

Contents

<i>Introduction to the second edition</i>	xi
<i>Acknowledgements</i>	xiii
<i>About the companion website</i>	xv
Chapter 1 The basic principles of photosynthetic energy storage	1
1.1 What is photosynthesis?	1
1.2 Photosynthesis is a solar energy storage process	2
1.3 Where photosynthesis takes place	4
1.4 The four phases of energy storage in photosynthesis	5
References	9
Chapter 2 Photosynthetic organisms and organelles	11
2.1 Introduction	11
2.2 Classification of life	12
2.3 Prokaryotes and eukaryotes	14
2.4 Metabolic patterns among living things	15
2.5 Phototrophic prokaryotes	15
2.6 Photosynthetic eukaryotes	21
References	24
Chapter 3 History and early development of photosynthesis	27
3.1 Van Helmont and the willow tree	27
3.2 Carl Scheele, Joseph Priestley, and the discovery of oxygen	27
3.3 Ingenhousz and the role of light in photosynthesis	28
3.4 Senebier and the role of carbon dioxide	29
3.5 De Saussure and the participation of water	29
3.6 The equation of photosynthesis	29
3.7 Early mechanistic ideas of photosynthesis	30
3.8 The Emerson and Arnold experiments	32
3.9 The controversy over the quantum requirement of photosynthesis	34
3.10 The red drop and the Emerson enhancement effect	35
3.11 Antagonistic effects	36
3.12 Early formulations of the Z scheme for photosynthesis	37
3.13 ATP formation	38
3.14 Carbon fixation	38
References	38

Chapter 4	Photosynthetic pigments: structure and spectroscopy	41
4.1	Chemical structures and distribution of chlorophylls and bacteriochlorophylls	41
4.2	Pheophytins and bacteriopheophytins	47
4.3	Chlorophyll biosynthesis	47
4.4	Spectroscopic properties of chlorophylls	50
4.5	Carotenoids	54
4.6	Bilins	57
	References	58
Chapter 5	Antenna complexes and energy transfer processes	59
5.1	General concepts of antennas and a bit of history	59
5.2	Why antennas?	60
5.3	Classes of antennas	62
5.4	Physical principles of antenna function	63
5.5	Structure and function of selected antenna complexes	71
5.6	Regulation of antennas	82
	References	84
Chapter 6	Reaction centers and electron transport pathways in anoxygenic phototrophs	89
6.1	Basic principles of reaction center structure and function	90
6.2	Development of the reaction center concept	90
6.3	Purple bacterial reaction centers	91
6.4	Theoretical analysis of biological electron transfer reactions	96
6.5	Quinone reductions, role of the Fe and pathways of proton uptake	98
6.6	Organization of electron transfer pathways	101
6.7	Completing the cycle – the cytochrome <i>bc₁</i> complex	103
6.8	Membrane organization in purple bacteria	107
6.9	Electron transport in other anoxygenic phototrophic bacteria	108
	References	109
Chapter 7	Reaction centers and electron transfer pathways in oxygenic photosynthetic organisms	111
7.1	Spatial distribution of electron transport components in thylakoids of oxygenic photosynthetic organisms	111
7.2	Noncyclic electron flow in oxygenic organisms	113
7.3	Photosystem II structure and electron transfer pathway	113
7.4	Photosystem II forms a dimeric supercomplex in the thylakoid membrane	114
7.5	The oxygen-evolving complex and the mechanism of water oxidation by Photosystem II	116
7.6	The structure and function of the cytochrome <i>b₆f</i> complex	120
7.7	Plastocyanin donates electrons to Photosystem I	122
7.8	Photosystem I structure and electron transfer pathway	123
7.9	Ferredoxin and ferredoxin-NADP reductase complete the noncyclic electron transport chain	126
	References	129

Chapter 8	Chemiosmotic coupling and ATP synthesis	133
8.1	Chemical aspects of ATP and the phosphoanhydride bonds	133
8.2	Historical perspective on ATP synthesis	135
8.3	Quantitative formulation of proton motive force	137
8.4	Nomenclature and cellular location of ATP synthase	138
8.5	Structure of ATP synthase	138
8.6	The mechanism of chemiosmotic coupling	141
	References	143
Chapter 9	Carbon metabolism	147
9.1	The Calvin-Benson cycle is the primary photosynthetic carbon fixation pathway	147
9.2	Photorespiration is a wasteful competitive process to carboxylation	160
9.3	The C4 carbon cycle minimizes photorespiration	163
9.4	Crassulacean acid metabolism avoids water loss in plants	166
9.5	Algae and cyanobacteria actively concentrate CO ₂	168
9.6	Sucrose and starch synthesis	169
9.7	Other carbon fixation pathways in anoxygenic phototrophs	173
	References	173
Chapter 10	Genetics, assembly, and regulation of photosynthetic systems	177
10.1	Gene organization in anoxygenic photosynthetic bacteria	177
10.2	Gene expression and regulation of purple photosynthetic bacteria	179
10.3	Gene organization in cyanobacteria	180
10.4	Chloroplast genomes	181
10.5	Pathways and mechanisms of protein import and targeting in chloroplasts	182
10.6	Gene regulation and the assembly of photosynthetic complexes in cyanobacteria and chloroplasts	186
10.7	The regulation of oligomeric protein stoichiometry	188
	References	189
Chapter 11	The use of chlorophyll fluorescence to probe photosynthesis	193
11.1	The time course of chlorophyll fluorescence	194
11.2	The use of fluorescence to determine the quantum yield of Photosystem II	195
11.3	Fluorescence detection of nonphotochemical quenching	196
11.4	The physical basis of variable fluorescence	197
	References	197
Chapter 12	Origin and evolution of photosynthesis	199
12.1	Introduction	199
12.2	Early history of the Earth	199
12.3	Origin and early evolution of life	200
12.4	Geological evidence for life and photosynthesis	202
12.5	The nature of the earliest photosynthetic systems	206

12.6	The origin and evolution of metabolic pathways with special reference to chlorophyll biosynthesis	207
12.7	Evolutionary relationships among reaction centers and other electron transport components	212
12.8	Do all photosynthetic reaction centers derive from a common ancestor?	214
12.9	The origin of linked photosystems and oxygen evolution	215
12.10	Origin of the oxygen-evolving complex and the transition to oxygenic photosynthesis	218
12.11	Antenna systems have multiple evolutionary origins	221
12.12	Endosymbiosis and the origin of chloroplasts	223
12.13	Most types of algae are the result of secondary endosymbiosis	226
12.14	Following endosymbiosis, many genes were transferred to the nucleus, and proteins were reimported to the chloroplast	226
12.15	Evolution of carbon metabolism pathways	229
	References	230
Chapter 13	Bioenergy applications and artificial photosynthesis	237
13.1	Introduction	237
13.2	Solar energy conversion	237
13.3	What is the efficiency of natural photosynthesis?	239
13.4	Calculation of the energy storage efficiency of oxygenic photosynthesis	241
13.5	Why is the efficiency of photosynthesis so low?	241
13.6	How might the efficiency of photosynthesis be improved?	242
13.7	Artificial photosynthesis	243
	References	247
	<i>Appendix: Light, energy, and kinetics</i>	249
	<i>Index</i>	287