

# Contents

## I. Introduction

M. GIBBS and E. LATZKO (With 1 Figure) . . . . .	1
--	---

## II. CO<sub>2</sub> Assimilation

### II A. The Reductive Pentose Phosphate Cycle

#### 1. The Reductive Pentose Phosphate Cycle and Its Regulation

J.A. BASSHAM (With 1 Figure)

A. Introduction . . . . .	9
B. The Reductive Pentose Phosphate Cycle . . . . .	12
I. The Cyclic Path of Carbon Dioxide Fixation and Reduction . . . . .	12
II. Individual Reactions of the RPP Cycle . . . . .	12
III. Stoichiometry and Energetics . . . . .	14
C. Utilization of the Products of the RPP Cycle . . . . .	15
I. Starch Synthesis . . . . .	15
II. Triose Phosphate Export . . . . .	16
III. Glycolate Formation . . . . .	17
D. Mapping the RPP Cycle . . . . .	17
I. Early History . . . . .	17
II. First Products of CO <sub>2</sub> Fixation . . . . .	18
III. Sugar Phosphates . . . . .	18
IV. Studies of Light-Dark and High-Low CO <sub>2</sub> Transients . . . . .	19
V. Discovery of Enzymes of the RPP Cycle . . . . .	20
E. Metabolic Regulation of the RPP Cycle . . . . .	21
I. In Vivo Kinetic Steady-State Studies with Labeled Substrates . . . . .	21
II. Light-Dark Regulation . . . . .	21
III. Regulation of the RPP Cycle During Photosynthesis . . . . .	27
F. Concluding Remarks . . . . .	28
References . . . . .	28

#### 2. The Isolation of Intact Leaf Cells, Protoplasts and Chloroplasts

R.G. JENSEN

A. Introduction . . . . .	31
B. Isolation of Plant Leaf Cells and Protoplasts . . . . .	32
I. Mechanical Methods . . . . .	32
II. Enzymic Methods . . . . .	32
III. Cell and Protoplast Isolation from C <sub>3</sub> and C <sub>4</sub> Grasses . . . . .	33
C. Isolation of Intact Chloroplasts . . . . .	35
I. Plant Material and Media . . . . .	35
II. Isolation Methods . . . . .	36
III. Chloroplast Isolation from Other Plants . . . . .	38
References . . . . .	39

**3. Studies with the Reconstituted Chloroplast System****R.MCC. LILLEY and D.A. WALKER (With 1 Figure)**

A. Reconstituted Chloroplast Systems . . . . .	41
I. Introduction . . . . .	41
II. Definition . . . . .	42
III. Methods of Preparation . . . . .	43
IV. Activities Achieved . . . . .	43
V. Advantages and Drawbacks. . . . .	44
B. Factors Affecting the Activity of Partial Reaction Sequences in Reconstituted Chloroplast Systems. . . . .	44
I. The Light Reactions . . . . .	44
II. The Conversion of 3-Phosphoglycerate to Triose Phosphate . . . . .	46
III. The Conversion of Triose Phosphate to Pentose Phosphate . . . . .	48
IV. The Conversion of Ribulose-5-Phosphate to Ribulose-1, 5-Bisphosphate . . . . .	49
V. The Fixation of Carbon Dioxide . . . . .	49
VI. Autocatalysis . . . . .	50
C. Reconstituted Chloroplast Systems and the Regulation of Photosynthesis . . . . .	51
I. The Role of Magnesium, pH and Reductants . . . . .	51
II. The Role of the ATP/ADP Ratio . . . . .	52
References . . . . .	52

**4. Autotrophic Carbon Dioxide Assimilation in Prokaryotic Microorganisms****E. OHMANN (With 1 Figure)**

A. Introduction . . . . .	54
B. Principles of Autotrophic Carbon Dioxide Assimilation in Prokaryotic Cells . . . . .	55
C. The Pathway of Carbon Dioxide Assimilation in Green Sulfur Bacteria . . . . .	56
D. The Pathway of Carbon Dioxide Assimilation in Purple Bacteria . . . . .	58
E. The Pathway of Carbon Dioxide Assimilation in Blue-Green Algae . . . . .	59
F. The Pathway of Carbon Dioxide Assimilation in Chemolithotrophic Bacteria . . . . .	60
G. Regulatory Aspects of Carbon Dioxide Assimilation in Prokaryotic Microorganisms. . . . .	61
References . . . . .	65

**5. Light-Enhanced Dark CO<sub>2</sub> Fixation****S. MIYACHI (With 5 Figures)**

A. Light-Enhanced Dark CO <sub>2</sub> Fixation in C <sub>3</sub> Plants . . . . .	68
I. Introduction . . . . .	68
II. Capacity for Light-Enhanced Dark CO <sub>2</sub> Fixation . . . . .	68
III. Products . . . . .	69
IV. RuBP, NADPH, and ATP Levels . . . . .	70
V. Fate of PGA . . . . .	72
VI. Higher Plants . . . . .	73
B. Light-Enhanced Dark CO <sub>2</sub> Fixation in C <sub>4</sub> Plants . . . . .	73
References . . . . .	75

**II B. The C<sub>4</sub> and Crassulacean Acid Metabolism Pathways****6. The C<sub>4</sub> Pathway and Its Regulation****T.B. RAY and C.C. BLACK (With 4 Figures)**

A. Discovery of C <sub>4</sub> Photosynthesis . . . . .	77
B. Kranz Leaf Anatomy . . . . .	78
I. Variations in Leaf Anatomy . . . . .	79

C. Environmental Regulation of C <sub>4</sub> Photosynthesis . . . . .	81
I. Light Intensity . . . . .	82
II. CO <sub>2</sub> Concentration . . . . .	82
III. O <sub>2</sub> Concentration . . . . .	83
IV. Temperature . . . . .	83
V. Water . . . . .	83
VI. Salinity . . . . .	84
VII. Nitrogen Supply . . . . .	84
D. Biochemical Schemes for the C <sub>4</sub> Pathway . . . . .	84
E. Regulation via Enzymatic and Metabolic Compartmentation into Leaf Cell Types . . . . .	86
F. Efficiency of C <sub>4</sub> Leaf Photosynthesis . . . . .	89
I. CO <sub>2</sub> Pools . . . . .	89
II. CO <sub>2</sub> Trapping . . . . .	89
III. CO <sub>2</sub> Fixation by Bundle Sheath Cells . . . . .	90
G. C <sub>3</sub> -C <sub>4</sub> Intermediate Plants . . . . .	92
H. Criteria for the Presence of C <sub>4</sub> Photosynthesis . . . . .	95
I. Conclusions in the Regulation of C <sub>4</sub> Photosynthesis in Leaves . . . . .	97
References . . . . .	98

## 7. C<sub>4</sub> Metabolism in Isolated Cells and Protoplasts

**G.E. EDWARDS and S.C. HUBER (With 1 Figure)**

A. Introduction . . . . .	102
B. Three Groups of C <sub>4</sub> Plants . . . . .	102
C. Localization of Enzymes of C <sub>4</sub> Metabolism in C <sub>4</sub> Plants . . . . .	102
I. Intercellular Localization . . . . .	102
II. Intracellular Localization . . . . .	103
D. Criteria for Intactness of Cellular Preparations . . . . .	104
I. Mesophyll Preparations . . . . .	104
II. Bundle Sheath Preparations . . . . .	104
E. Variations in C <sub>4</sub> Metabolism . . . . .	106
I. Mesophyll Cells of C <sub>4</sub> Plants . . . . .	106
II. Bundle Sheath Cells of C <sub>4</sub> Plants . . . . .	107
F. Energetics in C <sub>4</sub> Metabolism . . . . .	108
G. Future Studies on C <sub>4</sub> Metabolism with Cells and Protoplasts . . . . .	109
I. Transport Studies . . . . .	109
II. Screening for Inhibitors of C <sub>4</sub> Photosynthesis . . . . .	110
References . . . . .	111

## 8. The Flow of Carbon in Crassulacean Acid Metabolism (CAM)

**M. KLUGE (With 4 Figures)**

A. Introduction . . . . .	113
B. Basic Phenomena of CAM . . . . .	113
C. The Metabolic Sequences of CAM . . . . .	114
I. The Flow of Carbon During the Night . . . . .	115
II. The Flow of Carbon During the Day . . . . .	118
D. Regulation of Carbon Flow in CAM . . . . .	122
E. Conclusions . . . . .	123
References . . . . .	124

## 9. CAM: Rhythms of Enzyme Capacity and Activity as Adaptive Mechanisms

**O. QUEIROZ (With 9 Figures)**

A. Introduction . . . . .	126
B. Endogenous Versus Nonendogenous Rhythms: A Necessary Distinction . . . . .	126

C. Enzyme Capacity and Enzyme Activity: Two Distinct Levels of Control . . . . .	127
D. Rhythms Connected with CAM . . . . .	128
I. Components of the Malate Rhythm . . . . .	128
II. CO <sub>2</sub> Uptake and CO <sub>2</sub> Output . . . . .	128
III. PEP Carboxylase . . . . .	129
IV. Malate Dehydrogenase . . . . .	132
V. Malic Enzyme (NADP) . . . . .	132
VI. Aspartate Aminotransferase . . . . .	133
VII. Enzymes of the Glycolytic Pathway . . . . .	133
VIII. Tricarboxylic Acid Cycle . . . . .	133
E. Working Hypothesis and Models . . . . .	133
I. Seasonal Adaptation . . . . .	133
II. Timing CAM . . . . .	135
References . . . . .	137

## 10. $\delta^{13}\text{C}$ as an Indicator of Carboxylation Reactions

**J.H. TROUGHTON**

A. Introduction . . . . .	140
B. Carbon Isotope Fractionation and Its Measurement . . . . .	140
C. Variation in $\delta^{13}\text{C}$ Values Between Plants . . . . .	141
I. Discrimination Caused by the Photosynthetic Pathway . . . . .	141
II. Variation in $\delta^{13}\text{C}$ Values Between Plant Varieties and Species . . . . .	141
III. Variation in $\delta^{13}\text{C}$ Values Within a Plant . . . . .	142
IV. Fractionation Associated with Carboxylation Enzymes . . . . .	142
V. Compartmental Organisation and Isotope Fractionation . . . . .	143
VI. Respiration . . . . .	144
D. Environmental Effects on the $\delta^{13}\text{C}$ Value of Plants . . . . .	144
I. Temperature . . . . .	144
II. Carbon Dioxide Concentration . . . . .	144
III. Oxygen Concentration Effects on Discrimination . . . . .	145
IV. Light Level . . . . .	145
V. Availability of Water . . . . .	145
VI. Salinity and Carbon Isotope Fractionation . . . . .	146
E. Implications of Variation in $\delta^{13}\text{C}$ Values Among Plant Species . . . . .	146
I. Natural Products . . . . .	146
II. Paleoecology . . . . .	146
III. Physiology – Plant, Animal, and Human . . . . .	147
F. Conclusions . . . . .	147
References . . . . .	147

## II C. Factors Influencing CO<sub>2</sub> Assimilation

### 11. Interactions Between Photosynthesis and Respiration in Higher Plants

**D. GRAHAM and E.A. CHAPMAN (With 2 Figures)**

A. Introduction . . . . .	150
I. The Relevance of Photosynthetic and Respiratory Interactions . . . . .	150
B. Physiological Observations . . . . .	151
I. Plants with C <sub>3</sub> -Type Photosynthesis . . . . .	151
II. Plants with C <sub>4</sub> -Type Photosynthesis . . . . .	153
C. Biochemical Observations . . . . .	153
I. Plants with C <sub>3</sub> -Type Photosynthesis . . . . .	153
II. Plants with C <sub>4</sub> -Type Photosynthesis . . . . .	159
D. General Conclusions . . . . .	160
References . . . . .	160

**12. The Interaction of Respiration and Photosynthesis in Microalgae****E.H. EVANS and N.G. CARR (With 2 Figures)**

A. Introduction . . . . .	163
B. The Kok Effect . . . . .	163
C. Electron Transport Mechanisms for the Kok Effect . . . . .	164
I. General Considerations . . . . .	164
II. Prokaryotes . . . . .	166
III. Eukaryotes . . . . .	167
D. The Interaction of Oxygen with the Photosynthetic Electron Transport Chain . . . . .	167
E. Metabolically Mediated Control of Oxygen Uptake . . . . .	169
F. Synopsis . . . . .	171
References . . . . .	171

**13. Effect of Light Quality on Carbon Metabolism****N.P. VOSKRESENSKAYA**

A. Introduction . . . . .	174
B. Principal Effects of Blue and Red Light on Carbon Metabolism . . . . .	174
C. Specific Features of Blue Light Action on Carbon Metabolism . . . . .	175
I. In the Absence of Photosynthesis . . . . .	175
II. In the Presence of Photosynthesis . . . . .	176
D. Direct Regulation of Certain Enzymes by Blue Light in Vitro and Its Possible Realization in Vivo . . . . .	176
E. Long-Term Effects of Light Quality on Biosyntheses and Chloroplast Organization . . . . .	177
F. Conclusion . . . . .	179
References . . . . .	179

**14. Photoassimilation of Organic Compounds****W. WIESSNER**

A. Introduction . . . . .	181
B. Definitions . . . . .	181
C. Pathways and Products of Photometabolism . . . . .	182
D. Photoassimilation of Acetate . . . . .	183
E. Photoassimilation of Glucose . . . . .	186
References . . . . .	187

**15. Biochemical Basis of Ecological Adaptation****A. SHOMER-ILAN, S. BEER and Y. WAISEL**

A. Introduction . . . . .	190
B. Biochemical Variations in C <sub>3</sub> Plants . . . . .	191
C. Biochemical Adaptation of CAM and C <sub>4</sub> Plants . . . . .	192
I. Adaptive Value of C <sub>4</sub> Metabolism . . . . .	194
D. Induced Variations in Carbon Fixation Pathways . . . . .	196
I. Effects of Age, CO <sub>2</sub> -Concentration, and Nitrogen Nutrition . . . . .	196
II. Effect of NaCl . . . . .	197
E. Concluding Remark . . . . .	199
References . . . . .	199

## II D. Regulation and Properties of Enzymes of Photosynthetic Carbon Metabolism

### 16. Light-Dependent Changes of Stromal $H^+$ and $Mg^{2+}$ Concentrations Controlling $CO_2$ Fixation H.W. HELDT (With 1 Figure)

A. Background . . . . .	202
B. Measurement of the pH in the Stroma and the Thylakoid Space of Intact Spinach Chloroplasts . . . . .	202
C. pH Dependence of $CO_2$ -Fixation . . . . .	203
D. Measurement of the Stromal $Mg^{2+}$ Concentration in Intact Spinach Chloroplasts . . . . .	204
E. $Mg^{2+}$ Dependence of $CO_2$ Fixation . . . . .	205
F. Concluding Remarks . . . . .	206
References . . . . .	206

### 17. Ribulose-1,5-Bisphosphate Carboxylase

T. AKAZAWA (With 6 Figures)

A. Fraction-1-Protein and RuBP Carboxylase . . . . .	208
B. Molecular Structure of RuBP Carboxylase . . . . .	210
C. Reaction Mechanism and Regulation . . . . .	214
D. RuBP Oxygenase . . . . .	219
E. Biosynthesis of RuBP Carboxylase . . . . .	222
References . . . . .	225

### 18. Carbonic Anhydrase

R.P. POINCELOT

A. Introduction . . . . .	230
B. Characterization . . . . .	230
I. Histochemical and Other Detection . . . . .	230
II. Occurrence . . . . .	230
III. Location . . . . .	231
IV. Levels of Activity . . . . .	231
V. Isolation and Purification . . . . .	232
VI. Enzymic Parameters . . . . .	232
C. Function . . . . .	236
I. Chloroplast Envelope Membrane Permease . . . . .	236
II. Carbonic Anhydrase – RuBP Carboxylase Complex . . . . .	236
III. Proton Source, Buffering Capacity and Ionic Flux Regulation . . . . .	237
References . . . . .	237

### 19. Enzymes of the Reductive Pentose Phosphate Cycle

E. LATZKO and G.J. KELLY (With 1 Figure)

A. Introduction . . . . .	239
B. Characteristics of Regulatory Enzymes . . . . .	239
C. Activities and Location of Calvin Cycle Enzymes . . . . .	240
D. Glycerate-3-P Kinase . . . . .	241
E. Glyceraldehyde-3-P Dehydrogenase . . . . .	241
F. Triose-P Isomerase and Aldolase . . . . .	245
G. Fructosebisphosphatase and Sedoheptulosebisphosphatase . . . . .	246
H. Transketolase, Pentose-P Epimerase, and Pentose-P Isomerase . . . . .	247
I. Ribulose-5-P Kinase . . . . .	247
J. Concluding Remarks . . . . .	248
References . . . . .	249

**20. Enzymes of C<sub>4</sub> Metabolism****J. COOMBS (With 2 Figures)**

A. Introduction . . . . .	251
B. Isolation of Enzymes from Tissues of C <sub>4</sub> Plants . . . . .	252
C. Carboxylation – PEP Carboxylase . . . . .	252
I. General Characteristics . . . . .	252
II. Physical Properties and Kinetics . . . . .	253
III. Regulation, Activation and Inhibition . . . . .	254
D. Formation of C <sub>4</sub> Acids by Reduction and Transamination . . . . .	255
I. Reduction . . . . .	255
II. Transamination . . . . .	257
E. Decarboxylation . . . . .	258
I. NADP-Malic Enzyme (E.C.1.1.1.40) . . . . .	258
II. NAD-Malic Enzyme (E.C.1.1.1.39) . . . . .	258
III. PEP Carboxykinase (E.C.4.1.1.49) . . . . .	259
F. Substrate Regeneration . . . . .	259
I. Pyruvate P <sub>i</sub> Dikinase (E.C.2.7.9.1) . . . . .	260
II. Alanine Aminotransferase (E.C.2.6.1.2) . . . . .	260
G. Summary . . . . .	261
References . . . . .	261

**21. Enzymes of Crassulacean Acid Metabolism****P. DITTRICH**

A. Introduction . . . . .	263
B. Enzymes of Starch Metabolism . . . . .	263
C. Glycolytic Enzymes . . . . .	264
D. Gluconeogenic Enzymes . . . . .	265
E. Carboxylating Enzymes . . . . .	265
I. The Formation of Malate . . . . .	265
II. The Photosynthetic Fixation of CO <sub>2</sub> . . . . .	267
F. Decarboxylating Enzymes . . . . .	267
I. The Decarboxylation of Malate . . . . .	267
II. The Decarboxylation of Oxaloacetate . . . . .	268
G. Respiratory Enzymes . . . . .	269
H. Conclusion . . . . .	269
References . . . . .	270

**22. Interaction Between Photochemistry and Activity of Enzymes****L.E. ANDERSON (With 4 Figures)**

A. Introduction . . . . .	271
B. Light-Mediated Modulation . . . . .	271
I. Occurrence . . . . .	271
II. Metabolic Significance . . . . .	271
III. Mechanism . . . . .	272
IV. Special Cases . . . . .	278
C. Dark Modulation . . . . .	278
D. Thylakoid-Generated Effectors . . . . .	279
I. pH . . . . .	279
II. Mg <sup>2+</sup> . . . . .	279
III. Energy Charge . . . . .	279
E. Conclusion . . . . .	280
References . . . . .	280

## II E. Metabolism of Primary Products of Photosynthesis

### 23. Metabolism of Starch in Leaves

J. PREISS and C. LEVI (With 2 Figures)

A. Introduction . . . . .	282
B. Starch Biosynthesis . . . . .	282
I. Reactions Involved in Starch Biosynthesis . . . . .	282
II. The Predominant Pathway of Starch Synthesis . . . . .	283
III. Regulation of Starch Biosynthesis . . . . .	285
IV. Properties of the ADPglucose: 1,4- $\alpha$ -D-glucan 4- $\alpha$ Glucosyltransferase . . . . .	293
V. $\alpha$ -1,4-Glucan: $\alpha$ -1,4-Glucan 6-Glycosyl Transferase (Branching or Q Enzyme) . . . . .	296
VI. Remaining Problems in Starch Synthesis . . . . .	298
C. Starch Degradation . . . . .	299
I. Reactions Involved in Starch Degradation . . . . .	299
II. Degradation of Intact Granules in Vitro . . . . .	304
III. Starch Degradation in Vivo: Germinating Seeds . . . . .	304
IV. Starch Degradation in Vivo: Leaves . . . . .	304
References . . . . .	308

### 24. The Enzymology of Sucrose Synthesis in Leaves

C.P. WHITTINGHAM, A.J. KEYS, and I.F. BIRD

A. Introduction . . . . .	313
B. Physiological Relationships of Sucrose in Leaves . . . . .	314
C. Enzymology . . . . .	315
I. Sucrose Phosphate Synthetase E.C.2.4.1.14 and Sucrose Synthetase E.C.2.4.1.13 . . . . .	315
II. Sucrose Phosphatase (E.C.3.1.3.24) . . . . .	317
III. UDPglucose Pyrophosphorylase (E.C.2.7.7.9) . . . . .	317
IV. Sucrose Phosphorylase (E.C.2.4.1.7) . . . . .	318
V. Invertase (E.C.3.2.1.26) . . . . .	318
VI. Enzyme Control Mechanisms . . . . .	318
D. Intracellular and Intercellular Site of Sucrose Synthesis in Leaves . . . . .	320
I. Chloroplast or Cytoplasm? . . . . .	320
II. Intercellular Localization of Sucrose Synthesis in C <sub>4</sub> Plants . . . . .	321
III. Intercellular Distribution Between Cells Containing Chlorophyll and Vascular Tissue . . . . .	322
References . . . . .	323

## II F. Glycolic Acid and Photorespiration

### 25. Glycolate Synthesis

E. BECK

A. Introduction: Glycolate Formation, Photorespiration and the Warburg Effect . . . . .	327
B. Environmental Factors Affecting Glycolate Synthesis . . . . .	327
C. Mechanisms of Glycolate Formation . . . . .	328
I. Reductive Glycolate Formation . . . . .	328
II. Oxidative Glycolate Synthesis . . . . .	329
D. Photosynthetic Glycolate Formation in Vivo; Which Reaction Predominates? . . . . .	332
I. Glycolate Synthesis by C <sub>3</sub> Plants . . . . .	332
II. Glycolate Formation by C <sub>4</sub> Plants . . . . .	335
E. Conclusion: The Inhibition of Glycolate Formation by Some Common Metabolites - an Open Question . . . . .	335
References . . . . .	335



**26. Glycolate Metabolism by Higher Plants and Algae**

**N.E. TOLBERT (With 1 Figure)**

A. Introduction . . . . .	338
B. Glycolate Biosynthesis . . . . .	340
I. Properties of Ribulose- $P_2$ Carboxylase/Oxygenase for Phosphoglycolate Biosynthesis . . . . .	340
II. Phosphoglycolate Phosphatase and Phosphoglycerate Phosphatase . . . . .	340
C. Glycolate Pathway . . . . .	342
I. Pathways in Peroxisomes . . . . .	342
II. Mitochondrial Interconversion of Glycine and Serine . . . . .	343
D. $O_2$ and $CO_2$ Exchange and Energy Balance . . . . .	344
I. Sites of $O_2$ Uptake and $CO_2$ Release in the Glycolate Pathway . . . . .	344
II. $O_2$ Uptake During Photosynthesis . . . . .	345
III. Energy Balance . . . . .	346
E. Leaf Peroxisomal Membrane and Transport . . . . .	346
F. Glycerate and Sucrose from Glycolate . . . . .	347
G. The Glycolate Pathway in Algae . . . . .	348
I. Introduction . . . . .	348
II. Glycolate Excretion . . . . .	348
III. Glycolate Dehydrogenase . . . . .	349
IV. Glycerate-Serine Pathway in Algae . . . . .	351
References . . . . .	351

**27. Photorespiration: Studies with Whole Tissues**

**I. ZELITCH (With 2 Figures)**

A. Discovery of Photorespiration . . . . .	353
B. Assays of Photorespiration in Leaves . . . . .	354
I. Post-Illumination $CO_2$ Outburst . . . . .	354
II. Inhibition of Net $CO_2$ Assimilation by Oxygen . . . . .	354
III. $CO_2$ and $^{14}CO_2$ Efflux in $CO_2$ -Free Air . . . . .	356
IV. Short-Time Uptake of $^{14}CO_2$ and $^{12}CO_2$ . . . . .	357
V. The Magnitude of Photorespiration in Leaves . . . . .	358
C. Photorespiration in Algae and Submerged Aquatic Plants . . . . .	358
D. Photorespiration in Callus, Isolated Plant Cells, and Protoplasts . . . . .	359
E. The Control of Photorespiration . . . . .	361
I. The Energetics and Possible Origins of Photorespiration . . . . .	361
II. Biochemical Inhibition of Glycolate Oxidation . . . . .	362
III. Biochemical Inhibition of Glycolate Synthesis . . . . .	363
IV. The Metabolic Regulation of Photorespiration . . . . .	364
References . . . . .	365

**28. Photorespiration: Comparison Between  $C_3$  and  $C_4$  Plants**

**D.T. CANVIN (With 12 Figures)**

A. Introduction . . . . .	368
B. Terminology and Perception . . . . .	368
C. Measurement of Photorespiration . . . . .	370
D. Characteristics of Photorespiration in $C_3$ Plants . . . . .	371
I. Rates of Photorespiration . . . . .	372
II. The Post-Illumination Burst . . . . .	373
III. Compensation Point . . . . .	373
IV. Effect of $CO_2$ Concentration . . . . .	374
V. Effect of $O_2$ . . . . .	374
VI. Effect of Temperature . . . . .	375

VII. Interaction of Oxygen, Carbon Dioxide, and Temperature . . . . .	375
VIII. Effect of Light Intensity . . . . .	376
IX. The Glycolate Pathway . . . . .	376
E. Photorespiration in C <sub>4</sub> Plants . . . . .	378
I. Photorespiration as CO <sub>2</sub> Evolution . . . . .	378
II. Photorespiration as Oxygen Uptake . . . . .	382
III. Photorespiration in C <sub>4</sub> Plants – Indirect Evidence . . . . .	385
IV. Evidence Against Photorespiration in C <sub>4</sub> Plants . . . . .	388
F. Concluding Remarks . . . . .	390
References . . . . .	391

### III. Ferredoxin-Linked Reactions

#### 1. Transhydrogenase

##### P. BÖGER (With 1 Figure)

A. Introduction and Definitions . . . . .	399
B. Soluble Flavoproteins with Transhydrogenase Activity . . . . .	400
I. Bacterial Enzymes . . . . .	400
II. Ferredoxin-NAD(P) <sup>+</sup> Reductases . . . . .	401
C. Membrane-Bound (Particulate) Transhydrogenases . . . . .	405
I. Mitochondrial and Bacterial Transhydrogenases; General Aspects . . . . .	405
II. Transhydrogenase of Photosynthetic Bacteria . . . . .	406
References . . . . .	407

#### 2. Oxygen Activation and Superoxide Dismutase in Chloroplasts

##### E.F. ELSTNER (With 2 Figures)

A. Introduction . . . . .	410
B. Principles of Oxygen Activation . . . . .	410
C. Superoxide Anion and Superoxide Dismutase . . . . .	410
I. Dismutation of the Superoxide Anion (O <sub>2</sub> <sup>-</sup> ); Superoxide Dismutase in Plants . . . . .	410
II. Superoxide Dismutase in Chloroplasts . . . . .	411
III. Monovalent Oxygen Reduction in Chloroplasts . . . . .	412
D. Determination of the Products of Oxygen Reduction . . . . .	412
E. Possible Functions of Reduced Oxygen Species in Chloroplasts . . . . .	413
I. Desaturation of Fatty Acids . . . . .	413
II. Hydroxylation of Aromatic Compounds . . . . .	413
III. Photorespiration . . . . .	413
IV. Ethylene Formation . . . . .	414
F. Conclusions . . . . .	414
References . . . . .	414

#### 3. Ferredoxin-Linked Carbon Dioxide Fixation in Photosynthetic Bacteria

##### B.B. BUCHANAN (With 2 Figures)

A. Introduction . . . . .	416
B. Ferredoxin-Linked Carboxylation Reactions . . . . .	417
I. Synthesis of Pyruvate . . . . .	417
II. Synthesis of $\alpha$ -Ketoglutarate . . . . .	418
III. Synthesis of $\alpha$ -Ketobutyrate . . . . .	418
IV. Synthesis of Phenylpyruvate . . . . .	418
V. Synthesis of $\alpha$ -Ketoisovalerate . . . . .	419
VI. Synthesis of Formate . . . . .	419
C. The Reductive Carboxylic Acid Cycle . . . . .	420
D. Concluding Remarks . . . . .	422
References . . . . .	423

**4. Reduction of Nitrate and Nitrite****B. VENNESLAND and M.G. GUERRERO**

A. Introduction . . . . .	425
B. Reduction of Nitrate to Nitrite . . . . .	426
I. Assimilatory Nitrate Reductase of Eukaryotes . . . . .	426
II. Assimilatory Nitrate Reduction in Prokaryotes . . . . .	430
C. Reduction of Nitrite to Ammonia . . . . .	431
I. Nitrite Reductase of Photosynthetic Cells . . . . .	431
II. Nitrite Reductase of Nonphotosynthetic Cells . . . . .	433
D. Control of Nitrate Reduction . . . . .	433
I. Synthesis and Degradation of Enzymes . . . . .	433
II. Utilization of Nitrate . . . . .	435
III. Reversible Inactivation of Nitrate Reductase . . . . .	435
IV. Localization of Enzymes and Effect of Light and Carbohydrate on Nitrate Utilization . . . . .	437
V. Conclusions . . . . .	439
References . . . . .	439

**5. Photosynthetic Ammonia Assimilation****P.J. LEA and B.J. MIFLIN (With 3 Figures)**

A. Introduction . . . . .	445
B. Photosynthetic Ammonia Assimilation in Intact Organisms . . . . .	446
C. Localization of Enzymes Involved in Ammonia Assimilation . . . . .	447
I. Glutamate Dehydrogenase . . . . .	447
II. Glutamine Synthetase . . . . .	448
III. Glutamate Synthase (GOGAT) . . . . .	449
D. Photosynthetic Ammonia Assimilation in Isolated Intact Chloroplasts . . . . .	450
E. Photorespiratory Ammonia Evolution and Reassimilation . . . . .	453
F. Conclusions . . . . .	454
References . . . . .	455

**6. N<sub>2</sub> Fixation and Photosynthesis in Microorganisms****W.D.P. STEWART (With 1 Figure)**

A. Introduction . . . . .	457
B. Distribution of Nitrogenase Among Photosynthetic Prokaryotes . . . . .	457
C. Oxygen Sensitivity and Protection of Algal Nitrogenase . . . . .	458
D. Requirements for an Active Nitrogenase . . . . .	460
E. The Provision of Reductant and ATP in Photosynthetic Prokaryotes . . . . .	461
I. Electron Donation . . . . .	461
II. The Production of ATP . . . . .	462
F. The Nitrogen-Fixing System of Heterocysts of <i>Anabaena cylindrica</i> . . . . .	463
G. Nitrogenase and Its Possible Regulation by Glutamine Synthetase . . . . .	467
References . . . . .	468

**7. Symbiotic N<sub>2</sub> Fixation and Its Relationship to Photosynthetic Carbon Fixation in Higher Plants****B. QUEBEDEAUX (With 2 Figures)**

A. Introduction . . . . .	472
B. Relationship of N <sub>2</sub> Fixation to Carbon Assimilation . . . . .	472
I. Nitrogenase . . . . .	472
II. ATP and Reductant . . . . .	474

III. Ammonia Assimilation . . . . .	475
IV. Photosynthate as the Limiting Factor . . . . .	476
V. Translocation and Partitioning of Nitrogen and Carbon Assimilates . . . . .	477
References . . . . .	479

## **8. Photosynthetic Assimilation of Sulfur Compounds**

### **A. SCHMIDT (With 1 Figure)**

A. Introduction . . . . .	481
B. Observations with Whole Organisms . . . . .	481
C. Observations with Isolated Organelles . . . . .	482
D. Cell-Free Systems . . . . .	483
I. Sulfate Activation and Degradation of Active Sulfate . . . . .	483
II. Transfer of Sulfate from Sulfonucleotides for Further Reduction. . . . .	485
III. Reduction to the Level of Sulfide . . . . .	487
IV. Biosynthesis of Cysteine . . . . .	489
E. Regulation of Assimilatory Sulfate Reduction in Photosynthetic Organisms. . . . .	491
References . . . . .	493

## **9. Hydrogen Metabolism**

### **A. BEN-AMOTZ (With 1 Figure)**

A. Introduction . . . . .	497
B. Hydrogenase . . . . .	498
I. Occurrence of Hydrogenase in Photosynthetic Cells . . . . .	498
II. Adaptation and Deadaptation. . . . .	498
III. Cell-Free Preparations of Hydrogenase . . . . .	499
C. Evolution of H <sub>2</sub> . . . . .	500
I. Dark Evolution of H <sub>2</sub> . . . . .	500
II. H <sub>2</sub> Photoevolution . . . . .	500
III. H <sub>2</sub> Evolution by Blue-Green Algae . . . . .	502
D. Consumption of H <sub>2</sub> . . . . .	502
I. Dark Absorption of H <sub>2</sub> . . . . .	502
II. Photoreduction . . . . .	503
References . . . . .	504

<b>Author Index . . . . .</b>	<b>507</b>
-------------------------------	------------

<b>Subject Index . . . . .</b>	<b>569</b>
--------------------------------	------------