The Processes of Life

An Introduction to Molecular Biology

Lawrence E. Hunter

The MIT Press
Cambridge, Massachusetts
London, England
Index

Figures are indicated by italic; footnotes are indicated by n. followed by note number.

aciclovir, 200
acid-base interactions, 61–62
acids, 61–62
acquired immunodeficiency syndrome (AIDS), 200–201
actin, 169–172
in eukaryotic cell, 124
action potentials, 173–174
activation barriers, 68–69
overcoming, 70
activation energy, 68–69
active transport, across cell membrane, 75
adaptor proteins, 146
adenine
functions of, 83n.6
structure of, 84
adenosine diphosphate (ADP), 77, 80
adenosine triphosphate (ATP), 16, 70
in bacterial energy metabolism, 80
in bacterial metabolism, 77
depletion of, 192
in eukaryotic mitochondria, 126–130
production of in eukaryotes, 131–133
ADP. See adenosine diphosphate (ADP)
adrenaline, in homeostasis, 167
aging, cancer and, 207
agonists, 208
agriculture, molecular biology in, 245–246
AKAP79-GFP fusion protein, 225, 226
alanine, 93, 94t
Albert, Bruce, 117
alleles
complete set of, 25–26
dominant and recessive, 25
expressed, 24–25
independently assorted, 27
in inheritance, 24–25
migration or transfer of, 35
possible combinations of, 26
reshuffling of, 29–30
selective advantage of, 36–37
allometry, 162
allosteric regulation, 98
Alon, Uri, 187
alpha carbon, 92
alpha helices, 99, 101
structure of, 100
alpha-ketoglutarate, transamination of, 130
altruistic genes, 144
amino acid polymerase, 110
amino acids, 12, 92
interactions of, 96
kinds of, 93
properties of, 94t
residue of, 92
sequences of, 94–95
in protein structure, 102
structures of, 93
aminoacyl-tRNA synthetase, 108
AMPA receptors, 185
anabolism, 77
anatomy, 165
of organ systems, 167–168, 175–185
angina, 203
angiotensin, 204–205
angiotensin-conversion enzyme (ACE) inhibitors, 204–205
animal experimental subjects, regulation of, 249
anion, 59
Anker, Suzanne, 240
antagonists, 208
antenna complex, 130
antibiotics, 196
disrupting bacterial cell walls, 76
infectious disease and, 200–201
antibodies, 180
anticancer drugs, 207
antigens, 180
antiparallel beta sheet, 99
apolipoproteins, 204
apoptosis, 152, 193–194
apoptotic signals, 152
Arabidopsis thaliana, as molecular biotechnology model, 233
arachidic acid, 66
arachidonic acid, 66
Archaea, 5–6, 10
arrhythmias, 201
arrowroot plant, morphology of in different environments, 22
arteries, 176
arterioles, 177
arteriosclerosis, 202n.5
arthropods
body division in, 149
cerebral ganglion in, 182
ventral nerve cord in, 182
aspartate, tRNA for, 108
aspen grove, as single organism, 5–6
assemblies, emergent properties of, 165
assortative mating, 35–36
atherosclerosis, 202–203
atomic mass, 51
atomic number, 51
atoms, 50–54
bonding of, 53, 57
combination of, 53
constituents of, 50–51
donor and acceptor, 58
electronic structure of, 53
functional groups of, 64
ATP. See adenosine triphosphate (ATP)
ATP synthase, 78
Aulehla, Alexander, 148n.5
autophagy, 191
autophosphorylation, 146
autotrophs, 4
bacterial, 74
awareness, in bacteria, 88, 88n.7
B-cells, 180–181
bacteria, 10
awareness and choice in, 88, 88n.7
backwards TCA cycle in, 129
beneficial, 73
binary fission of, 86
biomass of, 73
central functions of, 74–75
chromosomes and genomes of, 82–86
colonies of, versus multicellular organisms, 139
communities of, 86
cytoplasm and metabolism of, 77–82
defenses against, 178
in environment, 87
in human body, 73
life of, 86–88
literature on, 88–89
membranes and boundaries of, 75–76
movement of, 87–88
reproduction in, 74
speed of reproduction in, 83
structure of, 75
taxa of, 8–9
bacterial infections, antibiotics for, 200
bacterial ribosomes, 107
baroreceptors, 177
basement membrane, 169
bases, 61–62
Beauchamps, Tom, 251
beta cells, in homeostasis, 166
beta oxidation, in eukaryotes, 129
beta sheet, 99, 100
beta strand, 98–99, 101
Bhattacharya, Debashish, 137
Bilateria, 145–146
body development in, 148
eye development protein in, 150
immune systems of, 179
nervous system of, 182
binary fission, 86
binding affinity, 224
biodiversity, 3, 5–11
molecular biology and, 247
bioethics
definition of, 241
literature on, 251
of molecular biotechnology, 241–251
biological molecules, elements in, 62–66
biology
diversity of, 3, 5–11
lack of generalizing theory in, 2–3
biomass, 73
bioprospecting, 247
birds, number of species of, 8
blastula, 153
blood, 175–176
cell types of, 176
circulation of, 176
blood clotting, 196–197
in heart disease, 203
blood pressure, 177
blood vessels, 176
body divisions, 149
bond energy, 69
bonds
carbon, 63–64
covalent, 54
cyclic, 64
double, 54
ionic, 54
molecules and, 54–58
in polypeptide chain, 94–95
Bonds, Barry, 248–249
bone morphogenetic proteins (BMPs), 156
botulism toxin (Botox), cosmetic uses of, 249
bowerbird nest, in sexual selection, 40–41
brain, 182
specialized formations of, 183
**BRCA** genes, 199
breast cancer genes, 199
budding, 144
butane, structure of, 63
butene, structure of, 63
cadherins, 153
**Caenorhabditis elegans**
development of, 152
developmental program of, 161
in molecular biotechnology, 233–234
nervous system of, 182
calcium
kinases and, 185
in myosin activation, 173
Calvin cycle, 131–133
Cambrian Explosion, 44, 46, 145
cancer
defective p53 protein in, 152
genetics in, 199
monoclonal, 206
pathology and treatment of, 205–207
capillaries, 176
development of, 159
carbohydrates, 65–66
carbon atoms, 62–63
in amino acids, 92
bonds of, 63–64
carbon-containing molecules, 55
carboxyl carbons, 92
carboxylases, 103
cardiac muscle, 172–173
cardiac precursor cells, 158–159
cardiopulmonary resuscitation (CPR), 202
cardiovascular system, 175–178
diseases of, 201–205
hydraulics of, 177
organogenesis of, 158–159
Carroll, Sean, 148n.5, 163–164
caspases, 194
catabolism, 77
catalysts
in bacterial metabolism, 77–78
protein, 92–104
Cavenagh, John, 240
cell adhesion molecules, 153
cell adhesion protein, interactions of, 156
cell fate
control of, 144–145
mapping in nematodes, 233–234
cell lines, 231
cell-mediated immune response, 181
cell membranes, 76
bacterial, 75–76
receptors on, 75–76
rupturing of, 76
cell-to-cell signaling, 151–153
cells
atrophy of, 191
bacterial, 75
cycle of, in eukaryotes, 134–135
death of, 193–194
differentiation of, 156–158
regA gene in, 143–144
environmental signals in activity of, 146
growth and size of, 161
hyperplasia of, 191
hypertrophy of, 191
injury to, 192–193
causes of, 190–191
lineage of, 157
metaplasia of, 191–192
motion of, 153–156
proliferation of, 160
specialization of, 140
in embryonic development, 155
terminally differentiated, 157
types of, 156
need for new, 157
cellular respiration, 129
cellular stress, responses to, 190–192
cellulose, 66
Cenozoic Era, 46
centrifuge, 50, 216
centromeres, 124
cerebellum, 183
**CFTR** allele, deleterious, 36, 37
charge measurement, 216–221
chemical fossils, 42–43
chemical reactions. See reactions
chemotaxis, 74–75
in bacterial life, 88
chip assays, 229–230
chip-chip array, 230
chlorophyll, 130
chloroplast, 130–133
choice, capacity for in bacteria, 88, 88n.7
cholesterol, 203–204
blood levels of, 204–205
chromatin, 124
chromosomes, 27–28
bacterial, 82–86
definition of, 82–83
diploid, 27
cilia, 169
evolution of, 136–137
circulation, systemic and pulmonary, 177
circulatory system, 167, 175–176
development of, 158–159
cis regulatory sequences, 114
clonal colony, 74
clonality, 142
cloning, 235
ethics of, 244
coagulation cascade, 197
coevolution, 39
adaptive immunity and, 179–180
predator-prey, 39, 136

collagen, 12
molecular rendering of, 13
in organ formation, 155
colony, bacterial, 74
colony formation, 140
columnar epithelium, 171
combinatorial chemistry, 209
commensal bacteria, 73
competitors, coevolution of, 39
complement system, 179
complex abilities, evolutionary origin of, 31–32
compounds, 50
molecular weight of, 55
molecules of, 52
cones, 74
conformations, 95
connective tissue, 169
coprolites, 42
coronary artery disease (CAD), 202–203
covalent bond, 57
crossover, 29
curative interventions, 195–196
cyclic adenosine monophosphate (cAMP), creation of, 147
cyclopentane
bonding patterns of, 64
structure of, 63
cysteine, 93, 94t
cytochrome b6f complex, 130–131
cytoplasm, 75
bacterial metabolism and, 77–82
cytosine, structure of, 84
cytoskeleton, 124

Daltons, 216
Danio rerio, as molecular biotechnology model, 234
Darwin, Charles, 19
descent with modification concept of, 20–21
on origin of species, 21
reproductive isolation theory of, 33–34
on sexual selection, 39
variation account of, 104
Davidson, Eric, 164
Dawkins, Richard, 127n.4
dehydrogenases, 103
Deinococcus radiodurans, tomographic reconstruction of, 7
dendrites, 183
in information transmission, 184
Dennett, Daniel, 47, 88n.7
deoxyribonucleic acid (DNA), 12–16, 83
base pairs, 84–85
coding sequences (CDS) of, 104–105
complementary (cDNA), 228
complementary strand of, 84, 85–86
deletions and insertions in, 114
in eukaryotic transcription, 122, 123
evolution of, 111–116
exchange of in bacteria, 74n.2
homologous recombination of, 115–116
information encoded on, 15–16
inversions of, 116
lagging strand of, 113
leading strand of, 112–113
methylation of, 178
molecules
bacterial, 83–84
coding and replication functions of, 83–84
function of, 14
segment of, 14
noncoding regulatory sequences of, 105
nucleotides assembling into, 85
packaging of in eukaryotes, 125
protein synthesis and, 104–107
recombinant (rDNA), 236
template-directed repair of, 115–116
transpositions of, 116
deoxyribose, 83
descent, 19
with modification, 20–21
development
cell motion in, 153–156
cell-to-cell signaling in, 151–153
definition of, 145
differentiation in, 156–158
molecular maps in, 148–151
of multicellular organisms, 145–148
organogenesis in, 158–159
Deyer, Betsey Dexter, 88–89
diabetes
discovery of allele related to, 242–243
genetics in, 199
diagnostic procedures, molecular biotechnology in, 194–195
Dictyostelium
cell differentiation in, 154
life cycle of, 141
 multicellularity of, 140
differentiation. See also cells, differentiation of
Index

definition of, 156
at molecular level, 158
digestive system, 167
dimers, 96–98
dinitrogen heterocycles, 83
disaccharides, 66
disease
agents causing, 190–191
definition of, 190
etiology of, 190
genetics and, 198–199
personalized, 243–244
predisposing conditions of, 242–243
prevention of, 195
dissociation, 58–59
diversifying selection, 37
diversity, 3, 5–11
DNA. See deoxyribonucleic acid (DNA)
DNA ligase, 113
DNA polymerase, DNA-directed, 112–113
repair mechanisms of, 115–116
replication of, topoisomerase in, 112
sequences of
promoter, 106
repressor, 106
DNA polymerase III, 112
DNA primase, 112
DNA sequencer, 225–226
DNA sequencing technologies, 226–228, 230
doping controversies, 248–249
Drosophila, pair-rule genes in, 148n.5
Drosophila melanogaster model, 234
drug discovery process, 208–211
literature on, 213
druglike compounds, identifying, 208
drugs. See also pharmaceuticals; specific agents
clinical trials of, 210–211
high-throughput screening of, 209
preclinical research on, 210
toxicities of, 211
dystrophin, 163
ear, in balance, 182
ecological approaches, 17
ecosystems, 17
in reproductive success, 21
ectoderm, formation of, 153
egg yolk, 161–162
eggs, 23
creation of, 28–29
size of, 161
of terrestrial animals, 162
electrolytes, 166
electron transport chain, 78
electron negativity, 53–54
bonding of, 54–55
electrons
distribution of in molecule, 54–55
in oxidation-reduction reactions, 62
quantum view of, 51n.2
taking from other atoms, 53–54
electrostatic force, 57
elements, 50
of biological macromolecules, 62
compounds of, 52
periodic table of, 51–52
elongation factors, 108–110
embryo
circulatory system of, 158
molecular maps in, 148–149
morphogenic fields of, 149–150
endocardium, development of, 158
endocrine system, 167
endoderm, formation of, 153, 155
endoplasmic reticulum, 119, 126
endosymbiosis, 126–127
endothelial reactions, 67
energy, 66
ATP and, 70
of bonds, 69
concentrated versus dispersed, 67–68
flow of, 70
in life, 70
management of, 11
metabolism of in bacteria, 78–80
of a system, 67
thermodynamics of, 67–70
ways of changing, 67
enthalpy, 67
entropy, 68
environment
fitness in, 22–23
in reproductive success, 21
enzymes
active sites of, 98
in bacterial metabolism, 78
for DNA, 112–113
in eukaryotic transcription, 124
names and functions of, 80n.5
recognition site for, 98
for tRNA, 108–110
epithelial cells
human, 170
types of, 168–169
epithelium, 168
from gallbladder and lung, 171
keratinized, 169
equilibrium, 60
equilibrium calculation, 68
equilibrium constant, 60–61
erucic acid, 66
erythroblasts, stem cell production of, 157
erthrocytes, 176
Escherichia coli, as molecular biotechnology model, 232
ethane, structure of, 63
ethanol, chemical structure of, 64
ebukaryotes, 10, 119–120
cellular components of, 124–134
DNA packing in, 125
gene structure and transcription in, 120–124
lifestyles of, 134–137
literature on, 137–138
single-cell, 134–137
eukaryotic cells, 119
structural complexity of, 119–120
evo devo (evolutionary development), 145–159
evolution
advantageous mutations in, 30
in defining life, 4–5
definition of, 19
descent in, 19
descent with modification in, 20–21
directed, 237–238
doing of DNA, 111–116
ethics of teaching, 250–251
fossils in learning about, 41–43
history of life and, 41–46
inheritance in, 23–28
life and, 47
linking small changes in, 30–33
literature on, 47
molecular machines in, 91–92
of protein, 102–103
of selection in, 34–40
single nucleotide polymorphisms in, 114
variation in, 28–34
variation source in, 19
exons, 121
exonuclease, 113, 121
exothermic reactions, 67
experimental approach, 186
experimental methodologies, 17
expression array, 230
extracellular matrix (ECM), 169
formation of, 155
extremophiles, 6
eye, retina in, 182
fatty acids
forms of, 66
monounsaturated and polyunsaturated, 65
fibroblasts, 169
fibronectin, in organ formation, 155
finches, reproductive isolation of, 33–34
fish
eggs of, 161–162
number of species of, 8
fitness, 21, 22
absolute, 36
characteristics determining, 22–23
fitness landscape, 37–39
fittest, survival of, 21–22
flagellum
on bacterial cell membrane, 76
in bacterial movement, 87–88
in predation, 136
selection for in Volvocales, 143
flight ability, evolutionary origin of, 31–32
flowering plants, number of species of, 8–9
fluorescent resonance energy transfer (FRET), 225
Food and Drug Administration (FDA),
regulating molecular biology, 249–250
food supply, GMO contamination of, 245–246
fossils, 41–43
dating of, 42–43
free loaders, 141–142
fructose, 66
fruit fly, 234
function, structure and, 2
functional groups, 64
fungal infections, 201
G protein, in cell signaling system, 147
G protein coupled receptors (GPCRs), 135n.7, 147
Galapagos Islands, reproductive isolation on, 33–34
gallbladder, epithelium from, 171
gamete, 23. See also germ cells
gap genes, 148
gap junctions, 173
gastrulation, 153–155
gel electrophoresis, 216–218, 219
GenBank public database, 228
gene duplication, 29, 114–115
gene family, 115
gene flow, 35
gene linkage, 27
gene product, 111
gene therapy, 199, 238
ethics of, 244
generalizing theory, lack of, 2–3
genesis
essential, 224
eukaryote, 120–124
expression of protein in, 105
horizontal transmission of, 74n.2
in inheritance, 24
proteins and, 104
RNA coding, 108
genetic code, 105
genetic defects, 212
genetic discrimination, 248
genetic drift, 35
genetic engineering, 235–238, 239
genetic locus, 26
genetic pollution, 246
genetic predispositions, 242
genetic recombination, 28–29
genetic switch, 232
genetic testing, ethics of, 242–243, 244
genetically modified organisms (GMOs), 245–246
genetics, disease and, 198–199
genomes
  bacterial, 82–86
  control of, 244
  definition of, 82
  modification of, 237
  of plant species, 233
genotype, 25–26
  absolute fitness of, 36
  deleterious, 36
  frequencies of, Hardy-Weinberg equilibrium and, 34–35
  selection for, 142
  small changes in, 32–33
  genotyping array, 230
  genus name, 9–10
  germ cell, creation of, 28–29
  germ layers, 153
  germine, 139
  germ line cells, segregation of, 153
  GFP bunny, 239
  Gibbs free energy, 68
  Gilbert, Scott, 162n.10
  Gilbert, Wally, 225–226
  glands, 168
  glia, 174
  Glick, Bernand, 240
  global fairness issues, 247–248
  global temperature, mass extinction and, 45–46
  glucagon, 166
  gluconeogenesis, 129
  glucose, 65–66
  in glycolysis, 79, 80
  glyceraldehyde 3-phosphate (G3P), 133
  glycerol, 65
  glycine, 93, 94t
  glycogen, 66
  glycolysis, 81–82
  glycolysis pathway, 78–80
  golgi apparatus, 126
  Gould, Stephen J., 47
  granulation tissue, formation of, 197–198
  green fluorescent protein (GFP), 225
  Gross, Jurgen, 239–240
  gross anatomy, 165
  group selection, 140–142
  growth, in multicellular organisms, 159–162
  growth factors
    in cell differentiation, 156
    in organogenesis, 158
  guanine, structure of, 84
  guanosine diphosphate (GDP), 147
  guanosine triphosphate (GTP), 147
  Haldane, J.B.S., 142
  Hardy, G.H., 34–35
  Hardy-Weinberg equilibrium, 34–35, 36
  Hazen, Robert, 137
  healing, 196–198
  heart
    chambers of, 177–178
    development of, 158
    genetics in diseases of, 199
  heart failure, 201
  hedgehog genes, 151–152
  helicase, 111–112
  helminths, infections by, 201
  hepatitis C, 201
  heritable characteristics, 19
  Herrmann, Bernard, 148n.5
  heterochromatin, 124
  heterotrophs, 4
  heterozygous gene, 25
  hexokinase, 79, 80
  histidine, 93, 94t
  histology, 165
  of tissues, 168–175
  histones, 124
  homeobox (Hox) genes, 149
  homeostasis, 165–168
  Homo habilis, 46
  Homo species, hierarchical grouping of, 10
  homologs, 31–32, 102
  serial, 149
  homozygous gene, 24–25
  hormones, 12
  in intercellular signaling, 153
  Houdebine, Louise-Marie, 240
  human cell, nucleus of, 120
  human experiments, regulation of, 249
  human immunodeficiency virus (HIV), 200–201
  human interferon protein, 201
  human karyotype, 28
  humanity
    adaptations of, 163
    development and growth of, 162–163
    molecular biotechnology and, 238–239
    multicellular life and, 162–163
humoral immune response, 180
hybridization, 228–229
hybridization-based assays, 230
hydra, layers in, 154–155
hydrocarbons, 55
chemical properties of, 63–64
saturated, 63
structures of, 63
visualizations of, 56–57
hydrogen bonds, 58
hydrogen ion, 78n.4
hydrolases, 103
hydroxide, formation of, 61
hydrosol, 180
hydrosomes, 180
hyperplasia, 191
hypertrrophy, 191
hypothosis-driven approaches, 186–187
hyperxia, 190, 192
ichnofossils, 41–42
imatinib (Gleevec), 207
immune memory, 180
immune response
cell-mediated, 181
humoral, 180
immune system, 167, 178–181
in cancer, 206
immunity, adaptive, 179–180
immunization, 195
immunoglobulin A (IgA), 180
immunoglobulins, 180
immunoprecipitation, 225
individuality, evolution of, 142n.3
infarction, 193
infectious disease, antibiotics and, 200–201
inflammation, 197
inhibition, 23–28
initiation factors, 108–110
innate immunity, 179
insects
eggs of, 161
origins of Flight in, 31–32
social, 140
Institutional Animal Care and use Committees (IACUCs), 249
Institutional Review Boards (IRBs), 249
Instituto Nacional de Biodiversidad (INBio), 247
insulin, 12
in different species, 102
molecular rendering of, 13
structure of, 96–98
insulin/glucagon signaling mechanism, 166–167
integumentary system, 167
interneurons, 174–175
specialized formations of, 183
interstitial fluid, in homeostasis, 166
introns, 120–121
invagination, 155
in vitro fertilization (IVF), 244
involution, 155
ionic bond, 57
ions, 51
homeostasis of, 166
ischemia, 193
ischemic heart disease, 201, 202–203
isobutane, structure of, 63
isomers, 64
isotope ratio dating methods, 43
isotopes, 51
karyotype, 28
Katz, Laura, 137
Kelly, Evelyn, 240
keratin, 169
Kessler, Andy, 213
kin selection, 142–143
kinases, in glycolysis, 79, 80
kinetics, 61
Kingsley, David, 32n.5
Klein, David, 71
knockdown experiments, 223
knockouts, 223
inducible, 224, 237
Kunkel, Louis, 212
labyrinth, 182
lactose, 66
metabolism pathway of, 106
Lamarckian inheritance, 29–30
laminin, in organ formation, 155
Lane, Nick, 138
larva, undifferentiated cells in, 161
lateral inhibition, 151
lead compounds, discovering and optimizing, 209–210
Leakey, Richard, 46n.11
learning, 185
leucine, 93, 94t
leukocytes, 176
Lewin, Roger, 46n.11
life (on Earth)
approaches to study of, 1–5
bioethics of teaching, 250–251
brief history of, 41–46
chemistry and, 70
difficulty of defining, 4
evolution and, 47
extremes of, 6–7
holistic nature of, 1
macromolecules in, 116–117
Index

origin of, 43–44
process of, 2
substance of, 2
timeline of, 44
life support measures, 195
ligands, 146
ligases, 103
limbic system, 183
linoleic acid, 66
lipidomics, 221
lipids, 16, 65
  excessive accumulation of, 203–204
  separation and identification of, 221
Lipinski, Christopher, 208
lipoproteins
  in atherosclerosis, 202–203
  in hyperlipidemia, 203–204
liver, glucagon receptors in, 166
living things
  critical functions and characteristics of, 11
  diversity of, 3, 5–11
  factors defining, 4–5
  genus and species names of, 9–10
  hierarchiacal grouping of, 10–11
  locomotion, muscle function and, 169
Lodish, Harvey, 117
long-term potential (LTP), 185
longevity spectrum, extremes of, 6–7
Luisi, Pier, 43n.9
lung, epithelium from, 171
lyases, 103
Lysenko, Trofim, 30n.3
lysis, 76
lysosome, 133–134
Maastricht Treaty, 250
macroevolution, 30
microevolution in, 30–33
macromolecules, 15
biological, 91–117
definition of, 91
life and, 116–117
structure determination of, 221–223
structures and functions of, 117
macrophages, 179
Macugen, approval of, 237–238
magnetic resonance spectroscopy (MRS), 222
major histocompatibility complex (MHC), 181
malaria, 201
malignant cells, 205–206
mammals
  hierarchical grouping of, 10
  number of species of, 8
Marden, Jim, on origins of insect flight, 31n.4
mass
  adding or removing, 67
  heating, 67
  measurement of, 216–221
  mass extinctions, 44–46
  molecular ecology studies and, 247
  mass spectrometer, 218–221
  mass spectrum, 220
  mating choices, 39–41
  matter, 49–50
  mayfly, 8
  lifespan of, 6
McGee, Harold, 95n.3
medicine
  advances in, 189
  molecular, 211–212, 242–245
  predictive, 243
  research and literature on, 212–213
meiosis, 23
  allele selection in, 25
  in eukaryotes, 134–135
Mendel, Gregor, 24
Mendelian human diseases, deleterious
  genotypes in, 36
Mendel’s Laws of Inheritance (Mendelian inheritance), 24–28
of disease, 198
proteins in, 104
mesenchyme, 155
mesoderm, formation of, 153, 155
mesosome, 86
Mesozoic Era, 46
metabolic pathway, 77–78
metabolism
  of bacteria, 74, 77–82
  core and secondary, 77
  in defining life, 4
  definition of, 77
  proteins in, 92–104, 103–104
  metabolomics, 221
  metaplasia, 191–192
  metastases, 205
  molecular basis of, 206
  metazoans, 145. See also multicellular organisms
Metformin, 243
methane
  reactions of, 60
  renditions of, 56
methylazione, 124
micro-RNAs (miRNA), 111
microarrays, 229–230
microevolution, 30
  in macroevolution, 30–33
mitochondria
  in eukaryotic cells, 126–130
  research on, 138
mitochondrial Eve, 127n.4
mitotic division, 134–135
mixtures, 49
homogeneous, 49–50
model organisms, 230–235
mole, 59–60
molecular activity assays, 223–224
molecular biology
central dogma of, 15, 105, 110
ethics of, 241–251
human subjects in, 249
learning, 1–2
macromolecular structure determination in, 221–223
mass and charge measurements in,
  216–221
of model organisms, 230–235
molecular activity assays in, 223–224
molecular distribution in, 224–225
nucleic acid instrumentation in, 225–230
in pharmaceutical development, 189
social concerns in, 247–249
molecular biotechnology, 215
human life and, 238–239
instrumentation in, 215–230
in medicine, 211–212
regulation and control of, 249–250
research and literature on, 239–240
molecular complex, 91
molecular ecology studies, 246–247
molecular homology, 31–32, 116–117
molecular machine, 91–92
molecular maps, 148–151
molecular medicine, 211–212, 242–245
molecular weight, 55
molecules. See also specific types
  bonds and, 54–58
carbon-containing, 55
categories of, 11–16
chemical properties of, 55–56
chiral, 56
definition of, 52
dissociation of, 58–59
distribution of in time and space, 224–225
electron distribution within, 54–55
forces on, 57–58
hydrophobic, 55
measuring mass and change of, 216–221
polar and nonpolar, 55
reactions of, 58–62
small, 15
visualizations of, 56–57
monocytes, 179
monomers, 11–12
monosaccharides, 65–66
Montague, Read, 88n.7, 185n.1
Morowitz, Harold, 129, 137
morphogen, 148–149
morphogenes, mutations in molecular structure of, 150–151
morphogenetic movement, 155
morphogenic fields, 149–151
morphogenic map, global, 151–152
morphology, 22–23
morula, 153
mouse genome, 235
multicellular group, of same genomes, 142
multicellular organisms
advantages of, 166
cancer in, 205–207
cell motion in, 153–186
cell-to-cell signaling in, 151–153
definition of, 139
development of, 145–159
differentiation in, 156–158
evolution of, 31
growth of, 159–162
homeostasis in, 165–168
humanity and, 162–163
literature on, 163–164
molecular maps of, 148–151
organogenesis in, 138–159
origin of, 139–145
size of, 159–160
Mus musculus model, 235
muscle cells, excitability of, 172
muscle tissue, 169–173
fascicles of, 173
ionic concentration in, 173
muscular dystrophy, genetic defect in, 212
musculoskeletal system, 167–168
mutations, 19
in bacteria, 74
neutral, deleterious, and advantageous, 30
selfish, 144–145
silent, 113
single nucleotide polymorphisms in, 114
in variation, 29–30
mutualism, 39
mutualists, bacterial, 73
myelin, 174
myocardial infarction (MI), 203
myocardium, development of, 158
myofibrils, 173
myosin, 169–172
activation of, 173
NADH, in bacterial energy metabolism, 81
NADPH, 131–133
National Drug Codes, 196n.3
natural killer (NK) cells, 179
natural selection, 20–21
in evolutionary process, 34–40
for multicellularity, 140–142
necrosis, 193
negative feedback loops, 166
Index

Nelkin, Dorothy, 240
nematodes, as model organisms, 233–234
nervous system, 168, 181–185
  information transmission in, 184
nervous tissue, 173–175
neuromuscular junction, 174, 182
neurons, 173–174
  connections among, 183
sensory and motor, 174–175
neurotransmitters, 183–185
  in information transmission, 184
neutrophils, 179
niche, fitness to, 22
nicotinamide adenine dinucleotide (NAD),
  in bacterial energy metabolism, 78–80, 81
Niehoff, Debra, 164
Noble, Denis, 187
nongen molecule, 55
nuclear magnetic resonance spectroscopy (NMR), 221–223
nucleic acid instrumentation, 225–230
nucleic acids, 12–16, 104
nucleolus, 126
nucleotides, 83
  assembling into DNA double helix, 85
  in DNA molecule, 14
lost, 114
structure of, 84
nucleus
  of eukaryotic cell, 119, 124–126
  of human cell, 120
Nusslein-Volhard, Christiane, 164
octet rule, 53
Okazaki fragments, 113
oleic acid, 66
oncogenes, 205–206
Opabinia, 7
  imaginary reconstruction of, 10
open system, 67
operons, 106
orbitals, 53
organ systems, 167–168, 175
  cardiovascular, 175–178
  development and interconnection of, 159
  immune, 178–181
  nervous, 181–185
  pathology of, 190
organelles, of eukaryotic cell, 119
organic chemistry, 62–66
organic molecules
  chemistry of, 62–66
  classes of, 65
organogenesis, 158–159
Orphan Drug Act, U.S., 243–244
osmotic pressure, 76
oxidation-reduction reactions, 62
oxidative phosphorylation, 127–129
oxidative stress, 193
oxidizers, 62
oxidoreductases, 103
oxygen, in chemical reactions, 62
oxygen pollution, mass extinctions and, 45
p53 protein, phosphorylation of, 152
paclitaxel, discovery of, 209
pair-rule genes, 148–149
Paleozoic Era, 44
palmitic acid, 66
pancreas, beta cells of, 166
paralogs, 115
paramecium, specialized organization of, 136–137
parasites, 9
  bacterial, 73
  coevolution of, 39
  freeloading, 141–142
  immunity against, 179–180
parental traits
  averaging of, 23–24
  particulate nature of, 24
  possible combinations of, 26–27
  particular, focus on, 2–3
pathogenesis, 190
pathogens, 190–191
pathology. See also disease
  principles of, 190–194
Pauling, Linus, scale of electronegative of, 54
pax-6 protein, conservation of, 150
peacock tail, in sexual selection, 40
Peichel, Katie, 23n.5
Pennisi, Elizabeth, 11n.10
peptide bond, 92, 93
peptides, antimicrobial, 179
peptidoglycans, 76
peritoneum, formation of, 155
permeability, selective, 75
peroxisome, 133–134
pH, 61–62
  molecular charge and, 218
phages, 178
phagocytes, 179
pharmaceutical small molecules, 196
pharmaceuticals
  discovery and development of, 208–211
  molecular biology in development of, 189
pharmacogenomics, 211
pharmacophore, 209
phenotype, 22
  alleles influencing, 24–25
  mutant, 223–224
  mutations and, 33
phenotypic plasticity, 23
phenylketonuria (PKU), 198–199
Index

pheromone, 135
phosphate, 64
structure of, 84
phosphate bonds, breaking, 70
phosphatidylcholine, structure of, 16
phosphoglucose isomerase, 80
phospholipids, 65
of cell membrane, 75
phosphorylation, 80
photoreceptors, 174
photosynthesis, 82
ATP production in, 140
in eukaryotes, 130
photosystem, type II, 130
physiology, 165
of organ systems, 175–185
piptidase, 103
plants
model organism for biology of, 233
number of species of, 8–9
plasma, 175–176
plasma cells, 181
plasmids, 74n.2
plasticity, 23, 168
phenotypic, 185
plastids, in eukaryotes, 133
platelets, 176
pleiotropy, 33
polar molecule, 55
polygenic traits, in selection, 37
polymerase chain reaction (PCR), 228
denaturing of, 95–96
of eukaryotic cell, 119
function of, 103–104
homologous, 102
identification of, 220–221
kinds of, 11
molecular renderings of, 13
polyubiquitinated, 133
posttranslational modifications (PTMs) of, 99–102
recognition site on, 98
sequence of, 12
structure of, 11–12, 95–102
determining, 221–223
primary, 98–99, 101
quaternary, 99, 101
secondary, 99, 100, 101
tertiary, 99, 101
superfamilies of, 103
voltage-sensitive membrane channel, 174
protein databank (PDB), 223
protein folding problem, 96
protein structure prediction, 96
protein turns, 98–99
proteomic technologies, 220–221
protists, 119
defense systems of, 179
infections by, 201
predatory abilities of, 135–136
sexual reproduction in, 135
proton pump, 78n.4
Provine, William B., 47
psychology, 185
public health measures, 195
punctuated equilibrium hypothesis, 30
purifying selection, 37
pyruvate
in bacterial energy metabolism, 81
in glycolysis, 79, 80
Racaniello, Vincent, 248
radiodurans, 5–6
reactions, 50, 58–62
kinetically unfavorable, 61
in metabolic pathways, 78
rate of, 61
Index

reversible, 60
thermodynamically feasible, 68–69
thermodynamically infeasible, 70
reactive oxygen species (ROS), 192–193
receptor molecules, 146
receptor tyrosine kinases (RTKs), 146
recombination, in adaptive immunity, 180
red blood cells, 176
Red Queen hypothesis, 135n.9
reflexes, 182
regA gene, in cell differentiation, 143–144
replication fork, 112
repressors, 106
reproduction
asexual, 135n.8
in bacteria, 74
speed of, 83
by binary fission, 86
in defining life, 4
as function of living things, 11
inheritance and, 23–28
sexual, 19, 23–24
versus asexual, 135n.8
in eukaryotes, 134–135
research on, 137–138
variation in, 28–34
reproductive isolation, 33–34
reproductive success
definition of, 21
differential, 34
factors influencing, 21–23
reproductive system, 168
respiratory system, 168
restriction enzymes, 178
Retroviruses, RNA information in, 15–16
Rhodes, Gale, 240
ribonucleic acid (RNA), 12–16
double-stranded (dsRNA), 178–179
in eukaryotes, 120–121
in eukaryotic cell nucleus, 124–126
information transcribed to, 15
messenger (mRNA)
in eukaryotic cell nucleus, 124
production of, 106–107
spliced, ends of, 121
noncoding (ncRNA), 111
nucleic acid in, 83
protein synthesis and, 107–111
ribosomal (rRNA), 107
in eukaryotic cell nucleus, 125
sequences of, in protein synthesis, 105–106
small interfering (siRNA), 179
transfer (tRNA), 107–108
types of, 107–108
ribose, 83
structure of, 84
ribosomes, 104, 107, 108–109
enzymes and, 108–110
translational apparatus at, 109
ribozymes, 110
Ridley, Matt, Red Queen hypothesis of, 135n.9, 138
RNA. See ribonucleic acid (RNA)
RNA genes, non-protein-coding, 231–232
RNA-induced silencing complex, 110–111
RNA interference (RNAi), 110–111
RNA polymerase, DNA-directed, 107
RNA polymerase II, 106–107
in transcription, 107
RNA polymerase III, 108
RNA polymerase III, 108
RNA world, 110
Robinson, Richard, 43n.9
saccharides, 65–66
Saccharomyces cerevisiae
meiosis in, 134–135
in molecular biotechnology, 232–233
Sanger, Frederick, 225–226
Sanger sequencing gel, 227
SDS-PAGE, 216–218
Sears, Cynthia, 73n.1
selection
balancing or diversifying, 37
directional or purifying, 37
in evolutionary process, 34–40
fitness in, 37–39
mass extinctions and, 45
sexual, 39–41
selex, 237–238
selfish DNA phenomenon, 116
selfish genes, 142
selfish mutants, 144–145
senescence, 206–207
sense organs, 182
sensory signals, transforming into motor activity, 182–183
septic shock, 200
septicemia, 200
serine, 93, 94t
serine proteases, 197
sex, evolution of, 138
sexual reproduction. See reproduction, sexual
sexual selection, 39–41
SH2/SH3 domains, 146
shotgun sequencing, 226–227
signal transduction pathways, 146–148
single nucleotide polymorphisms (SNPs), 113–114
in homologous genes, 116
size, evolution of, 160
skeletal muscle, 172–173
cells of, 174
SMADs, 160
Index

Smith, John Maynard, 140n.1
smooth muscle, 172–173
Snyder Sachs, Jessica, 89
social insects, group selection and, 140
social issues, molecular biology in, 246–249
solute, 49
solutions, 49
acid and base, 61–62
aqueous, 50
dissociation of, 59
molarity of, 61
solvation effect, 59
solvent, 49–50
soma, 139
somatic cell nuclear transfer, 245
somatic cells
differentiation of, 139–140
in photosynthesis, 140
sonic hedgehog, 151–152
Southern, Edward, 218
Southern blot, 218
species
fluctuating number of, 45
increasing numbers of in Cambrian
Explosion, 46
names of, 9–10
new classes of, 46
number of, 7–9
potentially interbreeding, 7–8
Spencer, Herbert, 21
sperm, 23
creation of, 28–29
mitochondria and, 127n.4
spinal cord, 182
spliceosome, 120–121
sports doping controversies, 248–249
squamous epithelium, 169, 170
staining techniques, 224–225
starches, 66
StarLink transgene, 245–246
statolith, 133
stearic acid, 66
stem cells, 157
hematopoietic, 157
research on, 244–245
totipotent and pluripotent, 157
unipotent, 157
steroids, in heart disease, 204
sticklebacks, small genetic changes in, 32–33
stoichiometry, 59
stonefly, skimming speed of, 32
stop codons, 105
stromatolites, fossils of, 43
structure, function and, 2
substrates, enzymes and, 78
sucrose, 66
sweat glands, stratified cuboidal epithelium of, 170
synapse, in information transmission, 184
*Synechococcus elongates*, 74
DNA of, 84
proteins in, 11
synthetic lethality experiment, 224
system
heat content of, 67
transition state in, 68–69
systems biology, 165, 186–187
Szathmáry, Eörs, 140n.1

T-cells, 180–181
in apoptosis, 194
cytotoxic, 181
helper, 181
tandem mass spec, 220–221
taxa, definition of, 8
TCA (tricarboxylic acid) cycle
backwards, 129
in eukaryotic mitochondria, 127–130
telomerases, 124
termination factors, 110
terpenes, 133
therapeutics, principles of, 194–196
thermodynamics, 67–70
definition of, 66
first law of, 67
second law of, 68
as a system, 67
thrombocytes, 176
thromboxane, activation of, 203
thrombus formation, 203
thylakoids, 130
thymine
in DNA structure, 107
structure of, 84
Timberlake, Karen, 71
tissue plasminogen activator, recombinant (r-TPA), 203
tissues
growth of, 175
growth rates of, 162
organization of, 168–175
topoisomerases, 111–112, 124
tortoise
lifespan of, 6–7
of Mohave Desert, 9
traits, 19
fixed, 21
monogenic, 27
polygenic, 27
transamination, 130
transcript processing pathway, eukaryotic, 122, 123
transcription
of eukaryotic genes, 120–124
eukaryotic regulation mechanisms of, 121
mRNA in, 107
transcription factor binding sites (TFBS), 114
  evolution of, 150–151
transcription factors, 106
  activation of, 185
  enhancer and repressor, 121
Hox-based position-specific, 158
transcriptional control, 105–106
transcripts, 107
transferases, 103
transforming growth factor beta (TGF-β), superfamily of, 160
transgenics, 236–237
transposon, 116
trastuzumab (Herceptin), 207
triglyceride, 65
tryptophan, 93, 94t
tumor necrosis factor (TNF), 194
tumor suppressor genes, 205–206
tumors, 205

ubiquitin, 133
ultracentrifuge, 216
uracil, 83
  in RNA structure, 107
urinary system, 168

vacuoles, 137
valence, 53
Van der Waals force, 58
variation
  in evolutionary process, 28–34
  factors in, 20–21
  source of, 19
vasculature, growth and development of, 159
vasoconstriction, 176
vasodilation, 176
Veatch, Robert, 251
veins, 176
vertebrates
  backbone development in, 149
  growth in, 161–162
  immune system of, 178–180
viruses, 9
  antibiotics for, 200–201
RNA, 113n.11
visual cortex, 183
volcanism, global temperature and, 45–46
voltage-gated protein, 173
Volvocales, multicellular development of, 142–145
Volvox, cell differentiation in, 154

Wade, Nicholas, 47
water, formation of, 59–60
Watson, James, 117
Weinberg, Wilhelm, 34–35
wild type phenotype, 223–224

wound healing, stages of, 196–198
Wright, Sewall, fitness landscape concept of, 37–39
X-ray crystallography, 221–223
yeast two-hybrids, 224
yeasts
  as model organisms, 232–233
  pheromone receptors, 135
Z-scheme, 130
zebrafish, 234
zygote, 24–25