epidermal cells, that there is a preceding change in the orientation of the cytoskeletal microtubules. The central role of microtubules in morphogenesis is further underscored by numerous examples of plant cells without walls in which cytoskeletal microtubules control shape directly (Marchant).

How microtubules control cellulose orientation is reviewed by Heath and Seagull, who compare and contrast several models. Many schemes invoke a flow of membrane components (such as cellulose synthetases) driven or aligned by microtubules (Heath and Seagull; Palevitz), but beyond the frequent observation of cross bridges between microtubules and the plasma membrane (Palevitz) very little is known about the interaction of the two. Two chapters emphasize the role of the plasma membrane in structural (Montezinos) and biochemical (Maclachlan and Fèvre) aspects of wall formation. Particles observed in freeze-fracture preparations that are localized with impressions of cellulose fibers provide for interesting speculation about wall formation (Montezinos), but the particles require biochemical characterization before specific models of function can be seriously entertained (Maclachlan and Fèvre).

Although the discussion of the involvement of cortical microtubules in cell wall formation dominates the book, discussions of other aspects of cytoskeletal function contribute importantly to it. Forer reminds us that, in addition to the microtubules, the mitotic apparatus contains components such as actin microfilaments and membranes, that may participate in chromosome motion. The process of cytokinesis and the factors that define the place of the cell plate are thoughtfully reviewed by Gunning, who devotes special attention to the structure and function and the pre-prophase band of microtubules, an enigmatic grouping of cortical microtubules that appears early in mitosis and indicates the place where the cell plate will fuse but disappears long before cytokinesis begins. Here and in chapters by Lloyd and Barlow and by Schnepf the commonly observed polarization of plant cell cytoplasm is emphasized. Specific movements and placements of the nucleus and organelles are controlled in part by the cytoskeleton and may lead to highly asymmetric positioning of cytoplasmic constituents that are essential to a subsequent division and cell differentiation (Schnepf).

The participation of microtubules in a myriad of events raises the crucial but vexing question of how the cytoskeletal elements themselves are controlled. It is amply demonstrated by Lloyd and Barlow that the coordination of cell division and elongation in a complex tissue requires precise control over the positioning and time of activation of the microtubule organizing centers. Several chapters address the nature of such centers from different perspectives. Brown *et al.* review evidence concerning the structure and function of the more discretely delimited microtubule organizing centers, such as centrioles and basal bodies, that are found commonly in lower plants and in all animal cells. A more puzzling situation occurs in higher plants, in which microtubule nucleation appears to be associated with amorphous aggregates from which microtubules radiate (Lloyd and Barlow; Palevitz; Hardham). The discovery of these amorphous structures was an important advance of the last few years, but what they are chemically and how they work await future clarification.

In summary the book provides a thoughtful and up-to-date accounting of the cytoskeleton in plant cells. Nevertheless, one is likely to come away from reading it with a sense of disappointment because the field it reviews leaves so many questions unanswered and has seemed to be so slow in moving into new lines of inquiry and in adopting or developing new techniques. One welcomes the application of immunofluorescent antibody labeling techniques to plant cells (Lloyd and Barlow; Gunning), but this approach is in its infancy and has not yet offered any information leading to new ideas. In short, the excitement that currently surrounds cytoskeletal studies of animal cells is lacking in cytoskeletal studies of plant cells.

Plant cells, largely because of their walls, are difficult objects for biochemical and histochemical studies. Even so the wall may be a blessing as well as a curse. The pattern of cellulose microfibrils impressed upon the wall is the direct product of cytoskeletal activity and can be used to provide important spatial and temporal information about cytoskeletal function. Investigations of the structure and biochemical properties of the plasma membrane, which resides at the interface between the cytoplasmic microtubule and the extracellular cellulose, might produce promising leads and should be pursued with vigor. In general our understanding of the biochemistry of the plant cytoskeleton is badly deficient; quite likely many components, including proteins like erythrocyte spectrin and ankyrin, are present but are unknown.

The book in a sense draws to a close the early stages of cytoskeletal research on plant cells. Further observations of parallel orientation between microtubules and cellulose microfibrils, or studies that show altered cellulose deposition in the presence of anti-microtubule drugs, for example, will be redundant. It is time for fresh ideas and approaches. Although the book is not too helpful in providing direction for future research, it should well serve the important role of informing us of what has been done and may provide valuable suggestions concerning unique botanical systems for new experimentation.

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Photosynthetic Systems

Photosynthesis. GOVINDJEE, Ed. Academic Press, New York, 1982. In two volumes. Vol. 1, Energy Conversion by Plants and Bacteria. xxx, 800 pp., illus. $79. Vol. 2, Development, Carbon Metabolism, and Plant Productivity. xxvi, 580 pp., illus. $59. Cell Biology.

The discussion of photosynthesis in most biochemistry textbooks is dominated by "green plant" or "oxygenic" photosynthesis, which utilizes water as a hydrogen donor and produces oxygen as a byproduct. However, there is a type of photosynthesis that produces no oxygen. It utilizes hydrogen donors other than water, such as hydrogen sulfide, and produces such byproducts as elemental sulfur. Anoxygenic photosynthesis is carried out by a small group of microorganisms known as photosynthetic bacteria. Although studies with these bacteria have had major impacts on our understanding of the mechanism of photosynthesis, they are usually overlooked because the organisms are specialized.

The book under review not only allows the bacterial photosynthetic system to share center stage with its larger, more prominent chloroplast counterpart, it integrates the studies with bacteria into a broad context, describing recent progress concerning molecular aspects of the subject in a manner not available elsewhere.

The book is a comprehensive survey of the subject. The first volume, "Energy Conversion by Plants and Bacteria," considers how light energy is converted into the high-energy products adenosine triphosphate and reduced pyridine nucleotide. The volume discusses the structure of the photosynthetic apparatus, primary photochemistry, electron transport

mechanisms, photophosphorylation, and pigment biosynthesis. The reader is introduced (systematically and logically) to the current biochemical and biophysical understanding of the capture of photons, the separation of primary charges, the photoinduction of electron flow, the establishment of proton gradients across a biomembrane, and the use of the established proton motive force via a chemiosmotic mechanism to synthesize ATP. The unique feature of this volume is that whenever appropriate the chapters are written by two experts, one dealing with plant photosynthesis and the other with bacterial photosynthesis. One comes away from these chapters with a strong impression of the similarities that exist in a wide variety of photosynthetic membranes. This is seen most significantly in reaction center processes, where the similarity between components of the bacterial and chloroplast systems has become obvious. Electron transfer through a chain of carriers that involves the *b* and *c* type cytochromes takes place in both the plant and the bacterial systems, and the recent characterization of isolated cytochrome complexes from these two types of organisms has revealed another similarity between the two systems. ATP synthetase also is similar in the plant and bacterial systems.

In a volume of this nature some duplication inevitably occurs. The composition of the bacterial reaction center is discussed in several chapters, for example. The book omits some of the most recent developments in the field; for example, the crystallization of the bacterial reaction center and the results that indicate a lateral heterogeneity of the chloroplast membrane complexes within different types of thylakoid membranes are not discussed. The latter findings have important implications for processes such as energy and electron transfer, which are discussed at great length in this volume. Finally, the elegant studies of regulatory mechanisms involving thylakoid phosphorylation are briefly described, but the most recent findings in this important field are not mentioned. On the whole, the coverage is comprehensive, with background and recent research results being presented to bring each subject into perspective.

The second volume, "Development, Carbon Metabolism, and Plant Productivity," not only describes basic biochemical pathways, such as those involved in the fixation of CO_2, it covers the development, molecular biology, and genetics of photosynthetic systems and topics related to increasing plant productivity. The emphasis in this volume is more on higher plant systems, and the integrated approach used in volume 1 is not appropriate for many of the subjects discussed in volume 2, though it is used in chapters on CO_2 fixation, biogenesis of the photosynthetic apparatus, and molecular biology.

As is the case with the first volume, the coverage of topics in volume 2 is excellent and as up to date as is possible in a rapidly moving field. There are again developments that are not discussed because they were not available at the time of writing. The recent description of transformation systems in several plant systems is one such development.

An additional volume devoted entirely to molecular biology may be appropriate in a short time. In the meantime *Photosynthesis* will be a useful reference work and will serve as a more than basic introduction to this complex subject for students in many fields.

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(Continued on page 682)