211–15
- diprotic acid 210–11, 211
- dissipation 402
- dissociation constant 253, 402
- distribution 402
 energy 7–10, 10
- disulfide bonds, lysozyme 218, 220–2, 402
- DNA *see* deoxyribonucleic acid
- Donnan equilibrium 157–8, 159, 402
 DNA example 157–8
 red blood cells 158
- dose–response curves 165
- drug development, pharmaceutical 375
- DSC (differential scanning calorimetry) 49, 50, 235–6, 373–4
- dualism 351
- dynamic equilibria 92, 211, 402
- Earth 11, 19
- economy, energy 5, 6, 7–9
- ecosystems 2, 354
- EDTA (cation chelator) 105–7
- effectors 271, 402
- efficiency 22, 303, 402
- electromagnetic spectrum 4
 theory 3
- electromotive force 120, 402
- electron transfer 121, 297–9, 298
- electroneutrality 157, 402
- electrostatics 30
- electroweak interactions 335, 403
- ELISA (enzyme-linked immunosorbent assay) 172–4, 173, 282
- endergonic reaction 403
- endothermic reactions 41, 403
- energy, nature of 326–9; *see also* First Law of thermodynamics
 biologically useful 76
 definitions 6–7, 326–7, 328, 403
 Einstein's formula 327
 energy as property of matter 327
 energy resource management 339
 fluid properties of heat 327–8
 and infinity 329
 and information 5, 145, 169, 339–, xiii
 and mass 328
 photon energy 327
 study exercises 366–8
- energy barrier 282–3
- energy profile, generic chemical reaction 282, 283
- energy states/levels 216–22, 217, 218, 233
 Boltzmann energy distribution equation 220
 conformational entropy 221
- disulphide bonds, lysozyme 219, 220
 reference state 220
- energy transducers 118
- energy transformation 1–7, 6–7
 as basis of all phenomena 326
 distribution of energy 7–10, 10
 energy consumption 2, 4, 13–17, 17, 75
 energy flow mechanisms 5
 energy transformations on Earth, log plot 5
- forms of energy 9
 money energy analogy 5, 6, 7–9
 study exercises 21–4
 surroundings 11
 systems 11–12
- energy well 185, 403
- enthalpy 38–41, 403, xiv
 and ATP hydrolysis 143
 hydration 46, 47, 403
 Kirchhoff's law 49
 polymerase chain reaction 179
 states 233, 234
 transition states 296
 unfolding hen lysozyme 45, 45
 van't Hoff 229, 236–7
 water at melting point 41
- enthalpy–entropy compensation 190, 374, 403
- entropy xiv, 61–6, 403
Arum maculatum scent example 65, 206
 conformational 219
 of different energy types 70
 diffusion example 62, 63
 and heat 65–6
 and information content 344
 order 62
 and osmosis 148–9, 153
 polymerase chain reaction 179–80
 rubber band machine 35, 62–4, 69
 transition states 296
 of universe 69–70
- environment 12, 75
- enzyme/s; *see also* lysozyme
 binding 46
 catalysis 215, 333
 cofactors 251–2
 DNA polymerase 331–2
 engineering 190
 RNA activity 335–7
 /substrate interactions 162–4, 163
- enzyme kinetics 299–304, 300, 304
 chirality 300
 hexokinase 300
 lysozyme 301
 Michaelis constant 302
 Michaelis–Menten equation 302–3, 303
 steady state assumption 301
 turnover number 301
- enzyme-linked immunosorbent assay (ELISA) 172–4, 173

- equilibrium, 403; *see also* chemical equilibrium
 constant 108–10, 109, 403
 Donnan 157–8, 159
 dynamic 92, 211
 effect of temperature 109, 113–14
 glycolysis 110
 Le Châtelier's principle 109–10
 liquid water, reliance of life on 114
 van't Hoff graph 113
- equilibrium distribution 216
- erectile tissue 317
- ergodic hypothesis 224, 403
- Escherichia coli* 347–8, 349
- eukaryotic cells
 complexity 353
 DNA 176
 membrane transport 158
- evolution and thermodynamics 77,
 355–, 403; *see also* origins of life
 driving of evolution by Second Law
 357–8
 expressed/potential complexity
 357
 increasing complexity 355
 interaction between reactions 356
 noise/fluctuations 355
 non-equilibrium thermodynamics
 356
 persistent forms/local minima
 358–, 359
 purposefulness 357
 self-organizing systems 355–6
 sexual reproduction 358
 speciation 357, 358
 as violation of Second Law 355
- exchange, hydrogen *see* hydrogen
 exchange
- excrement 51
- exercise 23
- exergonic reaction 117, 403
- exothermic
 processes 41
 reaction 403
- extensive property 30
- extremization 342
- extremophiles 337, 403
- extrinsic property 403, 405
- facilitated diffusion 215, 403
- Faraday constant 121
- feedback inhibition 270–1, 403
- fertilization 317
- fever 254; *see also* immune system
- fire example, reaction kinetics 283
- First Law of Thermodynamics 25–9,
 28, 35–8, 58–9, 59; *see also* work
- biochemical examples 42–6, 46
 definitions 25–6, 26–7, 403
 energy conservation in living
 organism 51
 enthalpy 38–41
 heat capacity 47–9
 hydrogen bonds of biological
 importance 43
 internal energy 29–31
 law of constant summation 39
 mechanical energy conservation
 36
 molecular interactions,
 noncovalent energetics 43
 nanocalorimetry 49–50
 non-equilibrium thermodynamics
 193, 195
 standard state 41–2
 study exercises 53–7
 water stirring experiment 36–7
- first-order reactions 287, 288,
 288–90, 290, 403
- fish; *see also* animals
 ATP hydrolysis 145
 flounders 104
- flavin adenine dinucleotide 138, 252
- fluctuations 42, 78, 114, 175, 191
- fluorescence emission 313
- fluorimetry 224
- food
 consumption 75
 energy value/nutrient content 378
- force 31, 404
- fossil fuel 16
- fractional saturation 253, 262, 263,
 264
- free energy *see* Gibbs free energy
- freezing of living organisms 74
- frequency factor 287, 287, 404
- function 404
 heat capacity functions 234, 235–6
 internal energy 30–1
 partition function 219–23
 potential 87–8
- gas constant 33, 40, 99
- gas expansion 215–16, 216
- Gaussian distribution 268
- genetic code 350
- genetic landscape 359
- genome, structural integrity 340
- geometry of life xi
- giant panda 4
- Gibbs free energy 85–8, 134, 404, xiv;
see also chemical equilibrium;
 chemical potential; equilibrium
 constant
 acids and bases 115–17, 117, 210
 chemical coupling 117–19, 118
 effect of solutes on boiling/freezing
 points 102–4
 and First Law of Thermodynamics
 38, 40
 free energy definition 87
 ideal solutions 100
 ionic solutions 104–8
 lipids 96, 96–8
 phase transitions 95–8, 95
 potential functions 87–8
 Raoult's law 100
 redox reactions 120–3, 121, 122
 reversible processes 86, 93–4
 and Second Law of
 Thermodynamics 60, 70, 71
 standard state, biochemical
 definition 110–12
 study exercises 126–33, 199–206
- Gibbs paradox 82
- glucose 404
 molecular behavior 213
 oxidation 161
 phosphorylation 118–19
- glycogen 145
- glycolysis 110, 136–8, 137, 138, 404
- grasshoppers 63–4, 68
- gravitation 9, 11, 31, 118
- group transfer 404
- GTP (guanosine triphosphate) 146,
 315, 383
- guanidine hydrochloride 256
- guanidium chloride 107
- guanosine triphosphate 146, 315, 383
- Guinness beer 59
- haemoglobin *see* hemoglobin
- Haemophilus influenza* 346–7
- half-life 288–9
- half-reaction 404
- halobacteria 135
- halophile bacteria 107
- handedness, protein 300, 334–5
- heart, mammalian 319

- heat 31–2, 404
 capacity 47–9, 234, 404
 defining 14–15
 denaturation, protein *see* protein denaturation
 denaturation
 engines *see below*
 and entropy 65–6
 fluid properties 210, 327–8
 sign conventions 36
 specific heat capacity 47
 transfer/flow 15, 35
 heat engines 34–5, 66–9, 404
 and biological systems 67–9
 grasshopper example 63–4, 68
 helix–coil transition theory 240–3, 240
 helix propensity scale 242, 243
 Lifson–Roig model 242
 mutation studies 242
 Zimm–Bragg model 240–2
 heme 135, 170, 253, 261
 hemoglobin 170–2, 171, 252; *see also* red blood cells
 association constants 264
 binding curve 262
 binding equilibria 261–5, 261
 carbon monoxide 170–1
 dissociation constants 262
 Hill equation 263, 274
 molecular switching 262
 oxygen binding 170, 250
 oxygenation in solution 171–2
 proton binding 272–3
 self-regulation 261
 sickle-cell/variant 170–1, 171
 statistical factors 264
 structural differences 261
 thermodynamics 332
 Henderson–Hasselbalch equation 274, 404
 Hess's Law 41, 404
 heteroallostery 404
 hexokinase 300
 Hill equation 263, 263, 266, 274, 404
 Hill plot 266, 267, 404
 histidine, feedback inhibition 270–1
 homoallostery 271, 404
 humans
 global energy use 17
 molecular communication 349
 hydration enthalpy 46
 hydrochloric acid secretion, gut 159
 hydrogen 1
 bonds 43
 electrode 404
 exchange *see* hydrogen exchange
 hydrogen bomb 351
 hydrogen exchange 192, 307–11, 404
 equilibrium exchange 309–10
 exchangeable protons 308
 intrinsic rate of exchange 308
 local unfolding/breathing 309
 mass spectrometry 309, 311
 NMR spectrometry 308, 309
 pH dependence 308, 309
 protection factor 310
 quenched-flow pulse labeling 309, 311
 hydrophobic interaction 404
 hydrothermal vents 338
 ideal gas law 33–4, 40, 404
 imidazole 115
 immune response 254
 immune system 172–3
 and osmosis 153–4
 vertebrate 350
 immunoglobulin binding 45
 infinity 329
 information theory, biological
 context 342–7, 401, 405
 actual and potential information 345, 400, 407
 biological information expression 333
 biological information mechanisms 5
 DNA sequences 343, 346–7, 347–8, 349
 and energy xiii, 5, 145, 169, 339–40
 and entropy 344
 information 343
 information content 343, 404
 letter combinations example 345–6, 346
 macroscopic state 344
 meaning 343
 molecular communication 348–9
 nervous system and information processing 349
 observer 344, 345
 symbols 344
 and thermodynamics 348
 work and information 344
 inherent meaning 344, 405
 inhibition
 competitive 304–6
 feedback 270–1
 non-competitive 304–6
 inhibitor 304–6
 insects, jumping 63–4, 68
 insulin 251
 binding 169
 intensive property 30
 interaction free energy 238–9, 238
 internal energy 29–31, 195, 405
 intrinsic property 405
 intrinsic rate of exchange 308, 405
 ion hydration enthalpies 47
 ionic activity 107
 ionic solutions 104–8
 EDTA (cation chelator) 105–7
 guanidinium chloride 107
 halophile bacteria 107
 mean ionic activity coefficient 107
 theory of strong electrolytes 107
 ionic strength 107, 183
 ionization 73, 111
 IRATE computer program 385
 irreversibility 194, 405; *see also* reversibility
 aging 77
 biologically useful energy 76
 evolution 77
 and life 75–8
 many-body systems 78
 order 77
 time 76–7
 isoelectric point 183, 405
 isolated systems 12, 405
 isosbestic point 229, 405
 isothermal systems 70–2, 405; *see also* thermoregulation
 isothermal titration calorimetry (ITC) 45, 46, 257, 259, 374–6, 405
 antibody binding example 375
 pharmaceutical drug development 375
 joules xiv
 Kepler's laws 26, 27
 kinetic barrier 295, 405
 kinetic energy 34
 kinetic theory of gases 9, 292
 Kirchhoff's enthalpy law 49, 405
 KNF model of allostery 405

- α -lactalbumin 230–1
 β -lactoglobulin 183
 Langmuir adsorption isotherm 253, 254, 405
 latent heat 405; *see also* heat
 law 405; *see also* FirstSecond and Third Laws of thermodynamics
 Boltzmann 293
 as boundary conditions 284
 constant summation 39
 Hess 41
 Kirchoff enthalpy 49
 mass action 88
 Maxwell 293
 Raoult 100
 rate 408
 van't Hoff 151
 Le Châtelier's principle 109–10, 405
 least squares analysis 265
 life 405
 origins *see* origins of life
 Lifson–Roig model 240–2, 405
 ligands 165–9, 168, 405
 light 3, 4–5, 22
 linear motor molecules 319
 linking number 177, 405
 lipids 96–8, 96
 cholesterol 96
 membranes 96, 97
 myelin sheath 96
 van der Waals forces 97
 lizards, temperature-dependent sex determination 12
 local minima 358–9, 359
 lysozyme 153
 amyloid fibrils 314
 amyloidogenic 314
 denaturation 224
 disulfide bonds, lysozyme 219, 220
 enthalpy of unfolding 45, 45
 enzyme kinetics 301
 multi-state equilibria 230–1
 reaction mechanism 306–7, 305
 spontaneous refolding 356
 machine 405; *see also* heat engines;
 motors analogy/living
 organisms 194, 351–2
 macromolecular
 binding xiv
 precursors/origins 332–3
 macroscopic
 association constant 255, 257
 motors 319
 particle properties 208–11
 state 344
 system 405
 Marcus theory 297–9, 406; *see also*
 electron transfer
 mass 328
 action 406
 spectrometry 309, 311
 mathematics xiii; *see also* data
 analysis; statistical
 thermodynamics
 modeling osmosis 149–52
 matter, energy as property of 327
 Maxwell
 distribution of molecular speeds 10
 law 293
 mean free path 213, 406
 meaning 343
 mechanical coupling 117–18
 mechanical energy conservation 36
 mechanics, statistical *see* statistical
 thermodynamics
 melting, protein *see* protein
 denaturation
 melting temperature 45, 45, 186, 406
 membrane/s 96, 97
 cell 140
 mitochondrial 161, 162
 semi-permeable 148
 membrane transport 158–62
 active/passive 159
 ATP synthesis in mitochondrial
 membranes 161, 162
 charge 159–60, 162, 162
 nerve impulses/neurons 160–1
 numerical example 159–60
 and osmosis 152
 metabolism 144, 270, 406
 meteorites 291, 332, 334–5
 methanogen bacteria 338
 Michaelis constant 302
 Michaelis–Menten equation 302–3,
 303, 406
 microfossils 332
 microscopic
 association constant 257, 273
 particle properties 208–11
 system 406
 microtubules 315–16, 315
 mitochondria 140, 146, 161, 162
 mixing 58, 59, 61, 76, 90, 91, 100,
 180
 modeling, mathematical 149–52
 modulators, allosteric regulation 271
 molarity, 99
 mole fraction 101, 103, 108, 205
 molecular
 communication *see* molecular
 communication
 interactions, non-covalent
 energetics 43
 motion 27
 motors 318, 319, 406
 pharmacology 165–9; *see also*
 binding interactions
 speeds, Maxwell distribution 10
 switching 262, 332, 339, 406
 thermodynamics 331
 molecular communication 348–9
 biological information and
 thermodynamics 348
 cAMP 144, 145, 348
 humans 349
 molten globules 231, 406
 momentum 34, 406
 money energy analogy 5, 6, 7–9
 motion
 molecular 27, 292
 organized 410
 random 34, 60, 101, 404
 motive force, proton 140, 141
 motors
 macroscopic/muscular 319
 molecular/protein motors 318, 319
 multi-state equilibria 228–34, 232,
 233, 234
 enthalpy states 233, 234
 heat capacity function 234
 isobestic point 229
 lysozyme/-lactalbumin example
 230–1
 molten globules 231
 Pascal's triangle 233, 233
 muscle contraction 317–19
 mutation
 and pathological proteins 191
 somatic mutation theory 350, 354
 studies 242
m-value 257
 MWC model 271, 272, 272, 406; *see*
 also allosteric regulation
 myelin sheath 96
 myoglobin, binding equilibria 261–5,
 261; *see also* hemoglobin
 myosin 32, 318, 318, 319

- nano
 calorimetry 49–50
 machines 340
 technology 252, 406
 natural selection 336, 354, 358
 Nernst equation 122, 406
 nerve impulses/neurons 46, 160–1
 nervous system 349
 neuritic plaques 314
 neurofibrillary tangles 314
 Newton's laws 26, 27, 265, 331
 nicotinamide adenine dinucleotide
 123, 135, 138
 nipples 98
 nitrogenase enzyme 338
 nitroglycerin 283–4
 NMR spectroscopy
 hydrogen exchange 308, 309
 methodology 224
 protein dynamics 192
 protein solubility 183
 non-competitive inhibition 304–6,
 406
 non-covalent energetics 43
 non-equilibrium thermodynamics
 193–5; *see also* irreversibility
 evolution 356
 First Law 193, 195
 internal energy 195
 organisms and machines,
 differences 194
 organisms as open systems 193
 Second Law 193, 195
 steady state 193
 non-linear regression analysis,
 Scatchard/Hill plots 268, 268–9
 nuclear fusion 1, 21, 24
 nuclear magnetic resonance *see* NMR
 spectroscopy,
 nucleation 240–2, 406
 nucleic acids 335–7; *see also* origins of
 life
 panspermia hypothesis 337
 role of RNA 335–7
 RNA world 330–7, 408
 number of ways 218, 406
 nutrition 75, 378
 observable quantity 407
 observer 344, 407
 role 345
 oligonucleotide primers, PCR 178,
 179, 180
 open systems 11, 12, 13, 407
 organisms as 193
 optimization 340–2, 407
 order 62, 407; *see also* entropy
 and living organisms 77
 maintaining 5
 in non-living systems 352–3; *see*
also complexity
 origins of life 351
 abiotic synthesis of biopolymers
 333–4
 adsorption onto clay 334
 cell component biosynthesis 333
 enzyme catalysis 333
 macromolecules 332–3
 microfossils 332
 nucleic acids 335–7
 panspermia hypothesis 291, 332,
 337
 role of phosphates 334
 role of RNA 335–7
 osmosis 147–54, 148, 407
 bacterial cell walls 153–4
 chemical potential 148, 150
 immune system 153–4
 increased entropy 148–9, 153
 mathematical modeling 149–52
 membrane transport 152
 particle momentum 153
 red blood cells/hemoglobin 152,
 153
 semi-permeable membranes 148
 and statistical thermodynamics
 215
 van't Hoff law 151
 osmotic pressure 149, 150–2, 151,
 407
 osmotic work 407; *see also* work
 oxidants 120, 407
 oxidation 15, 16
 oxidation–reduction reactions *see*
 redox reactions
 oxidative phosphorylation/ATP
 hydrolysis 135–7, 138, 139–46,
 141, 142, 144, 145
 actomyosin-mediated 318
 biochemistry 142–3
 bioenergetics 139
 brown adipose tissue/
 thermogenesis 146
 cellular role 140–2, 144–6
 chemiosmotic theory 140
 definition 139
 energy and information 145
 enthalpy change 143
 mitochondria 140, 146
 phosphoanhydride bond 140
 phosphoryl group-transfer
 potential 143
 proton motive force/proton
 movement 140, 141
 rate of reaction 285, 285
 second messengers 144, 145
 oxygen
 binding 170, 250
 interactions with hemoglobin/
 myoglobin 252–3
 transport 261–5; *see also*
 hemoglobin; red blood cells
 utilizing bacteria 337
 panspermia hypothesis 291, 332,
 334–, 337, 407; *see also* origins of
 life
 parameters, adjustable 227, 400
 particle momentum 153
 partition function 219–23, 407
 Pascal's triangle 233, 233
 passive transport 159, 407
 path function 38, 407
 pathological proteins 191
 misfolding/aggregation 313–14
 PC analogy, living organisms 352
 PCR *see* polymerase chain reaction
 penicillin 304
 peptide hormone binding 100–1
 perfume molecule diffusion 60, 65,
 149, 206
 PGK (phosphoglycerate kinase) 238–9
 pH 115–17
 denaturation 188, 189
 dependence 308, 309
 and protein solubility 183
 pharmacology 375
 phase 407
 phase transitions 95–8
 behavior of water 96
 first-order 95, 95–6
 lipids 96, 96–8
 phenomenological perspective 282
 phenylalanine 181
 phosphates 407
 role in origins of life 334
 phosphoanhydride bond 140, 407
 phosphofructokinase 138, 146
 phosphoglycerate kinase (PGK) 238–9

- phosphoryl transfer 119, 169
 phosphotyrosine-mediated binding 167–9
 photon energy 327
 photosynthesis 3, 135, 136, 407; *see also* plant pigments
 redox reactions 123
 physical chemistry xiv, xii
 physicochemical basis of order 351
 pigments, plant 3, 3, 135, 183
 pK_a 115–17, 133, 143, 183, 210, 274
 Planck's radiation law 295
 plant pigments 3, 3, 135, 183
 plasmid DNA 176
 plasticity, protein 190
 pollination 65
 pollution 84
 polymerase chain reaction (PCR) 178, 178–80
 enthalpy 179
 entropy 179–80
 oligonucleotide primers 178, 179, 180
 polymerization 314–17
 actin filaments 314, 315, 316, 316–17
 lysozyme amyloid fibrils 314
 microtubules 315–16, 315
 polymerization assays 317, 407
 polyprotic acids 117, 117
 population of states 227, 234
 potassium transport 159
 pregnancy testing 172
 pressure 33, 407
 gas 170, 211, 216
 osmotic 149, 150–2, 151
 prions 337
 process 407
 prokaryotic organisms 354
 propagation 240–2, 407
 protection factor 407; *see also* hydrogen exchange
 proteins 334–5, xi, xiii
 anti-freeze 104
 chemical equilibrium 93
 chirality/handedness 334–5
 denaturation *see* protein denaturation
 DNA encoding 350
 dynamics *see* protein dynamics
 electroweak interactions 335
 folding *see* protein folding
 heat capacity functions 235–6
 hyperthermophilic 230
 melting *see* protein denaturation
 mobility/flexibility *see* protein dynamics
 as nanomachines 340
 as organic crystals 191, 192
 pathological 191, 313–14
 repair mechanisms 351
 solubility *see* protein solubility
 space/meteoritic origins 332, 334–5
 stability *see* stability
 structural levels 240
 structure 44
 turnover/renewal 352
 unfolding, induction 107, 256
 protein denaturation 45, 45, 185–9;
 see also protein stability
 chemical denaturation 188–9
 cold denaturation 188
 DNA melting 44, 72, 176
 lysozyme denaturation 224
 melting/heat-denaturation temperature 45, 45, 186
 pH denaturation 188, 189
 and second law 72–4
 stability 186
 temperature of maximum stability 187
 transition temperature 187
 protein dynamics 191–3
 atomic fluctuations 192
 breathing motions 192, 261, 309
 collective motions 192
 hydrogen exchange 192
 NMR spectroscopy 192
 triggered conformational changes 192
 protein folding 311–14, 312
 chaperones 313
 circular dichroism spectroscopy 312, 312
 fluorescence emission 313
 misfolding 313–14
 pathological misfolding/aggregation 313–14
 reversibility 185, 373
 protein solubility 182–4, 183
 amino acid composition 183
 isoelectric point 183
 nuclear magnetic resonance (NMR) spectroscopy 183
 pH dependence 183
 salting in/out 183–4
 proton
 binding 272–5
 motive force 140, 141, 407
 protonation kinetics 381
 PTB domain 168, 183, 255
 pV -work 38, 40, 55, 71, 92, 94, 121, 155
 pyrimidine synthesis 128, 271
 pyruvate reduction 122–3
 Pythagorean theorem 28
 quenched-flow pulse labeling 309, 311, 408
 randomness 214, 214, 408
 Raoult's law 100
 rate constant 286
 rate-determining factors 296, 297
 rate-determining step 408
 rate law 408
 rate of reaction 284–6, 408
 reaction kinetics 281–4, xiv; *see also* enzyme kinetics; hydrogen exchange; protein folding; transition state theory
 activation energy 282–3
 ATP hydrolysis 285, 285
 collision theory 291–3, 294
 electron transfer kinetics 297–9, 298
 first-order reactions 284, 287, 288–90, 290
 frequency factor 287, 287
 inhibition 304–6, 304, 306
 lysozyme reaction mechanism 306–, 307
 muscle contraction 317–19
 order of reaction 286
 phenomenological perspective 282
 polymerization 314–17
 rate constant 286
 rate of reaction 284–6
 second-order reactions 287, 289, 289–, 290
 study exercises 322–5
 temperature effects 290–1
 receptor–ligand interactions, binding equilibria 250
 rectangular hyperbolae 165, 408
 red blood cells

- Donnan equilibrium 158
 osmosis 152, 153
 redox reactions 120–3, 122, 408
 electromotive force 120
 electron transfer 121
 Nernst equation 122
 oxidants 120
 photosynthesis 123
 pyruvate reduction to lactate
 example 122–3
 reductants 120
 standard redox potential 120, 121,
 121
 reductants 120, 408
 reference state 219, 408
 regression analysis 268–9, 268
 reproduction 357, 358
 resilin 63–4, 68
 respiration 13, 408
 reversibility 185, 373, 408; *see also*
 irreversibility
 rhodopsin 128
 ribonuclease A (RNase A) 162–4
 ribonucleic acid (RNA) 335–7
 RNA world 330–7, 408
 RNase A 250
 rubber band machine 35, 62–4, 69
- salt bridge 408
 salting in/out 183–4, 408
 saturation 408
 Scatchard equation 265
 Scatchard plot 265–9, 266, 408
 binding interactions 166, 166
 Gaussian distribution 268
 linearization 268
 non-linear regression analysis
 268, 268–9
 science xiii
 Second Law of Thermodynamics
 58–61, 408; *see also* entropy; heat
 engines; irreversibility
 formulations of law 61; *see also*
 third law
 and Gibbs free energy 60, 70, 71
 perfume molecule diffusion
 example 60, 65, 149, 206
 isothermal systems 70–2
 jumping insects 63–4, 68
 non-equilibrium 193, 195
 and protein denaturation 72–4
 study exercises 80–4
 second messengers 144, 145, 408
- second-order reactions 287, 289,
 289–90, 290, 408
 self-organization 408
 semantic level 408; *see also*
 information theory
 semi-permeable membranes 148
 sequential model of allosteric
 regulation 270, 271–2
 sexual reproduction 357, 358
 SH2 domain 167, 168, 255
 sickle-cell anaemia 170–1, 171
 sign conventions 36
 signal transduction 169, 254
 simplicity, and universe 329–30; *see*
 also complexity
 single molecule studies 218, 331, 332
 single-site model 253–5
 site-directed mutagenesis 376
 sliding filament model 318, 408
 sodium transport 159
 solar spectrum 9
 solubility 408; *see also* protein
 solubility
 solute 99, 100, 101–2, 102–4
 solutions, thermodynamics 98–102
 solvation 30, 105
 somatic
 mutation 350, 354, 409
 recombination 350, 409
 space, and origin of life 291, 332,
 334–5
 speciation 357, 358; *see also* evolution
 specific heat capacity 47, 409
 spectrometry/spectroscopy; *see also*
 NMR
 circular dichroism spectroscopy
 312, 312
 mass spectrometry 309, 311
 sperm 317
 spontaneity 409
 stability curve 409
 stability, protein 42–4, 48–9, 184–91,
 185, 187, 189, 409; *see also*
 protein denaturation
 amino acids 341
 death, programmed 191
 disulfide bonds, lysozyme 219, 220
 energy well 185
 enthalpy–entropy compensation
 190, 374
 enzyme engineering 190
 native/denatured equilibrium 184
 plasticity 190
- protein degradation 190–1
 reversibility 185
 stability curve 186
 thermodynamic hypothesis 185
 van't Hoff analysis 185
 stable/unstable equilibria 90
 standard free energy change 98
 standard redox potential 120, 121,
 409
 standard state 33, 110–12, 409
 state/s; *see also* energy states;
 multi-state equilibria
 functions 30–1, 409
 reference 219
 systems 11, 409
 state variables 409
 statistical thermodynamics xiv, 60–3,
 207–, 209, 211; *see also* data
 analysis; diffusion; multi-state
 equilibria
 Boltzmann distribution 215–22,
 223, 233
 cooperative transitions 236–7, 237
 energy states/levels 216–22, 217,
 218, 233
 equilibrium distribution 216, 216
 helix–coil transition theory 240,
 240–, 243
 interaction free energy 238–9, 238
 partition function 220, 222
 protein heat capacity functions
 235–6
 study exercises 246–9
 steady state 409
 assumption 301, 409
 non-equilibrium thermodynamics
 193
 strong electrolytes, theory of 107
 substrate 409
 cycles 146–7, 409
 succinic acid 210, 211, 382
 sulfanilamide 304
 sulfate-reducing bacteria 337, 409
 Sun 354–5
 as primary energy source 1–3, 2
 solar spectrum 9
 supercoiling 409
 surroundings, definition 11, 409
 switching, molecular 262, 332, 339
 symbols 344, 409
 systems 409
 closed 11, 11
 isolated 12

- isothermal 70–2
 systems (cont.)
 microscopic 329–32
 open 11, 12, 13, 193, 351, 352
 surroundings 11
- tau 314
 tea 22, 61, 92, 352
 temperature 409; *see also* heat
 absolute 33
 protein melting/heat-denaturation
 45, 45, 186
- tensin 255
 thalassemia 273
 theory of strong electrolytes 107
 thermal energy 33, 410
 thermal equilibrium 33
 thermodynamic/s 26–7, 410, xii–xiii;
 see also statistical
 thermodynamics
 biological applicability 5–6
 classical 208, 209, 223
 cycle 30
 definitions 14
 hypothesis 185
 laws 6, 27, xii; *see also* First Law;
 Second Law; Third Law
 optimization of amino acid
 sequences 340–2
 of solutions 98–102
 of very small systems 329–32
 thermogenesis 147, 262; *see also*
 thermoregulation
 brown adipose tissue 146
 thermophilous organisms 338
 thermoreception 292–3
 thermoregulation 29; *see also*
 thermogenesis
 anticipatory 105
 body temperature and longevity in
 mice 145–6
 isothermal systems 70–2
 in plants 29
 thermostability *see* stability
 Third Law of Thermodynamics 410
 and biology 74–5, 122
 thyroid hormones 147
 time 76–7, 211
 titration 257–60, 258, 410
 transfer free energy *see* Gibbs free
 energy
 transition states, reaction kinetics
 283, 294–7, 410
 activated complex 294
 activation barrier/kinetic barrier
 295
 enthalpy/entropy 296
 Planck's law 295
 rate-determining factors 296,
 297
 transition temperature 187, 410
 transmission coefficient 295, 410
 transport
 active 159
 membrane *see* membrane
 transport/passive 159
 treadmilling 316, 410
 tris 133, 381, 382
 tubeworms 80–4
 tubulin 315
 turnover number 301, 410
 twist 177, 410
 two-state approximation 224, 410
- universe
 entropy of 69–70
 and laws of thermodynamics
 329–30
 possible universes 330, 330
 urea 155, 256
 as chemical denaturant 181, 182
 uridine triphosphate (UTP) 144
 urine 57, 82
- van der Waals forces/interactions 97,
 174, 410
 van't Hoff
 analysis 185
 enthalpy 229, 236–7, 410
 graph 113, 113, 410
 law 151
 viruses 337
 voltage *see* electromotive force
- water
 behavior at freezing point 85–6, 86
 chemical potential 86, 98
 enthalpy at melting 41
 phase transitions 96
 reliance of life on 114
 structure under specific conditions
 47–, 48
 weak nuclear force 335
 work 31–5, 37–8, 38, 410
 boundary phenomena 31–2
 force 31
 heat 31–2
 heat engine 34–5
 heat transfer 35
 ideal gas law 33–4, 40
 and information 344
 kinetic energy 34
 momentum 34
 pressure 33
 sign conventions 36
 temperature 33
 thermal energy 33
 thermal equilibrium 33
 writhe 177, 410
- X-ray crystallography 189, 192, 221,
 334
- Zeroth Law 27–8, 33, 210, 410
 Zimm-Bragg model 240–2, 410