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Final Report

of

The Center for the Study of Early Events in Photosynthesis

Arizona State University
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I. Overview.

The ASU Center for the Study of Early Events in Photosynthesis was established in 1988 with funding through a five-year grant from the USDA/DOE/NSF Plant Science Center program and a grant from the NSF Biological Facilities program. Its scientific objective is to elucidate the basic principles that govern photosynthetic energy collection and storage. Understanding these principles is vital to mankind, as photosynthesis provides most of our food, fiber and energy needs. The Center attempts to fulfill this objective through research of the highest standard, coupled inextricably with quality education at the undergraduate, graduate and postdoctoral levels. These goals are met via a network of collaborative, interdisciplinary research groups comprising 100 personnel within the Department of Chemistry and Biochemistry, the Department of Botany, and the Department of Physics and Astronomy. The work of these research groups is facilitated by the Center through a variety of important infrastructural functions.

During its six years of existence, the Center, through its associated personnel, has:

- Contributed 238 research articles to respected scientific journals and books.
- Presented numerous papers at scientific meetings.
- Played a major role in the scientific education of 65 graduate students and 40 undergraduate researchers.
- Provided 24 postdoctoral scholars with the opportunity to develop professionally through stays of one or more years.
- Developed a graduate-level course in photosynthesis, and contributed to the content of a variety of other courses at the graduate and undergraduate levels.
- Facilitated the addition of five new faculty members to the University.
- Helped bring five new research specialist positions to the University.
- Hosted five scientific meetings of regional, national and international scope at the University and other locations.
- Sponsored seminar presentations by 155 scientists, the majority of whom were visitors from around the world.
- Hosted 17 visiting scientists of international stature for periods of several months each.
- Housed the editorial offices of the international journal *Photosynthesis Research.*
- Taken responsibility for the major photosynthesis internet communications center.

The Center intends to grow in both the quality and quantity of its research output and student alumni. The youth and high quality of its research programs auger well for this expectation. The Center is already known world wide for its photosynthesis research effort, and plans to greatly enhance this reputation over the coming years, thus bringing additional recognition to the University as a whole.

The backbone of Center research funding is provided by individual research grants garnered by single investigators or groups and shared instrumentation grants for expensive, multi-user equipment. The Plant Science Center grant and generous associated University cost share augment these funds and provide the necessary Center infrastructure.

II. History and Organization.

A. History of the Center.

As a relative newcomer to the ranks of research universities, Arizona State has adopted the strategy of selecting promising programs and allocating sufficient resources to build them up to considerable strength. One of these programs has been photosynthesis research. The ASU effort in photosynthesis began in the late 1970's with the work of Devens Gust and Thomas A. Moore on synthetic models for photosynthetic reaction centers. Subsequently, several additional research groups were established, and by 1988 there were seven faculty-rank investigators in Chemistry and Botany with photosynthesis as a major focus of their research programs.

This concentration of investigators attacking the same research problem using a variety of complementary techniques and approaches naturally began to generate opportunities for joint research projects involving graduate and undergraduate students from both Departments and shared use of expensive instrumentation. In addition, it had the potential to serve as a magnet to attract other talented researchers in many capacities. Missing was an organizational infrastructure which would facilitate the collaborative, multidisciplinary aspects of the program. In order to build the necessary infrastructure, the photosynthesis researchers initiated a proposal to the newly established Plant Science Centers program of the U. S. Department of Agriculture, Department of Energy, and National Science Foundation. The purpose of this joint grant program was to set up centers for the study of various aspects of plant science and fund them for a period of five years. The program was highly competitive, and only three awards were to be made. At the same time, the researchers applied for a major equipment grant under the National Science Foundation Biological Facilities program. Both proposals were funded in 1988, along with a proposal to the DOE University Research Instrumentation program. Total Federal funding amounted to $3,231,340, including indirect costs. The University contributed generously to these proposals, providing a 40% funding match on equipment and guaranteeing the addition of three tenure-track faculty members, research specialists, and an administrative associate.

During the six years of its existence, the Center has developed rapidly. The three new faculty lines have been filled, and two additional faculty have become associated with the Center. The research programs of the Center faculty have expanded, as has external funding for their support. Along with this expansion have come additional graduate and undergraduate students, a number of research personnel at the postdoctoral, visiting scientist or research specialist levels, and new multi-user research instrumentation. Center faculty contribute to teaching in one or both Departments, and offer a graduate photosynthesis course and seminar program. In addition, the Center helps fill the broader needs of the photosynthesis community in a number of ways. In recognition of this progress, the Center was designated a Regents' Center of the University in November of 1990.

B. Personnel.

The Center currently has approximately 100 affiliates, including 11 faculty members, 6 research specialists, 10 postdoctoral fellows, 39 graduate students, 16 undergraduate researchers and aides, one administrative associate, and a variety of visiting scientists and technicians. Appendix A contains a listing of all Center participants as of Fall, 1994. The vitae of the faculty and senior research personnel are included in Appendix B. Various categories of personnel are discussed in more detail in later sections of this report.

C. Organization of the Center.

1. Place of the Center in the University Community.

As the purpose of the Center is to facilitate interdisciplinary research and education at the graduate and undergraduate levels, it exists administratively within the usual academic structure of the institution. The Center Director reports to the Vice President for Research through the Dean of the College of Liberal Arts and Sciences and the Chairs of the Department of Chemistry and Biochemistry and the Department of Botany. All regular faculty in the Center are members of one of the Departments, and contribute to its teaching and service obligations. Faculty do not hold their appointments within the Center itself. Center courses are offered through either or both Departments. Graduate and Undergraduate students associated with the Center pursue degrees in one of the two Departments, and meet the regular degree requirements. Some interdisciplinary students are taking advantage of the newly established Molecular and Cellular Biology degree program. Research specialists in the Center who are paid from State funds are also associated with one of the Departments. The Center has no building of its own, and its laboratories are housed within the two Departments.

As suggested by the above facts, the Center regards itself as an integral part of the educational framework of the University, and attempts to fulfill its mission within that framework. However, carrying out its mission does require financial resources. For the first five years of the Center's existence, these resources are being supplied by individual and joint research and shared instrumentation grants, the Plant Science Center grant and associated University cost share.

2. Internal Organization.

The Center is governed by an Executive Committee made up of the associated faculty. The Director serves as Chair of the Executive Committee, appoints members of the Center committees, serves as an *ex officio* member of all standing committees, and represents the Center to the University administration and the general public. The Director is elected by the Executive Committee for a term of three years. Robert Blankenship served as the first Director (1988–1991), and was succeeded in 1991 by Devens Gust.

Standing Committees on Personnel, Facilities and Equipment, Finance, Seminars, and Publications and Conferences make recommendations to the Executive Committee, which is the final decision-making body for all major issues. A list of the current committee assignments is given in Appendix C.

The daily operational tasks of the Center are handled by Lawrence Orr, the Administrative Associate. These tasks are numerous and cover a wide scope of activities.

III. Goals and Objectives.

A. Research Objectives.

The overall scientific objective of the Center is to elucidate the basic principles that govern photosynthetic energy collection and storage. Understanding photosynthesis is of vital importance to mankind. All agriculture is based, directly or indirectly, on photosynthesis. Thus, all of our food, much of our fiber, and many of our building material needs are filled by photosynthesis. Most of the energy we use today is the legacy of ancient photosynthesis in the form of coal, oil and natural gas. A better understanding of the photosynthetic process will improve the ability of mankind to control it, and thus to enhance agricultural and energy production. Increased knowledge of photosynthesis will also permit a better evaluation of the effects of global changes such as depletion of atmospheric ozone and increased atmospheric carbon dioxide. In addition, the basic chemical and physical principles which underlie natural photosynthesis can be adapted to artificial solar energy harvesting technologies to help meet future energy needs. An understanding of the basic natural photosynthetic energy harvesting units, which are in fact miniature photovoltaic devices, can be applied to the design of man-made electronic components of molecular dimensions. Finally, photosynthesis research even fosters "spin-offs" in areas such as photomedicine and cancer treatment.

Because photosynthesis is an extremely complex process, no single experimental methodology can hope to unravel its intricacies. Within the Center, researchers with a wide range of approaches and very different areas of expertise bring their talents to bear on the problem. The Center exists to facilitate this multifaceted, multidisciplinary attack on the photosynthesis question.

The precise focus of the Center is what is known as the *early events* of photosynthesis, which involve light absorption and energy transfer, the pathways and mechanisms of primary photochemistry in plant and bacterial reaction centers, and secondary electron and proton transfer processes. Included are modeling by artificial and biomimetic photosynthetic systems, the study of the function, structure and assembly of photosynthetic antennas, reaction centers, electron transfer proteins and membranes, and the elucidation of the basic mechanisms of energy and electron transfer. These topics are investigated using a wide variety of techniques and approaches, ranging from molecular biology and biochemistry to physical and organic chemistry, ultrafast laser spectroscopy, X-ray crystallography, electron spin resonance, nuclear magnetic resonance, and theoretical chemistry. Details of the scientific investigations appear in the Faculty Research Descriptions section later in this report.

B. Graduate and Undergraduate Education.

In the Center, as elsewhere in the University, scientific research and education at the undergraduate, graduate and postdoctoral levels are inextricably intertwined. Learning to do research is a major part of an education in the sciences, and most research projects depend heavily on input from student researchers. Thus, education at all levels is a primary objective of the Center. Center educational efforts include not only laboratory experience for developing scientists, but also the introduction of new courses, the enrichment of established courses by the inclusion of material garnered from Center expertise and research results, and other less formal educational enhancements. The Center actively seeks external grants explicitly for the training of graduate and undergraduate students. In 1993 the Center received a one-year NSF grant award for Research Experience for Undergraduates (REU) to give a group of ten undergraduates from other universities and colleges a chance to do laboratory research at ASU. Based on the success of that program, the NSF awarded the Center a three-year REU grant covering the summers of 1994-1996.

C. Enhancement of the Research and Educational Environment.

The Center is more than a collection of independent research groups. It can contribute most effectively to its research and educational goals by facilitating multidisciplinary, synergistic interactions among the researchers. It seeks to accomplish this in part through support of interdisciplinary research personnel who contribute to many research group efforts, and the acquisition of sophisticated and often expensive research instrumentation which is of great value to many of the research groups, but whose cost could not be readily justified by any single researcher. In addition, the Center attempts to facilitate interaction of scientists and students in both Departments with one another and with fellow scientists from the world-wide photosynthesis community through an interdisciplinary seminar program, a visiting scientist program, and the hosting of national and international meetings. Finally, the international journal, *Photosynthesis Research,* is edited at ASU and a world-wide photosynthesis research computer bulletin board is managed here.

IV. Accomplishments.

Although the Center has existed for only six years, and only four as a Regents' Center, it has made remarkable progress toward its long-range goals. This progress is summarized in the sections below.

A. Research Achievements.

1. General Measures of Research Accomplishment.

The true measure of the research accomplishments of the Center personnel lies in the content of the research publications emanating from the Center and its long-term contribution to the advancement of science. Individual faculty research progress will be briefly summarized in Section IV.A.2.

A major goal of the Center is to foster collaborative, interdisciplinary research. It has succeeded well in this effort. It will be noted that all Center investigators are actively involved in at least one joint project, and in many cases teams of several research groups are attacking specific photosynthesis problems. This is exactly the kind of collaboration envisioned when the Center was established. It is particularly necessary in photosynthesis research, as the scientific problems are highly complex and can only be expected to yield to a multidisciplinary approach. It will be noted that several of the collaborations have led to joint research funding. The collaborative endeavors extend beyond the boundaries of the University. Table I shows collaborations with researchers outside ASU which have led to published papers or meeting presentations.

In the sciences, the results of research and creative activity are communicated to others in the discipline and society at large through publications in refereed journals. Each publication prepared by Center researchers receives a Center publication number, and an acknowledgment of Center support. Currently, the publication list, which appears in Appendix D, contains 128 entries. The major scientific periodicals in the field are well represented: *Science, The Proceedings of the National Academy of Sciences, Biochemistry, The Journal of the American Chemical Society, Physical Review,* and a variety of more specialized but highly respected journals. Center investigators have also been invited to contribute reviews of their work to a number of well-known scientific periodicals and books.

The Center has attracted considerable attention in the scientific press. Articles about Center research developments have appeared in *Science World, Discover, Chemical and Engineering News, Science News, New Scientist, Analytical Chemistry, The Futurist, Mensa Bulletin, Boardroom Reports, Insider R&D, Bild der Wissenschaft, Business Week,* and a variety of other magazines and newspapers, including the *New York Times.*

The Center has also been well represented at scientific meetings. Center personnel, including not only faculty members but also research specialists, postdoctoral associates and graduate students, have presented their research at a wide variety of scientific conferences. These presentations range from plenary lectures to short talks and posters.

Table I: Collaborations Outside ASU

Collaborations with senior scientists from 1986 to the present that have led to published papers or abstracts.

James Allen

G. Feher, University of California, San Diego
D. C. Rees, California Institute of Technology
J. Deisenhofer, Howard Hughes Medical Institute, Dallas
H. Michel, Max Planck Institut für Biochemie, Frankfurt
R. Huber, Max Planck Institut für Biochemie, Martinsried
M. Y. Okamura, University of California, San Diego
M. Plato, Freie Universität, Germany
K. Möbius, Freie Universität, Germany
W. Lubitz, Technical University, Germany

Robert Blankenship

R. C. Fuller, University of Massachusetts
Govindjee, University of Illinois at Urbana/Champaign
C. Kirmaier, Washington University
D. Holten, Washington University
W. W. Parson, University of Washington
D. B. Knaff, Texas Tech University
T. Nozawa, Tohoku University, Japan
M. L. W. Thewalt, Simon Fraser University, Canada
G. Tollin, University of Arizona
M. A. Cusanovich, University of Arizona
T. E. Meyer, University of Arizona
M. Mimuro, National Institute for Basic Biology, Japan
I. Yamazaki, Hokkaido University, Japan
R. S. Knox, University of Rochester
J. M. Olson, Odense University, Denmark
G. Hauska, University of Regensburg, Germany
J. Amesz, Leiden University, The Netherlands
J. Sanders-Loehr, Oregon Graduate Institute
J. van Beeumen, University of Gent, Belgium
V. Godik, Moscow State University, Russia

Wayne Frasch

R. R. Sharp, University of Michigan
R. E. Sayre, Ohio State University

J. Devens Gust Jr., Ana Moore, Thomas A. Moore

R. V. Bensasson, Muséum National d'Histoire Naturelle, Paris, France
F. C. DeSchryver, Katholieke Universiteit Leuven, Belgium

M. van der Auweraer, Katholieke Universiteit Leuven, Belgium
A. R. Holzwarth, Max Planck Institute, Mülheim, Germany
M. R. Wasielewski, Argonne National Laboratory, Argonne, IL
J. S. Connolly, SERI, Golden, CO
H. A. Frank, University of Connecticut
R. J. Cogdell, University of Glasgow, UK
Y. Sakata, University of Osaka, Japan
N. Mataga, University of Kyoto, Japan
S. Misumi, University of Osaka, Japan
E. J. Land, Christie Hospital, Manchester, UK
P. Seta, CNRS, Montpellier, France
E. Bienvenue, CNRS, Montpellier, France
D. Lexa, University of Paris, France
J. R. Norris, Argonne National Laboratory
H. Levanon, University of Jerusalem, Israel
G. Jori, University of Padova, Italy
Mark Ondrias, University of New Mexico

J. Kenneth Hoober

L. Paavola, Temple University
D. Marks, Temple University
N. Yamamoto, Temple University
D. Ash, Temple University
D. van Weltstein, Carlsberg Lab, Copenhagen
G. Kanaugara, Carlsberg Lab, Copenhagen

Sheng Lin

W. Domcke, Munich, Germany
B. Fain, Tel Aviv, Israel
Y. Fujimura, Sendai, Japan
N. Hamer, Los Alamos National Laboratory
A. A. Villaeys, Strasbourg, France
C. Y. Yeh, Salt Lake City, Utah
G. Y. C. Wu, Taipei, Taiwan
R. Islampour, Teacher Training University, Tehran, Iran
H. Hayashi, National Inst. for Basic Biology, Japan

Willem Vermaas

J. G. K. Williams, Du Pont
B. A. Diner, Du Pont
A. W. Rutherford, CEN Saclay, France
P. Mathis, CEN Saclay, France
C. J. Arntzen, Texas A&M University
M. Ikeuchi, RIKEN, Japan
Y. Inoue, RIKEN, Japan
Ö. Hansson, Chalmers Institute, Sweden
Govindjee, University of Illinois
J. R. Bowyer, Royal Holloway and Bedford New College, UK
P. Camilleri, Smith Kline Beecham Research Ltd., UK

H. B. Pakrasi, Washington University
M. Edelman, Weizmann Institute, Israel
I. Ohad, Weizmann Institute, Israel
P. Sétif, CEN Saclay, France
G. Hauska, University of Regensburg, Germany
N. Nelson, Roche Institute of Molecular Biology, Nutley, NJ

Andrew Webber

R. Malkin, University of California, Berkeley
J. C. Gray, Cambridge, UK
J. Barber, Imperial College, London, UK
R. L. Heath, University of California, Riverside
N. R. Baker, University of Essex, UK
J. P. Markwell, University of Nebraska
I. P. Ting, University of California, Riverside
D. T. Sawyer, Texas A & M
M. F. Hipkins, London, UK

Neal Woodbury

W. F. Thompson, Carnegie Institution of Washington
S. G. Boxer, Stanford University
W. W. Parson, University of Washington
W. Lubitz, Technical University Berlin, Germany
J. Breton, CEN Saclay, France
E. Nabedryk, CEN Saclay, France
V. Godik, Moscow State University, Russia

Center faculty have received recognition for their research efforts in a number of ways. For example, Professors Vermaas and Woodbury have received Presidential Young Investigator awards. Professor Blankenship recently received the Alumni Achievement Award of Nebraska Wesleyan University and the ASU Graduate College Distinguished Research Award, and was elected chair of the prestigious Gordon Conference on Photosynthesis in 1991. He is Editor-in-Chief of *Photosynthesis Research.* Professor Lin has been recognized as a Regents' Professor at ASU, elected to the Academia Sinica, is an honorary professor at Nanking University, and has received fellowships from the Alfred P. Sloan Foundation, the John Simon Guggenheim Foundation, and the Alexander von Humboldt Foundation. He has also been awarded the ASU Graduate College Distinguished Research Award and the Chemistry Department's Award for Distinction in Graduate Teaching (1987, 1989). In addition, he is on the *Journal of Molecular*

Sciences' advisory board, is editor of *Advances in Multi-photon Processes*, and is a Scientific Advisor of the Institute of Atomic and Molecular Sciences of the Academia Sinica. Dr. Gust received the ASU Graduate College Award for Distinguished Research and Creative Activity for 1988-89, and was recently elected to the Council of the American Society for Photobiology and the Organizing Committee of the International Conference on Photochemical Conversion and Storage of Solar Energy. Last year, he was a co-organizer of the Tenth Anniversary Symposium of the US-Japan Cooperative Photochemistry and Photosynthesis Research Program. Professor T. A. Moore is a past Councilor of the American Society for Photobiology.

2. **Faculty Research Summaries.** The short research summaries below describe the programs of the Center faculty and some of the research specialists, and delineate recent achievements. References are to the Center publication list, Appendix D.

James P. Allen

The overall goal of my current research is to understand biological processes in terms of physical mechanisms, *i.e.* on a molecular level. The primary biological question addressed is the conversion of energy in photosynthesis. Several different projects have been initiated using a variety of methodologies, ranging from biochemistry and molecular biology to X-ray diffraction, magnetic resonance, and optical spectroscopy. One direction of my research is to understand the relationship between the structure and function of the reaction center (RC) from *Rb. sphaeroides.* For example, in the RC a non heme iron atom is located midway between the primary and secondary electron acceptors. The iron is ligated to 4 histidines and 1 glutamic acid that are highly conserved in bacterial and plant systems. However, the iron atom does not change oxidation state during electron transfer and no functional role has been established. To determine such a role for iron, each of the five iron ligands has been mutated to 3-5 other residues. Preliminary results show that the binding affinity for iron has greatly decreased in some mutants; these mutants have either no metal or contain another metal atom (such as Zn). Associated with these changes are electron transfer rates that differ by up to two orders of magnitude from the native rates. A second project recently begun with N. Woodbury and S. Lin is a study of the influence of the protein structure on the electronic properties of the primary electron donor. Preliminary results indicate that the midpoint potential of the primary electron donor can be increased by 200mV by mutating residues near the donor; further mutagenesis experiments are underway to better understand the influence of the residues on the electronic state of the dimer. The approach of characterizing functional changes by spectroscopy and structural changes by protein crystallography is planned. These results will be used in developing theoretical models of electron transfer processes.

The second direction of my research is to use X-ray diffraction to determine the three dimensional structures of membrane associated protein complexes using the newly funded X-ray diffraction facilities. Structures of integral membrane proteins have only been determined for RCs from purple bacteria. To better characterize photosynthetic complexes in other bacterial and plant systems, we plan to determine the three dimensional structures of these complexes. One project is the characterization of the RC-cytochrome complex. *In vivo,* the RC is reduced by a secondary electron donor, a water soluble cytochrome c_2 . Despite a general structural homology between cytochromes, the binding constants of different cytochromes to the RC vary by orders of magnitudes. This motivated us to determine the structure of the cytochrome c_2 from *Rb. sphaeroides* to a resolution limit of 2.5Å. Now that the structure has been determined, we will model the electrostatic interactions that determine the binding of the cytochrome to the RC. Interactions between specific residues will be further studied by site directed mutagenesis and crystallizing the intact RC-cytochrome complex. Another project is a collaboration with W. Frasch to determine the structure of coupling factor, ATPase, from spinach. Crystals have been obtained that diffract well but the crystals are twinned, i.e., groupings of several crystals rather than a single crystal. We are altering the crystallization conditions in order to grow single crystals suitable for X-ray diffraction studies.

Robert E. Blankenship

Antenna Organization in Green Photosynthetic Bacteria: Photosynthetic antennas collect sunlight and transfer its energy to the photochemical reaction center, where long term energy storage takes place. This project is concerned with the structure and function of the chlorosome antennas found in green photosynthetic bacteria. Chlorosomes are ellipsoidal structures attached to the cytoplasmic side of the inner cell membrane. They contain approximately 10,000 molecules of bacteriochlorophyll (BChl) *c*, *d* or *e* that absorb light and transfer energy into the membrane and eventually into the reaction center. Evidence is now overwhelming that the chlorosome represents a very different type of antenna from that found in any other photosynthetic system yet studied (5).

The past several years have seen some major advances in our understanding of the chlorosome antenna system. The idea that the pigments in chlorosomes are organized into molecular aggregates by direct pigment-pigment interactions has now gained essentially universal acceptance among the workers in the field of photosynthesis, largely due to the work from our laboratory. The challenge is now to understand at a molecular level how the pigment oligomers are packaged into the chlorosome and how they function to make an efficient antenna system (12, 24, 41, 49, 80, 87, 102, 120). In addition to these developments that refine views we have been developing in our lab for several years, a recent conceptual breakthrough was the discovery of a previously unrecognized control system that serves to regulate the flux of energy through the system in response to the redox potential inside the cell (22, 27, 103, 119).

Evolution of Photosynthesis: Photosynthesis in higher plants is a very complex process involving two photosystems linked together into a single electron transport chain. Various photosynthetic bacteria contain simpler reaction centers similar to one or the other of the two plant reaction center complexes. A major interest in my lab is to learn as much as possible about the evolutionary developments that led from the earliest photosynthetic organisms to the very complex systems found in plants (86).

The heliobacteria are a newly discovered family of non-oxygen evolving photosynthetic bacteria that have a reaction center that is broadly similar to Photosystem I of oxygen evolving organisms. The goal of this project is to develop the heliobacteria as a bacterial model for Photosystem I in the same way that the purple photosynthetic bacteria have been very successfully used as a model for Photosystem II. We have isolated the reaction center from *Heliobacillus* *mobilis* in an active form (23, 35), and are characterizing its chemical and physical properties using a variety of techniques (93, 116).

Oligonucleotides designed on the basis of the protein sequence were used to identify the gene for the 47 kDa reaction center protein, in collaboration with the Vermaas group. The gene has now been isolated and completely sequenced (117). The protein sequence derived from the gene sequence has been compared to the analogous sequences from the proteins that make up other photosynthetic reaction centers. The sequence clearly indicates that there is an evolutionary relationship between the heliobacterial reaction center and Photosystem I.

Other Projects: Additional projects in my laboratory are concerned with the detailed chemical, spectroscopic and structural characterization of several electron transfer proteins isolated from photosynthetic organisms. These include copper proteins (95), iron sulfur proteins (222), cytochromes (6, 13, 23, 84), and photosynthetic reaction centers (17, 20, 62, 101).

Wayne D. Frasch

The immediate products of solar energy conversion by the photosynthetic reaction centers of plants are reducing equivalents in the form of NADPH and the generation of a proton-motive force (pmf). This force is comprised of a proton concentration gradient and an electrical potential across the thylakoid membrane driven by the electron transfer reactions. The pmf has three problems serving as a source of energy to drive cellular processes. First, there is a storage problem, because the pmf is rapidly dissipated by diffusion across the membrane. Second, the energy is localized on the thylakoid membrane and, thus, cannot be transported to other parts of the cell. Third, very few reactions in the cell can access the energy in this form. These problems are solved by the Energy Transducing Complex, a thylakoid bound enzyme that uses the pmf to synthesize ATP from ADP and phosphate. The chloroplast energy-transducing complex or coupling factor is composed of an intrinsic membrane sector that serves as a proton channel (CF_0) and an extrinsic membrane portion that synthesizes ATP (CF_1). This multisubunit enzyme contains multiple binding sites for nucleotides that bind as a complex with metals that facilitate the reaction. ATP synthesis is highly regulated to ensure a constant flow of energy to the cell.

We are currently taking a multidisciplinary approach to study the structure and mechanism of F_1. A major limitation is the lack of structural data which prompted Frasch and Allen to initiate protein crystallography studies to determine the three dimensional structure of the catalytic b subunit. Preliminary studies have produced crystals that diffract well but contain a disorder that currently prevents data analysis. These studies will provide the detailed structural information necessary to define the catalytic site. To probe the contribution of specific amino acids in the b subunit to the mechanism of ATP synthesis, Frasch and Webber are constructing site-directed mutations in *Chlamydomonas* using the Biolistic technology described by A. Webber. This technique facilitates the transformation of organellar DNA which allows the mutant protein subunits to be expressed and the entire enzyme complex to assemble in the organelle. Biochemical analyses of these mutants in terms of enzymatic activities and determination of binding affinities of the substrates are being complemented by biophysical analysis by Frasch. This includes NMR spectroscopic studies (using the NMR facility run by Nieman) that identify the immobilization of specific amino acid moieties upon binding substrates, and electron paramagnetic resonance (EPR) spectroscopic studies (using the EPR facility run by LoBrutto) that characterize the amino acids, nucleotide phosphates and solvent water molecules that comprise the ligands to the metal cofactors of the enzyme.

Devens Gust, Thomas A. Moore, Ana L. Moore

Our approach to the study of photosynthesis is to prepare and investigate artificial photosynthetic systems in which the structural role of the protein is mimicked by covalent linkages which force the pigments and other small donor and acceptor molecules to assume defined relationships to one another. A major portion of this work is concerned with investigating the multistep electron transfer strategy of natural reaction centers whereby light energy is used to create long-lived, energetic charge separated states in high quantum yield. In this approach, a hypothetical single, long range electron transfer step which would occur with a negligible quantum yield is replaced by a series of short range, and therefore fast and efficient steps.

This work began a number of years ago with the preparation of a carotenoid (C) porphyrin (P) quinone (Q) triad molecule which generated a long lived, energetic charge separated state of the form $C^{\cdot+}$-P-$Q^{\cdot-}$ upon excitation. The simple triad systems have now evolved into more complex molecular devices which can generate longer-lived charge separated states with higher quantum yields. For example, we have reported a tetrad molecule of the type C-P-P-Q (1). Excitation of this molecule produces two porphyrin first excited singlet states, C-^{1}P-P-Q and C-P-^{1}P-Q, which exchange excitation energy rapidly by a singlet-singlet energy transfer process. The C-P-^{1}P-Q state donates an electron to the attached quinone to produce C-P-$P^{\cdot+}$-$Q^{\cdot-}$ with a rate constant of 2.4 x 10^8 s^{-1}. Subsequent electron transfer competes with charge recombination to yield a final $C^{\cdot+}$-P-P-$Q^{\cdot-}$ state. This state is long lived (2.9 μs in anisole solution), and is formed with an overall quantum yield of 0.25.

In other work, a C-P-Q_A-Q_B tetrad was prepared (10). As with the C-P-P-Q molecule discussed above, excitation of the porphyrin moiety leads to photoinitiated electron transfer to the quinone Q_A to yield C-$P^{\cdot+}$-$Q_A^{\cdot-}$-Q_B with a quantum yield >0.98. In this tetrad, two electron transfer steps compete with charge recombination to generate C-$P^{\cdot+}$-Q_A-$Q_B^{\cdot-}$ and $C^{\cdot+}$-P-$Q_A^{\cdot-}$-Q_B, both of which go on to yield the same final $C^{\cdot+}$-P-Q_A-$Q_B^{\cdot-}$ species. The final state has a lifetime of 460 ns in dichloromethane (4 μs in acetonitrile), and is formed with an overall quantum yield of 0.23 at ambient temperatures and 0.50 at 240 K. Comparison of the results for this molecule with those obtained for two model triads demonstrated that although the tetrad is a considerably more complex molecular device, the additional electron transfer pathways lead to an increased quantum yield of long-lived, energetic charge separated states.

In related experiments, the magnetic properties of the C-P- Q_A-Q_B tetrad have been investigated using time-resolved Fourier transform and CW EPR techniques (53, 54). This work has been collaborative with workers at the Argonne National Laboratory and in Israel. The long lifetime of the final charge-separated state coupled with the time resolution of modern EPR techniques have made it possible to directly observe the transient $C^{\cdot+}$-P-Q_A-$Q_B^{\cdot-}$ state. These studies have verified that electron transfer occurs from the singlet state of the porphyrin to ultimately produce the terminal benzoquinone radical anion and the carotenoid radical cation.

Studies of the magnetic properties of multicomponent molecules using the CIDNP technique have also been initiated. These were carried out in collaboration with Dr. Seely. A paper dealing with CIDNP resulting from electron transfer from porphyrins to quinone acceptors has appeared (66).

The expertise gleaned from the preparation and study of these two tetrad molecules led to the design and synthesis of a C-P_{Zn}-P-Q_A-Q_B molecular pentad (40, 43). Excitation of the free base porphyrin moiety in a chloroform solution of the pentad yields an initial charge-separated state, C-P_{Zn}-$P^{\cdot+}$- $Q_A^{\cdot-}$-Q_B, with a quantum yield of 0.85. Subsequent electron transfer steps lead to a final charge-separated state, $C^{\cdot+}$-P_{Zn}- P-Q_A-$Q_B^{\cdot-}$, which is formed with an overall quantum yield of 0.83 and has a lifetime of 55 µs. Irradiation of the free-base form of the pentad, C-P-P-Q_A-Q_B, gives a similar charge separated state with a lower quantum yield (0.15 in dichloromethane), although the lifetime is increased to ~340 µs. The pentads preserve about 1.0 eV of the initial excitation energy (1.9 eV) in the long lived charge separated state. Thus, the pentad molecules are very successful mimics of the overall photosynthetic energy conversion process, although they do not address some important details which are currently not understood.

The three classes of molecules discussed above all feature photoinitiated electron transfer from porphyrins to quinones as the initial step in the electron transfer cascade. The molecules bearing two porphyrin moieties did not demonstrate interporphyrin electron transfer to yield a $P^{\cdot+}P^{\cdot-}$ state because the energy of this state was above those of the porphyrin first excited singlet states. The initial electron transfer events of photosynthesis, on the other hand, occur between cyclic tetrapyrrole molecules. One way to permit electron transfer between porphyrins in synthetic systems is to attach substituents to the porphyrin moieties which stabilize a positive charge on one and a negative charge on the other. Thus, the energy of $P^{\cdot+}$-$P^{\cdot-}$ can be lowered to the point where it is energetically accessible from ^{1}P-P or P-^{1}P. We have recently begun an investigation of this strategy. The photophysical properties of a tetraarylporphyrin bearing an electron withdrawing nitro group in one of the pyrrole ß positions have been reported (11). In addition, long-lived charge separation has been observed in a series of C-P_A-P_B triad molecules. Excitation of either porphyrin moiety is followed by electron transfer to yield C-$P_A^{\cdot+}$-$P_B^{\cdot-}$. A second electron transfer from the carotenoid yields the final $C^{\cdot+}$-P_A-$P_B^{\cdot-}$ state. These states have lifetimes of hundreds of nanoseconds and can be produced with quantum yields of up to 0.32. An initial report of this work has been published (64). All of the molecular devices mentioned above have in common certain electron and energy transfer processes. A detailed investigation of the physical mechanisms of these steps using simple carotenoporphyrin dyads has recently been completed (97).

A number of methods for harvesting the energy stored in the long lived charge separated states are being investigated. Recently, the incorporation of artificial photosynthetic molecules into Langmuir-Blodgett films has been studied. In the initial phase of the work, lipid diluents which dissolve tetraarylporphyrins to form monolayers consisting of a single, a homogeneous phase have been found. Absorption, fluorescence, and time resolved fluorescence studies of L-B films cast from these monolayers show an absence of interporphyrin interaction. These results, which have recently been published (65), set the stage for the incorporation of two-, three- or four-part molecular devices related to those discussed above into the films and the possible observation of photoinitiated electron transfer across the monolayer. Another approach to harvesting stored energy involves self-assembly of monolayer films on gold surfaces. An initial report of this work has appeared (98).

Much of the work mentioned above as well as work previously done in our laboratories has been summarized in several review articles (9, 33, 46, 91, 145). These will serve as a good resource for scientists interested in our work as well as that of other investigators in the field of artificial photosynthesis.

We are continuing our studies of multicomponent molecular devices which mimic photosynthetic electron, singlet energy, and triplet energy transfer. The work involves the design and synthesis of new molecules followed by a variety of spectroscopic studies, most of which can now be done at ASU, thanks to our recently acquired Center instrumentation and collaboration with Center experts in its use. New types of porphyrin dyads are being prepared, including some that structurally mimic the special pair. In others, the free energy dependence of interporphyrin electron transfer is being investigated. These new dyads will form the basis of more complex molecules which feature one- and two-electron transfer cascades which are initiated by interporphyrin photodriven electron transfer.

John Kenneth Hoober

Our major project is based on a kinetic analysis of the assembly of light-harvesting chlorophyll-protein complexes (LHCs) during linear greening of *Chlamydomonas reinhardtii y-1* at 38°C. LHC assembly and association with reaction centers can be measured over a span of a few minutes in these cells, a rate higher than in any other system. Our recent data indicate that newly formed PSII units are fully functional and that transfer of electrons between PSII and PSI occurs rapidly. We are examining the fluorescence induction kinetics of PSII units in order to understand the basis for this efficient energy transfer and to correlate these results with biochemical analysis of thylakoid membranes. The data obtained in the last three years support the hypothesis that the chloroplast envelope is the site of assembly of thylakoid membranes, which also is being examined by electron microscopy. Mutations are being constructed in a gene for a chlorophyll *a/b*-binding protein, the major component of LHCs, to probe for regions important in interaction of the protein with chlorophyll and with thylakoid membranes.

Chlorophyll (Chl) *b* is required for assembly of LHCs. Its pathway of synthesis is unknown, although genetic studies have shown only a single gene product is specifically involved in chlorophyllide *b* synthesis. Synthesis of chlorophyllide *b* is promoted by phenanthrolines in *Chlamydomonas reinhardtii y-1* in a reaction that does not require light. Possibly, the phenanthrolines mimic a role for chlorophyllide *a* in this reaction. We are developing a program to isolate the gene for Chl *b* synthesis and examine *in vitro* the mechanism of this reaction. The *Chlamydomonas* system is quite amenable to solving this long-standing problem.

Sheng H. Lin

Recently, my research group has been working on the theoretical treatments of photoinduced electron transfer (ET) and femto-second (fs) processes. In order to understand the mechanism of ET in photosynthetic reaction centers (RCs), we have developed a theory to study the effect of spacer groups between donor and acceptor on ET . In particular, we have studied how the location of LUMOs (lowest unoccupied molecular orbitals) of the spacer and the number of spacers affect ET and the temperature dependence of ET. Based on this theory, we have developed a theoretical model for the ET of RCs and the effect of anharmonicity on ET . We have also investigated the electric field effect on ET and absorption spectra. This electric field effect may be due to external applied electric field or due to chemical potential gradients of ions across the membrane.

Because a laser pulse of 100 fs duration will produce an energy uncertainty of about 10^2 cm^{-1}, the fs experiments for large molecular systems require special theoretical treatments. The theories should take into account the dynamics of both population and coherence of the system in order to be able to analyze the fs time-resolved spectra properly. We have treated the fs pump-probe experiment, fs time-resolved fluorescence and fs time-resolved resonance Raman scattering. In collaboration with Professors Allen and Woodbury, we have one NSF postdoctoral fellow (Rhett Alden) performing fs transient absorption measurements on bacterial photosynthetic RCs. Dr. Alden is in the process of carrying out fs time-resolved resonance Raman scattering of RCs in order to determine the mechanism of ET in RCs.

Currently, we are developing the so-called excitonic-vibronic coupling model to treat electron transfer (ET) dynamics and spectroscopy of RCs. This is motivated by the fact that, depending on temperatures, the primary ET of RCs takes place in 1–4 ps. In this time range, the assumption of complete vibrational relaxation before ET may not be valid so that the conventional ET theory is not applicable. In this model, eight electronic states and six vibrational modes are considered. These vibronic states are coupled together either directly or indirectly. Vibrational relaxation and dephasing processes are taken into account. Our preliminary calculations show that if vibrational relaxation is in the time scale of 1 ps or slower, then the participation of P^+B^-H is significant. However, if vibrational relaxation is fast, in the time scale of 0.1 ps, the participation of P^+B^-H is negligible. Vibrational relaxation and vibrational coherence in RCs have indeed been observed recently by two research groups. To improve this excitonic-vibronic coupling model, molecular orbital calculations will be performed to determine the electronic states, the interactions between these electronic states, the coupling constants between vibronic states of the vibrational modes involved in the model. To determine the vibrational modes involved in the absorption spectra and ET in RCs, the resonance Raman scattering is a powerful method to use.

Professor Blankenship and I are collaborating on the studies of spectroscopic properties of chlorophyll aggregates. Professor T. Moore and I are investigating the physical mechanism of the quenching of singlet oxygen in solutions.

Willem F. J. Vermaas

Photosystem II: In our laboratory, efficient procedures for site-directed mutagenesis of a number of photosystem II (PS II) proteins in the cyanobacterium *Synechocystis* sp. PCC 6803 have been developed (3, 15A, 16, 83, 118). We now also have been able to generate mutants devoid of photosystem I and most phycobilisome components, so that virtually all pigments are associated with PS II (113). Site-directed mutagenesis procedures are used to generate genetically well-defined mutants, which are analyzed by a variety of biophysical and biochemical techniques. In this way, effects of small modifications in the protein environment on the function and properties of cofactors and prosthetic groups can be analyzed. From this, rather precise structure-function relationships can be determined in the PS II proteins, which is important for understanding the factors critical for efficient and rapid energy and electron transfer. This information is useful in a number of areas, for example in the design of biomimetic devices. Emphasis in our laboratory is on the reaction center protein D2, and on the chlorophyll-binding proteins CP47 and CP43.

The D2 protein: This protein is centrally involved in electron transfer through PS II, and work has focused on determining the protein residues close to a variety of cofactors involved in PS II function, and analyzing the functional modifications of these cofactors upon single mutations in specific residues in the protein environment. Upon analysis of site-directed mutants, we have identified a redox-active Tyr-residue in D2 (2); this Tyr residue is oxidized in the light, and at that time presented one of the first examples of direct involvement of amino acid sidechains in redox reactions in proteins. Other PS II cofactors whose environment we have studied by site-directed mutagenesis include Mn involved in the water-splitting system (44), the primary electron-accepting quinone QA (47), the non-heme iron (85), and bicarbonate. In addition, various mutants have been very important in identifying factors that are required for assembly and stability of D2 and the entire PS II complex (45; 115, 126). Also the causes for the increased light sensitivity observed in selected mutants have been determined (82). These results provide important contributions to the search for the factor(s) primarily responsible for inhibition of photosynthesis in high light (photoinhibition). A number of laboratories in six different countries are involved in collaborative projects involving analysis of site-directed mutants generated at ASU. With the wide variety of high-quality spectroscopic equipment (for both optical and electron paramagnetic resonance) available at ASU, a number of exciting collaborative projects with other Photosynthesis Center members are under way.

The chlorophyll-binding proteins CP47 and CP43: A number of site-directed mutations have been introduced in conserved His residues in hydrophobic regions of CP47 and CP43. The results obtained support the notion that these residues are involved in binding of chlorophyll (114). In addition, fluorescence decay kinetics with ps resolution have been determined in these and other mutants affected in chlorophyll proteins (21, 76). Work on the chlorophyll-binding proteins in PS II also involves analysis of the function of a large hydrophilic loop present in both CP47 and CP43. This loop has been found to be involved in stability and assembly of the PS II complex (83; 118) as well as in determining properties of the water-splitting system.

Photosystem I: A number of PS II mutants do not accumulate any PS II in their thylakoids. Such mutants are particularly good experimental systems for spectroscopic analysis of photosystem I in cyanobacteria. Using these mutants, Bruce Wittmershaus and collaborators have convincingly demonstrated by fluorescence polarization measurements the presence of C705, a hotly debated chlorophyll component associated with photosystem I (88).

Heliobacillus mobilis: A collaborative project in the Vermaas and Blankenship laboratories regarding DNA and protein analysis of *Heliobacillus mobilis*, an evolutionarily ancient photosynthetic organism, has revealed that the photosynthetic reaction center in this bacterium contains only a single core polypeptide (117). This is in contrast to virtually all other photosynthetic reaction centers, which are formed by two similar polypeptides that probably originate, in an evolutionary sense, from gene duplication followed by divergence. This organism may present an interesting opportunity for comparative studies of the function of homo- and heterodimeric reaction centers.

Andrew N. Webber

Research is focused on understanding the synthesis, assembly and function of chloroplast membrane protein complexes involved in the primary processes of photosynthetic energy transduction The chloroplast is a membrane bound organelle that contains its own genetic information encoding approximately half of the thylakoid membrane proteins. The remainder of the thylakoid proteins are encoded by genes located in the nucleus. The synthesis and assembly of a thylakoid membrane protein complex therefore requires very precise coordination of expression of nuclear and chloroplast genes. This report outlines our progress in understanding the regulation of chloroplast gene expression and also our efforts in genetic engineering of the chloroplast genome.

As a model for the study of thylakoid membrane protein complexes our work has focused on the photosystem I reaction center. The photosystem I reaction center is a multiprotein complex that utilizes light energy to transfer electrons across the membrane from plastocyanin ferredoxin. The initial electron transfer components are the P700 reaction center chlorophyll, a chlorophyll primary electron acceptor, called A_0, a quinone electron acceptor, A_1 and a [4Fe-4S] iron sulfur center, F_X. All these electron acceptors are bound to two homologous polypeptides termed A_1 and A_2 encoded by the chloroplast *psaA* and *psaB* genes. One highly conserved region of approximately 100 amino acids binds Fx and has been proposed to bind the reaction center chlorophyll P700. Also within this conserved region is a leucine zipper motif proposed to be involved in dimerization of the *psaA* and *psaB* gene products (Webber and Malkin, 1990 FEBS Lett. 264, 1-4). Our aim is to use specific mutagenesis techniques to explore the role of the *psaA* and *psaB* products in binding electron transfer components and in mediating reaction center assembly. Towards this aim we have developed an efficient system for the transformation of the chloroplast of *Chlamydomonas reinhardtii* with genes encoding the photosystem I reaction center polypeptides. We have obtained a strain of *C. reinhardtii*, called *ac-u-g-2.3*, that is unable to make photosystem I due to a mutation in the chloroplast *psaB* gene. The *ac-u-g-2.3* mutant is unable to grow photosynthetically, but can be maintained by supplying acetate as an external carbon source. Using the biolistics technique (whereby DNA, carried on small tungsten particles, can be shot into the cell and organelles) we have introduced the wild type *psaB* gene into the chloroplast of the *ac-u-g-2.3* mutant resulting in restoration of photosynthetic growth. The ability to use the biolistics transformation procedure to complement the *ac-u-g-2.3* mutation and restore the capability of the organism to grow photosynthetically makes this a very useful procedure for the introduction and selection of altered genes into the chloroplast genome. We have successfully utilized this approach to experimentally demonstrate that a conserved cysteine is essential for photosystem I assembly supporting the hypothesis that it is one of the four cysteine ligands to the 4Fe-4S iron sulfur center F_X (142). We have also shown that a conserved histidine is critical to excitation energy transfer to P700 supporting its role as a ligand to a chlorophyll cofactor.

The *ac-u-g-2.3* mutant cell line has been of value to our understanding of the regulation of chloroplast gene expression. Northern blot analysis shows that the steady state level of mRNA from the *psaB* gene accumulates to a level over 2 fold greater than in wild-type cells. By complementing the *ac-u-g- 2.3* mutation mRNA accumulation is restored to normal levels, confirming that the altered mRNA accumulation is a direct consequence of the psaB mutation. Using pulse labeling of the mRNA with ^{32}P we have demonstrated that this is a result of increased stability of the transcripts. Therefore, when the photosystem I reaction center is unable to assemble there is increased accumulation of the *psaB* mRNA. Sequencing of the mutant *psaB* gene isolated from the *ac-u-g-2.3* strain has shown that there is a single base pair deletion resulting in premature termination of polypeptide synthesis. Inhibitors of chloroplast protein synthesis have also been shown to cause increased stability of the *psaB* mRNA. This implies a relationship between the rate of decay of chloroplast mRNAs and their translation. The inhibitor studies have also shown that association with the translational apparatus (ribosomes) is not critical, but that active protein translation is apparently the important factor (143). A hypothesis currently being tested is that optimal chloroplast gene expression requires that ribosomes travel the entire length of the mRNA and terminate protein synthesis at the correct location.

Neal W. Woodbury

Our laboratory (Taguchi and Woodbury) collaborates closely with the laboratory of Allen and Williams to understand structure/function relationships in the bacterial reaction centers from *Rhodobacter sphaeroides* and *Rhodobacter capsulatus*. The reaction center is the complex which performs the solar energy conversion in photosynthesis and bacterial reaction centers of this type have been characterized in detail structurally by X-ray crystallography. The team of researchers involved in this project include Jim Allen, a crystallographer and structural biochemist, JoAnn Williams and Aileen Taguchi, molecular biologists, and myself (my background is in spectroscopic analysis of electron transfer, the primary reaction of solar energy conversion in photosynthesis). Between this group, reaction centers are structurally altered by genetic engineering, the resulting functional changes are monitored by ultrafast absorption and fluorescence spectroscopy and ultimately the precise structural changes in the mutants are determined by crystallography. Thus we can take the solar energy conversion device, alter its primary amino acid sequence at will and monitor in great detail both the effects on the light driven chemical reactions and the structural perturbations which have been introduced by the mutations.

A few of the most mature and successful projects are outlined below, but the basic results obtained thus far are that we can predictably change the thermodynamic parameters of the electron transfer reactions in photosynthesis by specific mutation and in so doing, can change the rates and yields of these reactions in an understandable manner. Not only does this have important implications in the study of the solar energy conversion reactions themselves, but it speaks to the much broader issue of how proteins modify the characteristics of the cofactors that they contain in order to accomplish specific, controlled reactions in biological systems.

We began work in the ASU Chemistry Department shortly before the inception of the Center in 1988. Several projects have been performed involving mutagenesis of bacterial reaction centers from *R. capsulatus* and *R. sphaeroides*. Some of the most important aspects of this work are the study of chimeric reaction centers created by homologous recombination between the reaction center operons of different species (19 and a manuscript in preparation) and a study of reaction center symmetry mutations in which essentially all of the amino acids which define the environment of the RC cofactors in the M subunit have been replaced by their L counterparts (51, 104 and 105). Analysis of one of these symmetry mutants near P has been performed at a very detailed level. Electron transfer is still largely unidirectional and still occurs very rapidly (15 ps), but the redox potential of the special pair is increased dramatically from about 425 mV to over 520 mV. We have collaborated with Jim Allen and JoAnn Williams to create this mutant as well as a series of related site specific mutants in *R. sphaeroides* and have analyzed many of these.

The results of this work have indicated that hydrogen bonding between P and the surrounding protein plays a major and predictable role in the modification of P's midpoint potential. Addition of a hydrogen bond to P increases its redox potential by 50 to 100 mV; removal of a bond decreases the redox potential of P by a similar amount. A series of well defined single site mutants has been made in this way with redox potentials form 800mV below w.t. to almost 200mV above. These mutants are now being used for a series of detailed femtosecond time-resolved absorption experiments to study the kinetics of electron transfer and the identity of intermediate states (107-110, 121 and manuscripts in preparation). The basic results of this work are that the initial reaction rate decreases with decreasing driving force (a factor about five in 100mV) but does not increase significantly with increasing driving force.

We also have found in both wild type and in one of the symmetry mutants that bleaching of the bacteriopheophytin or the B-side occurs at the 5–10% level during the initial electron transfer reaction. We are presently studying these phenomena more carefully in order to determine whether or not this represents true electron transfer down the "wrong" path or some other interaction between RC cofactors.

B. Contributions to Graduate and Undergraduate Education.

Understanding science means understanding the methods of science and the process of scientific discovery. Because serious science students must do science, as well as learn about it in the classroom, science education goes hand-in-glove with scientific research at an educational institution. Graduate and undergraduate education is thus a high priority of the Center. Most of this education occurs in the laboratory setting. There are currently 39 graduate students and 11 undergraduates associated with the Center (Appendix A).

Graduate students form the backbone of the Center research effort. In all, 18 graduate degrees have been awarded to Center students in the first four years of the Center's existence. Appendix E lists these students, and reports their current employment. Most have gone on to postdoctoral or industrial laboratory positions.

Recruitment of high-quality graduate students is extremely important. Substantial funds for graduate student support were included in the Plant Science Center grant. The Center's first priority has been to use these funds to recruit promising students to the program from outside the University. With support of the Graduate College, the Center has prepared a flyer to aid in graduate student recruitment. It contains information on the research programs of the faculty members of the Center, instrumentation and equipment, and graduate research assistantships. This flyer has been sent out to departments of chemical, plant and biochemical sciences and to faculty interested in photosynthesis. In addition, it is included with information packages sent to prospective graduate students in the Departments of Chemistry and Biochemistry, and Botany. A copy of the flyer is appended.

A graduate recruitment poster has also been developed. This poster, with tear-off reply postcards, is sent to chemistry, biochemistry, botany, biology, and related departments nationwide. A total of approximately 175 cards were returned during the 1992/1993 recruitment season, and packages with further information regarding graduate programs in the Botany and Chemistry and Biochemistry Departments at ASU were sent to individuals sending in the cards. Especially promising students are invited to visit the Department of their choice in order to help them become better acquainted with the Center and ASU.

In spite of these efforts, the Center has not been able to recruit as many excellent graduate students as it would like. The problem is due to a nationwide shortage of young people interested in pursuing careers in the sciences, and is being faced by essentially all graduate schools nationwide. A result of this competition for high-quality graduate students has been a national increase in graduate stipends. Currently, the Center is able to offer support amounting to about $15,000 per year to qualified students, but even this level is not sufficient to match offers from other institutions. The problem of graduate student numbers and stipends is being addressed by the Center in conjunction with the Department of Botany and the Department of Chemistry and Biochemistry.

Although most of the financial support for graduate students in the Center comes from individual research grants or through teaching assistantships in the associated Departments, a significant amount has been provided by the Plant Science Center grant itself. This grant terminates at the end of August, 1994. The Center is seeking external funds to continue graduate support through various Federal research training grant programs and private foundations.

Undergraduate students also play an important role in Center research efforts (Appendix A). Thus far, the Center has involved 40 undergraduates in research in some capacity. Some of these students do research under one of the undergraduate research course numbers, while others are supported through research grants. These students work in the laboratory alongside the faculty, postdoctoral associates, and graduate students, and receive an early introduction to the world of scientific research. Many of the Center publications feature undergraduates as coauthors who have made significant contributions to the research. Several of the undergraduate students have received summer financial support through supplements to faculty grants from the National Science Foundation. The Center has set up a more formal program for the support of undergraduate research in the summers through a proposal to the NSF Research Experiences for Undergraduates program. The proposal has been funded through 1996.

Laboratory-based research training for Center students at all levels is supplemented by formal lecture and laboratory course work. These courses are offered by Center faculty through one or both of the Departments. In addition to the basic courses of the disciplines, Center faculty offer advanced courses which draw upon their particular areas of expertise. Thus, courses in spectroscopic techniques such as nuclear magnetic resonance and electron paramagnetic resonance, as well as specialized subjects such as molecular biology, photochemistry, and biophysical chemistry have been given. The Center offers a graduate course in photosynthesis which is listed in both Departments, and is taught jointly by three or more members of the Center. The photosynthesis course covers topics in: theory of energy transfer, techniques for measuring energy and electron transfer in photosynthetic systems, photosynthetic electron transfer in bacterial reaction centers, structure of bacterial reaction centers, photosynthetic model systems, molecular genetics of photosynthetic bacteria, structure and function of cytochrome complexes, photosynthetic electron transfer chains in cyanobacteria and chloroplasts, regulation of photosynthetic electron transfer, Photosystem II, Photosystem I, oxygen evolving complex, ATP synthase, molecular biology of photosynthesis, chloroplast biogenesis, carotenoids, carbon metabolism and RUBISCO, C4 and CAM metabolism, and evolution of photosynthesis. Attendance has been satisfyingly high.

In addition to laboratory work and formal course work, a substantial fraction of graduate and undergraduate education occurs through less formal mechanisms including interactions with experienced research scientists visiting the Center and research specialists, seminars, and attendance at scientific meetings. The Center provides many such opportunities, some of which are discussed in the next section.

C. Enhancement of the Research and Educational Environment.

Both research advances and education at the graduate and undergraduate levels occur through interactions among individuals. The role of the Center is to provide a basic infrastructure which supports the individual researchers so that they can realize their potential, and encourages synergistic interactions among them. In this section of the report, some Center functions of this type are outlined.

1. Research Personnel.

Part of the mission of the Center has been to build a strong, vigorous group of research personnel capable of interacting to push forward the frontiers of the field. During its start-up period, the Center has added both faculty and research specialists to its ranks.

Faculty. As a part of the cost-share commitment by the University to support the Center, a variety of professional positions were made available in order to bring new scientists to ASU.

At the assistant professor level, three lines were designated for young faculty who would become integral members of the Center. These positions were made especially attractive through generous start up provisions provided by the University and up to three years of reduced teaching loads. Immediately after funding for the Center was announced, international searches were mounted to fill the three positions. It was decided that two would go formally into the Botany Department and the third would be in Chemistry and Biochemistry. Fortunately, we were able to fill all three positions during the first year with people whose expertise complemented that already here while maintaining the Center's tight programmatic focus. The faculty position in Chemistry and Biochemistry was filled by Dr. James P. Allen, a protein crystallographer who had solved the crystal structure of the photosynthetic reaction center of the bacterium *Rb. sphaeroides* while a postdoctoral associate of Professor George Feher at the University of California at San Diego. In the Botany Department two new faculty were hired; Dr. Wayne Frasch and Dr. Andrew Webber. Dr. Frasch has studied the oxygen evolving complex of higher plants as well as the ATP synthesizing enzyme. Dr. Webber has expertise in the genetic engineering of polypeptides found in chloroplast membranes, and is exploring the assembly of these proteins.

In 1989 Professor Ana Moore joined the faculty of the Department of Chemistry and Biochemistry and the Center. Dr. Moore is a native of Argentina. In much of her work, she collaborates with Dr. Gust and her husband, Dr. T. Moore, on the synthesis of model photosynthetic systems. Recently, Professor Ken Hoober joined the University and Center as Chair of the Department of Botany. Dr. Hoober comes to ASU from the Temple University School of Medicine, where he was Acting Chair of the Department of Biochemistry. Dr. Hoober's research in membrane assembly (see section IV.A.2) brings a new dimension to the Center, and increases its expertise in the biological area.

Ph.D. Level Personnel. As detailed in the proposals which established the Center, the University agreed to provide support for four full time Ph.D.-level research scientists. The University has honored this commitment. These positions provide the scientists with the opportunity to perform independent research, but also include a service or support component for Center research groups. It was hoped that these positions would become permanent state funded lines by the end of the five year grant period. Two of them have now been assimilated by the University. The lines are staffed as follows.

Dr. Scott Bingham, a specialist in molecular biology, was recruited by the Center to work in the Botany Department. To date, he has participated extensively in research with Drs. Webber and Vermaas while also running the oligonucleotide synthesizer facility, which serves the University community. His position is state funded. Dr. Bingham has had research support from his previous employer, Martek Corporation, and has a joint grant with Dr. Webber.

Dr. Dan Brune was recruited by the Center to direct the protein sequencer facility. Dr. Brune collaborates with several Center faculty and provides protein sequencing service to research groups outside the Center. His position is now a permanent one in the Chemistry and Biochemistry Department. Dr. Brune and Bingham recently moved to the biotechnology resource facility in the newly opened Goldwater Center for Science and Engineering.

Another of the research specialist positions was used to bring on board a person having synthetic organic chemistry skills. Dr. Paul Liddell holds this position. He obtained his Ph.D. at ASU some years ago, and returned to the University after several years of postdoctoral experience at the University of Pennsylvania and the University of California at Davis. Dr. Liddell works extensively with Drs. Gust, Moore, and Seely, and contributes to Dr. Blankenship's research.

The fourth research specialist position was used to hire Dr. Gilbert Seely, a research professor who brings skills to the Center acquired from his extensive experience in the spectroscopy and electrochemistry of molecules involved in photosynthesis. In addition to collaborating with the Gust and Moore groups, Dr. Seely is the principal investigator in a project involving artificial photosynthesis. A portion of his salary is derived from external grants.

Two other Ph. D. level personnel who hold permanent positions at the University are involved with the faculty in research projects and currently have release time budgeted in the Center for these projects. Dr. Ronald Nieman directs the nuclear magnetic resonance facility of the Chemistry and Biochemistry Department. Included in this facility is the Center 500 MHz NMR instrument and the Iris computer workstation. Dr. Nieman has been very active in collaborating with Center faculty in the use of NMR as a tool for elucidating the structures of both pigment-protein complexes and complicated organic chemical species. His release time has been used to help hire Dr. Scott Smith to handle some of the responsibilities of this rapidly growing laboratory which serves a wide variety of University users.

Dr. Bruce Wittmershaus directs the laser facility which is housed in the Department of Physics and Astronomy and which supports most of the Center laser activities. Dr. Wittmershaus has used his release time to hire an undergraduate student to work with him and Dr. Vermaas on a research project involving PS I fluorescence.

With the recent funding of the DOE Instrumentation Grant for an electron paramagnetic resonance spectrometer, an Academic Professional position that was available in the Botany Department has been used to provide an EPR specialist. This position has been filled by Dr. Russ LoBrutto. Dr. LoBrutto comes to us from Northeastern University where he established a reputation for research in the area of pulsed EPR of metal proteins.

Postdoctoral scholars. The Center has attracted numerous postdoctoral scholars to work in its laboratories. During the last four years, 24 such individuals have studied here. Many of these scientists are supported by individual research grants. However, the Plant Science Center grant contains funds for several postdoctoral fellows each year. It is expected that the majority of these scientists will join one or more of the research groups for their major research project. The selection procedure is for the Center Personnel Committee to review the many applications received. The most qualified candidates are recommended for approval by the Executive Committee. At both of these levels we attempt to make an equitable distribution among the research groups, but never at the expense of selecting a less qualified candidate. The quality of postdoctoral applicants has been outstanding, and the Center has had no problem filling these positions with excellent scientists. Two examples will be given. Dr. Rhett Alden came to the Center from the University of New Mexico, where he worked with Dr. Mark Ondrias on resonance Raman studies of the molecular structure and dynamics of metalloporphyrins subsequent to photo-excitation. In the Center, he has been working most closely with Professors Lin, and Woodbury. Following a year of Center support, he was awarded a prestigious and very competitive NSF Postdoctoral Fellowship for continuation of his research here. Dr. Su Lin received her Ph.D. degree from Professor Robert Knox at the University of Rochester in laser physics, and continued her work in the application of laser technology to photosynthetic problems with Professor Walter Struve at Iowa State. Dr. Lin is an excellent laser scientist who is responsible for the operations of the Center femtosecond laser flash absorption spectrometer. The Center hopes to retain Dr. Lin as a laser research specialist on a long term basis.

2. Shared Instrumentation.

Because the research of the Center is rather tightly focused and highly collaborative, good opportunities exist for the acquisition of major research instrumentation for joint use whose purchase could not be justified on the basis of any individual user. The Center personnel have been quite successful at obtaining needed instrumentation through federal research grants. The funding for this increase in our instrument capabilities has come from several sources: 1) four DOE University Research Instrumentation grants, 2) an NSF Biological Facilities grant, 3) individual awards to investigators, 4) University sources, and 5) the Plant Science Center grant. A list of the major Center instrumentation is given in Table III and summarized in broad outline below. Many smaller items have been obtained as well with funds from a variety of sources.

The bulk of the major shared equipment in the Center comes from the five instrumentation grants. Each of these was authored by a large subset of the principal investigators in the Center, and all equipment purchased is available to all Center personnel and used very heavily by multiple laboratories. Much of this equipment experiences substantial use by Departmental and other investigators outside the Center as well.

One of the purchases made using these funds was a Varian 500 MHz NMR spectrometer (NSF Biological Facilities grant). This instrument is housed in the Chemistry NMR laboratory and supervised by Dr. Ronald Nieman. It has been used for the determination of the structure and motional behavior of the complex photosynthetic model systems developed by Drs. Gust, A. Moore and T. Moore and for the 2-D NMR structure determination of proteins such as the small blue copper protein auracyanin discovered and characterized in Dr. Blankenship's laboratory. In addition, this instrument is used by Dr. Allan Bieber, who was a coauthor of the original facilities grant but not a Center member, for the structure determination of small peptide snake toxins. Also purchased using the NSF funds were a protein sequencer (used heavily in projects involving Drs. Blankenship, Vermaas, Allen, Webber and Brune) and a Silicon-Graphics work station (4D 80 GT) for design, display, and refinement of the structures of both synthetic organic molecules and protein structures.

In addition, the NSF funds were used to purchase part of the instrumentation which makes up the femtosecond transient absorption apparatus. The remainder of the funds for the fast absorption apparatus came from a DOE University Research Instrumentation grant. This instrument is now capable of measuring absorption changes between 400 and 1100 nm with excitation between 590 and 900 nm and a time resolution of better than 150 fs. It has been used most heavily by Drs. Woodbury, Allen, Gust, A. Moore, T. Moore, Blankenship and Lin in the analysis of both intact biological photosynthetic systems and model electron and energy transfer systems. Increased use by other Center members and Departmental investigators is expected as the capabilities of the instrument are expanded.

Another DOE instrumentation grant funded the purchase of a picosecond resolution time-correlated single photon counting apparatus. This has been an extremely productive instrument for the measurement of short fluorescence decay times associated with photosynthetic antennas, reaction centers, and model systems. The spectrometer has been used extensively by Drs. Gust, A. Moore, T. Moore, Blankenship, Woodbury, Seely and Vermaas with increasing use expected soon by Allen. Professor Seth Rose of the Department of Chemistry and Biochemistry has also used this instrumentation.

The Center was successful in obtaining funds to purchase an EPR/ENDOR instrument. This instrument has been installed in the Department of Botany and has now become operational. Extensive use of this spectrometer by Drs. Allen, Blankenship, Brune, Frasch, Gust, A. Moore, T. Moore, Vermaas, Webber and Woodbury is ongoing.

Finally, funds for the purchase of a protein X-ray diffractometer were recently awarded by the DOE. This instrument is now housed in a laboratory set up by Dr. Allen. Most Center investigators are planning to use this instrument on a collaborative basis.

Virtually none of the major instrumentation purchases mentioned above could have been justified by a single-investigator research program. The acquisition of this equipment well illustrates the synergistic role of the Center. In addition to the purchase of needed instrumentation, the Center plays a major role in the maintenance and expansion of existing equipment. An excellent example is the recent replacement of a microchannel plate photomultiplier tube for the time-resolved single photon counting instrument. This component failed catastrophically about two years ago, and without an $8,000 infusion of funds from the Center, it would have been impossible to replace in the short term, leaving our time-resolved fluorescence apparatus severely crippled. The availability of flexible Center funds for the purchase, repair and maintenance of equipment has had a major impact on our ability to quickly and effectively meet instrumentation needs. Without such funds, it would be more difficult to perform innovative, technically sophisticated experimental science in a timely fashion. It is important that additional funds be found for maintenance and support of this instrumentation after the Plant Science Center grant expires.

3. Photosynthesis Seminar Program.

The photosynthesis seminar program, sponsored by the Center, consists of a series of weekly research lectures delivered by invited speakers from the US and abroad. In addition, local members of the Center including graduate students, faculty, staff and postdoctoral personnel give talks. Although anyone is, of course, welcome to attend, the seminar is offered as an official graduate course. It is held every Thursday at 4 PM, and is preceded by a brief social reception with refreshments. The seminar series runs through both the academic year and the summer period. In addition, the Center sometimes co-sponsors seminars presented at the weekly Molecular and Cellular Biology seminar and the Botany and Chemistry and Biochemistry departmental seminars. A list of Center seminars is included as Appendix F. The list of speakers features many world-famous scientists including Nobel laureates and members of the National Academy of Sciences. The seminar series serves to expose students and other researchers to outside viewpoints and approaches to photosynthesis and related research, and to introduce the visiting speakers to Arizona State University.

4. Visiting Scientist Program.

An important mechanism by which the Center acquaints students with the latest ideas and techniques in research and interfaces with the photosynthesis community at large is through the visiting scientist program. The Center has budgeted around $20,000 per year to provide partial support to established scientists who would like to be in residence at ASU for an extended time. Participants in this program to date have included Dr. J. Olson (Denmark), Dr. M. Mimuro (Japan), Dr. Wu (China), Dr. C. Yeh (Taiwan), Dr. V. Godik (Russia), Dr. S. Padhye (India), Dr. I. Ohad (Israel), Dr. L. Sereno (Argentina), Dr. S. Ermakova (Russia), Dr. W. -X. Wu (China), Dr. J. Silber (Argentina), Dr. S. Boussiba (Israel), Dr. G. Schmetterer (Switzerland), and Dr. A. Krasnovsky, Jr. (Russia). These are all well respected scientists in the photosynthesis community whose presence has enhanced the educational and research environment in the two Departments and brought additional international visibility to ASU.

In addition to visiting scientists given Center financial support, we have also played host to a number of self-supported scientists who have worked here while on sabbatical leave in order to collaborate with our research teams. These visitors have included Dr. Govindjee (Urbana, IL), Dr. M. Ikeuchi (RIKEN, Japan), Dr. D. Nicodem (Brazil), Dr. H. Kang (Korea), Dr. E. Shin (Korea), Dr. S. Nonell (Spain), and Dr. R. Islampour (Iran).

5. Scientific Meetings Hosted by the Center.

Recognizing that scientific meetings are another important mechanism for exchange of ideas, the Center has organized several conferences. These conferences also serve to bring added visibility to the University.

In October, 1990, a one-day Joint US/USSR Symposium on Molecular Mechanisms of Photosynthesis was held at ASU: In this symposium, supported by the Graduate College at ASU, scientists from the USSR (Drs. N.N. Karapetyan, V.V. Klimov, N.N. Lebedev, and V.A. Shuvalov) and from ASU gave presentations. The oral presentations were followed by poster viewing and tours of the ASU photosynthesis-related facilities. The USSR scientists were in the US for a conference organized by the US and USSR Academies of Sciences.

Regional Photosynthesis Conferences are held both in the Midwest and on the East Coast; these meetings present a prime opportunity for graduate students and postdoctoral associates to interact and to present their research results. Given the growth in the photosynthesis area in Arizona and continued strong photosynthesis research in California, the Center decided to organize a Western Regional Photosynthesis Conference. Announcements stating that we would hold such a conference at ASU in January 1991 were sent to potentially interested individuals and departments in Arizona, California, Colorado, Nevada, New Mexico, Oregon, Texas, Utah, and Washington. Initial responses indicated a clear interest, and we proceeded with the organization. Financial support was obtained from the Vice President for Research, the Graduate College, and various interested companies. Registration fees, particularly those for students, were kept low. The total number of participants was 138, of which 62 were from ASU. This conference initiated a new tradition; the 1993 Western Regional Photosynthesis Conference was organized by the University of California, Berkeley, and was held in January 1993 at Asilomar, California. The 1994 Conference was organized by the University of California, Los Angeles, and was also held at Asilomar. The Center for the Study of Early Events in Photosynthesis organized the January 1995 Conference and, it too, was held at Asilomar.

In October 1991, the Third Congress of the International Society for Plant Molecular Biology was held in Tucson AZ. The Center organized a satellite conference on the Molecular Biology of Photosynthesis, which was held at ASU, in the Hotel Mission Palms. Approximately 90 researchers from around the world attended.

In June 1994, the Center served as the local host for the Twenty-Second Annual Meeting of the American Society for Photobiology (ASP) which met in Scottsdale. Following the meeting, the Center hosted a mini-symposium on June 29 at Arizona State University for several of the ASP members that are active in photosynthesis research.

6. Student Travel.

Recognizing that making a presentation at a scientific meeting is an important part of a student's scientific maturation, the Center encourages travel to relevant meetings by graduate students. Typically, the student can request up to one-half of the cost of travel to a meeting where he or she makes a presentation. The remaining cost is borne by the research group or the student. During its first four years, the Center has contributed to the meeting travel expenses of 33 students at all levels . This program has been well received by students, who consider such meeting attendance as one of the high points of their graduate careers.

7. Photosynthesis Research: An International Journal.

The editorial offices of the international journal *Photosynthesis Research* are housed within the Center. Professor Robert Blankenship is Editor-in-Chief of this journal, which is published by Kluwer Academic Publishers, Dordrecht, The Netherlands. The Center Administrative Associate, Lawrence Orr, assumes the duties of editorial assistant of the editorial office and edits the well-received *Directory of Scientists Engaged in Photosynthesis Research.* The costs of this service are compensated by a contribution of funds from the publisher. *Photosynthesis Research* is an internationally respected forum for dissemination of research results in the field, and as such, it brings welcome visibility to the University and the Center.

8. Photosynthesis Listserver and Other Internet Functions.

As of August 15, 1992, the Center Administrative Associate, Lawrence Orr, took over supervision of Photosynthesis Listserver, the international computer bulletin board for photosynthesis researchers. This vehicle is used to provide early notification of the contents of upcoming journal issues in the photosynthesis area, to announce scientific meetings, postdoctoral openings, special journal issues, etc., and to exchange scientific findings on an informal basis. In late 1994, the listserver was incorporated into the Bionet Newsgroup on the Usenet. Lawrence then set up a local Gopher site to store information about the Center for the Study of Early Events in Photosynthesis and other photosynthesis matters. Finally, in early 1995, he set up a World Wide Web site for the Center (URL = http://aspin.asu.edu/provider/photosyn/), linking it to the Bionet group and the Gopher, as well as numerous other photosyntheis oriented sites. This web site has become one of the major communication centers for the international photosynthesis community.

V. Appendices.

Appendix A:

ASU Center for the Study of Early Events in Photosynthesis

Participant List
As of September 1, 1994

Director:

Willem F. J. Vermaas, Professor of Botany

Primary Investigators:

James P. Allen, Assistant Professor of Chemistry
Robert E. Blankenship, Professor of Chemistry
Wayne D. Frasch, Associate Professor of Botany
Devens Gust, Professor of Chemistry
Ken Hoober, Chair and Professor of Botany
Sheng Lin, Regents Professor of Chemistry
Ana L. Moore, Associate Professor of Chemistry
Thomas A. Moore, Professor of Chemistry
Gilbert R. Seely, Research Professor of Chemistry
Andrew N. Webber, Assistant Professor of Botany
Neal W. Woodbury, Associate Professor of Chemistry

Staff Participants:

Scott Bingham, Molecular Biology Research Scientist, Botany
Daniel C. Brune, Biochemistry Research Specialist, Chemistry
Paul Liddell, Organic Chemistry Research Scientist, Chemistry
Russ LoBrutto, EPR Research Scientist, Botany
Ronald A. Nieman, NMR Research Specialist, Chemistry
Bruce P. Wittmershaus, Laser Research Scientist, Physics

Faculty Research Associates:

Aileen Taguchi, Chemistry
JoAnn C. Williams, Chemistry

Postdoctoral Fellows:

Jim Campbell, Chemistry
Svetlana Ermakova, Botany
Gary Hastings, Chemistry
Andrew Houseman, Botany
Frank Kleinherenbrink, Chemistry
Hadar Kless, Botany
Jeff Lewis, Chemistry

Su Lin, Chemistry
Alisdair Macpherson, Chemistry
Paula van Noort, Chemistry

Visiting Scientists:

Michitushi Hayashi, Chemistry
Ganesh Pandey, Chemistry
Eun Ju Shin, Botany
Zhen Bao Yu, Botany

Graduate Students:

Katie Artz, Chemistry
Chu-kuan Chiou, Chemistry
Hung-Cheng Chiou, Chemistry
Don Crampton, Botany
Lying Cui, Botany
Liza Eastman, Chemistry
Dennis Gallo, Botany
Christine Hatch, Botany
Qingfang He, Botany
Michael Hu, Chemistry
Su-Chun Hung, Chemistry
Keith Idso, Botany
Myungnyun Kim, Chemistry
Yutaka Komine, Botany
Hyeonmoo Lee, Chemistry
Seung-Joo Lee, Chemistry
Woo-Yiel Lee, Chemistry
Shumin Li, Chemistry
Xiaoyan Li, Chemistry
Yi-Fen Li, Chemistry
Pradip Manna, Botany
Nyangenya Maniga, Chemistry
Tom McHugh, Chemistry
Lori Noss, Chemistry
Soley, Ozer, Chemistry
Jeff Peloquin, Chemistry
Laura Reed, Chemistry
Evelyn Santana, Botany
Fabiyola Selvaraj, Chemistry
Dierk Seeburg, Botany
Shan Shao, Chemistry
John Sumida, Chemistry
Satoru Suzuki, Chemistry
Chu-Kang Tang, Chemistry
Martin Tichy, Botany
Yann-Ping Way, Chemistry
Richard White, Botany
Jody Wissel, Chemistry
Wenli Zhou, Chemistry

Judy Zhu, Chemistry
Hui Zu, Botany

Undergraduate Research Students:

Nazila Adib, Botany
Paul Albrecht, Botany
Karin Brueschweiler, Botany
Emily Carbouel, Chemistry
Kristine Clark, Chemistry
Anna-Marie Grace, Chemistry
Jesse Johnson, Chemistry
Eric Knight, Botany
Min Li, Chemistry
Lola Morgan, Botany
Shannon Ryan, Chemistry
Brooke Shireman, Botany
Trieva Turanchik, Chemistry

Research Technicians:

Stewart Hanson, Botany
John Lopez, Chemistry
Cathy Madsen, Botany
Xuan Nguyen, Chemistry

Student Lab Assistants:

Almaz Gebregiorgis, Botany
Bruce Lazar, Chemistry
Krista Long, Botany
Alyson Roskelley, Botany
Stan Williams, Botany
Alex Wu, Chemistry

Center Office Staff:

Larry Orr, Administrative Associate
David Schiller, Administrative Student Aide

Appendix B:

Curriculum Vitae

James P. Allen

Address:
Arizona State University
Department of Chemistry and Biochemistry
Tempe, Arizona 85287-1604

Personal Information:
Date of Birth: [redacted]
Birthplace: [redacted]

Education:

Saint Joseph's University, Philadelphia PA. B.S., Physics	1977
University of Illinois, Urbana. M.S., Physics	1979
University of Illinois, Urbana. Ph.D., Physics *Thesis:* Protein Conformation from Electron Spin Relaxation Data, Prof. Harvey Stapleton, Advisor	1982

Professional Experience:

Arizona State University, Assistant Professor, Chemistry	1989 - present
University of California, San Diego, Asst. Research Physicist	1985 - 1989
University of California, Los Angeles, Asst. Research Chemist	1985
University of California, San Diego, Postdoctoral Fellow	1982 - 1985
University of Illinois, Urbana, Research and Teaching Asst.	1977 - 1982
Saint Joseph's University Philadelphia PA, Laboratory Asst.	1973 - 1977

Memberships:
American Crystallographic Association
American Physical Society
Biophysical Society
Sigma Xi

Selected Publications:

Williams, J.C., Alden, R.G., Murchison, H.A., Peloquin, J.M., Woodbury, N.W., and Allen, J.P. (1992) Effects of mutations near the bacteriochlorophylls in reaction centers of *Rhodobacter sphaeroides. Biochemistry* **31**, 11029-11037.

Nabedryk, E., Allen, J., Taguchi, A., Williams, J., Woodbury, N., and Breton, J. (1993) Fourier Transform Infrared Study of the primary donor in chromatophores of *Rhodobacter sphaeroides* with reaction centers genetically modified at residues M160 and L131. *Biochemistry* **32**, 13879-13885.

Mattioli, T.A., Williams, J.C., Allen, J.P., and Robert, B. (1994) Changes in primary donor hydrogen bonding interactions in mutant reaction centers from *Rb. sphaeroides*: Identification of the vibrational frequencies of all conjugated carbonyl groups of the primary donor. *Biochemistry* **33**, 1636-1643.

Lin, X., Murchison, H.A., Nagarajan, V., Parsons, W.W., Allen, J.P., and Williams J.C. (1994) Specific alterations of the oxidation potential of the electron donor in reaction centers from *Rhodobacter sphaeroides*. *Proc. Natl. Acad. Sci. USA* **91**, 10265-10269.

Allen, J.P. (1994) Crystallization of the reaction center form *Rhodobacter sphaeroides* in a new tetragonal form. *Proteins: Structure, Function, and Genetic* **20**, 283-286.

Graduate students who graduated during the past five years:

Shaojie Wang (Ph.D., Chemistry) Currently at Duke University Medical Center

Current graduate students:

Katie Artz (Ph.D., Chemistry)
Chu-kuan Chiou (Ph.D., Chemistry)
Xiaoyan Li (Ph.D., Chemistry)
Yi-fen Li (Ph.D., Chemistry)
Xiaomei Lin (Ph.D., Chemistry)
Yan-Ping Way (Ph.D., Chemistry)

Curriculum Vitae

Robert E. Blankenship

Address:
Arizona State University
Department of Chemistry and Biochemistry
Tempe, Arizona 85287-1604
Phone: (602) 965-1439, -1963
Email: Blankenship @ asuchm.la.asu.edu

Personal Information:
Birthdate: [redacted]
Birthplace: [redacted]
Family Status: [redacted]

Education:

Nebraska Wesleyan University, Lincoln, NE. B.S., Chemistry (with Distinction)	1970
University of California, Berkeley, CA. Ph.D., Chemistry *Thesis*: The Role of Manganese in the Mechanismof Photosynthetic Oxygen Evolution. Prof. Kenneth Sauer, Advisor	1975

Professional Experience:

Arizona State University, Prof. Chem.	1988 - present
Assoc. Prof. Chem.	1985 - 1988
Amherst College, Asst. Prof. Chem.	1979 - 1985
University of Washington, Seattle Postdoctoral with Prof. William Parson	1976 - 1979

Honors, Awards, and Service to Profession:

Program Manager, USDA Competitive Research Grants, Photosynthesis, 1995
Grant Review Panel Member, NASA Exobiology, 1994-present
Editor, with M. Madigan and C. Bauer, *Anoxygenic Photosynthetic Bacteria*, Kluwer
Editor-in-Chief for *Photosynthesis Research*, 1988 - present
Grant Review Panel Member, NSF Biophysics, 1991-1994
Swedish Natural Science Research Council Expert Committee Member in Biophysical Chemistry, 1992
Graduate College Distinguished Research Award, Arizona State University, 1992
Alumni Achievement Award, Nebraska Wesleyan University, 1991
Site Review Team Member, Ames Laboratory, 1989, 1992
Director, Arizona State Univ. Center for the Study of Early Events in Photosynthesis, 1988-1991
Vice Chairman (1990) and Chairman (1991) of Gordon Research Conferences on Photosynthesis
Site Review Team Member, Medical Free Electron Laser Program, Office of Naval Research, 1990
Grant Review Panel Member, DOE Energy Biosciences Program, 1988
Local Arrangements Chairman, Biophysical Society Annual Meeting, 1988
NIH Special Study Section Member, Sequencers, etc., 1987
Editorial Advisory Board Member for *Photosynthesis Research*, 1986–88
Grant Review Panel Member, USDA Competitive Research Grants, 1985, 1986, 1989
Organizer, First Eastern U.S. Photosynthesis Conference, 1984
Director, NSF Undergraduate Research Participation Summer Research Program at Amherst College, 1981
NSF National Needs Postdoctoral Fellowship, 1977
Student Body President, Nebraska Wesleyan University, 1969–70

Selected Publications: (108 Total)

Savikhin, S., Zhou, W., Blankenship, R.E., and Struve, W.S. (1994) Femtosecond energy transfer and spectral equilibration in bacteriochlorophyll *a*–protein trimers from the green bacterium *Chlorobium tepidum. Biophys. J.* **66**, 110-114.

Lin, S., Chiou, H.-C., Kleinherenbrink, F.A.M., and Blankenship, R.E. (1994) Time-resolved spectroscopy of energy and electron transfer processes in the photosynthetic bacterium *Heliobacillus mobilis. Biophys. J.* **66**, 437-445.

Kleinherenbrink, F.A.M., Hastings, G., Wittmershaus, B.P., and Blankenship, R.E. (1994) Delayed fluorescence from Fe-S type photosynthetic reaction centers at low redox potential. *Biochemistry* **33**, 3096-3105.

Hastings, G., Kleinherenbrink, F.A.M., Lin, S., and Blankenship, R.E. (1994) Time-resolved fluorescence and absorption spectroscopy of photosystem I. *Biochemistry* **33**, 3185-3192.

Hastings, G., Kleinherenbrink, F.A.M., Lin, S., McHugh., T., and Blankenship, R.E. (1994) Observation of the reduction and re-oxidation of the primary electron acceptor in photosystem I. *Biochemistry* **33**, 3193-3200.

Zhou, W., LoBrutto, R., Lin, S., and Blankenship, R.E. (1994) Redox effects on the bacteriochlorophyll *a*-containing Fenna-Matthews-Olson protein from *Chlorobium tepidum. Photosynth. Res.* **41**, 89-96.

Kleinherenbrink, F.A.M., Chiou, H.C., LoBrutto, R., and Blankenship, R.E. (1994) Spectroscopic evidence for the presence of an iron-sulfur center similar to F_X of photosystem I in *Heliobacillus mobilis. Photosynth. Res.* **41**, 115-123.

Blankenship, R.E. (1994) Protein structure, electron transfer and evolution of prokaryotic photosynthetic reaction centers. *Antonie van Leeuwenhoek* **65**, 311-329.

Savikhin, S., Zhu, Y., Lin, S., Blankenship, R.E., and Struve, W. (1994) Femtosecond spectroscopy of chlorosome antennas from the green photosynthetic bacterium *Chloroflexus aurantiacus. J. Phys. Chem.* **98**, 10322-10334.

Lin, S., Kleinherenbrink, F.A.M., Chiou, H.-C., and Blankenship, R.E. (1994) Spectral heterogeneity and time-resolved spectroscopy of excitation energy transfer in membranes of *Heliobacillus mobilis* at low temperatures. *Biophys. J.* **67**, 2479-2489.

Graduate students who graduated during the past five years:

John C. Freeman (Ph.D., Chemistry) Currently a faculty member at Converse College, Spartansburg, PA

Jeffrey T. Trost (Ph.D., Chemistry) Currently a research scientist with Pharmacia Corp.

James D. McManus, Ph.D., Chemistry) Currently a research scientist with Clorox Corp.

Peiling Cheng (Ph.D., Chemistry) Currently a research scientist with Parke-Davis Corp.

Stephanie Hsiao-Hsien Wang (M.S., Chemistry) Currently employed by Life Tech GIBCO BRL Co., Ltd., Taiwan

George Hamilton King (M.S., Chemistry) Currently an attorney with a Phoenix law firm

Pushpa Ramakrishna (M. Nat. Science) Currently an instructor at Chandler-Gilbert Community College

Current graduate students:

Hung Cheng Chiou (Ph.D., Chemistry)
Tom McHugh (Ph.D., Chemistry)
Wenli Zhou (Ph.D., Chemistry)
John Lopez (M.S., Mol. Cell Biology)
Tony Wellborne (M.S., Chemistry)
Woo-Yiel Lee (Ph.D., Chemistry)
Fabiyola Selvaraj (Ph.D., Chemistry)
Yinwen Judy Zhu (Ph.D., Chemistry)
Laura Reed (M.S., Chemistry)

Curriculum Vitae

Wayne D. Frasch

Address:

Arizona State University
Department of Botany
Tempe, Arizona 85287-1601
Tel: 602-965-8663
Fax: 602-965-6899
Email: atwdf@asuvm.inre.asu.edu

Personal Information:

Birthdate [redacted]

Education:

Hope College, Holland, MI. B.A.	1972
University of Kentucky, Lexington, KY. Ph.D.	1979
Thesis: The Mechanism of Inactivation of the Oxygen Evolving System by Tris. Prof. George Cheniae, Advisor	

Professional Experience:

Arizona State University, Assoc. Prof. Botany	1994-present
Arizona State University, Asst. Prof. Botany	1989-1994
University of Michigan, Ann Arbor, Asst. Prof. Biology	1982-1989
University of Wisconsin, Madison, Dept. Biochemistry Postdoctoral with Prof. Bruce Selman	1979-1982
Marine Biological Laboratory, Woods Hole, MA, Research Fellow	1975

Honors, Awards, and Service to Profession:

Golden Key National Honor Society Award	1994
Eli Lilly Postdoctoral Fellow	1984
NSF Postdoctoral Travel Award	1983
H. Rackham Postdoctoral Fellow	1981
NSF Predoctoral Fellow	1975

Selected Publications (40 Total):

Frasch, W.D. (1991) Alternate substrates as probes of the mechanism of the oxygen-evolving complex. In: *Manganese Redox Enzymes* (V.L. Pecoraro, ed.), pp. 47-70. VCH Publishers.

Bradley, R.L., Long, K.M., and Frasch, W.D. (1991) The involvement of photosystem II-generated H_2O_2 in photoinhibition. *FEBS Lett.* **286**, 209-213.

Fine, P.L., and Frasch, W.D. (1992) The oxygen-evolving complex requires Cl^- to prevent hydrogen peroxide formation. *Biochemistry* **31**, 12204-12210.

Frasch, W., LoBrutto, R., and Roskelley, A. (1992) Characterization of the metal ligands at nucleotide binding sites of CF_1. In: *Research in Photosynthesis* (N. Murata, ed.), Vol. II, pp. 745-748. Kluwer Academic Publishers, Dordrecht.

Houseman, A., LoBrutto, R., and Frasch, W. D. (1994) Coordination of nucleotides to the metals at the M2 and M3 metal-binding sites of the spinach chloroplast F_1-ATPase. *Biochemistry* **33**, 10000–10006.

Frasch, W.D. (1994) The F-type ATPase in Cyanobacteria: Pivotal Point in the Evolution of a Universal Enzyme. In: *The Molecular Biology of Cyanobacteria* (D. Bryant, ed.). Kluwer Academic Publishers, Dordrecht, in press.

Houseman, A., Morgan, L., LoBrutto, R., and Frasch, W.D. (1994) Characterization of ligands of a high affinity metal binding site in the latent chloroplast F_1-ATPase by EPR spectroscopy of bound VO^{2+}. *Biochemistry*, in press.
Houseman, A., LoBrutto, R., and Frasch, W.D. (1995) The effects of nucleotides on the ligands of the metals bound to the M2 and M3 metal binding sites of the chloroplast F_1-ATPase from spinach. *Biochemistry*, in press.

Current graduate students:

Chia-Yuan Hu (Ph.D., Chemistry)
Donald Crampton (Ph.D., Botany)
Ryan Bradley (M.S., Botany)
Christine Hatch (M.S., Botany)

Curriculum Vitae

J. Devens Gust, Jr.

Address:
Arizona State University
Department of Chemistry and Biochemistry
Tempe, Arizona 85287-1604

Personal Information:
Date of Birth: [redacted]
Place of Birth: [redacted]

Education:

Stanford University. B.S. (Prof. Harry Mosher, advisor)	1967
Princeton University	1967-1969
(U.S. Army)	(1969-1971)
Princeton University. M.A.	1972
Princeton University. Ph.D. (Prof. Kurt Mislow, advisor)	1974

Professional Experience:

Arizona State University, Professor of Chemistry	1985-present
Director, Center for the Study of Early Events in Photosynthesis	1991-1994
Asst. Chair for Graduate Studies	1986-1988
Assoc. Professor	1980-1985
Asst. Professor	1975-1980
Katholieke Universiteit Leuven, Belgium	
Visiting Scientist	1987, 1988
Visiting Professor of Chemistry	1989-1990
Muséum National d'Histoire Naturelle, Paris	
Visiting Professor of Biophysics	1982, 1985
Visiting Scientist	1986,87,88
CEN/Saclay, Départment de Physico-Chimie, Visiting Scientist	1982,84,86
California Institute of Tech., Postdoc. Research Fellow (Prof. J. D. Roberts, advisor)	1974-1975

Honors, Awards, and Service to Profession:

International Organizing Committee, International Conference on Photochemical Conversion and Storage of Solar Energy	1992-present
Co-Organizer, 10th Anniversary Symposium of the Japan-US Cooperative Photoconversion and Photosynthesis Research Program	1991
Councilor, American Society for Photobiology	1992-1995
Chair, Publications Committee, ASP	1993-present
Arizona State University Distinguished Research and Creative Activity Award, Graduate College	1988-1989

Selected Publications:

Gust, D., and Moore, T.A. (1993) Multistep electron and energy transfer in artificial photosynthesis. In: *The Photosynthetic Reaction Center,* Volume II (J. Deisenhofer and J.R. Norris, eds.), pp. 419-464. Academic Press, New York.

Gust, D., Moore, T.A., Moore, A.L., Macpherson, A.N., Lopez, A., DeGraziano, J.M., Gouni, I., Bittersmann, E., Seely, G.R., Gao, F., Nieman, R.A., Ma, X.C., Demanche, L., Luttrull, D.K., Lee, S.-J., and Kerrigan, P.K. (1993) Photoinitiated electron and energy transfer in molecular pentads. *J. Am. Chem. Soc.* **115**, 11141-11152.

Gust, D., Moore, T.A., Moore, A.L., Krasnovsky, Jr., A.A., Liddell, P.A., Nicodem, D., DeGraziano, J.M., Kerrigan, P., Makings, L.R., and Pessiki, P.J. (1993) Mimicking the photosynthetic triplet energy transfer relay. *J. Am. Chem. Soc.* **115**, 5684-5691.

Hermant, R.M., Liddell, P.A., Lin, S., Alden, R.G., Kang, H.K., Moore, A.L., Moore, T.A., and Gust, D. (1993) Mimicking carotenoid quenching of chlorophyll fluorescence. *J. Am. Chem. Soc.* **115**, 2080-2081.

Gust, D., Moore, T.A., and Moore, A.L. (1993) Molecular mimicry of photosynthetic energy and electron transfer. *Accounts of Chemical Research* **26**, 198-205.

Gust, D. (1994) Molecular wires and girders. *Nature* **372**, 133-134.

Seely, G.R., Gust, D., Moore, T.A., and Moore A.L. (1994) The effect of anions on the electrochemistry of zinc tetraphenylporphyrin. *J. Chem. Phys.* **98**, 10659-10664.

Krasnovsky, Jr., A.A., Lopez, J., Chen, P., Liddell, P.A., Blankenship, R.E., Moore T.A., and Gust, D. (1994) Generation and quenching of singlet molecular oxygen by aggregated bacteriochlorophyll-*d* in model systems and chlorosomes. *Photosynth. Res.* **40**, 191-198.

Gust, D., Moore, T.A., and Moore, A.L. (1994) Photosynthesis mimics as molecular electronic devices. *IEEE Engineering in Medicine and Biology Magazine* **13**, 58-66.

DeGraziano, J.M., Liddell, P.A., Leggett, L., Moore, A.L., Moore, T.A., and Gust, D. (1994) Free energy dependence of photoinduced charge separation rates in porphyrin dyads. *J. Phys. Chem.* **98**, 1758-1761.

Reddi, E., Segalla, A., Jori, G., Kerrigan, P., Liddell, P.A., Moore, A., Moore, T., and Gust, D. (1994) Carotenoporphyrins as selective photodiagnostic agents for tumors. *British J. Cancer* **69**, 40-45.

Graduate students who graduated during the past five years:

Janice M. DeGraziano (Ph.D., Chemistry) Currently holds a faculty position at Worcester Polytechnic Institute
Susan Ann Hatlevig (Ph.D., Chemistry) Currently a postdoc at Oregon State Univesity
Larry O. G. Harding (Ph.D., Chemistry) Currently employed at Phillips Petroleum
Feng Gao (Ph.D., Chemistry) Currently a postdoc at Johns Hopkins University
David Keith Luttrull (Ph.D., Chemistry) Currently employed at Nalco Chemical Company
Lana Sue Leggett (Ph.D., Chemistry) Currently holds a position with Isis Pharmaceuticals
Seung-Joo Lee (Ph.D., Chemistry) Currently holds a faculty position at Phoenix College
Xiaochun Sharon Ma (Ph.D., Chemistry)

Current graduate students:

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Nyangenya Maniga (Ph.D., Chemistry)
Lori Noss (M.S., Chemistry)
John Sumida (Ph.D., Chemistry)

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Citizenship: USA

Education:

Goshen University, Goshen, Indiana. B.A., Chemistry	1960
University of Michigan, Ann Arbor. M.S., Biochemistry	1962
University of Michigan, Ann Arbor. Ph.D., Biochemistry Thesis: The differential incorporation of amino acids (*in vivo*) into proteins of the newborn rat epidermis	1965

Professional Experience:

Chair, Department of Botany, Arizona State University	1991-present
Acting Chair, Department of Biochemistry, Temple University School of Medicine	1989-1991
Professor of Biochemistry, Temple University School of Medicine	1977-1991
Associate Professor of Biochemistry, Temple University School of Medicine	1971-1977
Assistant Professor of Biochemistry, Rutgers University Medical School	1968-1971
Guest Investigator, Cell Biochemistry, The Rockefeller University, with Philip Siekevitz and George Palade	1966-1968
Research Associate, Biochemistry, Vanderbilt University, with Stanley Cohen	1965-1966
Teaching Assistant, Biochemistry, The University of Michigan, with I. Bernstein	1961-1965

Representative Publications:

Maloney, M.A., Hoober, J.K., and Marks, D.B. (1989) Kinetics of chlorophyll accumulation and formation of chlorophyll-protein complexes during greening of *Chlamydomonas reinhardtii* y-1 at 38 °C. *Plant Physiol.* **91**, 1100–1106.

Hoober, J.K., Maloney, M.A., Asbury, L.R., and Marks, D.B. (1990) Accumulation of chlorophyll *a/b*-binding polypeptides in *Chlamydomonas reinhardtii* y-1 in the light or dark at 38 °C. Evidence for proteolytic control. *Plant Physiol.* **92**, 419–426.

Hoober, J.K., Boyd, C.O., and Paavola, L.G. (1991) Origin of thylakoid membranes in *Chlamydomonas reinhardtii y-1* at 38°C. *Plant Physiol.* **96**, 1321–1328.

Hoober, J.K., and Hughes, M.J. (1992) Purification and characterization of a membrane-bound protease from *Chlamydomonas reinhardtii. Plant Physiol.* **99**, 932–937.

Phinney, D.G., and Hoober, J.K. (1992) Regulation of expression by divalent cations of a light-inducible gene in *Arthrobacter photogonimos*. *Arch. Microbiol.* **158**, 85–92.

Hoober, J.K., White, R.A., Marks, D.B., and Gabriel, J.L. (1994) Biogenesis of thylakoids with emphasis on the process in *Chlamydomonas*. *Photosynth. Res.* **39**, 15–31.

White, R.A., and Hoober, J.K. (1994) Biogenesis of thylakoid membranes in *Chlamydomonas reinhardtii* y1. A kinetic study of initial greening. *Plant Physiol.* **106**, 583–590.

Wolfe, G.R., and Hoober, J.K.. Evolution of thylakoid structure. In *Oxygenic Photosynthesis: The Light Reactions* (D.R. Ort and C.F. Yocum, eds.) Kluwer Academic Publishers, Dordrecht, in press.

Graduate students who graduated in the past five years:

Donald G. Phinney (Ph.D., Biochemistry) Currently a postdoc at Fox Chase Cancer Center
Evelyn Santana (M.S., Botany) Currently in Ph.D. program, Thomas Jefferson University
Richard A. White (Ph.D., Molecular and Cell Biology) Currently a postdoc at Mayo Clinic, Rochester, MN
Hsin-Sheng Yang (Ph.D., Molecular and Cell Biology) Currently a postdoc at SUNY Buffalo

Current graduate students:

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Yutaka Komine (M.S., Botany)
Hyoung-Shin Park (M.S., Botany)

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Citizenship: USA

Education:

Universidad Nacional de La Plata, Argentina. B. of Pharmacy	1964
Universidade Federal do Rio de Janeiro, Brazil. M.Sc.	1966
Texas Tech University. Ph.D.	1972

Professional Experience:

Arizona State University, Assoc. Prof. Chem.	1989-present
Ctr. for the Study of Early Events in Photosyn., Res. Spec.	1988-1989
Research Associate	1982-1988
Laboratoire de Physico-Chimie des Systèmes Polyphasés, Associé au CNRS (UA.330), Visiting Scientist	1984-1988
Muséum National d'Histoire Naturelle Lab. de Biophysique, Paris, Visiting Scientist	1982-1983
Arizona State University Am. Assoc. of Univ. Women Fellow	1980-1981
Visiting Assistant Professor	1977-1982
Teaching Intern	1976-1977
University of Washington, Research Associate	1974-1976
Teaching Associate	1973-1974
Texas Tech University, Welch Foundation Predoctoral Fellow	1968-1972
Teaching assistant	1967-1968
Universidad de La Plata, C.O.N.I.C.E.T. (Argent.) Res. Fellow	1966-1967
Teaching Assistant	1963-1966

Selected Publications:

Gust, D., Moore, T.A., Moore, A.L., Kang, H.-K., De Graziano, J.M., Liddell, P.A., and Seely, G. (1993) The effect of coordinated ligands on interporphyrin photoinduced electron transfer rates. *J. Phys. Chem.* **97**, 136-142.

Gust, D., Moore, T.A., Moore, A.L., Macpherson, A.N., Lopez, A., DeGraziano, J.M., Gouni, I., Bittersmann, E., Seely, G.R., Gao, F., Nieman, R.A., Ma, X.C., Demanche, L., Luttrull, D.K., Lee, S.-J., and Kerrigan, P.K. (1993) Photoinitiated electron and energy transfer in molecular pentads. *J. Am. Chem. Soc.* **115**, 11141-11152.

Gust, D., Moore, T.A., Moore, A.L., Krasnovsky, Jr., A.A., Liddell, P.A., Nicodem, D., DeGraziano, J.M., Kerrigan, P., Makings, L.R., and Pessiki, P.J. (1993) Mimicking the photosynthetic triplet energy transfer relay. *J. Am. Chem. Soc.* **115**, 5684-5691.

Hermant, R.M., Liddell, P.A., Lin, S., Alden, R.G., Kang, H.K., Moore, A.L., Moore, T.A., and Gust, D. (1993) Mimicking carotenoid quenching of chlorophyll fluorescence. *J. Am. Chem. Soc.* **115**, 2080 - 2081.

Gust, D., Moore, T.A., and Moore, A.L. (1993) Molecular mimicry of photosynthetic energy and electron transfer. *Accounts of Chemical Research* **26**, 198-205.

Lee, S.-J., DeGraziano, J.M., Macpherson, A.N., Shin, E.-J., Seely, G.R., Kerrigan, P.K., Moore, A.L., Moore, T.A., and Gust, D. (1993) Photoinitiated charge separation in a carotenoid-porphyrin-diquinone tetrad: Enhancement of quantum yields via control of electronic coupling. *J. Chem. Phys.* **176**, 321-336.

Reddi, E., Segalla, A., Jori, G., Kerrigan, P., Liddell, P.A., Moore, A., Moore, T., and Gust, D. (1994) Carotenoporphyrins as selective photodiagnostic agents for tumors. *British J. Cancer* **69**, 40-45.

Hung, S.-C., Lin, S., Macpherson, A.N., DeGraziano, J.M., Kerrigan, P.K., Liddell, P.A., Moore, A.L., Moore, T.A., and Gust, D. (1994) Kinetics of multistep photoinitiated electron transfer reactions in a molecular triad. *J. Photochem. Photobiol. A: Chem.* **77**, 207-216.

Moore, T.A., Gust, D., and Moore, A.L. (1994) Carotenoids: Nature's unique pigments for light and energy processing. *Pure & Appl. Chem.* **66**, 1033-1040.

DeGraziano, J.M., Liddell, P.A., Leggett, L., Moore, A.L., Moore, T.A., and Gust, D. (1994) Free energy dependence of photoinduced charge separation rates in porphyrin dyads. *J. Phys. Chem.* **98**, 1758-1761.

Graduate students who graduated in the past five years:

Su-Chun Hung (Ph.D., Chemistry) Currently a postdoc at UC-Berkeley
Pamela K. Kerrigan (Ph.D., Chemistry) Currently an Assist. Prof. at Manhattan College, NY
Shan Shao (M.S., Chemistry) Currently holds an industrial position in Phoenix, AZ
Arnaldo Lopez-Torres (M.S., Chemistry) Currently holding an industrial position in Ponce, PR

Current graduate students:

Jody Wissel (Ph.D., Chemistry)

Curriculum Vitae

Thomas A. Moore

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Personal Information:
Date of Birth: [redacted]
Place of Birth: [redacted]

Education:

Texas Tech University. B.A.	1968
Texas Tech University. Ph.D.	1975
Thesis: Electronic Excited States of Carotenoid Polyenes, Prof. Pill-Soon Song, Advisor	

Professional Experience:

Arizona State University, Prof. Chem.	1985 - present
Associate Professor	1981 - 1985
Assistant Professor	1976 - 1981
Laboratoire de Physico-Chimie des Systèmes Polyphasés, Associé au CNRS (UA.330), Visiting Scientist	1984, 1986, 1987, 1988
Chercheur Associé au CNRS	1985
CEN/Saclay, Dept. Biol. Service Biophysique,	1982 - 1983
Visiting Scientist	1984, 1987
University of Washington, Dept. of Chem., Lecturer	1974 - 1976
Research Associate, with Alvin Kwiram	1973, 1976

Selected Publications:

Gust, D., Moore, T.A., Moore, A.L., Kang, H.-K., De Graziano, J.M., Liddell, P.A., and Seely, G. (1993) The effect of coordinated ligands on interporphyrin photoinduced electron transfer rates. *J. Phys. Chem.* **97**, 136-142.

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Gust, D., Moore, T.A., Moore, A.L., Krasnovsky, Jr., A.A., Liddell, P.A., Nicodem, D., DeGraziano, J.M., Kerrigan, P., Makings, L.R., and Pessiki, P.J. (1993) Mimicking the photosynthetic triplet energy transfer relay. *J. Am. Chem. Soc.* **115**, 5684-5691.

Hermant, R.M., Liddell, P.A., Lin, S., Alden, R.G., Kang, H.K., Moore, A.L., Moore, T.A., and Gust, D. (1993) Mimicking carotenoid quenching of chlorophyll fluorescence. *J. Am. Chem. Soc.* **115**, 2080-2081.

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Lee, S.-J., DeGraziano, J.M., Macpherson, A.N., Shin, E.-J., Seely, G.R., Kerrigan, P.K., Moore, A.L., Moore, T.A., and Gust, D. (1993) Photoinitiated charge separation in a carotenoid-porphyrin-diquinone tetrad: Enhancement of quantum yields via control of electronic coupling. *J. Chem. Phys.* **176**, 321-336.

Reddi, E., Segalla, A., Jori, G., Kerrigan, P., Liddell, P.A., Moore, A., Moore, T., and Gust, D. (1994) Carotenoporphyrins as selective photodiagnostic agents for tumors. *British J. Cancer* **69**, 40-45.

Hung, S.-C., Lin, S., Macpherson, A.N., DeGraziano, J.M., Kerrigan, P.K., Liddell, P.A., Moore, A.L., Moore, T.A., and Gust, D. (1994) Kinetics of multistep photoinitiated electron transfer reactions in a molecular triad. *J. Photochem. Photobiol. A: Chem.* **77**, 207-216.

Moore, T.A., Gust, D., and Moore, A.L. (1994) Carotenoids: Nature's unique pigments for light and energy processing. *Pure & Appl. Chem.* **66**, 1033-1040.

DeGraziano, J.M., Liddell, P.A., Leggett, L., Moore, A.L., Moore, T.A., and Gust, D. (1994) Free energy dependence of photoinduced charge separation rates in porphyrin dyads. *J. Phys. Chem.* **98**, 1758-1761.

Graduate students who graduated in the past five years:

Robert E. Belford (Ph.D., Chemistry) Currently employed as a free-lance consultant
Eric L. Farringer (Ph.D., Chemistry) Currently president of Microprop
Isabelle Gouni (M.S., Chemistry) Currently with Microsoft
Jeff Lewis (Ph.D., Physics) Currently a postdoc at Arizona State University

Current graduate students:

Dereck Tatman (Ph.D., Chemistry)

Curriculum Vitae

Willem F. J. Vermaas

Address:
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Tempe AZ 85287-1601, USA
(602)965-3698

Personal Information:
Date of Birth: [redacted]
Place of Birth: [redacted]
Citizenship: Dutch (US resident)

Education:

Agricultural University, Wageningen, The Netherlands. Kandidaats degree in Biology (cum laude)	1979
Agricultural University, Wageningen, The Netherlands. Ingenieurs degree in Biology (cum laude)	1982
Agricultural University, Wageningen, The Netherlands. Doctorate degree in Agricultural Sciences (cum laude)	1984

Professional Experience:

Arizona State University; Center for the Study of Early Events in Photosynthesis; Director	1994-present
Arizona State University; Department of Botany; Professor	1994-present
Stockholm University, Stockholm, Sweden; Department of Biochemistry; Visiting Professor	1992-93
Arizona State University; Department of Botany; Associate Professor	1990-94
Assistant Professor	1986-90
E.I. du Pont de Nemours and Co., Inc., Wilmington DE; Central Research and Development Department; Visiting Scientist	1984-86
Agricultural University, Wageningen, The Netherlands; Department of Plant Physiological Research; Scientist	1983-84
Technische Universität Berlin, Berlin, Germany; Max-Volmer-Institute of Physical and Biophysical Chemistry; Research Associate	1982-83
Michigan State University, East Lansing MI; MSU/DOE Plant Research Laboratory; Research Associate	1981-82
University of Illinois at Urbana/Champaign, Urbana IL; Departments of Botany, and Physiology and Biophysics; Research Associate	1980-81

Honors, Awards, and Service to Profession:

Panel member, NSF Young Investigator Award program	1994
Member, Organizing Committee, International Biotechnology Conference	1993
Organizer, International Symposium on Molecular Biology of Photosynthesis	1991
Organizer, First Western Regional Photosynthesis Conference	1991
NSF Presidential Young Investigator Award	1990
Member, Editorial Board, *Photosynthesis Research*	1990-present
Deutsche Akademische Austauschdienst fellowship	1982
Research Award, Dutch Ministry of Agriculture and Fishery	1981
Unilever (The Netherlands) Award in Chemistry	1980

Ten Selected Publications:

Eggers, B., and Vermaas, W. (1993) Truncation of the D2 protein in *Synechocystis* sp. PCC 6803: A role of the C-terminal domain of D2 in photosystem II function and stability. *Biochemistry* **32**, 11419-11427.

Shen, G., Boussiba, S., and Vermaas, W.F.J. (1993) *Synechocystis* sp. PCC 6803 strains lacking photosystem I and phycobilisome function. *Plant Cell* **5**, 1853-1863.

Vermaas, W.F.J. (1993) Molecular-biological approaches to analyze photosystem II structure and function. *Ann. Reviews Plant Physiol. Plant Mol. Biol.* **44**, 457-481.

Vermaas, W.F.J., Shen, G., and Styring, S. (1994) Electrons generated by photosystem II are utilized by an oxidase in the absence of photosystem I in the cyanobacterium *Synechocystis* sp. PCC 6803. *FEBS Lett.* **337**, 103-108.

Vermaas, W., Vass, I., Eggers, B., and Styring, S. (1994) Mutation of a putative ligand to the non-heme iron in photosystem II: Implications for Q_A reactivity, electron transfer, and herbicide binding. *Biochim. Biophys. Acta* **1184**, 263-272.

Shen, G., and Vermaas, W.F.J. (1994) Chlorophyll in a *Synechocystis* sp. PCC 6803 mutant without photosystem I and photosystem II core complexes: Evidence for peripheral antenna chlorophylls in cyanobacteria. *J. Biol. Chem.* **269**, 13904-13910.

Shen, G., and Vermaas, W.F.J. (1994) Mutation of chlorophyll ligands in the chlorophyll-binding CP47 protein as studied in a *Synechocystis* sp. PCC 6803 photosystem I-less background. *Biochemistry* **33**, 7379-7388.

Vermaas, W.F.J. (1994) Evolution of heliobacteria: Implications for photosynthetic reaction center complexes. *Photosynth. Res.* **41**, 285-294.

Vermaas, W.F.J. (1994) Molecular-genetic approaches to study photosynthetic and respiratory electron transport in thylakoids from cyanobacteria. *Biochim. Biophys. Acta* **1187**, 181-186.

Tommos, C., Madsen, C., Styring, S., and Vermaas, W. (1994) Point-mutations affecting the properties of $Tyrosine_D$ in photosystem II. Characterization by isotopic labeling and spectral simulation. *Biochemistry* **33**, 11805-11813.

Graduate students who graduated during the past five years:

Shelly Carpenter (M.S., Botany) At School of Oceanography, University of Washington
Beth Eggers (M.S., Molecular and Cell Biology) At Barrows Neurological Hospital, Phoenix
Gaozhong Shen (Ph.D., Molecular and Cell Biology) At Pennsylvania State University
Jiujiang Yu (Ph.D., Botany) At USDA Southern Regional Research Center, New Orleans
Michael Zianni (M.S., Botany) At Ohio State University, Columbus

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Pradip Manna (Ph.D., Molecular & Cell Biology)
Dierk Seeburg (Ph.D., Botany)
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Collaborators:

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J. Bowyer	M. Ikeuchi	G. Renger	S. Styring
P. Camilleri	Y. Inoue	A.W. Rutherford	I. Vass

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University of Essex, U.K., Ph.D., Biology,	1984
University of Essex, Colchester, Essex, U.K., B.Sc. (Hons., Class 2(i)), Biological Chemistry	1980

Professional Experience:

Assistant Professor, Department of Botany, Arizona State University	1989-present
Postdoctoral scientist, University of California, Berkeley	1988-1989
SERC Postdoctoral Research Fellow, Botany Department, University of Cambridge, U.K.	1986-1988
Postdoctoral scientist, University of California, Riverside, California.	1984-1986
Visiting Postdoctoral Fellow, Department of Biochemistry, University of Nebraska, Lincoln, NE	1984

Honors, Awards and Service to Profession:

Director, NSF Research Experience for Undergraduate Summer Research Program, Arizona State University	1993-present
Postdoctoral Fellowship, Science and Engineering Research Council	1986-1988
Wain Postdoctoral Fellowship, Agricultural and Food Research Council	1984
Natural Environment Research Council Studentship	1980-1983

Selected Publications:

Bingham, S.E., Xu, R.-H., and Webber, A.N. (1991) Transformation of chloroplasts with the *psaB* gene encoding a polypeptide of the photosystem I reaction center. *FEBS Lett.* **292**, 137-140.

Hird, S.M., Webber, A.N., Dyer, T.A., and Gray, J.C. (1991) Differential expression of the chloroplast genes for the 47kDa chlorophyll *a*-protein and the 10 kDa phosphoprotein during chloroplast development in wheat. *Curr. Genetics* **19**, 199-206.

Ikeuchi, M., Eggers, B., Shen, G., Webber, A., Yu, L., Hirano, A., Inoue, Y., and Vermaas, W. (1991) Cloning of the *psbK* gene from *Synechocystis* sp. PCC 6803, and characterization of photosystem II mutants lacking PS II-K. *J. Biol. Chem.* **266**, 11111–11115.

Webber, A.N., Gibbs, P.B., Ward, J.B., and Bingham, S.E. (1993) Site-directed mutagenesis of the photosystem I reaction center in chloroplasts: the proline-cysteine motif. *J. Biol. Chem.* **268**, 12990-12995.

Xu, R.-H., Bingham, S.E., and Webber, A.N. (1993) Increased mRNA accumulation in a chloroplast *psaB* frameshift mutant of *Chlamydomonas reinhardtii* suggests a role for translation in *psaB* mRNA stability. *Plant Mol. Biol.* **22**, 465-474.

Webber, A.N., Nie, G.-Y., and Long, S.P. (1994) Acclimation of photosynthetic proteins to raising CO_2. *Photosynth. Res.* **39**, 413–426.

Bingham, S.E., and Webber, A.N. (1994) Maintenance and expression of heterologous genes in the chloroplast of *Chlamydomonas reinhardtii*. *J. App. Phycol.* **6**, 239–245.

Nie, G.-Y., Kimball, B.A., Pinter, P.J., Wall, G.W., Garcia, R.L., LaMorte, R.L., Webber, A.N., and Long, S.P. (1995) Free-air CO_2 enrichment effects on the development of the photosynthetic apparatus in wheat, as indicated by changes in leaf proteins. *Plant Cell Envir.*, in press.

Webber, A.N., and Baker, N.R. (1995) Control of thylakoid membrane development and assembly. In: *Oxygenic Photosynthesis: The Light Reactions* (D.R. Ort and C.F. Yocum, eds.). Kluwer Academic Publishers, in press.

Cui, L., Bingham, S.E., Kuhn, M.B.H., Lubitz, W., and Webber, A.N. (1995) Site-directed mutagenesis of conserved histidines in the helix VIII domain of PsaB impairs assembly of the photosystem I reaction center without altering spectroscopic characteristics of P700. *Biochemistry*, in press.

Graduate students who graduated in the past five years:

Liying Cui (M.S., Botany)

Current graduate students:

Hyeonmoo Lee (Ph.D., Molecular and Cell Biology)
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Curriculum Vitae

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Education:

University of California at Davis. B.S., Biochemistry	1979
University of Washington. Ph.D., Biochemistry	1986
Thesis: The Primary reactions of Bacterial Photosynthesis: Delayed Fluorescence and Picosecond Resolution Transient Absorption Spectroscopy. Prof. William Parson, Advisor.	

Professional Experience:

Arizona State University, Assoc. Prof. Chem.	1994 - present
Asst. Prof. Chem. (on leave 1987)	1987 - 1994
Stanford University, NSF Postdoctoral Fellow with Steven Boxer	1987 - 1988
Carnegie Inst. of Washington, Dept. of Plant Biology, NSF Postdoctoral fellow with William Thompson	1986 - 1987
Univ. of Washington, Graduate Research with William Parson	1979 - 1986
University of California at San Diego, Undergraduate Research with Russell Doolittle	1978 - 1979

Honors, Awards, and Service to the Profession:

NSF Presidential Young Investigator Award	1991
NSF Postdoctoral Fellowship in Plant Molecular Biology	1985
National Institutes of Health Competitive Molecular and Cellular Biology Predoctoral Training Grant	1981

Selected Publications:

Taguchi, A.K.W., Stocker, J.W., Alden, R.G., Causgrove, T.P., Peloquin, J.M., Boxer, S.G., and Woodbury, N.W. (1992) Biochemical characterization and electron-transfer reactions of *sym1*, a *Rhodobacter capsulatus* reaction center symmetry mutant which affects the initial electron donor. *Biochemistry* **31**, 10345–10355.

Peloquin, J.M., Williams, J.C., Lin, X., Alden, R.G., Murchison, H.A., Taguchi, A.K.W., Allen, J.P., and Woodbury, N.W. (1994) Time-dependent thermodynamics during early electron transfer in reaction centers from *Rhodobacter sphaeroides*. *Biochemistry* **33**, 8089–8100.

Woodbury, N.W., Peloquin, J.M., Alden, R.G., Lin, X., Lin, S., Taguchi, A.K.W., Williams, J.C., and Allen, J.P. (1994) Relationship between thermodynamics and mechanism during photoinduced charge separation in reaction centers from *Rhodobacter sphaeroides*. *Biochemistry* **33**, 8101–8112.

Xiao, W, Lin, S, Taguchi, A.K.W., and Woodbury, N.W. (1994) Femtosecond pump-probe analysis of energy and electron transfer in photosynthetic membranes of *Rhodobacter capsulatus*. *Biochemistry* **33**, 8313–8322.

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Graduate students who graduated during the past five years:

Dennis M. Gallo, Jr. (Ph.D., Chemistry) Currently a postdoc at Chicago State University
Jeffrey M. Peloquin (Ph.D., Chemistry) Currently a postdoc at the University of California at Davis
Weizhong Xiao (Ph.D., Chemistry) Currently a postdoc at the University of Pennsylvania

Current graduate students:

J. Elizabeth Eastman (Ph.D., Chemistry)
Chu-Kang Tang (Ph.D., Chemistry)

Appendix C:

ASU Center for the Study of Early Events in Photosynthesis

1994–1995 Committee Roster

Executive Committee:

James Allen
Robert Blankenship
Wayne Frasch
Devens Gust
Kenneth Hoober
Sheng Lin (on leave)
Ana Moore
Thomas Moore
Wim Vermaas, Chair and Director of Center
Andrew Webber
Neal Woodbury

Standing Committees*

Facilities and Equipment:

N. Woodbury, Chair
D. Brune
R. LoBrutto
R. Nieman

Finance:

R. Blankenship, Chair
D. Gust
K. Hoober

Personnel:

W. Frasch, Chair
J. Allen
T. Moore

Publications and Conference:

A. Webber, Chair
S. Bingham
N. Woodbury

Seminar:

J. Allen, Chair
A. Moore
A. Webber

All committee recommendations are subject to approval by the Executive Committee.
*The Center Director is an *ex officio* member of all standing committees.

Appendix D:

Scientific Publications

Arizona State University
Center for the Study of Early Events in Photosynthesis

1. Gust, D., Moore, T., Moore, A., Makings, L., Seely, G., Ma, X., Trier, T. and Gao, F. (1988) A carotenoid-diporphyrin-quinone model for photosynthetic multistep electron and energy transfer. *J. Am. Chem. Soc.* 110: 7567–7569.

2. Vermaas, W., Rutherford, A.W. and Hansson, Ö. (1988) Site-directed mutagenesis in Photosystem II of the cyanobacterium *Synechocystis* sp. PCC 6803: Donor D is a tyrosine residue in the D2 protein. *Proc. Natl. Acad. Sci. USA* 85: 8477–8481.

3. Vermaas, W. (1988) Photosystem II function as probed by mutagenesis. *Light-Energy Transduction in Photosynthesis: Higher Plant and Bacterial Models*, Stevens, S.E., Jr. and Bryant, D.A., Eds., American Society of Plant Physiologists, Rockville MD, 197–214.

4. Carpenter, S.D. and Vermaas, W.F.J. (1988) *Synechocystis* 6803 mutants with a CP43 protein from spinach. *Light-Energy Transduction in Photosynthesis: Higher Plant and Bacterial Models*, Stevens, S.E., Jr. and Bryant, D.A., Eds., American Society of Plant Physiologists, Rockville MD, 327–331.

5. Blankenship, R.E., Brune, D.C. and Wittmershaus, B.P. (1988) Chlorosome antennas in green photosynthetic bacteria. *Light-Energy Transduction in Photosynthesis: Higher Plant and Bacterial Models*, Stevens, S.E., Jr. and Bryant, D.A., Eds., American Society of Plant Physiologists, Rockville MD, 32–46.

6. Freeman, J.C. and Blankenship, R.E. (1990) Isolation and characterization of the membrane-bound cytochrome *c*-554 from the thermophilic green photosynthetic bacterium *Chloroflexus aurantiacus*. *Photosynth. Res.* 23: 29–38.

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8. Brune, D.C. (1989) Sulfur oxidation by phototrophic bacteria. *Biochim. Biophys. Acta* 975: 189–221.

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10. Gust, D., Moore, T.A., Moore, L., Seely, G., Liddell, P., Barrett, D., Harding, L.O., Ma, X.C., Lee, S.-J. and Gao, F. (1989) A carotenoid-porphyrin-diquinone tetrad: Synthesis, electrochemistry and photoinitiated electron transfer. *Tetrahedron* 45: 4867–4891.

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14. Fain, B., Lin, S.H. and Hamer, N. (1989) Two-dimensional spectroscopy: Theory of non-stationary, time-dependent absorption and its application to femtosecond processes. *J. Chem. Phys.* 91: 4485–4494.

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photosynthetic reaction centers. *Advances in Multiphoton Processes and Spectroscopy*, Vol. 7, World Publishing Co., pp. 239–311.

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Blankenship, R.E., Madigan, M. and Bauer, C.E., eds. Kluwer Academic Publishers, Dordrecht, in press.

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229. Saviken VanNoort , Blankenship, Struve Chem Phys, in press

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232. Webber, A.N. and Baker Neil (1995) Control of thylakoid membrane development and assembly. In: Ort, D.R. and Yocum C.F. (eds) Oxygenic Photosynthesis: The Light Reactions, pp . Kluwer Academic Publishers, Dordrecht in press

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235. Webber, A.N., Bingham, S.E. and Lee, H. (1995) Genetic engineering of thylakoid protein complexes by chloroplast transformation in *Chlamydomonas reinhardtii*. *Photosynth. Res.*, in press

236. Kless, H. and Vermaas, W.F.J. (1995) Tandum sequence duplications functionally complement deletions in the D1 protein of Photosystem II J Biol Chem, in press.

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Appendix E: Former Students

Degrees Awarded

Arizona State University
Center for the Study of Early Events in Photosynthesis

Doctor of Philosophy:

Spring 1989

John C. Freeman, Chemistry
B.S. Whitworth College, 1984
Dissertation: "Isolation and Characterization of the Membrane Bound Cytochrome *c*-554 from the Thermophilic Green Photosynthetic Bacterium *Chloroflexus aurantiacus*".
Prof. Robert E. Blankenship, Advisor.
Currently a Postdoctoral Fellow at Penn State University with J. Villafranca.

Susan Ann Hatlevig, Chemistry
B.S. Arizona State University, 1983
M.S. University of California, San Diego, 1984
Dissertation: "Synthesis and Photophysical Studies of Photosynthetic Model Compounds".
Prof. Devens Gust, Advisor.
Currently with Unocal.

Fall 1989

Larry O. G. Harding, Chemistry
B.S. University of Sierra Leone, 1978
Dissertation: "Preparation and Photochemistry of Photosynthesis Model Systems".
Prof. Devens Gust, Advisor.
Currently a Postdoctoral Fellow at the University of Texas at Arlington with M. Pomerantz.

Pei Chung Chen, Chemistry
Dissertation: "A Theoretical Model of the Hole Burning Spectroscopy and the Kinetic Studies of the N,N'–Diacetylindigo".
Prof. Sheng H. Lin, Advisor.
Currently fulfilling military obligation in Taiwan.

Fall 1990

Jeffrey T. Trost, Chemistry
B.S. Bacteriology and Biochemistry, U. of Wisconsin, Madison, 1985.
Dissertation: "Characterization of the Photosynthetic Reaction Center-Core Antenna Complex form the Heliobacteria".

Prof. Robert E. Blankenship, Advisor.
Currently a Research Scientist at Pharmacia.

James D. McManus, Chemistry
B.A. Biology and B.S. Chemistry, Nebraska Wesleyan University, 1986.
Dissertation: "Auracyanin: A Novel Class of Blue Copper Proteins from the Photosynthetic Bacterium Chloroflexus Aurantiacus".
Prof. Robert E. Blankenship, Advisor.
Currently a Research Scientist with Clorox Corp.

Feng Gao, Chemistry
Dissertation: "Synthesis, Photochemistry and Electrochemistry of Photosynthetic Model Systems".
Prof. Devens Gust, Advisor
Currently a Postdoctoral Fellow at Wright State University with J. Kane.

Spring 1991

David Keith Luttrull, Chemistry
B.A., Point Loma Nazarene College, 1985
M.S., Bowling Green State University, 1987
Dissertation: "Photophysics and Scanning Tunneling Microscopy of Porphyrin-Based Molecular Devices".
Prof. Devens Gust, Advisor
Currently a Postdoctoral Fellow at the University of Rochester with Ian Gould.

Summer 1991

Xiaochun Sharon Ma, Chemistry
B.S., Peking University, 1985
Dissertation: "Nuclear Magnetic Resonance Studies of Photosynthetic Macromolecular Systems".
Prof. Devens Gust, Advisor

Fall 1991

Jiujiang Yu, Botany

Prof. Wim Vermaas, Advisor
Currently employed by U.S. Government in Louisiana

Fall 1992

Peiling Cheng, Chemistry
B.S., Arizona State University, 1988
Dissertation: Characterization of Energy Transfer and Structure of Antenna System of Green Photosynthetic Bacteria
Prof. Robert E. Blankenship, Advisor

Lana Sue Leggett, Chemistry
B.S., University of Missouri, 1983
M.S., University of Missouri, 1988
Dissertation: Photoinduced Energy and Electron Transfer in Diporphyrins
Prof. Devens Gust, Advisor

Spring 1993

Robert Eugene Belford, Chemistry
B.S., Arizona State University, 1987
Dissertation: Nitoxyl Free Radical Enhancement of the Forbidden Singlet Oxygen Luminescent Transition
Profs. Thomas A. Moore and Sheng H. Lin, Advisors

Seung-Joo Lee, Chemistry
B.S., Kyung Hee University, 1981
M.S., Kyung Hee University, 1984
Dissertation: Synthesis and Photochemistry of a Photosynthetic Molecular Tetrad
Prof. Devens Gust, Advisor

Jeffrey Earl Lewis, Physics
B.S., University of Nevada, 1981
M.S., University of Nevada, 1984
Dissertation: The Triplet Energy of a Carotenoid Pigment Determined by Photoacoustic Calorimetry
Prof. Thomas A. Moore, Coadvisor

Summer 1993

Pamela Katherine Kerrigan, Chemistry
B.A., Lakeland College, 1981
B.S., University of Wisconsin at Milwaukee, 1986
Dissertation: Carotenoporphyrins in Cancer Diagnosis and Phototherapy
Prof. Ana L. Moore, Advisor

Fall 1993

Janice M. DeGraziano, Chemistry
B.S., University of Maine, 1986
Dissertation: Photoinitiated Interporphyrin Electron Transfer in Photosynthetic Model Systems
Prof. Devens Gust, Advisor

Gaozhong Shen, Molecular and Cellular Biology
B.Agronomy, Sichuan Agricultural University, 1982
M.Agronomy, Sichuan Agricultural University, 1984
Dissertation: Genetic Engineering of Genes Coding for Components of the Photosynthetic Apparatus in Cyanobacteria
Prof. Wim Vermaas, Advisor

Shaojie Wang, Chemistry
B.S., Shanghai Medical University, 1984
Dissertation: Biochemical and Genetic Studies of Reaction Centers form Purple Bacteria
Prof. James Allen, Advisor

Master of Science:

Spring 1990

Shelly D. Carpenter, Botany
B.S. Microbiology, Arizona State University, 1987
Thesis: "Structure/Function Relationships of the Photosystem II Protein CP 43 as Probed by Mutagenesis".
Prof. Willem Vermaas, Advisor.
Currently at School of Oceanography, University of Washington.

Michael Zianni, Botany
B.S. Biology, Westminster College, New Wilmington, PA, 1987.
Thesis: "Ultrastructure of Phycobilisomes in the Cyanobacterium *Synechocystis* sp. PCC6803".
Prof. Willem Vermaas, Advisor.
Currently an Instructor at Westminster College.

Summer 1991

Stephanie Hsiao-Hsien Wang, Chemistry
B.S.
Thesis: Purification and Characterization of APS Reductase from the Photosynthetic Bacterium *Thiocapsa roseopercicina.*
Prof. Robert E. Blankenship, Advisor.
Currently enrolled in Ph.D. program.

Fall 1991

George Hamilton King, Chemistry
B.S., Chemistry, Arizona State University, 1984
J.D., Law, Arizona State University, 1990
Thesis: "Spectral Properties of Various Oligomers of Bacteriochlorophyll *c*".
Prof. Robert E. Blankenship, Advisor.
Currently an attorney with Phoenix law firm.

Ruohui Xu, Botany
Thesis: "Regulation of gene expression in a chloroplast Photosystem I mutant of *Chlamydomonas reinhardtii*".
Prof. Andrew Webber, Advisor.
Currently working as a Research Assistant at Johns Hopkins University.

Summer 1992

Beth Eggers, Molecular and Cellular Biology
Prof. Wim Vermaas, Advisor
Currently working with NIH in Phoenix, AZ.

Arnaldo Lopez-Torres, Chemistry
Prof. Ana L. Moore, Advisor

Shan Shao, Chemistry
Prof. Sheng H. Lin, Advisor

Spring 1993

Yi Fen Li, Chemistry
Prof. Sheng H. Lin, Advisor

Fall 1993

Chu-Kang Tang, Chemistry
Profs. Sheng H. Lin and Neal Woodbury, Advisors

Fall 1994

Liying Cui, Botany
Thesis: "Mutagenesis of conserved histidines in the membrane span VIII domain of PsaB"
Prof. Andrew N. Webber, Advisor

Master of Natural Science:

Spring 1990

Pushpa Ramakrishna, Chemistry

B.S. Chemistry, M.S. Biochemistry, Bangalore University, India.
Thesis: "Cloning of the Auracyanin Gene from the Thermophilic Green Photosynthetic Bacterium *Chloroflexus aurantiacus*".
Profs. Robert E. Blankenship and Willem Vermaas, Advisors.
Currently at Karkinos Biochemistry, Inc.

Fall 1991

Xiaoxiang Sarah Xu, Chemistry
B.S. Xi'an Jiatong University, China
Profs. Sheng H. Lin and Neal Woodbury, Coadvisors
Currently enrolled in the College of Engineering

Appendix F: Seminars

Arizona State University
Center for the Study of Early Events in Photosynthesis

Seminars
1988-89

Date	Speaker	Affiliation	Title
9/20/88	Thomas Moore	Arizona State University	Mimicry of the Triplet Energy Transfer Relay of *Rb. sphaeroides*
10/7/88	Noam Adir	Hebrew Univ., Israel	Structural Properties of the D1 Protein as Related to Its Light Dependent Turnover
10/18/88	Gilbert Seely	Arizona State University	Chlorophyll in Cationic Inverted Micelles: A New Model System?
11/1/88	Ana Moore	Arizona State University	Diporphyrin Models for Photosynthetic Multistep Electron Transfer
11/15/88	Sheng Lin	Arizona State University	Theory of Photo-induced Intramolecular Electron Transfer
11/29/88	Aileen Taguchi	Arizona State University	Recent Developments in the Study of Chaperonian Mediated Assembly of Protein Complexes
12/12/88	Elizabeth Gross	Ohio State Univ.	Chemical Modification of Plastocyanin and its Interaction with Cytochrome *f*
1/10/89	Mark Trulson	Massachusetts Institute of Technology	UV Resonance Raman Investigations of Early Photochemical Dynamics
1/17/89	David Luttrull	Arizona State University	Fluorescence Studies of Molecular Dynamics of Two Biomimetic Systems
1/20/89	William Rutherford	CEN-Saclay, France	Tetraheme Cytochrome *c* Complex of *R. viridis* Reaction Centers
1/31/89	Philip Thornber	University of California-Los Angeles	Molecular Organization of Pigments in Higher Plant Chloroplasts
2/20/89	Robert Haselkorn	University of Chicago	Molecular Genetics of Herbicide Resistance in Cyanobacteria
2/21/89	Leslie Dutton	University of Pennsylvania	Intra-Protein Electron Transfer

2/23/89	John Biggins	Brown University	Regulation of the Distribution of Excitation Energy in Photosynthesis
2/28/89	John Olson	Odense University, Denmark	Evolution of Photosynthesis
3/1/89	John McCracken	Albert Einstein Medical College, New York	Electron Spin Echo Studies of the Nickel Binding Site of *D. gigas* hydrogenase
3/13/89	James Allen	University of California-San Diego	Structure of the Reaction Center of the Photosynthetic Bacterium *Rhodobacter sphaeroides*
3/14/89	Richard Debus	University of California-Riverside	Site Directed Mutagenesis Identifying Two Tyrosine Residues Shown to be Redox Components of Photosystem II
3/15/89	Stephen Fodor	University of California-Berkeley	Phototransduction and Proton Pumping
3/27/89	Johann Deisenhofer	University of Texas, S.W., Medical Center	The Three-Dimensional Structure of the Photosynthetic Reaction Center from *Rhodopseudomonas viridis*
4/18/89	Timothy Causgrove	Arizona State University	Excitation Energy Transfer in Photosynthetic Antennae Studied by Polarized Pump-Probe Spectroscopy
4/25/89	Barry Bruce	University of California-Berkeley	Structure, Function and Assembly of Higher Plant Photosynthetic Complexes
5/9/89	Jeffrey Trost	Arizona State University	Isolation of the Photosynthetic Reaction Center from *Heliobacillus mobilis*
6/16/89	Elias Greenbaum	Oak Ridge National Laboratory	Kinetics and Mechanistic Studies of Vectorial Photoelectrochemistry of Photosynthesis
6/22/89	Alexander A. Krasnovsky, Jr.	State University of Moscow, Russia	Singlet Oxygen Luminescence in Photobiological Systems
7/11/89	Aden Rehms	Arizona State University	Two-Photon Spectroscopy of Indoles
7/18/89	Mark Evans	Arizona State University	Light Harvesting in Purple Photosynthetic Bacteria
7/25/89	Silvia Braslavsky	Max-Planck-Institut für Strahlenchemie, Mülheim, Germany	Optoacoustic Studies on Photosynthetic Units

1989-90

Date	Speaker	Affiliation	Title
9/7/89	Robert Blankenship	Arizona State University	Redox Control of Energy Transfer in Chlorosome Antennas of Green Photosynthetic Bacteria
9/14/89	Julian Eaton-Rye	Arizona State University	The Influence of Anions on Q_A^- Oxidation and the Function of the N-Terminus of the Extrinsic 33 kD Protein from PS II
9/21/89	Gilbert Seely	Arizona State University	Energy Transfer in PCP Complexes
9/28/89	Neal Woodbury	Arizona State University	Structure-Function Studies of Photosynthetic Reaction Centers from *Rb. capsulatus*
10/5/89	Bruce Wittmershaus	Arizona State University	The Light-Harvesting System of Photosystem I
10/12/89	Mark Ondrias	University of New Mexico	Time-Resolved Optical Spectroscopic Studies of Metalloporphyrins and Heme Proteins
10/19/89	Barry Osmond	Duke University	Photoinhibition at Low Temperatures
10/26/89	Jim McManus	Arizona State University	Biochemical Characterization and Phylogenetic Analysis of Auracyanin, a Blue Copper Protein from the Photosynthetic Bacterium *Chloroflexus aurantiacus*
10/30/89	Albert Weller (Chemistry)	Max-Planck-Institut für Biophysikalische Chemie, Göttingen, Germany	Photoinduced Bimolecular Electron Transfer Reactions in Polar Solvents: Kinetics, Spin Dynamics, and Magnetic Field Effects
10/31/89	Albert Weller (Chemistry)	Max-Planck-Institut für Biophysikalische Chemie, Göttingen, Germany	Photoinduced Intramolecular Electron Transfer Processes in Polymethylene Linked Donor Acceptor Systems: Chain Dynamics and Magnetic Field Effects
11/9/89	Chin Yeh	Arizona State University	Electronic Structure and Spectra of Chlorophylls

11/16/89	David Luttrull	Arizona State University	Photophysical Studies of Two Strategically Functionalized Tetraarylporphyrins: Potential Components in Molecular Electronic Devices
11/30/89	Daniel Brune	Arizona State University	Sulfur Globules Formed During Oxidation of H_2S by Photosynthetic Bacteria
12/7/89	Robert Belford	Arizona State University	Solvent Deactivation of Singlet Oxygen ($^1\Delta_g$)
12/13/89	Edith Bittersmann	Arizona State University	Time-resolved Fluorescence of Cyanobacterial Photosystem II-Mutants
1/5/90	Jim Barber	Imperial College, London, U.K.	Similarities and Differences Between Reaction Centers of Photosystem II and Purple Bacteria
1/11/90	Mamoro Mimuro	National Inst. for Basic Biology, Japan	Excitation Energy Flow in Purple Photosynthetic Bacteria: Analysis by Means of Time-Resolved Fluorescence Spectra
1/22/90	Arvi Freiberg	Institute of Physics Estonian Academy of Sciences, Tartu, Estonia	Time-Resolved Fluorescence Studies in Photosynthetic Systems
1/25/90	John Golbeck	Portland State University	Resolution and Reconstitution of the Photosystem I Complex
2/1/90	Mel Okamura	University of California-San Diego	Proton Uptake and Herbicide Resistance in Reaction Centers from *Rb. sphaeroides*
2/8/90	Barbara Demmig-Adams	University of Colorado	Photoprotection by Carotenoids
2/15/90	Ora Canaani	Weizmann Institute of Science, Rehovot, Israel	Regulation of Excitation Energy Distribution Between the Two Photosystems and the Role of Cytochrome *b*-559 *in vivo*
2/19/90	Jonathan Moore	Institut für Molekularbiologie und Biophysik, ETH Zurich, Switzerland	Three Dimensional Solution Structure of Plastocyanin

2/22/90	Vincent Pecoraro	University of Michigan	Manganese in Biological Systems: From Voodoo to Oxygenic Photosynthesis
3/1/90	Roger Isaacson	University of California-San Diego	EPR and ENDOR in Bacterial Photosynthesis
3/8/90	Hans Matthijs	University of Amsterdam, The Netherlands	*Prochlorothrix hollandica*: the Granddaddy of Chloroplasts?
3/9/90	Robert Knox	University of Rochester	Primary Antenna Fluorescence of Chloroplasts and *Chlamydomonas*
3/15/90	Steven Boxer	Stanford University	Mechanisms of Charge Separation and Recombination in Photosynthetic Reaction Centers: Electric Field Effects
3/16/90	Achim Trebst	Lehrstuhl für Biochemie der Pflanzen, Ruhr-Universität Bochum, Bochum, Germany	Topography of Photosystem II and Molecular Mechanisms of Photoinhibition
3/29/90	John Mullet	Texas A & M University	Regulation of Gene Expression During Chloroplast Biogenesis
4/5/90	George Atkinson	University of Arizona	Picosecond Time-Resolved Raman Spectroscopy of Photosynthetic Systems
4/12/90	Martina Huber	University of California-San Diego	Porphyrin-Quinone Model Compounds: Theoretical and Experimental Aspects of Electron Transfer
4/12/90	Gernot Renger	Max Volmer Inst. for Biophysical and Physical Chemistry, Technical University, Berlin, Germany	Recent Results on the Structure and Function of Photosystem II in Higher Plants
4/19/90	Bruce Mainsbridge	Murdoch University Murdoch, Australia	Scanning Tunneling Microscopy and Imaging of Biological Surfaces
5/3/90	Matthias Kuhn	Arizona State University	Photoinhibition in Photosystem II Membrane Fragments from Higher Plants

5/10/90	Govindjee	University of Illinois, Urbana	Photosystem II and Bicarbonate
5/17/90	Gordon Tollin	University of Arizona	Site-Directed Mutagenesis as a Tool in Elucidating Biological Electron Transfer Mechanisms: The cyt *c* – cyt *c* Peroxidase System from Yeast
5/25/90	Craig Schenck	Colorado State University	Site-Directed Mutants Affecting Primary Photochemistry in the Bacterial Reaction Center
5/31/90	Sergei Shestakov (MCB)	University of Moscow and Vavilov Institute of Genetics, Russia	Cyanobacterial Transformation and Mutant Complementation
6/21/90	Wolfgang Lubitz	Physikalische Institut, Universität Stuttgart, Germany	ENDOR Studies of Photosynthetic Pigments and Reaction Centers
8/2/90	Jan Verhoeven	Universiteit van Amsterdam, The Netherlands	Electrons and Molecules Put in Motion by Light
8/6/90	Alfred R. Holzwarth	Max-Planck-Institut für Strahlenchemie Mülheim, Germany	Energy Transfer and Charge Separation Processes in Green Photosynthetic Bacteria Studied by Picosecond Spectroscopy
8/9/90	Irmgard Sinning	Max-Planck-Institut für Biophysik Frankfurt, Germany	Recent Advances in the X-ray Structure Analysis of Herbicide-Resistant Mutants from *Rhodopseudomonas viridis*
8/9/90	Ute Feiler	Max-Planck-Institut für Biophysik Frankfurt, Germany	Characterization of an Improved Reaction Center Preparation from *Chlorobium*
8/22/90	Neil Baker	University of Essex, U.K.	Molecular Basis of Low Temperature Induced Photoinhibition in Maize

1990-91

Date	Speaker	Affiliation	Title
9/10/90	Robert E. Blankenship	Arizona State University	Hints on the Evolution of Photosynthesis by Analysis of Reaction Centers from Primitive Photosynthetic Bacteria
9/11/90	N. Lebedev	A. N. Bakh Institute of Biochemistry, Moscow, U.S.S.R.	Reversible Reorganization of Photosystem II in the Dark
9/20/90	JoAnn Williams	Arizona State University	Probing the Role of the Iron Atom in Bacterial Reaction Centers
9/27/90	Peter Ogilby (Chemistry)	University of New Mexico	Excited State Interactions Between Molecular Oxygen and Organic Molecules in Gases, Liquids, and Solid Polymers
10/11/90	Jeff Trost	Arizona State University	Characterization of the Photosynthetic Reaction Centers from the Heliobacteria: A Bacterial Model System for Photosystem I
10/18/90	Pam Gibbs	Arizona State University	Regulation of Excitation Energy Distribution in Algae with a Chlorophyll *a*, *c* Fucoxanthin Light Harvesting Antenna Protein
10/25/90	Don Hendrix	USDA Western Cotton Research Lab., Phoenix	Application of Recent Developments in Photosynthetic Partitioning to Cotton Physiology
11/1/90	Frans van Mieghem	CEN Saclay, France	EPR Studies on the Reaction Center Triplet of Photosystem II
11/8/90	Peter Rentzepis (Chemistry)	University of California-Irvine	Picosecond X-ray Diffraction: a Novel Means for Chemical and Biological Dynamics
11/15/90	Aileen Taguchi	Arizona State University	Chimeric Rescue: A Novel Method for the Generation of Photosynthetic Reaction Center Mutants in *Rhodobacter capsulatus*
11/29/90	Rhett Alden	Arizona State University	Investigations of the Early Electron Transfer Steps in Bacterial Photosynthetic Reaction Centers

12/6/90	Tim Causgrove	Arizona State University	Spectroscopic Characterization of a Bacteriochlorophyll *c* Aggregate
12/13/90	Jiujiang Yu	Arizona State University	Destabilization of Photosystem II Reaction Centers in Cyanobacterial Mutants
12/20/90	Stella Dracheva	Arizona State University	The Four-Heme Cytochrome *c* Subunit from Reaction Centers of Photosynthetic Bacteria
1/16/91	Russell LoBrutto (Botany)	Northeastern University	Structure and Function of Metal Centers in Proteins: Pulsed EPR Studies
1/23/91	Curtis Hoganson (Botany)	Michigan State University	Flash Photolysis Studies of Photosystem II: Throwing Light on the Mystery of Water Oxidation
1/24/91	Martin Gibbs	Brandeis University	Carbohydrate Respiration in Chloroplasts from Spinach and *Chlamydomonas*
2/4/91	Barry Marrs (MCB)	E. I. duPont de Nemours & Co., Wilmington, DE	How Oxygen Controls Photosynthetic Membrane Development in *Rhodobacter capsulatus*
2/5/91	Robert Hwang-Schweitzer	University of Rochester	Fluorescence Studies of Photoregulation in the Chrysophytic Alga *Ochromonas danica*
2/12/91	Vladimir Shinkarev	University of Illinois	The Function of Quinone Acceptors in Different Types of Photosynthetic Bacteria
2/13/91	Mohanram Sivaraja (Botany)	Princeton University	Role of Calcium in Photosynthetic Oxygen Evolution
2/19/91	Howard Gest	Indiana University	Anoxygenic Photosynthetic Bacteria: New Species & New Research Directions
2/20/91	Michael Hendrich (Botany)	University of Minnesota	EPR from "EPR–Silent" Metalloproteins
2/20/91	Richard Friesner	Columbia University	Spectroscopy and Electron Transfer Dynamics of the Bacterial Photosynthetic Reaction Center
2/20/91	John Delaney	Rockefeller University	Electron Tunneling in a Cofacial Zinc Porphyrin Quinone Cage Molecule: Temperature and Solvent Dependence

2/21/91	Antony Crofts	University of Illinois	Mechanism of the Two-Electron Gate: Binding of Inhibitors and Inhibitor Resistance
2/28/91	Wolfgang Nitschke	CEN Saclay, France	Reaction Center Associated Cytochrome Subunits: An Overview
3/7/91	Colin Wraight	University of Illinois	Electron and Proton Transfer Pathways in Photosynthetic Reaction Centers
3/15/91	Gerald Babcock	Michigan State University	Electron Transport and Water Oxidation in Photosystem II
3/28/91	Valentina Godik	Moscow State University, Russia	Dynamics of Excitation Energy Transfer and Trapping in Purple Bacteria Probed by Picosecond Fluorescence
4/11/91	Therese Cotton	Iowa State University	Spectroscopic Studies of Photosynthetic Systems at Surfaces
4/22/91	Nai-Teng Yu	Hong Kong University of Science & Technology	Resonance Raman Studies of Ligand Binding to Allosteric Hemoproteins
4/23/91	Eugene Koonin	Institute of Microbiology, U.S.S.R. Academy of Science, Russia	What Can Be Derived From Comparison of Amino Acid Sequences?
4/24/91	Hugo Scheer	Botanisches Institut, Universität München, Germany	Bacterial Reaction Centers with Modified Bacteriochlorophylls and Bacteriopheophytins
5/2/91	Jeff Peloquin	Arizona State University	Study of Pigment Protein Interactions Using Resonance Raman Spectroscopy
5/9/91	Hermann Gleiter	Technical University of Berlin, Germany	Functional Properties of a Photosystem II Core Complex Preparation of Spinach
5/16/91	C. K. Tang	Arizona State University	Effect of Inhomogeneity on Absorption spectrum of Bacterial Reaction Centers
5/30/91	Alexander Krasnovsky, Jr.	A. N. Bakh Institute of Biochemistry, Moscow, Russia	Phosphorescence of Chlorophyll and its Precursors in Model Systems and Plants
6/18/91	Ursula Liebl	Arizona State University	*Heliobacillus mobilis*: Cloning the Reaction Center Gene(s): Sequence-Comparisons and Speculations

6/20/91	X. C. Sharon Ma	Arizona State University	Proton Assisted Photoinduced Electron Transfer from Porphyrin to Quinone: A Photo-CIDNP and Laser Flash Photolysis Study

1991-92

Date	Speaker	Affiliation	Title
9/12/91	Subhash Padhye	University of Poona, India	Thermoluminescence in Plants
9/19/91	Robert E. Belford	Arizona State University	Dual Exciplex Emission and Observation of an Isophotic Point: Nitroxyl Free Radical Enhancement of Singlet Oxygen Luminescence in Chlorinated Hydrocarbon Solvents
9/25/91	Alexander Darmanyan	University of California, Los Angeles	Effects of the Internal Heavy Atom and Charge-Transfer Interaction on Singlet Oxygen Generation by Carbonyl Compounds
9/26/91	Itzhak Ohad	The Hebrew University, Jerusalem, Israel	Dynamics of Photosystem II Under Light Stress Conditions
10/3/91	Nicholas W. Gillham	Duke University	The Present State of Chloroplast Transformation
10/10/91	John Shelnutt	Sandia National Labs, Albuquerque, NM	Molecular Design Using Non-planar Porphyrins
10/17/91	Sheng H. Lin	Arizona State University	Theory of Electron Transfer as Applied to Photosynthesis
10/24/91	Rhett Alden	Arizona State University	Spectroscopy and Dynamics of Photosynthetic Reaction Centers
11/6/91	Michael Seibert (Botany)	Solar Energy Research Institute, Golden, CO	The Photosystem II Reaction Center & Manganese Binding Related to Photosynthetic Oxygen Evolution
11/14/91	Heather Murchison	Arizona State University	Characterization of Several *Rb. sphaeroides* Mutants in the Vicinity of the Dimer

12/5/91	Frank Kleinherenbrink	State University of Leiden, The Netherlands	Radical Pair Recombination and Energy Transfer in the Photosynthetic Bacteria *H. chlorum* and *Rps. viridis*
12/10/91	Samuel Beale	Brown University	Biosynthesis of Phycobilins
12/18/91	Roel Hermant	Arizona State University	Efficient Quenching of the Porphyrin Singlet Excited State by Carotenoid to Porphyrin electron Transfer: Ultra-fast Charge Recombination
1/27/92	Charles Dismukes (MCB)	Princeton University	Active Site Structure and Catalysis of Multinuclear Manganese Enzymes: Manganese Catalase and Manganese Water Oxidase
1/30/92	Sherwood B. Idso	U.S. Water Conservation Lab, USDA, Phoenix	Response of Sour Orange Trees to atmospheric CO_2 Enrichment
2/6/92	Su Lin	Arizona State University	Pump-Probe Spectroscopy of Excitation Transport in Antennae of the Green Photosynthetic Bacterium *Chloroflexus aurantiacus*
2/18/92	Shuguang Wu	University of California, Los Angeles	Studies of Cation Binding and the Energy Transfer Between the Bonding Sites and the Retinal Chromophore in Bacteriorhodopsin
2/20/92	David L. Herrin	University of Texas, Austin	Splicing and Mobility of Chloroplast Group 1 Introns
2/27/92	Terry Bricker	Louisiana State University	Interaction of CPa-1 with the Oxygen Evolving Complex of Photosystem II
2/9/92	Carl Bauer (MCB)	Indiana University	Characterization of a Regulatory Network Controlling Photosynthesis in a Simple Phototroph
3/12/92	J. Kenneth Hoober	Arizona State University	Thylakoid Biogenesis in *Chlamydomonas*
3/19/92	Steven Theg	University of California, Davis	Transport and Assembly of Proteins in Chloroplasts
3/26/92	Andrew Houseman	Northwestern University	Q Band ENDOR of ^{2}H-, ^{13}C-, and ^{15}N- Labeled Tryptophan in Compound ES of Cytochrome *c* Peroxidase

4/2/92	Barry Whyte	University of California, Davis	Protochlorophyllide *a* Synthesis in Higher Plants
4/16/92	Donald Bryant	Penn State University	Structural and Functional Analyses of Photosystem I
4/10/92	Hans Freeman	University of Sydney, Australia	Recent X-ray Crystallographic and X-ray Spectroscopic Studies of "Blue" Copper Proteins
4/13/92	Alisdair Macpherson	Keele University, U.K.	Singlet Oxygen in Photosystem II Preparations
4/23/92	Bruce Wittmershaus	Arizona State University	The Mystery of the Low-Energy Chlorophylls
4/30/92	Sammy Boussiba	Ben-Gurion University of the Negev, Israel	The Biotechnology of Mass Cultivation of Microalgae
5/21/92	Tony A. Mattioli	CEN Saclay, France	Structure of the Primary Donor in Bacterial Reaction Centers from FT Resonance Raman Spectroscopy
6/16/92	Günter Hauska	Universität Regensburg, Germany	Reaction Center Genes from the Green Sulfur Bacterium *Chlorobium limicola*
6/22/92	Javier Fernandez-Velasco	University of Illinois, Urbana	On the Delocalization of Photosynthetic Electron Flow in Chromatophores and Intact Cells of *Rhodobacter sphaeroides*
6/25/92	Gary Hastings	Imperial College, London, U.K.	Femtosecond Spectroscopy of Photosystem II Reaction Centers
7/9/92	Sergei Shestakov	N. Vavilov Inst. of General Genetics, Russian Academy of Sciences, Moscow, Russia	Cloning and Molecular Analysis of Genes Involved in Photoautotrophy and Resistance to Herbicides in *Synechocystis* 6803
7/23/92	Dennis J. McCormac	University of Waterloo, Canada	Chloroplast Development in *Spirodela oligorrhiza*: Characterization of the Ability to Capture and Distribute Energy Between Photosystems
7/30/92	Jozef J. van Beeumen	State University of Ghent, Belgium	The Use of Plasma Desorption and Electrospray Mass Spectrometry in a Protein Chemistry Laboratory

8/26/92	Reinhard Bachofen	University of Zürich, Switzerland	*Chromatium* Monoculture in a Swiss Alpine Lake

1992-93

Date	Speaker	Affiliation	Title
9/10/92	Georg Schmetterer	University of Vienna, Austria	The Cytochrome Oxidase Genes of Cyanobacteria: A New Look at Respiration
9/24/92	Dan Brune	Arizona State University	Sulfur Storage Proteins from Two Species of Purple Photosynthetic Bacteria
10/1/92	Anastassios Melis	University of California, Berkeley	Mechanisms of Chloroplast Acclimation to Suboptimal and Adverse Irradiance
10/8/92	Rhett Alden	Arizona State University	Experimental and Theoretical Studies of Ultrafast Time-Resolved Absorption Surfaces of Photosynthetic Reaction Centers
10/15/92	David Knaff	Texas Tech University	Cytochrome bc_1 Complexes from Photosynthetic Bacteria
10/22/92	Michael Cusanovich	University of Arizona	Site-Directed Mutagenesis of *Rhodobacter capsulatus* Cytochrome c_2
10/29/92	Arthur Nanomura	Litchfield Park, AZ	Farmer Doubles the Power of Sunlight
11/5/92	Eduardo Zieger	University of California, Los Angeles	Carotenoids as Blue Light Photoreceptors in Guard Cells
11/19/92	John Nishio	University of Wyoming	Photosynthetic Gradients Across Leaves
11/30/92	Hiroshi Matsubara	Osaka University, Japan	Iron-sulfur Proteins Responsible for Light-independent Chlorophyll Synthesis
11/30/92	Hirozo Oh-oka	Osaka University, Japan	Reaction Centers of Photosystem I and Green Sulfur Bacteria
12/10/92	Bruce Wittmershaus	Arizona State University	The Mystery of the Low-Energy Chlorophylls—II: Suspect Found, Motive Unclear

1/21/93	Govindjee	University of Illinois	Bicarbonate and Photosystem II
1/28/93	John Whitmarsh	University of Illinois	Redox State of Cytochrome *b*-559 Controls Photoinhibition in Photosystem II
2/4/93	Tim Mueser	University of Iowa	High Resolution X-ray Analysis of Liganded Bovine Hemoglobin has a Preference for the R2 Quaternary State
2/11/93	Robert E. Blankenship	Arizona State University	Bacterial Models for Photosystem I
2/18/93	W. W. Thomson	University of California, Riverside	Plastid Structure and Development: A Personal History
2/25/93	Su Lin	Arizona State University	Time-Resolved Spectroscopy of Energy and Electron Transfer Processes in *Heliobacillus mobilis*
3/4/93	Mark Paddock	University of California, San Diego	Proton Transfer Pathways in Photosynthetic Reaction Centers Studied by Site-directed Mutagenesis
3/11/93	N. C. Yang	University of Chicago	Photoinduced Electron Transfer in Bichromophoric Molecules
3/25/93	Ratna Ghosh	University of Texas, Austin	Structure Elucidation of Organic and Organometallic Compounds
4/1/93	Russel LoBrutto	Arizona State University	Biological Applications of EPR: Metal-Nucleotide Complexes in Proteins
4/8/93	Donald Ort	University of Illinois	Inhibition of Photosynthesis in Tomato by Chilling: A Role for Interruption of Circadian Regulation of Transcription?
4/15/93	Guiying Nie	Brookhaven National Laboratory, Upton, NY	Atmospheric CO_2 Enrichment Effects on Photosynthesis and Gene Expression in Wheat
5/6/93	Sunney I. Chan	California Institute of Technology	Chemistry of a Redox Linked Proton Pump
5/13/93	David Christopher	Texas A&M	Role of a Blue Light-Regulated *psbD-psbC* Promoter During High Light-Induced Degradaion of D2 *in vivo*

1993-94

Date	Speaker	Affiliation	Title
8/26/93	Indrek Renge	Estonian Academy of Science	Matrix, Temperature and Electric Field Effects on the Optical Spectra of Photosynthetic Pigments: Applicability Ranges of Simple Models
9/2/93	Drew Houseman	Arizona State University	A Vanadyl EPR Probe for the F1-ATPase
9/9/93	Frank Kleinherenbrink	Arizona State University	The Electron Transfer Chain of Heliobacteria. A Model for Photosystem I?
9/16/93	Neal Woodbury	Arizona State University	Mechanistic Studies of Early Electron Transfer in Wild type and Mutant Reaction Centers From *Rhodobacter sphaeroides*
9/23/93	Ken Sauer	Lawrence Berkeley Laboratory	Picosecond Relaxation Kinetics of Phycocyanin Excited States
9/30/93	Gaozhong Shen	Arizona State University	Generation of in vivo Photosystem II Particles in *Synechocystis* 6803, and its Application Towards Directed Mutagenesis of Photosystem II
10/7/93	Gary Hastings	Arizona State University	Energy and Electron Transfer in Photosystem I
10/14/93	Jim Allen	Arizona State University	Mutations that Affect the Donor Midpoint Potential in Reaction Centers from *Rhodobacter sphaeroides*
10/21/93	Himadri Pakrasi	Washington University, St. Louis	ClpA, the C-Terminal Processing Protease from the D1 Protein of Photosystem II
10/28/93	Gerald Small	Iowa State University	Hole Burning: A New Window on Electronic Structure and Transport Dynamics of Photosynthetic Units
11/4/93	Tina Liguijt	Arizona State University	Photobiology and Bioenergetics of Ectothiorhodospira: A Study on Halophilic and Alkalaiphilic Purple Sulfur Bacteria
11/10/93	Leonas Valkuna	Institute of Physics, Vilnius, Lithuania	Theoretical Problems in Energy Transfer and Trapping

11/10/93	Arvi Freiberg	Estonian Academy of Science	Pressure Effects on Photosynthetic Proteins
11/18/93	Hiroshi Imahori	Institute of Scientific and Industrial Research, Osaka, Japan	Synthetic Approach for the Primary Processes of Photosynthesis
12/2/93	Wei-Zhong Xiao	Arizona State University	Energy Transfer and Electron Transfer in Rhodobacter capsulatus
1/27/94	Ana Moore	Arizona State University	Function of Carotenoids–Model Studies
2/3/94	Svetlana Ermakova	Arizona State University	Methods of Random Chemical Mutagenesis as Applied to Photosynthesis Genes in Cyanobacteria
2/10/94	Richard White	Arizona State University	Biogenesis of Thylakoid Membranes in *Chlamydomonas reinhardtii* y1. A Kinetic Study of Initial Greening
2/17/94	Jeff Peloquin	Arizona State University	The Effect of Excitation Wavelength on Electron Transfer in *Rhodobacter sphaeroides*
2/24/94	Richard Dilley	Purdue University	Calcium Regulation of Proton Flux Through Coupling Factor in Chloroplasts and *E. coli*
3/3/94	Stenbjörn Styring	Arrhenius Laboratories of the Natural Sciences, Stockholm University	Photoinhibition and Repair of Photosystem II: Mechanistic Aspects of D1 Turnover
3/10/94	Michael Elliott	Colorado State University	Intramolecular Electron Transfers in Flexible Systems–What Can We Learn?
3/24/94	William Cramer	Purdue University	2.3 Å Structure of Cytochrome *f*: Consequences for Electron Transfer and Protein Translocation

3/31/94	Alex Krasnovsky	Arizona State University	Phosphorescence of Pigments and Oxygen. Application to Photosynthesis Research
4/28/94	Vincent Pecoraro	University of Michigan	How Might Manganese Redox Enzymes Work?