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Minireview

Photosynthesis and the Web: 2001

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Abstract

First, a brief history of the Internet and the World Wide Web is presented. This is followed by relevant information on photosynthesis-related web sites grouped into several categories: (1) large group sites, (2) comprehensive overview sites, (3) specific subject sites, (4) individual researcher sites, (5) kindergarten through high school (K-12) educational sites, (6) books and journals, and, 7) other useful sites. A section on searching the Web is also included. Finally, we have included an appendix with all of the web sites discussed herein as well as other web sites that space did not allow. Readers are requested to send comments, corrections and additions to gov@uiuc.edu.

Abbreviations: ARPA – Advanced Research Projects Agency; ASU – Arizona State University; HTML – Hyper Text Markup Language; NCSA – National Center for Supercomputing Applications; TCP/IP – Transmission Control Protocol/Internet Protocol; UIUC – University of Illinois, Urbana-Champaign; URL – Universal Resource Locator; WWW – World Wide Web

Introduction

Three years ago we published a short paper detailing the then current state of photosynthesis web sites and how to find them (Orr and Govindjee 1998). This text was also available both at http://photoscience.la.asu.edu/photosyn and at http://www.life.uiuc.edu/govindjee. Although many fine sites were found and discussed, the number of sites was rather limited due to several reasons, including the inexperience of scientists with hypertext markup language (HTML), lack of reliable web server hardware, constantly changing web addresses, and difficulty in using search engines. Since then the World Wide Web (WWW) has grown many times over and users have become sophisticated enough that there has been an explosion of great web sites. The Web has now become an important resource for public awareness and for educating all the people of the world including its political leaders, students, researchers, teachers and ordinary citizens seeking information.

The Internet, over which the Web is accessed, took several years to develop. Originally it consisted of a number of smaller networks, the most important being a military network developed by the Advanced Research Projects Agency (ARPA), part of the US Department of Defense, it was also made available to various universities (ARPA 1996). Many other smaller networks began connecting to the Internet when a set of communications standards was adopted. These standards, TCP/IP (transmission control protocol/internet protocol), allowed the various universities, government agencies and the military to send files and e-mail messages back and forth without standardizing hardware as TCP/IP was a software that could be adapted to any operating system. The Internet became not a single large network, but a matrix of thousands of smaller networks with numerous redundant connections (Kroll 1992; Cerf 1993; Lenier et al. 2000).

The World Wide Web began in 1989 when Tim Berners-Lee proposed a hypertext project as a means for scientists at the European Particle Physics Laboratory, CERN (Conseil Européen pour Recherche Nucleaire), located in Geneva, Switzerland, to exchange data with other scientists around the world (Bernes-Lee 1989; Segal 1995; Schwartz 1997; Bernes-Lee et al. 1999). Hypertext had been suggested years earlier by Vannevar Bush (W3C 2000) and later developed by Ted Nelson as part of a project named Xanadu that was never completed (Wolf 1995; W3C 2000). Initially, only scientific data was exchanged via web servers on the Internet, though it soon became possible for persons on any computer hooked to the Internet to access the information located on another computer that acted as a web server. All that was needed was an Internet connection and the Universal Resource Locator (URL), or address, of the item wanted. Typing the URL or mouse clicking on it in another document would cause the other web server to send the new item to the user's computer. The material was usually displayed as lines of plain text. In 1993 the National Center for Supercomputing Applications (NCSA) at the University of Illinois at Urbana-Champaign (UIUC) released Mosaic, developed by Marc Andreessen and others, that allowed text documents to be displayed graphically on computer monitors (Engst 1998).

The scientific community quickly embraced Mosaic and other simple web readers, called web browsers. The capabilities of the web browsers were quickly grasped by most universities and many companies. The Web was suddenly accessible by anyone with an Internet connection and a browser. Information in the form of text, pictures, sound and movies became possible. Marc Andreessen joined Jim Clark to found the company that later became Netscape Communications (Goldberg 1994; Wolf 1994). They produced a commercial browser based on Mosaic, Netscape Navigator, which was so popular that it helped the Web explode into the 'entity' we know today. Later, Microsoft developed a competing browser, Internet Explorer, which it gave away for free. Soon the general public became involved in the Web in a big way. Commercial corporations were quick to establish web sites advertising their products or posting information that the public might want (Gromov 2000). Universities and research organizations began expanding their small informational sites to present massive amounts of information such as personnel directories, general and specific information for all facets of their organizations, course catalogs, registration forms, and, more recently, on-line classes. Elementary and high schools also began utilizing the Web for a variety of purposes, including the posting of lesson plans and the results of class projects done by their students (Williams 1996).

Web sites devoted to photosynthesis began appearing in late 1994. Some were large sites devoted to covering the entire field of photosynthesis, but many were designed to cover a specific area in great detail. Many individual researchers also began developing their own sites filled with information about their research, labs, and the courses they were teaching.

This Minireview will present relevant information on photosynthesis-related web sites grouped into several categories: 1) large group sites, 2) comprehensive overview sites, 3) specific subject sites, 4) individual researcher sites, 5) kindergarten (K)-12 educational sites, 6) books and journals, and, 7) other useful sites. A section on searching the Web is also included. Finally, we have included an appendix with all of the web sites discussed herein as well as other web sites that space did not allow. Because of time and length restrictions, as well as the dynamic nature of the Web, it is impossible to include every worthy web site in this review. Thus, we will highlight a few of the sites that we think epitomize the best the Web has to offer. Sites chosen for discussion will usually have a significant amount of information on one or more photosynthesis research areas and may include illustrations, movies and links to other sites of importance. Our sincere apologies to anyone whose site we have overlooked.

Group sites

One of the largest group sites, the Arizona State University (ASU) Photosynthesis Center site, went on-line in 1995. It was developed and is currently maintained by one of us (LO) and can be accessed at http://photoscience.la.asu.edu/photosyn/. This award-winning site is very comprehensive and showcases not only the operations and work of the Center, but also provides original material and numerous annotated links to individual and group photosynthesis research sites of interest to researchers, educators, students and the general public. One of its most popular items is its Nicelist, a list of photosynthesis researchers who do not mind receiving and answering emails (hence they are 'nice') and includes their e-mail addresses and, in most cases, their web site URLs (http://photoscience.la.asu.edu/photosyn/nicelist.html). Another popular area is the educational section that contains links to sites of interest to students and educators and has been annotated as to subject matter and appropriate age-level of understanding (http://photoscience.la.asu.edu/photosyn/education/learn.html). Some of the Center's other web pages will be mentioned in the sections that follow.

The University of Illinois at Urbana-Champaign (UIUC), the home of NCSA and Mosaic and therefore the 'mother' of all modern web browsers, hosts several important sites. A site by one of us (G) (http://www.life.uiuc.edu/govindjee/), is much more than an individual site as it includes information on a variety of topics, including course web pages, a major tutorial/essay on 'The Photosynthetic Process' (by J. Whitmarsh and Govindjee), movies, photos and several items of historical importance including PDF files of Personal Perspectives of some eminent scientists, as well as some Obituaries, and comments on Robert Emerson, Eugene Rabinowitch, William Arnold, Lou Duysens and Stacy French. There is also a tutorial on 'Photosynthesis and Time' and other teaching materials such as slides which can be used in the classroom. UIUC is also the home of the wonderful and highly educational site of A. R. Crofts (http://www.life.uiuc.edu/crofts/ahab/index.html). The Photosynthesis Research Unit (http://www.life.uiuc.edu/pru/), affiliated with the United States Department of Agriculture (USDA) Agricultural Research Service, covers many areas of photosynthesis crop research. The Theoretical Biophysics Group at UIUC is also present with an excellent site (http://www.ks.uiuc.edu/) with many important pages including 'Quantum Biology of the Photosynthesis Unit' (http://www.ks.uiuc.edu/Research/psu/psu.html), animations of various structures (http://www.ks.uiuc.edu/Overview/movie_gallery/) and much more.

The Plant Cell Biology group at Lund University, Sweden (http://plantcell.lu.se/) contains much useful information and links as well as interesting pages on 'Light, Time and Micro-Organisms' (http://plantcell.lu.se/ltm/default.html), imaging chlorophyll fluorescence and much more. Lund University is also the home of the Photosynthesis Group (http://www.biokem.lu.se/AFS-WWW/Research.html), led by Stenbjörn Styring, which studies Photosystem II and artificial photosynthesis.

The University College London Photosynthesis Research Group (http://www.ucl.ac.uk/biology/prg.htm) has pages devoted to their work with Photosystem (PS) II and chloroplasts from *Chlamydomonas reinhardtii.* The Photosynthesis Group at the University of Southern Denmark (Odense University) maintains a site about their work with light-harvesting antennas of green photosynthetic bacteria (http://www.sdu.dk/nat/biokemi/groups/photosyn/).

The Biophysics group at Leiden University (http://www.biophys.leidenuniv.nl/Research/) hosts a couple of important pages on 'Photophysical Processes in Photosynthetic Reaction Centers' and 'Energy and Electron Transfer in Photosynthetic Membranes'. The Photosynthesis Group at Göteborg University, Sweden, has a nice site with detailed descriptions of their work with plastocyanin and other areas of photosynthesis (http://www.bcbp.gu.se/photosyn/). The Avron-Wilstätter Center for Photosynthesis Research is located at the Weizmann Institute of Science (http://www.weizmann.ac.il/weiz/research/wilstatter_ctr.html) and is working with several groups to study many areas of photosynthesis.

Comprehensive overview sites

There are several sites devoted to the entire photosynthetic process. Although they may cover the same subject, the articles are written for a variety of audiences. Some are basic narratives aimed at the general public, others are comprehensive courses aimed at college students. All of these are quite good and several should be checked out for comparison.

'The Photosynthetic Process' by John Whitmarsh and Govindjee (http://www.life.uiuc.edu/govindjee/paper/gov.html) is a comprehensive chapter and covers photosynthesis history and every facet of photosynthesis research in a relatively detailed manner. J. M. Farabee from Estrella Mountain Community College also has written a highly recommended online biology course text that includes a detailed section on photosynthesis with emphasis on the physical aspects of the process. He also includes review questions, learning objectives and a nicely done illustrated glossary (http://gened.emc.maricopa.edu/bio/bio181/BIOBK/BioBookPS.html). Members of the Faculty of Biology at the University of Hamburg, Germany, have also produced an online botany textbook with an excellent section devoted to photosynthesis (http://www.rrz.uni-hamburg.de/biologie/b_online/e24/24.htm). MIT's Biology Hypertextbook also contains a very good section, called the 'Photosynthesis Directory', devoted to photosynthesis(http://esg-www.mit.edu:8001/esgbio/ps/psdir.html).

Wim Vermaas at ASU has written 'An Introduction to Photosynthesis and Its Applications' (http://photoscience.la.asu.edu/photosyn/education/photointro.html), which is a good introduction for the general public. The Alien Explorer web site explains photosynthesis in an interesting manner aimed at pre-high school level readers (http://www.alienexplorer.com/ecology/topic3.html). Kapiolani Community College in Hawaii has a web site devoted to the chemical equations of photosynthesis (http://naio.kcc.hawaii.edu/chemistry/everyday_photosyn.html).

Art's Biotech Resource (http://www.ahpcc.unm.edu/∼aroberts/) covers many areas involving biotechnology, including photosynthesis. Besides detailing the photosynthesis process on various pages, it also contains many good links to other sites.

Specific subject sites

There are many sites that specialize in a certain aspect of photosynthesis. Here are some of the best arranged by topic. There will be several sites that overlap somewhat and some may appear in more than one group.

A. History of photosynthesis/biographies/Nobel prizes

Surprisingly, not many sites are available for several of the famous photosynthesis pioneers – hopefully this will change.

'Milestones in Photosynthesis Research' by one of us (G) (http://www.life.uiuc.edu/govindjee/papers/milestones.html) explores many aspects of photosynthesis in a historic manner.

Another paper, 'Carotenoids in Photosynthesis: An Historical Perspective', explores the history of the study of carotenoids using numerous personal observations by one of the authors (G) who participated in some of the activities (http://www.life.uiuc.edu/govindjee/papers/CarFin1.html). Both these papers contain numerous references and anecdotes about pioneers in the field that can be found nowhere else.

A list of historical articles, published in Photosynthesis Research, are available at http://www.life.uiuc.edu/govindjee/history/articles.htm. Further, PDF files of articles by Howard Gest (on IngenHousz); Herb Dutton (on the discovery of energy transfer from carotenoids to chlorophyll); and Govindjee (on the quantum yield controversy between Emerson and Warburg) are also available at this site.

A brief biography of Joseph Priestley can be found at http://www.chem.mtu.edu/chemistry/PAGES/HISTORY/JosephPriestley.html. Other important historical documents are:

'Nobel Prize Winner in Photosynthesis Research' (http://www.life.uiuc.edu/govindjee/history/nobel-ps.htm) is a list of the many researchers who have won the Nobel Prize while or before studying photosynthesis.

'Personal Perspectives in *Photosynthesis Research*' (http://www.life.uiuc.edu/govindjee/perspectives.html) is a list of the Personal Perspectives, autobiographical retrospectives, that have appeared in the international journal *Photosynthesis Research*. Although these perspectives usually do not contain large amounts of science, they do discuss the major discoveries by some well-known researchers. In particular, they contain the personal reflections, memories and the obstacles the authors had to overcome and other surprises. For example, the Personal Perspective of David Walker begins, "This is the story of a young man who wished to go to sea like his father and finished up, instead, in photosynthesis." They are great reading and tell about scientific research the way it really is. A few of the perspectives are available as PDF files (please note that the first page of each file may be blank):

David **Krogmann** (http://www.life.uiuc.edu/govindjee/history/KrogmannDavidPP.pdf);
R. Clint **Fuller** (http://www.life.uiuc.edu/govindjee/history/FullerClintPP.pdf);
Georgio **Forti** (http://www.life.uiuc.edu/govindjee/history/FortiGeorgioPP.pdf);
André **Jagendorf** (http://www.life.uiuc.edu/govindjee/history/JagendorfAndrePP.pdf);

George **Feher** (http://www.life.uiuc.edu/govindjee/history/FeherGeorgePP.pdf);
David **Walker** (http://www.life.uiuc.edu/govindjee/history/WalkerPP.pdf).

Govindjee has also edited several obituaries that have been published (http://www.life.uiuc.edu/govindjee/history/obituaries.htm), with some of them available online as PDF files.

Carmen Giunta has collected excerpts from historically important papers and published them on his 'Classic Chemistry' web site. These include papers by Jan Ingenhousz (http://webserver.lemoyne.edu/faculty/giunta/Ingenhousz.html), Antoine Lavoisier (http://webserver.lemoyne.edu/faculty/giunta/lavoisier1.html), Joseph Priestley (http://webserver.lemoyne.edu/faculty/giunta/phlogiston.html).

Jim Holler from the University of Kentucky has posted a paper by C. V. Raman and K. S. Krishnan discussing Raman spectroscopy (http://www.uky.edu/~holler/raman.html).

The Nobel Prize site has pages devoted to all Nobel laureates. Some of interest to photosynthesis are:

Richard Martin **Willstätter**, Chemistry, 1915, won the prize for his research on chlorophyll and other plant pigments. His work is discussed at http://www.nobel.se/chemistry/laureates/1915/press.html and his biography is at http://www.nobel.se/chemistry/laureates/1915/willstatter-bio.html.

James **Franck**, Physics, 1925, won for his work (with Gustav Hertz) on electron-atom collisions; later he developed the principle known as the Franck–Condon principle which is often used in physical description of early events in photosynthesis. See http://www.nobel.se/physics/laureates/1925/press.html and his biography http://www.nobel.se/physics/laureates/1925/franck-bio.html.

Chandrasekhara Ventaka **Raman**, Physics, 1930, won his prize for his work on spectroscopy and the effect that now bears his name, Raman spectroscopy, which is used by many photosynthesis researchers: http://www.nobel.se/physics/laureates/1930/press.html. His biography is at http://www.nobel.se/physics/laureates/1930/raman-bio.html.

Hans **Fischer**, Chemistry, 1930, won for his work on porphyrins and blood and leaf pigments, particularly chlorophyll: http://www.nobel.se/chemistry/laureates/1930/press.html. His biography is at http://www.nobel.se/chemistry/laureates/1930/fischer-bio.html.

Otto Heinrich **Warburg**, Physiology or Medicine, 1931, won for his work on respiration and the identification of the respiratory enzyme: http://www.nobel.se/medicine/laureates/1931/press.html. His biography is at http://www.nobel.se/medicine/laureates/1931/warburg-bio.html. Warburg's insistence that the measured minimum quantum requirement for the evolution of one oxygen molecule in photosynthesis is 2.8 to 4 was proven to be wrong; it was shown to be 8-12, mainly by Robert Emerson and his students including one of us (G).

Paul **Karrer**, Chemistry, 1937, won for his work on carotenoids, flavins and vitamins: http://www.nobel.se/chemistry/laureates/1937/press.html. His biography is at http://www.nobel.se/chemistry/laureates/1937/karrer-bio.html.

Richard **Kuhn**, Chemistry, 1938, won for additional work on carotenoids and vitamins: http://www.nobel.se/chemistry/laureates/1937/press.html. His biography is at: http://www.nobel.se/chemistry/laureates/1938/kuhn-bio.html

Severo **Ochoa**, Physiology or Medicine, 1959, won for his work on enzymatic processes in biological oxidation and synthesis and the transfer of energy. His biography is at http://www.nobel.se/medicine/laureates/1959/ochoa-bio.html.

Melvin **Calvin**, Chemistry, 1961, won for his work on carbon dioxide assimilation in photosynthesis, the carbon cycle, also named 'The Calvin Cycle' after him: http://www.nobel.se/chemistry/laureates/1961/press.html. It is important to mention that Andrew Benson contributed heavily to this work, and the authors of this article prefer to call the cycle, 'Calvin–Benson' cycle. Calvin's biography is at http://www.nobel.se/chemistry/laureates/1961/calvin-bio.html. Also, an obituary may be found at http://www.lbl.gov/Science-Articles/Archive/Melvin-Calvin-obit.html; and another one at http://www.life.uiuc.edu/govindjee/history/obit/ObitMelvinCalvin.pdf.

Robert Burns **Woodward**, Chemistry, 1965, won for the total synthesis of chlorophyll, vitamin B12 and other natural products: http://www.nobel.se/chemistry/laureates/1965/press.html. His biography is at http://www.nobel.se/chemistry/laureates/1965/woodward-bio.html.

George **Porter**, Chemistry, 1967, won for his development of flash photolysis (along with Ronald Norrish). Lord George Porter later did work on aromatic molecules and chlorophyll, energy transfer in photosynthesis and primary photochemistry of photosynthesis in femtosecond-picosecond time scale: http://www.nobel.se/chemistry/laureates/1967/press.html. His biography is at http://www.nobel.se/chemistry/laureates/1967/porter-bio.html.

Peter D. **Mitchell**, Chemistry, 1978, won for his work on biological energy transfer through the formulation of the chemiosmotic theory: http://www.nobel.se/chemistry/laureates/1978/press.html. His biography is at http://www.nobel.se/chemistry/laureates/1978/mitchell-bio.html.

Aaron **Klug**, Chemistry, 1982, won for development of crystallographic electron microscopy and his structural elucidation of biologically important nucleic acid–protein complexes: http://www.nobel.se/chemistry/laureates/1982/press.html. His autobiography is at http://www.nobel.se/chemistry/laureates/1982/klug-autobio.html.

Jean-Marie **Lehn**, Chemistry, 1987, won for his work on mimicking natural processes such as photosynthesis and for doing the groundwork for small synthetic structures called 'molecular devices': http://www.nobel.se/chemistry/laureates/1987/press.html. His autobiography is at http://www.nobel.se/chemistry/laureates/1987/lehn-autobio.html.

Johann **Deisenhofer**, Robert **Huber and** Hartmut **Michel,** Chemistry, 1988, won, for determining the three-dimensional structure of bacterial reaction center using X-ray crystallography. A description of their work can be found at http://www.nobel.se/chemistry/laureates/1988/press.html. Deisenhofer's autobiography is at http://www.nobel.se/chemistry/laureates/1988/deisenhofer-autobio.html. Huber's is at http://www.nobel.se/chemistry/laureates/1988/huber-autobio.html, and Michel's is at http://www.nobel.se/chemistry/laureates/1988/michel-autobio.html.

Rudolph **Marcus**, Chemistry, 1992, won for his contributions to the theory of electron transfer reactions in chemical systems, including photosynthesis: http://www.nobel.se/chemistry/laureates/1992/press.html. His autobiography is at http://www.nobel.se/chemistry/laureates/1992/marcus-autobio.html.

Michael **Smith**, Chemistry, 1993, won for his fundamental contributions to the establishment of oligonucleotide-based, site-directed mutagenesis and its development for protein studies, which has become a common technique for studying photosynthetic organisms: http://www.nobel.se/chemistry/laureates/1993/press.html. His autobiography may be found at http://www.nobel.se/chemistry/laureates/1993/smith-autobio.html.

Paul D. **Boyer** and John E. **Walker**, Chemistry, 1997, won for their elucidation of the enzymatic mechanism underlying the synthesis of adenosine triphosphate (ATP): http://www.nobel.se/chemistry/laureates/1997/press.html. Boyer's autobiography is at http://www.nobel.se/chemistry/laureates/1997/boyer-autobio.html, and Walker's is at http://www.nobel.se/chemistry/laureates/1997/walker-autobio.html.

Ahmed H. **Zewail**, Chemistry, 1999, won for his studies of the transition states of chemical reactions using femtosecond spectroscopy: http://www.nobel.se/chemistry/laureates/1999/press.html. His autobiography may be found at http://www.nobel.se/chemistry/laureates/1999/zewail-autobio.html.

B. The light reactions

Michael Gretz from Michigan Technical University (http://www.bio.mtu.edu/~mrgretz/bl414web/bl414_97/photosn1.htm). This site gives, in an outline form, the basic characteristics of light; pigments; light absorption; antenna; reaction centers; and two light reactions. Figures are taken mostly from chapter 7 of Taiz and Zeiger's book on Plant Physiology.

From the Botany Online site at the University of Hamburg (http://www.rrz.uni-hamburg.de/biologie/b_online/e24/24c.htm), we get a brief history of the elucidation of the dark and light reactions. This is followed by an excellent description of phosphorylation and the two photosystems. It is profusly illustrated.

From the MIT Biology Hypertextbook (http://esg-www.mit.edu: 8001/esgbio/ps/light.html). This is a professionally done highly basic description of the light reactions of photosynthesis (recommended for the beginners).

'Photosynthesis and Time' by Govindjee and Matej Lexa (http://www.life.uiuc.edu/govindjee/ptime/). The time sequence of the light reactions of photosynthesis are taught through a 'click-on' window (with the four protein complexes in it), and through a movie. A clock covers the reactions from femtoseconds to milliseconds (recommended for all undergraduates and graduate students).

From Ross Koning of Eastern Connecticut State University (http://koning.ecsu.ctstateu.edu/Plant_Physiology/LightRxns.html). A concise description of the light reactions with figures.

The Z-Scheme is the crux of the light reactions of photosynthesis. The scheme and its description are presented at http://www.life.uiuc.edu/govindjee/textzsch.htm; for the scheme itself, see/ZSchemeG.html.

C. The dark reactions/Calvin–Benson cycle/carbon cycle

From the Botany Online site at the University of Hamburg (http://www.rrz.uni-hamburg.de/biologie/b_online/e24/24a.htm). This is a great site as the equations and the chemical structures are available. You may need to install some plug ins.

From Van Douglas Gooch of the University of Minnesota at Morris (http://www.mrs.umn.edu/∼goochv/CellBio/lectures/darkrxn/darkrxn.html). Basics and cycles are presented. The Calvin cycle should be called Calvin–Benson cycle in our opinion, and a large comprehensive scheme at the bottom of the page needs to be turned around and a better copy posted.

From the MIT Biology Hypertextbook (http://esg-www.mit.edu:8001/esgbio/ps/dark.html). A very simple, pleasant, and basic site, quite professionally done.

From Ross Koning of Eastern Connecticut State University (http://koning.ecsu.ctstateu.edu/Plant_Physiology/Calvin.html). It includes only the basic skeleton of the Calvin–Benson cycle.

From June B. Steinberg of National-Louis University (http://www2.nl.edu/∼jste/calvin_cycle.htm). A beautifully done site: the steps are clearly shown. It requires downloading plugins.

D. The photosynthetic unit/reaction centers

'Quantum Biology of the PSU' from the Theoretical Biophysics Group at UIUC (http://www.ks.uiuc.edu/Research/psu/psu.html). It is a great site showing beautiful structures of antenna of bacterial systems.

'Schematic Diagram of a Photosynthetic Unit Showing Exciton Transfer' is an animated web page from the University of Hamburg (http://www.rrz.uni-hamburg.de/biologie/b_online/library/bio201/psunit.html). It is lovely to watch it.

'Bacterial Reaction Center (RC)' by Rick Hallick of the University of Arizona (http://www.blc.arizona.edu/courses/181gh/rick/photosynthesis/pcr4.html). A nice picture of RC. It has a link to the 'Protein Data Bank' site.

'Tutorial on the Photosynthetic Reaction Centre of *Rhodopseudomonas viridis*' from Jonathan Marder at the Hebrew University of Jerusalem (http://indycc1.agri.huji.ac.il/∼marder/rc_view/). It is a lovely site. You will need to download 'plugins'.

'Press Release: The 1988 Nobel Prize in Chemistry' from the Royal Swedish Academy of Sciences, announcing the determination of the 3D structure of a photosynthetic reaction center (http://www.nobel.se/chemistry/laureates/1988/press.html). The text is great, but the figures are only in black and white.

'Thermodynamics of the Excited States of Photosynthesis' by Jerome Lavergne and Pierre Joliot is a chapter in an online textbook being sponsored by the Biophysical Society of America (http://biosci.umn.edu/biophys/BTOL/bioenerg/Lavergne.J.pdf). It is a 12-page article, with 6 references. It refers to the entire process of photosynthesis, not just the reaction centers.

E. Light-harvesting/ antennas

'Photosynthetic Antennas and Reaction Centers: Current Understanding and Prospects for Improvement', by Robert E. Blankenship at ASU (http://photoscience.la.asu.edu/photosyn/education/antenna.html). It is a well-done text with basic diagrams. We recommend it to all students. There are 12 references.

'Light Harvesting Complex II of Photosynthetic Bacteria' from the Theoretical Biophysics Group at UIUC (http://www.ks.uiuc.edu/Research/bio_ener/LH_2/) and also 'Inter-Complex Excitation Transfer in photosynthetic bacteria' (http://www.ks.uiuc.edu/Research/psu/psu_inter.html). Excellent colored versions of the antenna complexes in photosynthetic bacteria. Links are provided to PDF files of three of their research papers.

'Light Harvesting Complex II of Purple Bacteria' from the University of Leeds, UK (http://bmbsgi11.leeds.ac.uk/bmbknd/promise/LH2PB.html). This site contains an excellent description and an extensive bibliography of the light harvesting complex II of purple bacteria.

‘Light-Harvesting in Bacterial Photosynthesis’ from Glasgow University Protein Crystallography group (http://www.chem.gla.ac.uk/protein/LH2/lh2.html). It has a brief description, but it has links to nice pictures on structure and function of the antenna system in bacteria.

‘Chloroplast Light-Harvesting Complex II’ from Plant Cell Biology at Lund University, Sweden (http://plantcell.lu.se/Research/lhcii_chime.html). A beautiful site to visit. It is highly recommended. You can download chime and RasMol and watch the molecule listening to Bach.

F. Electron transfer

From Luis P. Candeias at the Delft University of Technology, The Netherlands. Section 6 of ‘Biological Electron-Transfer’. It covers mostly electron transfer in photosynthesis (http://iriaxp.iri.tudelft.nl/∼scwww/candeias/bio-et/photos.html). The text is at a basic level. The reader should look at all the lectures. Note that the links to the Marcus theory and equation did not work for us.

‘Electron Transport and Energy Transduction’ by John Whitmarsh at UIUC (http://www.life.uiuc.edu/pru/labs/whitmarsh/chapter7/contents.html). It is a good review chapter on electron transfer.

The Z-Scheme is the description of the electron transfer in oxygenic photosynthesis. The scheme and its description are presented at http://www.life.uiuc.edu/govindjee/textzsch.htm (for the scheme itself, see /ZSchemeG.html).

‘Introduction to Electron Transfer’ by R. M. Williams of the Universiteit van Amsterdam (http://orgwww.chem.uva.nl/phys/ET/). It is an excellent basic physico-chemical description of generalized electron transfer, and includes a very good exposure to the Marcus theory and the equations.

‘Electron Transfer in Hierarchical Photochemical Systems’ from Argonne National Laboratory (http://chemistry.anl.gov/photosynthesis/hierarchical_systems_Part2.html). It deals with bacterial as well as Photosystem I reactions; use of EPR, among other methods.

‘Solar Cell Model for Electron Transfer in Photosynthesis’ by T. Markvart and P. T. Landsberg of the Univerisity of Southampton, UK (http://www.soton.ac.uk/∼solar/photosynthesis/Quantsol2000.htm). To us, it seems like a technical paper.

G. Bacterial photosystem, Photosystems I and II

‘Bacterial Photosystem’ from Carl Bauer at Indiana University (http://sunflower.bio.indiana.edu/∼cbauer/bauerlab/research/photosystem.html). The site contains a nice description of bacterial photosynthesis, pathways of bacteriochlorophyll/chlorophyll biosynthesis, phototaxis in bacteria and molecular evolution. Some of the links are outdated, but the main text is complete.

‘Photosystem I: X-ray Structure Analysis’ from the Institute for Crystallography at the Free University Berlin (http://userpage.chemie.fu-berlin.de/∼phosys/) and also, from the same site, ‘The Electron Transfer and Core Antenna Systems of Photosystem I’ (http://userpage.chemie.fu-berlin.de/∼phosys/Structure.html). Both sites are outstanding to learn all you wanted to know about Photosystem I. Highly recommended.

‘Plastocyanin and Photosystem I. Ru-Modification’ by Örjan Hansson of Göteborg University, Sweden (http://www.bcbp.gu.se/∼orjan/res/pc-ps1-e.html). It deals mainly with plastocyanin. It has references of the authors.

‘Shedding New Light on the Earth’s Powerstation’ from NASA describes the crystallizing of PS I on the space shuttle (http://www.science.nasa.gov/newhome/headlines/msad27jul98_1.htm). It is a technical achievement.

‘Photosystem I and II and the Light Reaction’ (http://wwwfac.wmdc.edu/HTMLpages/Academics/Biology/botf99/photo/l4ightrx.html). It is a basic description. When reading it, correct the spelling of pheophytin (it is listed as pheophyton).

Both ‘Photosystem II’ (http://life.uiuc.edu/∼a-crofts/psiiwork.html) and ‘Structure and Function in Photosystem II’ (http://life.uiuc.edu/∼a-crofts/psiistrc.html) from Antony Crofts are good sites to learn about Photosystem II. There is some overlap in the two sites.

‘Photosystem II’ from Jim Barber at Imperical College (http://www.bc.ic.ac.uk/research/barber/photosystemII.html). It has a detailed description of Photosystem II based largely on the research in author’s laboratory.

A Photosystem II model paper and coordinates of this model are available at http://www.life.uiuc.edu/govindjee/Xiong98.pdf and http://www.life.uiuc.edu/govindjee/PSIIRCmodel.pdf.sit.

'A Sensitive Photosystem II-Based Biosensor for Detection of a Class of Herbicides' from the Institute of Microbiology, Trebon, Czech Republic at http://www.alga.cz/mk/papers/bs_98.htm. It is a research paper.

H. Cytochromes and cytochrome oxidase

'Cytochromes' from the University of Leeds, UK (http://bmbsgi11.leeds.ac.uk/promise/CYTOCHROMES.html). The site contains chemical structures and descriptions of most of the cytochromes.

'Models for Cytochrome *c* Biogenesis' from Washington University at St. Louis (http://www.biology.wustl.edu/faculty/models.html). It discusses three different systems for the biogenesis of cytochromes c.

'Cytochrome c Oxidase' from the Protein Data Bank, Molecule of the Month (http://rcsb.nist.gov/pdb/molecules/pdb5_1.html). An excellent basic description of the relationship of oxygen and life, structure of the enzyme, and the evolution of the enzyme.

'Cytochrome *c* Oxidase' from the Theoretical Biophysics Group at the University of Illinois at Urbana (http://www.ks.uiuc.edu/Research/bio_ener/cco/). There is a basic description, and there are some key references.

'Cytochrome c Oxidase' from the University of Leeds, UK (http://bmbsgi11.leeds.ac.uk/promise/COX.html). It contains chemical structures, a good description, and bibliography.

'The bc_1-Complex Site' from Antony Crofts at the University of Illinois at Urbana (http://www.life.uiuc.edu/crofts/bc-complex_site/index.html) and Ed Berry's Cyt *bc* page (http://www.lbl.gov/~berry/). These sites contain the structure obtained by Ed Berry's group; Crofts page has links to coordinate data files of structures including that from J. Deisenhofer's group; and has a good reference list until November 2000.

'Cytochrome b_6f Complex' from William Cramer at Purdue University (http://www.bio.purdue.edu/courses/Cramer_labpage/photosynth.html): Here, you will find an excellent description of this complex. The structures of cytochrome f and Rieske FeS protein are to be found at http://www.bio.purdue.edu/courses/Cramer_labpage/cytf.html and http://www.bio.purdue.edu/courses/Cramer_labpage/Rieske.html , respectively.

I. ATP synthase

'ATP Synthase' by John Walker, the work that won him the Nobel Prize (http://www.mrc-dunn.cam.ac.uk/pages/atpase.html). It is a simple and a beautiful page with nice colored illustrations.

'Animation Movies of ATP Synthase' by Hongyun Wang and George Oster of University of California, Berkeley (http://nature.berkeley.edu/~hongwang/Project/ATP_synthase/) are great fun. Enjoy the site and learn from it. It needs plugins.

'ATP Synthase', from Antony Crofts at the University of Illinois at Urbana, includes description and crystal structure (http://www.life.uiuc.edu/crofts/bioph354/lect10.html).

'The Photosynthetic ATP Synthase: Assembly of Hybrid Complexes from Bacterial and Plant Subunits Defines Their Roles in Catalysis' by Zippora Gromet-Elhanan at the Weizmann Institute of Science (http://www.weizmann.ac.il/Biological_Chemistry/scientist/Elhanan/elhanan.html). It contains results from her research and has references.

'ATP Synthase Sites for Biochemistry' by Sandra L. Jewett, contains many good links (http://www.csun.edu/~hcchm001/wwwatp2.htm). It is a site that contains links to several sites that contain information on Paul Boyer's binding change hypothesis and it contains movies of the ATP synthase. It is highly recommended by the authors.

J. C-3, C-4 and CAM (crasulacean acid metabolism) pathways

'C_3, C_4 and CAM, Regulation of the Activity of Photosynthesis' from Botany Online at the University of Hamburg (http://www.rrz.unihamburg.de/biologie/b_online/e24/24b.htm) describes what the title says.

'Types of Photosynthesis' from Brad Fiero at Pima Community College, Tucson (http://web.wc.pima.edu/bfiero/tucsonecology/plants/plants_photosynthesis.htm) gives an easy to understand outline view of C3, C4 and CAM.

'How Plants Cope with the Desert Climate', by Mark A. Dimmitt, Arizona-Sonoran Desert Museum (http://www.desertmuseum.org/week1.html). It is a basic general description of the CAM pathway written for the public.

The Princeton/Rutgers Environmental Science Institute has posted 'Global Warming Influences on C3 and C4 Photosynthesis', which is a workshop on the subject and contains information of possible interest to teachers: http://www.woodrow.org/teachers/esi/1999/princeton/projects/c3_c4/.

K. Chlorophyll fluorescence

'Chlorophyll Fluorescence' from Optisci (http://www.optisci.com/tutorial.htm) is a good introduction to chlorophyll fluorescence from a commercial company. We wish more companies would post instructive information such as this, besides merely advertising their products.

'Using Chlorophyll Fluorescence to Study Photosynthesis' from the Swiss Federal Institute of Technology, Zurich (ETH) (http://www.ab.ipw.agrl.ethz.ch/∼yfracheb/flex.htm). It is a fairly good site with many figures and references for students.

'Fluorescence as a Probe of Biological Structure and Function' from Govindjee at UIUC (http://www.life.uiuc.edu/govindjee/biochem494/biochem494a.html): You will find a bit of history, a basic description of Franck–Condon principle, basics of excitation energy transfer, some references; and a list of books. Date of site is Spring, 1999.

Govindjee has also set up a page for the Kautsky Effect with a QuickTime movie showing the effect (http://www.life.uiuc.edu/govindjee/movkautsky.html). A 3-D presentation is available at http://www.greentech.cz/science/lapi/3DKautsky.

L. On the use of herbicides

'Photosynthesis Inhibitors: Herbicides' by Michael De Felice (http://www.pioneer.com/usa/crop_management/corn/photo.htm). This site discusses history, mode of action, symptoms, and use of herbicides in corn and soybean.

'An Introduction to Herbicides' (http://ipmworld.umn.edu/chapters/wareherb.htm.). This site contains structures of many herbicides including Atrazine, Paraquat, Glyphosate, among others. There are also references.

'Mode of Action of Herbicides' by M.A. Ross and D.J. Childs of Crop Extension Service of Purdue University (http://www.agcom.purdue.edu/AgCom/Pubs/WS/WS-23.html) discusses the overall manner in which a herbicide affects a plant at the tissue or cellular level.

M. The chloroplast

'Virtual Cell' is a journey into the workings of the chloroplast, from the Department of Plant Biology at UIUC (http://www.life.uiuc.edu/plantbio/cell/). This award-winning site by Matej Lexa is indeed a fun site. You can cut, zoom, turn, and really look at the 'inners' of the chloroplast.

'Chloroplast Anatomy' from Bowdoin College (http://www.bowdoin.edu/dept/bio/bio104/photo/tool.html). A basic site to see grana and stroma.

'Chloroplast Genome Page' (http://reith.imb.nrc.ca/ct.htm). This site contains the genome of the red alga *Porphyra purpurea.* The page has links to (a) Plastid Gene nomenclature; and (b) Chlamydomonas Genetics Center.

N. Pigments/carotenoids

'Photosynthetic Pigments' from the University of California, Berkeley (http://www.ucmp.berkeley.edu/glossary/gloss3/pigments.html). It is a nice site discussing the three major pigments of plants, algae and cyanobacteria, chlorophylls, phycobilins, and carotenoids. The site also describes the characteristics of plants and cyanobacteria (there are nice pictures of cyanobacteria, and suspensions of some algae).

'Pigments' from Western Maryland College (http://wwwfac.wmdc.edu/HTMLpages/Academics/Biology/botf99/photo/p3igments.html). This site has basic description of pigments.

'Photosynthesis and Pigments' from a Nobel-laureate, George Wald (http://www.mbl.edu/animals/Limulus/vision/Wald/photosynthesis.html). It is a simple description of pigments, done a long time ago, but it is fun.

The Carotenoids Page (http://dcb-carot.unibe.ch/carotint.htm) is written by George Britton. It includes several pages on Introduction, Occurrence, Structure, and Biosynthesis of Carotenoids, followed by a list of references.

O. Rubisco (Ribulose bisphosphate carboxylase oxygenase)

'Rubisco: A First Look at the Mechanism' from the School of Crystallography at Birbeck, University of London (http://pps99.cryst.bbk.ac.uk/projects/jnixon/Title_Page.html). It is a very good site that tells you what RUBISCO is, its mechanism of action, and provides many useful references. Also see their 'Rubisco Structure in Relation to Mechanism' (http://pps99.cryst.bbk.ac.uk/projects/sgirdwood/Structmech.html).

'Ribulose-1,5-bisphosphate Carboxylase' from University of Hamburg (http://www.rrz.uni-hamburg.de/biologie/ialb/lehre/molbio/1rxo/e1rxoe.htm). The page opens with nice colored pictures of the enzyme. The site discusses in depth the mechanism of action as well as the structure of the enzyme. It requires downloading plug-ins.

A general article on RUBISCO by Jon Jefferson at Oak Ridge National Laboratory (http://www.ornl.gov/ornl93/life.html). It is a news item on Dr Hartman's talk at a conference. It is good for the beginners.

'Rubisco' from the University of Arizona (http://www.biochem.arizona.edu/classes/bioc462/462b/mol/chime/rubisco/rubisco.html). The site has structures. You need to download the CHIME plugin to enjoy the site.

If you like humorous top ten lists check out the 'I Love Rubisco' site at (http://www.sabregirl.freeservers.com/rubisco.html).

P. Whole plant photosynthesis and plant stress

'Field Photosynthesis Measurement Systems' from New Mexico State University (http://weather.nmsu.edu/Teaching_Material/soil698/Student_Material/Photosynthesis/). This site describes LICOR Gas exchange systems and their use for measuring whole plant photosynthesis. 'Plant Stress' from Plantstress.Com (http://www.plantstress.com/). The site contains news from various sources that are related to plant stress.

'FIFE Canopy Photosynthesis Rates Data Set Guide Document' is a technical report from Oak Ridge National Laboratory (http://www-eosdis.ornl.gov/FIFE/Datasets/Vegetation/Canopy_Photosynthesis_Rates.html). This site presents details of data on 'Canopy Photosynthesis', collected in 1987 at several sites.

'Effects of Mowing Disturbance on Photosynthetic Rates of a Herbaceous Community' by Lisa Bucci of Denison University (http://www.denison.edu/biology/faculty/firouznia/LisaBucci.html). There are pictures of the field and a brief description of questions asked and the results obtained.

Q. Bacterial (both oxygenic and anoxygenic) photosynthesis

'Introduction to the Cyanobacteria' from the University of California, Berkeley (http://www.ucmp.berkeley.edu/bacteria/cyanointro.html). It shows two nice photographs of cyanobacteria and gives a short description.

'Purple Non-Sulfur Photosynthetic Bacteria' from the University of Wisconsin (http://www.bact.wisc.edu/Bact102/102pnsb.html). It is a good teaching site at undergraduate level (their Bacteriology 102 course). It includes nice photos of bacterial cultures, description of bacteria and the media they are grown in.

'Going to Extremes' from Southern Illinois University at Carbondale, Illinois, discusses the work of Michael Madigan on photosynthetic bacteria in Antarctica (http://www.siu.edu/ perspect/00_sp/extremes1.html). The site discusses 'cold-loving' bacteria, doing research in extreme climate, and coaxing bacteria to grow in the laboratory.

'Energy Conversion by Photosynthetic Organisms' from the Food and Agriculture Organization of the United Nations (http://www.fao.org/docrep/w7241e/w7241e06.htm). The site provides some basic information on solar energy, plant and bacterial photosynthesis, and hydrogen production by photosynthetic organisms. There are references as well.

R. Evolution of photosynthesis

'Molecular Evolution of Photosynthesis' from Carl Bauer at Indiana University (http://sunflower.bio.indiana.edu/∼cbauer/bauerlab/research/evolution.html). The site has a clear text, beautiful evolutionary trees, and the photosynthetic gene cluster of heliobacteria.

'Evolution: When Did Photosynthesis Emerge on Earth?' by David J. Des Marais at NASA Ames Research Center (http://edmall.gsfc.nasa.gov/aacps/news/Photosynthesis.html) and his article 'Evolution of Earth's

Early Biosphere and Atmosphere' (http://astrobiology.arc.nasa.gov/palebluedot/abstracts/ddm.html). The first text consists of extracts from a paper by Jin Xiong and coworkers, published in Science (September 8, 2000).

S. Photosynthesis and the environment

'The Greenhouse Effect and the Ecological Consequences of Climate Change' from the University of Michigan (http://www.sprl.umich.edu/GCL/notes2/greenhouse.html). The site contains lecture notes and has a suggested reading list, good text, and great figures.

'Greenhouse Effect & Enhanced Greenhouse Effect' from the Center for Earth Observing and Space Research at George Mason University (http://www.science.gmu.edu/∼zli/ghe.html). It includes discussion on global warming as well as 'greenhouse myths'.

'Tropical Forests and the Greenhouse Effect: A Management Response' by Norman Myers and Thomas J. Goreau (http://www.ciesin.org/docs/002-163/002-163.html). It is a 1991 paper, has text and references, but no figures.

'Effects of CO_2 on the Rainforest Ecosystem' from Columbia University's Biosphere 2 (http://www.bio2.edu/Research/rnews98s7.htm). It is a short piece worth reading.

'New Studies of Forest Canopy Photosynthesis: Can Old-Growth Forests Make a Difference in Global Climate Change?' from the University of California, Davis and the National Institute for Global Environmental Change (http://nigec.ucdavis.edu/westgec/news/article2.html). It is a short item on the topic.

'Photoinhibition in Antarctic Phytoplankton by Ultraviolet-B Radiation in Relation to Column Ozone Values' from NSF's Office of Polar Programs (http://www.nsf.gov/od/opp/antarct/ajus/nsf9828/9828html/j1.htm). It is a short article, has some references, and deals with ozone-related problems.

'Helping Ocean Algae Could Beat Greenhouse Effect' from Environmental News Network describes how adding iron compounds to the water may help algae reproduce faster, thus removing more CO_2 from the atmosphere, (http://www.enn.com/news/wire-stories/2000/10/10122000/reu_algae_32447.asp). It is a 2-page news item.

T. Artificial photosynthesis

'Mimicking Nature's Engine' by Erik Ellis discusses some of the work of the ASU Center for the Study of Early Events in Photosynthesis (http://researchmag.asu.edu/articles/mimick.html). It is a news item with a short basic description.

'When Science Imitates Nature: Using Artificial Photosynthesis to Harness Solar Energy' by Hunter Whitney of Northwestern University (http://www.chem.nwu.edu/NanoWeb/earth.html). It is a nice-looking news item with statements by Drs Mike Wasielewski and John Connolly.

'A New Leaf' discusses the artificial photosynthesis work being done at CSIRO (Council of Scientific and Industrial Research Organization) in Australia (http://www.beyond2000.com/news/Nov_00/story_890.html). It has links to the work of Drs Tasso Melis and Mike Seibert on hydrogen production by algae (Slimy Green Power) and to 'Dirty Bloomers'.

'Energy at the Speed of Light' by Andrew Gathman at Penn State University (http://www.research.psu.edu/rps/0009/energy.html). It is a news item worth reading.

'Theory and Modeling of Biological Nanodevices' by Klaus Schulten at the UIUC (http://www.foresight.org/Conferences/MNT8/Abstracts/Schulten/) contains a brief summary of using photosynthesis to develop nanodevices – an area of research that is pushing the envelope of photosynthesis research.

'Reinventing the Leaf' by Philip Ball in Nature: Science Update (http://www.nature.com/nsu/991007/991007-3.html). It is a news item worth reading.

Individual researchers' sites

Three years ago the authors (Orr and Govindjee 1998) had a difficult time finding outstanding web sites for individual researchers as most of them did not have web sites, or their sites consisted of rather bland pages prepared by their departments. Today there are literally hundreds of web sites available and many of them are quite excellent. In this section we are listing a number of individual sites that we feel are quite well done. We favor sites that are created and maintained by the individuals themselves, not their departments, and which contain detailed research descriptions (not just brief summaries), useful figures, links to other sites, and personal information that help us see the researcher as a person. Many of the sites we have selected may seem a bit simple when first viewed, but their richness is revealed when links (sometimes very subtle) are followed. Many more web sites will be found in the 'Nicelist' web site maintained by one of us (LO) (http://photoscience.la.asu.edu/photosyn/nicelist.html). All sites are listed alphabetically by the researcher's last name. We apologize in advance to those we may have missed.

John F. **Allen** (http://plantcell.lu.se/john/). A deceptively simple site that contains quiet links to many areas of photosynthesis as well as interesting private places. There are tours, there is animation, and there is music. John Allen was one of the very first photosynthesis researchers to have his own site.

James **Barber** (http://www.bc.ic.ac.uk/research/barber/index.html). This site contains well-illustrated pages involving his research into Photosystem II (PS II) and other pages of interest. You can view pictures of 3-D PSII Supercomplex.

Carl **Bauer** (http://sunflower.bio.indiana.edu/∼cbauer/bauerlab/). Pages found here cover bacteriochlorophyll, phototaxis, molecular evolution of photosynthesis and more.

Robert E. **Blankenship** (http://photoscience.la.asu.edu/photosyn/faculty/Blankenship/Welcome.html). Interesting lab site with pages describing work on Photosystem I, chlorosomes, the Fenna–Mathews–Olson protein and even astrobiology.

Gary **Brudvig** (http://ursula.chem.yale.edu/∼brudvig/). A happy site that discusses Gary Brudvig's research with Photosystem II. It contains a model of Oxygen Evolving Complex, publication list, and photographs of students.

Donald **Bryant** (http://www.bmb.psu.edu/deptpage/bryant.htm). A single page site that discusses research on structure and function and biogenesis of the photosynthetic apparatus of cyanobacteria and green sulfur bacteria; control of gene expression, and physiology. It also has a publication list.

John M. **Cheeseman** (http://www.life.uiuc.edu/cheeseman/). Contains links to his research on mangroves and a software program (that you can download) for a multimedia textbook on photosynthesis (by M. Lexa and J. Cheeseman). The site contains links to courses on form and function in higher plants, introduction to plant biology, and field ecology.

Parag **Chitnis** (http://www.public.iastate.edu/∼chitnis/). This is a good page with links to research on Photosystem I. Includes a small form allowing readers to ask questions about the site. There are links to gene maps of cyanobacteria. Have fun with http://www.kazusa.or.jp/cyano/map/click/cmap.html for *Synechocystis* sp. PCC 6803, the favorite of many.

William **Cramer** (http://www.bio.purdue.edu/courses/Cramer_labpage/waclab.html). Contains good descriptions and figures of work with the structure of cytochrome b_6f complex, cytochrome *f* and the Rieske iron-sulfur protein.

Antony **Crofts** (http://www.life.uiuc.edu/crofts/ahab/home.html). This site is a virtual goldmine of information. There is much here on the cytochrome bc_1 complex and many other subjects, including many helpful links. It is great fun to watch the movement of the Rieske Iron sulfur protein.

Charles **Dismukes** (http://www.princeton.edu/∼catalase/). A good site that contains many links to research on photosynthetic water splitting enzyme, manganese catalase, manganese cubane, and paleobiochemistry, it has good figures and discussions. There is a link to all links in photosynthesis: http://www.alga.cz/links.htm.

Bob **Ford** (http://www.bi.umist.ac.uk/users/ford/lab/). This is a deep site with many layers of information regarding Photosystem II. There is 2D crystal, and a movie of the complex, among other things.

Harry **Frank** (http://chemistry.uconn.edu/FrankGroup/frankg.html). Contains several brief descriptions of work on the structure and function of carotenoids, role of xanthophylls in non-photochemical quenching of chlorophyll fluorescence, electrochemistry of cofactors of photosynthetic reaction centers, and even some interesting work with transgenic fish of economic importance.

Susan **Golden** (http://ACS.TAMU.EDU/∼ssg7231/index.html). There is a nice figure on regulation of photosynthetic genes, and list of publications on Circadian Rhythm as well as on regulation of genes in *Synechococcus*.

Govindjee (http://www.life.uiuc.edu/govindjee/). This site contains many links to all parts of the photosynthesis universe. There is a nice 'Photosynthesis Education' site at http://www.life.uiuc.edu/govindjee/Psed_index.htm), slides made in 1998 on various aspects of photosynthesis starting at http://www.life.uiuc.edu/SpringGov/lectures/lecture04/slides through lecture07/slides Research publications in the areas of primary photochemistry, role of bicarbonate in Photosystem II, chlorophyll *a* fluorescence, among other topics can be found arranged according to journals and to topics.

Arthur R. **Grossman** (http://carnegiedpb.stanford.edu/grossman/grossman.html). It has a description of research on responses of photosynthetic organisms to their environment. There is also a reference list.

Devens **Gust** (http://photoscience.la.asu.edu/photosyn/faculty/gust/index.htm). It has links to an article on 'Why Study Photosynthesis' and a discussion of artificial photosynthesis including the making of proton gradients, and molecular electronics.

Roger **Hangarter** (http://www.bio.indiana.edu/people/faculty/Hangarter.html). This site discusses environmental sensory response systems and plant development. It has plants-in-motion time lapse movies, information on *Arabidopsis* and links to *Arabidopsis* data bases, and it has laboratory exercises for teaching plant growth and motion from elementary schools through college. Although not directly related to photosynthesis, it is a fun site. See for yourself.

Alfred R. **Holzwarth** (http://www.mpi-muelheim.mpg.de/mpistr_holzwarth.html). There is a description of 'Biophysics and dynamics of pigment protein complexes'. It also has a list of 1995–1997 publications.

Kerry **Karukstis** (http://www2.hmc.edu/~karukstis/index.htm). There is a discussion of using chromophores and fluorophores to explore microenvironments within supramolecular species and macromolecular system. You will also find references to two of her books (1999: Chemistry Connections – The Chemical Basis of Everyday Phenomenon, and 1997: A Guide to Lasers in Chemistry) and publications.

Jonathan B. **Marder** (http://indycc1.agri.huji.ac.il/~marder/). For us, the best thing is the tutorial on photosynthetic reaction center, especially because it is accompanied by music (The Blue Danube Walz by Johann Strauss). There is a link to a fun site on second law of thermodynamics (http://www.secondlaw.com). Enjoy it.

Sabeeha **Merchant** (http://www.chem.ucla.edu/dept/Faculty/merchant/index.html). This is a wonderful site on 'Biochemistry of Molecular Genetics and Metal Metabolism'. It has publication lists since her PhD days, but more importantly many of her papers on cytochromes and plastocyanin and a major review are available in PDF files. We find her 'Useful Links' very useful indeed. They include research resources, companies, composition (that has the famous 'The Elements of Style' by William Strunk on line, loved by us), dictionaries, on-line journals, and genome data bases.

Kenneth R. **Miller** (http://biomed.brown.edu/Faculty/M/Miller/Miller.html). Structure and Function in Biological Membranes is the theme of research at this site. There is an interesting essay on 'Life's grand design', and a link to an interesting article in 'Discover' on 'Perils and pitfalls of life with a Y chromosome'. (Both of us needed to read it.) The site also contains information on beautiful biology text books by Miller and Joseph Levine.

Conrad W. **Mullineaux** (http://www.server.bcc.ac.uk/biology/conrad.htm). This site has thin section electron micrograph of *Synechocystis* sp. PCC 6803; fluorescence video imaging of colonies of cyanobacteria showing state-I and state II change mutants, mobility of phycobilisomes by FRAP (Fluorescence Recovery After Photobleaching), and confocal microscopy. We encourage the readers to see gorgeous fluorescence of cyanobacterial cells at http://www-server.bcc.ac.UK/biology/cyano.htm.

Gunnar **Öquist** (http://www.plantphys.umu.se/~gunnar/). His site discusses their research on 'Stress and Adaptation Mechanisms in Photosynthesis' at Umeå University.

Donald **Ort** (http://www.life.uiuc.edu/pru/labs/ort.html). The site describes the strategies used by his laboratory on "how component processes of photosynthesis integrate to determine photosynthetic performance under agronimically significant situations". There is an impressive picture of Don Ort, and a pretty model of light and dark reactions of photosynthesis. Further, it has link to equally beautiful sites of the Laboratories of Dan **Bush**, Archie **Portis**, and John **Whitmarsh**.

Richard **Sayre** (http://www.biosci.ohio-state.edu/~rsayre/). It is a nice looking page with pictures of plants, a *Chlamydomonas* cell, Photosystem II reaction center model, and photographs of his coworkers. Publication list of papers on Cassava, Heavy Metals Biology, and Photosynthesis are provided. The overall research area is 'Protein and Metabolic Engineering of Plants'.

Kintake **Sonoike** (http://www.biol.s.u-tokyo.ac.jp/users/sonoike/lab-e.htm). The site contains some background on photosynthesis. The group studies 'Dynamics of photosynthesis under different types of stresses'. These include temperature, low CO_2, and rain. There is a colored cartoon of the 4 protein complexes of the thylakoid membrane. A publication list is also included.

F. Robert **Tabita** (http://www.biosci.ohio-state.edu/∼microbio/frt.html). Molecular regulation, biochemistry and enzymology of carbon dioxide assimilation is the theme of research. In addition to a list of publications, and a text, you can study a conceptual model showing interplay of various factors involved in signal transduction and regulation of a gene. Further, structure predictions for archaeal RUBISCOs are shown.

Steve **Theg** (http://www-plb.ucdavis.edu/labs/theg/). The theme is 'Transport of proteins across biological membranes from peas, *Arabidopsis*, and the moss *Physcomitrella*'. Recent publications are listed in an elegant manner along with the photos of the cover pages of the journal; some are available as PDF files. An interesting text by Steve Theg is: 'Are You a Cell Biologist, a Biochemist or a Geneticist?' (/cartoon.htm). The site provides links to On-line journals, Resources, Data bases, Software, and Dictionary.

Elaine **Tobin** (http://www.mcdb.ucla.edu/Faculty/TOBIN/tobin.html). The theme here is phytochrome-regulated developmental processes, particularly of circadian clock in *Arabidopsis*. Publication list is very helpful. On the emotional side, you can see Philip Thornber's Memorial bench and its description by Alan Paulson.

Wim F. J. **Vermaas** (http://photoscience.la.asu.edu/photosyn/faculty/vermaas.html). The theme is the molecular genetics of photosynthetic proteins. Wim studies structure, function and assembly of photosynthetic proteins by genetic engineering. Recent publication list up to 1999 is available. Also, you can read 'An Introduction to Photosynthesis and Its Application', published in World & I in 1998. His link to one of the courses he teaches opens into his incredibly rich site on genetics and society.

Elizabeth **Vierling** (http://www.biochem.arizona.edu/vierling/). The theme is 'heat-shock proteins', as molecular chaperones, during seed development, in *Arabidopsis*, and in *Synechocystis*. A list of publications is also available.

Thomas **Vogelmann** (http://uwadmnweb.uwyo.edu/botany/fac/vogel.htm). The theme of research is 'Use of photoaccoustics to measure photosynthesis', and 'Ecophysiology of snow alga *Chlamydomonas nivalis*'. Students may enjoy Vogelmann's wacky web page for his basic course in biology.

David Alan **Walker** is a 'retired' professor of photosynthesis who is producing some very interesting books and other items related to photosynthesis filled with humor and good illustrations. Check out the nooks and crannies of his web site for a good time (http://www.alegba.demon.co.uk/index.html). His books appear in the section on 'Books' later on in this paper.

Michael R. **Wasielewski** (http://www.chem.northwestern.edu/∼wasielew/Homepage.html). The themes are photo-induced electron transfer, femtosecond-picosecond transient absorption changes, among others.

Neal **Woodbury** (http://www.public.asu.edu/∼laserweb/woodbury/woodbury.htm). The theme is 'Molecular dynamics and mechanisms in protein mediated chemical reactions'. Molecular level control of reaction mechanisms by protein structure is studied. Both antenna and reaction centers of photosynthetic bacteria are used. Ultrafast spectroscopy and hole burning methods are used.

Charles F. **Yocum** (http://www.biology.lsa.umich.edu/people/faculty/cyocum.html). The theme is biochemistry of Photosystem II and oxygen evolution. The site has a complete lecture (with figures) entitled 'Light, Life and Photosynthesis: How Plants Make Oxygen'. It is found under 'Sussman lecture'.

Kindergarten to grade 12 (K-12) educational sites

Of course, all of the web sites discussed thus far can be used for educational purposes, but there are some which are primarily aimed towards students and educators. Also included is a list of sites that contain science experiments involving photosynthesis. Some books that may be useful are listed in the section on books and journals.

One of the best sites is the ASU Photosynthesis Center site. It contains an entire educational area for information about photosynthesis ranked by appropriate age groups (http://photoscience.la.asu.edu/photosyn/education/learn.html). This site is maintained by one of us (LO) and is revised frequently.

‘Teaching Photosynthesis from the Internet’ is an ongoing project by one of us (G) to collect educational materials about photosynthesis in one easily accessed place (http://www.life.uiuc.edu/govindjee/photoweb/WWWoverview.html). It is very much like a condensed version of this entire paper and is organized by grade level.

The Discovery Channel has posted a definition of ‘Photosynthesis’ that is concise, but easily understandable by most (http://school.discovery.com/homeworkhelp/worldbook/atozscience/p/428180.html).

Devens Gust at ASU has written an important essay, ‘Why Study Photosynthesis’, which instead of explaining the workings of photosynthesis, tells why it is so important to the world. He shows how students can use photosynthesis as a means to learn about many areas that may not seem to be linked to photosynthesis (http://photoscience.la.asu.edu/photosyn/study.html).

‘Teaching Photosynthesis to All Ages: 5–105’ is another project by one of the authors (G) that lists educational links (http://www.photosynthesiseducation.bigstep.com/). However, it is being slowly replaced by a ‘photosynthesis education’ site at (http://www.life.uiuc.edu/govindjee/Psed_index.htm). The two are not identical.

Newton’s Apple, a PBS show, has produced ‘Photosynthesis: How Do Plants Make Food?’ which is a good introduction to photosynthesis to young readers (http://www.pbs.org/ktca/newtons/9/phytosy.html).

John Cheeseman from UIUC is producing a line of educational software for the classroom (http://www.life.uiuc.edu/cheeseman/JC.software.html).

A sample from the ‘National Science Education Standards’ regarding photosynthesis may be found at http://www.nap.edu/readingroom/books/nses/html/photo6e.html. Science Made Simple, a service available by subscription has many items of interest to teachers, including the very popular ‘Why Do Leaves Change Color in the Fall?’, which is available as a free sample on their web site (http://www.sciencemadesimple.com/leaves.html).

‘Patterns of Movement: The Carbon Cycle’ is intended for middle school, grades 6–8 (http://set.lanl.gov:80/programs/tops/tops9799/curriculum/lightyears/carbo.htm).

Kapi’olani Community College has a nice site for Oxidation/Reduction which is important to all life processes, not just photosynthesis (http://naio.kcc.hawaii.edu/chemistry/default.html). It also has a link to its section on photosynthesis equations (http://naio.kcc.hawaii.edu/chemistry/everyday_photosyn.html).

Tom Bitterwolf of the University of Idaho has another good site for oxidation/reduction chemistry (http://www.chem.uidaho.edu/∼honors/redox.html).

Experiments on the Web

There are many web sites detailing experiments that can be carried out in the classroom to show various aspects of photosynthesis. Some of the sites offer very simple experiments, while others are somewhat more involved.

Terry Coffeit and Dave Dierig from the US Water Conservation Laboratory have posted a lab on the ‘Effect of Light on Seed Germination’ for students in grades 7-12 (http://www.uswcl.ars.ag.gov/exper/lghtseed.htm).

The Russian space station Mir may be gone, but NASA has posted ‘Activity #1 Shuttle/Mir Seed Germination Activity’ that explores hydroponics, photosynthesis and seed germination (http://quest.arc.nasa.gov/smore/teachers/act1.html) which duplicates some of the experiments done on Mir.

Dr Richard G. Steane has a number of experiments involving starch and *Geraniums* at the web site for ‘Experiments to Show the Factors Required in Photosynthesis – Light and Carbon Dioxide’ (http://web.ukonline.co.uk/webwise/spinneret/plants/psfac2.htm). The same site has a section with experiments on ‘Chlorophyll’ in the plant *Zebrina* (http://web.ukonline.co.uk/webwise/spinneret/plants/psfac1.htm).

C. Ford Morishita has a web site involving starch pictures on leaves, ‘Photosynthetic Pictures Are Worth More Than a Thousand Words’ (http://www.accessexcellence.org/AE/AEC/AEF/1996/morishita_pictures.html).

Nelida Boreale has developed a lesson plan involving a simple experiment for ‘Photosynthesis and Transpiration’ (http://askeric.org/cgi-bin/printlessons.cgi/Virtual/Lessons/Science/Botany/BOT0046.html).

Flinn Scientific, Inc. has posted a page with an experiment on ‘Respiration versus Photosynthesis’ (http://www.flinnsci.com/homepage/bio/resphoto.html).

A number of sites have posted experiments involving experiments with leaf disks. One of the more complex ones is at ‘Photosynthesis and Transpiration (http://koning.ecsu.ctstateu.edu/Plant_Biology/pstranslab.html), which is intended for 2nd year college students. A similar experiment written for middle and high schools is ‘Plant Development and Physiology: Photosynthesis and Experimental Design’ (http://department.stthomas.edu/BIOL/

COURSES/Biology201/201LAB/LEAF_DISK.HTM). Scotland's Science and Plants for Food organization also has a site on 'The Response of Leaf Discs from Sun and Shade Plants to Green Light' (http://saps1.plantsci.cam.ac.uk/worksheets/disc.htm).

A high school level lab on 'Photosynthesis, Respiration, and the ATP-ADP Cycle' has been written by Clovis O. Price Jr. (http://www.iit.edu/ smile/bi9614.html), in which beans are used to represent the various atoms involved in the photosynthesis process and are pasted on posters. Models are also made using carved sponges. Finally, students will use tennis balls to demonstrate the ATP-ADP cycle.

Grace Guy has posted 'Unit Plan Incorporating Multicultural Perspective' (http://www.nyu.edu/classes/murfin/secmethodsboard/messages/308.html) which describes three labs using various plants and is suitable for grade level 10.

Access Excellence has a couple of interesting experiments using *Elodea* and other organisms. James Linhares offers 'A Constructivist Version of the Snail & Elodea Lab' (http://www.accessexcellence.com/AE/AEC/AEF/1996/linhares_lab.html). A similar lab has been written by Bob Culler, 'Mussel Your Way Through Photosynthesis', which uses zebra mussels and *Elodea* in a project suitable for grades 9 & 10 (http://www.accessexcellence.com/AE/AEC/AEF/1995/culler_photo.html).

There are several other sites with lab experiments that use the common aquarium plant *Elodea*. Although the procedures are very similar, the lessons are written with slightly different perspectives and age groups in mind. 'Lab Exercise of Photosynthesis' (http://filebox.vt.edu/users/kpotter/sharma/labexerciseonphotosynthesis.htm) is a simple experiment involving counting bubbles of oxygen arising from the elodea. A similar lesson has been written by Karen F. Adams of Burnside Scholastic Academy in Chicago (http://www.iit.edu/∼smile/bi9201.html). The same lab has been reformatted into HTML and can be found at http://www.mrwatkins.com/labs/biolabs/Photosynthesis.html. Finally, an experiment with elodea involving 'Light Intensity and Photosynthetic Rate' is found at The Mining Company (http://botany.miningco.com/science/botany/library/weekly/aa092000c.htm).

'Photosynthesis and Chromatography of Its Pigments' (http://www.science-projects.com/APPhotosynth0.htm) is a relatively simple experiment involving paper chromatography.

A complete lesson plan including experiments is included in 'Thin Layer Chromatography' (http://www.chem.hope.edu/labscape/catofp/chromato/tlc/tlc.htm), part of the Labscape project from the University of Wisconsin.

Neal Woodbury from ASU has set up a 'Virtual Experiment' which uses mutant bacteria to discover which proteins are necessary for photosynthesis. A virtual experiment is one in which the student follows a lab procedure on the computer screen rather than in a wet lab. Just like in the lab, the student has to correctly perform the parts of the experiment or it fails (http://photoscience.la.asu.edu/photosyn/education/experiments/protein_exp/cover.htm).

The Chlamydomonas Research Center has posted several experiments suitable for science fair projects (http://www.biology.duke.edu/chlamy/strains/projects.html). They also sell inexpensive kits that contain the algae required for the experiments.

Books and journals

Although books about photosynthesis have not been placed online for economic reasons, there are web sites that discuss them and commercial sites that sell them. Some of those sites will be listed here. Many of them will include reviews or summaries and list the table of contents and some may even provide a sample chapter.

Many journals are now becoming available online, but usually only to University libraries that pay for the service. Many Universities have discovered that it is cost effective (cheaper) to subscribe to the online journals on behalf of their students and faculty, than it is to try and subscribe to the hard copy versions of the journal which must be cataloged and archived by library personnel and is only available to one person at a time. Occasionally the journal is unavailable due to misfiling or during the time it is sent out to be bound with other issues. The online version is always available and to as many persons as the library has paid for. Even if the journal issue is not available, the journal publisher's website will often contain the table of contents, abstracts, instructions to authors, and sometimes sample issues or articles.

Books

The most current set of books on photosynthesis and related matters is the *Advances in Photosynthesis and Respiration* series being published by Kluwer Academic Publishers, with one of us (G) serving as its Series Editor. Descriptions and ordering information can be found at two sites: the publisher (http://www.wkap.nl/series.htm/AIPH), and at http://photoscience.la.asu.edu/photosyn/books/advances.html. This series currently contains 11 volumes:

1. *The Molecular Biology of Cyanobacteria* – edited by Donald A. Bryant.
2. *Anoxygenic Photosynthetic Bacteria* – edited by R.E. Blankenship, M.T. Madigan and C.E. Bauer.
3. *Biophysical Techniques in Photosynthesis* – edited by Jan Amesz and Arnold J. Hoff.
4. *Oxygenic Photosynthesis: The Light Reactions* – edited by Donald R. Ort and Charles F. Yocum.
5. *Photosynthesis and the Environment* – edited by Neil R. Baker.
6. *Lipids in Photosynthesis: Structure, Function and Genetics* – edited by P. A. Siegenthaler and N. Murata.
7. *The Molecular Biology of Chloroplasts and Mitochondria in Chlamydomonas* – edited by J.-D. Rochaix, M. Goldschmidt-Clermont and S. Merchant.
8. *The Photochemistry of Carotenoids* – edited by Harry A. Frank, Andrew J. Young, George Britton and Richard J. Cogdell.
9. *Photosynthesis: Physiology and Metabolism* – edited by Richard C. Leegood, Thomas D. Sharkey and Susanne von Caemmerer.
10. *Photosynthesis: Photobiochemistry and Photobiophysics* – authored by Bacon Ke.
11. *Regulation of Photosynthesis* – edited by Eva-Mari Aro and Bertil Andersson.

Other books of note are:

- *Aquatic Photosynthesis*, by Paul G. Falkowski (Brookhaven National Lab) and John Raven (University of Dundee), is listed at http://www.blackwell-science.com/~cgilib/bookpage.bin?File=3245 (1997, Blackwell Science). See also a review of this book by one of us (G) at http://www.life.uiuc.edu/govindjee/photoweb/4books.html.
- *Concepts in Photobiology: Photosynthesis and Photomorphogenesis* is listed at http://photoscience.la.asu.edu/photosyn/books/newbook.html
- *Membrane Biophysics*, by H. Ti Tien and Angelica Ottova-Leitmannova, is listed at http://www.elsevier.nl/gej-ng/29/50/show/
- *The Music of Sunlight*, by Wilbert Veit, Jr., is a science fiction book that asks the question: What if you could be an electron for one second? (http://www.molecadv.com/)
- *Photophysics of Photosynthesis. Structure and Spectroscopy of Reaction Centers of Purple Bacteria*, by A. J. Hoff and J. Deisenhofer. In: Physics Reports, 287 (1997) (web site is currently unavailable).
- *Photosynthesis*, by D.O. Hall and K.K. Rao, has gone through several editions and is still one of the best textbooks for the study of photosynthesis (http://www.cup.org/ObjectBuilder/ObjectBuilder.iwx?processName=productPage&product_id=0521430364&origin=redirect).
- *Photosynthesis: A Comprehensive Treatise*, edited by A. S. Raghavendra, is listed at http://www.cup.org/Titles/57/052157000X.html (1997,Cambridge Press). See also a review of this book by one of us (G) at http://www.life.uiuc.edu/govindjee/photoweb/4books.html.
- *Photosynthetic Excitions*, by Herbert van Amerongen, Rienk van Grondelle and Leonas Valkunas, is listed at http://www.worldscientific.com/books/lifesci/3609.html
- *Photosynthetic Unit and Photosystems – History of Research and Current Views (Relationship of Structure and Function,* by A. Wild and R. Ball (of Germany) (1997, Buckuys Publishers). See a review of this book by one of us (G) at http://www.life.uiuc.edu/govindjee/photoweb/4books.html.
- *Plant Biochemistry and Molecular Biology*, by Hans-Walter Heldt (Institute of Plant Biochemistry, Göttingen) (with the collaboration of Fiona Heldt), is listed at http://www1.oup.co.uk/bin/readcat?Version=900797103&title=Plant+Biochemistry+and+Molecular+Biology&TOB=209439&H1=185927&H2=209114&H3=209115&H4=209205&count=1&style=full (1997, Oxford University Press). See a review of this book by one of us (G) at http://www.life.uiuc.edu/govindjee/photoweb/4books.html.

– *Probing Photosynthesis: Mechanism, Regulation & Adaptation*, edited by M. Yunus, U. Pathre and P. Mohanty, is listed at http://photoscience.la.asu.edu/photosyn/books/probebk.html

David Walker has produced a set of books that approach photosynthesis from several different angles and which have been written for several age groups. *A Leaf in Time* (for ages 8–12) discusses photosynthesis and its relationship to energy, plants and people (http://www.portlandpress.co.uk/books/isbn/1855780976.htm). *Energy, Plants and Man* is a large, profusely illustrated book with a great deal of information presented in an uncomplicated and humorous manner (http://photoscience.la.asu.edu/photosyn/books/walkerbk.html). Finally, *Like Clockwork* is a book in PDF format on a CD/ROM disk. It covers the story of energy transduction in photosynthesis in an easily understood manner and contains many interesting links, including some surprises (http://www.oxygraphics.co.uk/). All of these works are highly recommended.

Links to older volumes and books intended for young readers and the general public can be found at http://photoscience.la.asu.edu/photosyn/books.html.

Also see http://www.life.uiuc.edu/govindjee/photoweb/2books.html for a list of single and two-authored books compiled by Govindjee. A list of other books edited by Govindjee are also available (http://www.life.uiuc.edu/govindjee/books.html)

Journals

– Archives of Microbiology (http://link.springer.de/link/service/journals/00203/).
– Australian Journal of Plant Physiology (http://www.publish.csiro.au/journals/ajpp/).
– Biochemistry (http://pubs.acs.org/journals/biochem.html).
– Biochimica et Biophysica Acta (BBA) (http://www.elsevier.nl/gej-ng/29/50/show/).
– Biophysical Journal (http://www.biophysj.org/).
– Cell (http://www.cell.com/).
– FEBS Letters (http://www.elsevier.nl/febs/show/).
– Journal of American Chemical Society (JACS) (http://pubs.acs.org/journals/jacsat/index.html).
– Journal of Biological Chemistry (http://www.jbc.org/).
– Journal of Computer-Aided Molecular Design (http://www.wkap.nl/journalhome.htm/0920-654X).
– Journal of Photochemistry and Photobiology B: Biology (JPP) (http://www.elsevier.com/inca/publications/store/5/0/4/0/9/2/).
– Journal of Physical Chemistry (http://pubs.acs.org/journals/jpchax/index.html).
– Nature (http://www.nature.com/nature/)
– Photochemistry and Photobiology (http://www.pol-us.net/PAPHome/).
– Photochemistry and Photobiology (http://www.pol-us.net/PAPHome)
– Photosynthesis Research (http://kapis.www.wkap.nl/journalhome.htm/0166-8595).
– Photosynthetica (http://www.ueb.cas.cz/ps/ps.htm).
– Plant Molecular Biology (http://kapis.www.wkap.nl/journalhome.htm/0167-4412).
– Plant Physiology (http://www.plantphysiol.org/).
– Proceedings of the National Academy Of Sciences (USA) (http://www.pnas.org/).
– Protein Science (http://www.proteinscience.org/).
– Science (http://www.sciencemag.org/).

Other sites

Societies and organizations

Some selected ones are listed below (mostly US):
– International Society of Photosynthesis Research: ISPR (http://www.photosynthesisresearch.org/).
– American Chemical Society (http://www.acs.org/).

– American Society for Horticultural Science (http://www.ashs.org/).
– ASP – American Society for Photobiology (http://www.kumc.edu/POL/).
– ASPB – American Society of Plant Biologists [formerly American Society of Plant Physiologists (ASPP)] (http://www.aspb.org/).
– Biophysical Society of America (http://www.biophysics.org/biophys/society/biohome.htm).
– Inter-American Photochemical Society (http://www.chemistry.mcmaster.ca/∼iaps/).
– International Carotenoid Society (http://www.carotenoid.uconn.edu/main.html).
– Japanese Society of Plant Physiologists (http://www.nacos.com/jspp/jspp01.html).
– Phycological Society of America (http://www.psaalgae.org/).

Related sites

The following sites contain information of interest to researchers studying photosynthesis:

– Arabidopsis: The Arabidopsis Information Resource: TAIR (http://www.arabidopsis.org/home.html).
– Chlamydomonas Genetics Center (http://www.biology.duke.edu/chlamy/).
– Cyanosite (http://www-cyanosite.bio.purdue.edu/index.html)
– CyBib (http://www-cyanosite.bio.purdue.edu/cybib/cybibhome.html).
– The ASU Photosynthesis Center site also maintains links to a number of commercial vendors providing equipment and software: http://photoscience.la.asu.edu/photosyn/links.html.

Searching

The old saying, 'Be careful what you wish for; you just might get it', applies to the World Wide Web and the search engines that try to index it. When the Web first appeared there were no search engines and it was not clear how they could even be developed considering the size of the internet and the rapidity with which it was expanding.

Some companies, such as Yahoo (http://www.yahoo.com), appeared presenting lists of links that had been submitted to it by the authors of the web sites. This was an index, a very good one and still is, but it was not a true search engine. The impossible happened and true search engines began to appear such as Lycos (http://www.lycos.com/) and Alta Vista (http://www.altavista.com). The only problem was that they were 'too good'. If you typed in a word to search for, say 'photosynthesis', you were presented with a staggering list of 40 000 to 50 000 sites or more. They were listed in no particular order so a really good site might be located at position 4,560 while a piece of email archived in a usenet group with a brief mention of photosynthesis might be at the top. This was not good.

In our earlier paper (Orr and Govindjee 1998) we recommended 'Hot Bot' (http://www.hotbot.com), a newer search engine, as it allowed very accurate searches through the use of its advanced search mode. When used in its normal mode, though, it too provided unhelpful lists of thousands of sites.

"Things have changed", to quote Bob Dylan. **Google** (http://www.google.com), a new search engine has been developed. Google produces large lists as the others do, but it attempts, with some success, to list the web sites it finds in ranked order by how useful the site is to the searcher. It does this by watching which sites are accessed the most and then puts them at the top of the list. Advanced searches are also available and work even better. A second search engine that works somewhat well is **Ask Jeeves** (http://www.askjeeves.com). This engine allows you to type in a query in 'plain language' and it gets you the information. It is not as good as Google, but does a better job than most of the other search engines. It is especially useful to students as it 'speaks' their language. Type in 'what is photosynthesis?' and you get a nice list of sites that would be useful and, in fact, most are mentioned in this paper.

The future of searching will be even better. Search engines that search for concepts rather than words are under development. The father of the Web, Tim Berners-Lee, and colleagues are already working on the next generation of the Web which will include semantic tags to allow searches by meaning or ontology (Berners-Lee et al. 2001).

Here, then, is our recommendation. Always start your search with Google. If you do not find what you want in the first couple pages, go to Google's advance search mode and try again. If you want to find something specific, you have to ask for a specific search. Next try Ask Jeeves. Also try Yahoo and its site for younger searchers, Yahooligans (http://www.yahooligans.com/). For completeness and comparison, try using the advanced search procedures in the major search engines, especially Hot Bot. Some others not mentioned above are nbci (http://www.nbci.com), GoTo.Com (http://www.goto.com), Direct Hit (http://www.directhit.com) and Excite (http://www.excite.com). Several of these search engines actually use the same basic underlying search engine, so results may look virtually identical – because they are. If you want further detailed information on search engines and searching techniques, try Search Engine Watch (http://www.searchenginewatch.com/).

Appendix: A listing of all web sites mentioned in this paper

Group sites

http://photoscience.la.asu.edu/photosyn/
http://photoscience.la.asu.edu/photosyn/nicelist.html
http://photoscience.la.asu.edu/photosyn/education/learn.html
http://www.life.uiuc.edu/govindjee/
http://www.life.uiuc.edu/crofts/ahab/index.html
http://www.life.uiuc.edu/pru/
http://www.ks.uiuc.edu/
http://www.ks.uiuc.edu/Research/psu/psu.html
http://www.ks.uiuc.edu/Overview/movie_gallery/
http://plantcell.lu.se/
http://plantcell.lu.se/ltm/default.html
http://www.biokem.lu.se/AFS-WWW/Research.html
http://www.ucl.ac.uk/biology/prg.htm
http://www.sdu.dk/nat/biokemi/groups/photosyn/
http://www.biophys.leidenuniv.nl/Research/
http://www.bcbp.gu.se/photosyn/
http://www.weizmann.ac.il/weiz/research/wilstatter_ctr.html

Comprehensive overview sites

http://www.life.uiuc.edu/govindjee/paper/gov.html
http://gened.emc.maricopa.edu/bio/bio181/BIOBK/BioBookPS.html
http://www.rrz.uni-hamburg.de/biologie/b_online/e24/24.htm
http://esg-www.mit.edu:8001/esgbio/ps/psdir.html
http://photoscience.la.asu.edu/photosyn/education/photointro.html
http://www.alienexplorer.com/ecology/topic3.html
http://naio.kcc.hawaii.edu/chemistry/everyday_photosyn.html
http://www.ahpcc.unm.edu/~aroberts/

Specific subject sites

History of photosynthesis/biographies/Nobel prizes

http://www.life.uiuc.edu/govindjee/papers/milestones.html
http://www.life.uiuc.edu/govindjee/papers/CarFin1.html
http://www.life.uiuc.edu/govindjee/history/articles.htm
http://www.chem.mtu.edu/chemistry/PAGES/HISTORY/JosephPriestley.html
http://www.life.uiuc.edu/govindjee/history/nobel-ps.htm
http://www.life.uiuc.edu/govindjee/perspectives.html
http://www.life.uiuc.edu/govindjee/history/KrogmannDavidPP.pdf
http://www.life.uiuc.edu/govindjee/history/FullerClintPP.pdf
http://www.life.uiuc.edu/govindjee/history/FortiGeorgioPP.pdf
http://www.life.uiuc.edu/govindjee/history/JagendorfAndrePP.pdf
http://www.life.uiuc.edu/govindjee/history/FeherGeorgePP.pdf
http://www.life.uiuc.edu/govindjee/history/WalkerPP.pdf
http://www.life.uiuc.edu/govindjee/history/obituaries.htm
http://webserver.lemoyne.edu/faculty/giunta/Ingenhousz.html
http://webserver.lemoyne.edu/faculty/giunta/lavoisier1.html
http://webserver.lemoyne.edu/faculty/giunta/phlogiston.html
http://www.uky.edu/ holler/raman.html
http://www.nobel.se/chemistry/laureates/1915/willstatter-bio.html

http://www.nobel.se/physics/laureates/1925/franck-bio.html
http://www.nobel.se/physics/laureates/1930/press.html
http://www.nobel.se/physics/laureates/1930/raman-bio.html
http://www.nobel.se/chemistry/laureates/1930/fischer-bio.html
http://www.nobel.se/medicine/laureates/1931/press.html
http://www.nobel.se/medicine/laureates/1931/warburg-bio.html
http://www.nobel.se/chemistry/laureates/1937/karrer-bio.html
http://www.nobel.se/chemistry/laureates/1937/press.html
http://www.nobel.se/chemistry/laureates/1938/kuhn-bio.html
http://www.nobel.se/medicine/laureates/1959/ochoa-bio.html
http://www.nobel.se/chemistry/laureates/1961/press.html
http://www.nobel.se/chemistry/laureates/1961/calvin-bio.html
http://www.lbl.gov/Science-Articles/Archive/Melvin-Calvin-obit.html
http://www.life.uiuc.edu/govindjee/history/obit/ObitMelvinCalvin.pdf
http://www.nobel.se/chemistry/laureates/1965/press.html
http://www.nobel.se/chemistry/laureates/1965/woodward-bio.html
http://www.nobel.se/chemistry/laureates/1967/press.html
http://www.nobel.se/chemistry/laureates/1967/porter-bio.html
http://www.nobel.se/chemistry/laureates/1978/press.html
http://www.nobel.se/chemistry/laureates/1978/mitchell-bio.html
http://www.nobel.se/chemistry/laureates/1982/press.html
http://www.nobel.se/chemistry/laureates/1982/klug-autobio.html
http://www.nobel.se/chemistry/laureates/1987/press.html
http://www.nobel.se/chemistry/laureates/1987/lehn-autobio.html
http://www.nobel.se/chemistry/laureates/1988/press.html
http://www.nobel.se/chemistry/laureates/1988/deisenhofer-autobio.html
http://www.nobel.se/chemistry/laureates/1988/huber-autobio.html
http://www.nobel.se/chemistry/laureates/1988/michel-autobio.html
http://www.nobel.se/chemistry/laureates/1992/press.html
http://www.nobel.se/chemistry/laureates/1992/marcus-autobio.html
http://www.nobel.se/chemistry/laureates/1993/press.html
http://www.nobel.se/chemistry/laureates/1993/smith-autobio.html
http://www.nobel.se/chemistry/laureates/1997/press.html
http://www.nobel.se/chemistry/laureates/1997/boyer-autobio.html
http://www.nobel.se/chemistry/laureates/1997/walker-autobio.html
http://www.nobel.se/chemistry/laureates/1999/press.html
http://www.nobel.se/chemistry/laureates/1999/zewail-autobio.html

The light reactions

http://www.bio.mtu.edu/ mrgretz/bl414web/bl414_97/photosn1.htm
http://www.rrz.uni-hamburg.de/biologie/b_online/e24/24c.htm
http://esg-www.mit.edu:8001/esgbio/ps/light.html
http://www.life.uiuc.edu/govindjee/ptime/
http://koning.ecsu.ctstateu.edu/Plant_Physiology/LightRxns.html
http://www.life.uiuc.edu/govindjee/textzsch.htm

The dark reactions/ Calvin–Benson cycle/carbon cycle

http://www.rrz.uni-hamburg.de/biologie/b_online/e24/24a.htm
http://www.mrs.umn.edu/~goochv/CellBio/lectures/darkrxn/darkrxn.html
http://esg-www.mit.edu:8001/esgbio/ps/dark.html
http://koning.ecsu.ctstateu.edu/Plant_Physiology/Calvin.html
http://www2.nl.edu/~jste/calvin_cycle.htm

The photosynthetic unit/reaction centers

http://www.ks.uiuc.edu/Research/psu/psu.html
http://www.rrz.uni-hamburg.de/biologie/b_online/library/bio201/psunit.html
http://www.blc.arizona.edu/courses/181gh/rick/photosynthesis/pcr4.html
http://indycc1.agri.huji.ac.il/~marder/rc_view/
http://www.nobel.se/chemistry/laureates/1988/press.html
http://biosci.umn.edu/biophys/BTOL/bioenerg/Lavergne.J.pdf

Light-harvesting/ antennas

http://photoscience.la.asu.edu/photosyn/education/antenna.html

http://www.ks.uiuc.edu/Research/bio_ener/LH_2/
http://www.ks.uiuc.edu/Research/psu/psu_inter.html
http://bmbsgi11.leeds.ac.uk/bmbknd/promise/LH2PB.html
http://www.chem.gla.ac.uk/protein/LH2/lh2.html
http://plantcell.lu.se/Research/lhcii_chime.html

Electron transfer

http://iriaxp.iri.tudelft.nl/~scwww/candeias/bio-et/photos.html
http://www.life.uiuc.edu/pru/labs/whitmarsh/chapter7/contents.html
http://www.life.uiuc.edu/govindjee/textzsch.htm
http://orgwww.chem.uva.nl/phys/ET/
http://chemistry.anl.gov/photosynthesis/hierarchical_systems_Part2.html
http://www.soton.ac.uk/~solar/photosynthesis/Quantsol2000.htm

Bacterial photosystem, Photosystems I and II

http://sunflower.bio.indiana.edu/~cbauer/bauerlab/research/photosystem.html
http://userpage.chemie.fu-berlin.de/~phosys/
http://userpage.chemie.fu-berlin.de/~phosys/Structure.html
http://www.bcbp.gu.se/~orjan/res/pc-ps1-e.html
http://www.science.nasa.gov/newhome/headlines/msad27jul98_1.htm
http://wwwfac.wmdc.edu/HTMLpages/Academics/Biology/botf99/photo/l4ightrx.html
http://life.uiuc.edu/~a-crofts/psiiwork.html
http://life.uiuc.edu/~a-crofts/psiistrc.html
http://www.bc.ic.ac.uk/research/barber/photosystemII.html
http://www.life.uiuc.edu/govindjee/Xiong98.pdf
http://www.alga.cz/mk/papers/bs_98.htm

Cytochromes and cytochrome oxidase

http://bmbsgi11.leeds.ac.uk/promise/CYTOCHROMES.html
http://www.biology.wustl.edu/faculty/models.html
http://rcsb.nist.gov/pdb/molecules/pdb5_1.html
http://www.ks.uiuc.edu/Research/bio_ener/cco/
http://bmbsgi11.leeds.ac.uk/promise/COX.html
http://www.life.uiuc.edu/crofts/bc-complex_site/index.html
http://www.lbl.gov/berry/
http://www.bio.purdue.edu/courses/Cramer_labpage/photosynth.html
http://www.bio.purdue.edu/courses/Cramer_labpage/cytf.html
http://www.bio.purdue.edu/courses/Cramer_labpage/Rieske.html

ATP synthase

http://www.mrc-dunn.cam.ac.uk/pages/atpase.html
http://nature.berkeley.edu/~hongwang/Project/ATP_synthase/
http://www.life.uiuc.edu/crofts/bioph354/lect10.html
http://www.weizmann.ac.il/Biological_Chemistry/scientist/Elhanan/elhanan.html
http://www.csun.edu/~hcchm001/wwwatp2.htm

C-3, C-4 and CAM (crasulacean acid metabolism) pathways

http://www.rrz.unihamburg.de/biologie/b_online/e24/24b.htm
http://web.wc.pima.edu/bfiero/tucsonecology/plants/plants_photosynthesis.html
http://www.desertmuseum.org/week1.html
http://www.woodrow.org/teachers/esi/1999/princeton/projects/c3_c4/

Chlorophyll fluorescence

http://www.optisci.com/tutorial.htm
http://www.ab.ipw.agrl.ethz.ch/~yfracheb/flex.htm
http://www.life.uiuc.edu/govindjee/biochem494/biochem494a.html
http://www.life.uiuc.edu/govindjee/movkautsky.html

On the use of herbicides

http://www.pioneer.com/usa/crop_management/corn/photo.htm
http://ipmworld.umn.edu/chapters/wareherb.htm
http://www.agcom.purdue.edu/AgCom/Pubs/WS/WS-23.html

The chloroplast

http://www.life.uiuc.edu/plantbio/cell/
http://www.bowdoin.edu/dept/bio/bio104/photo/tool.html
http://reith.imb.nrc.ca/ct.htm

Pigments/carotenoids

http://www.ucmp.berkeley.edu/glossary/gloss3/pigments.html
http://wwwfac.wmdc.edu/HTMLpages/Academics/Biology/botf99/photo/p3igments.html
http://www.mbl.edu/animals/Limulus/vision/Wald/photosynthesis.html
http://dcb-carot.unibe.ch/carotint.htm

Rubisco (Ribulose bisphosphate carboxylase oxygenase)

http://pps99.cryst.bbk.ac.uk/projects/jnixon/Title_Page.html
http://www.rrz.uni-hamburg.de/biologie/ialb/lehre/molbio/1rxo/e1rxoe.html
http://www.ornl.gov/ornl93/life.html
http://www.biochem.arizona.edu/classes/bioc462/462b/mol/chime/rubisco/rubisco.html
http://www.sabregirl.freeservers.com/rubisco.html

Whole plant photosynthesis and plant stress

http://weather.nmsu.edu/Teaching_Material/soil698/Student_Material/Photosynthesis/
http://www.plantstress.com/
http://www-eosdis.ornl.gov/FIFE/Datasets/Vegetation/Canopy_Photosynthesis_Rates.html
http://www.denison.edu/biology/faculty/firouznia/LisaBucci.html

Bacterial (both oxygenic and anoxygenic) photosynthesis

http://www.ucmp.berkeley.edu/bacteria/cyanointro.html
http://www.bact.wisc.edu/Bact102/102pnsb.html
http://www.siu.edu/~perspect/00_sp/extremes1.html
http://www.fao.org/docrep/w7241e/w7241e06.htm

Evolution of photosynthesis

http://sunflower.bio.indiana.edu/~cbauer/bauerlab/research/evolution.html
http://edmall.gsfc.nasa.gov/aacps/news/Photosynthesis.html
http://astrobiology.arc.nasa.gov/palebluedot/abstracts/ddm.html

Photosynthesis and the environment

http://www.sprl.umich.edu/GCL/notes2/greenhouse.html
http://www.science.gmu.edu/ zli/ghe.html
http://www.ciesin.org/docs/002-163/002-163.html
http://www.bio2.edu/Research/rnews98s7.htm
http://nigec.ucdavis.edu/westgec/news/article2.html
http://www.nsf.gov/od/opp/antarct/ajus/nsf9828/9828html/j1.htm
http://www.enn.com/news/wire-stories/2000/10/10122000/reu_algae_32447.asp

Artificial photosynthesis

http://researchmag.asu.edu/articles/mimick.html
http://www.chem.nwu.edu/NanoWeb/earth.html
http://www.beyond2000.com/news/Nov_00/story_890.html
http://www.research.psu.edu/rps/0009/energy.html
http://www.foresight.org/Conferences/MNT8/Abstracts/Schulten/
http://www.nature.com/nsu/991007/991007-3.html

Individual researchers' sites

http://photoscience.la.asu.edu/photosyn/nicelist.html
http://plantcell.lu.se/john/
http://www.bc.ic.ac.uk/research/barber/index.html
http://sunflower.bio.indiana.edu/~cbauer/bauerlab/
http://photoscience.la.asu.edu/photosyn/faculty/Blankenship/Welcome.html
http://ursula.chem.yale.edu/~brudvig/
http://www.bmb.psu.edu/deptpage/bryant.htm

http://www.life.uiuc.edu/cheeseman/
http://www.public.iastate.edu/~chitnis/
http://www.kazusa.or.jp/cyano/map/click/cmap.html
http://www.bio.purdue.edu/courses/Cramer_labpage/waclab.html
http://www.life.uiuc.edu/crofts/ahab/home.html
http://www.princeton.edu/~catalase/
http://www.bi.umist.ac.uk/users/ford/lab/
http://chemistry.uconn.edu/FrankGroup/frankg.html
http://ACS.TAMU.EDU/~ssg7231/index.html
http://www.life.uiuc.edu/govindjee/
http://www.life.uiuc.edu/govindjee/Psed_index.htm
http://www.life.uiuc.edu/SpringGov/lectures/lecture04/slides
http://carnegiedpb.stanford.edu/grossman/grossman.html
http://photoscience.la.asu.edu/photosyn/faculty/gust/index.htm
http://www.bio.indiana.edu/people/faculty/Hangarter.html
http://www.mpi-muelheim.mpg.de/mpistr_holzwarth.html
http://www2.hmc.edu/~karukstis/index.htm
http://indycc1.agri.huji.ac.il/~marder/
http://www.chem.ucla.edu/dept/Faculty/merchant/index.html
http://biomed.brown.edu/Faculty/M/Miller/Miller.html
http://www-server.bcc.ac.uk/biology/conrad.htm
http://www.plantphys.umu.se/~gunnar/
http://www.life.uiuc.edu/pru/labs/ort.html
http://www.biosci.ohio-state.edu/~rsayre/
http://www.biol.s.u-tokyo.ac.jp/users/sonoike/lab-e.htm
http://www.biosci.ohio-state.edu/~microbio/frt.html
http://www-plb.ucdavis.edu/labs/theg/
http://www.mcdb.ucla.edu/Faculty/TOBIN/tobin.html
http://photoscience.la.asu.edu/photosyn/faculty/vermaas.html
http://www.biochem.arizona.edu/vierling/
http://uwadmnweb.uwyo.edu/botany/fac/vogel.htm
http://www.alegba.demon.co.uk/index.html
http://www.chem.northwestern.edu/~wasielew/Homepage.html
http://www.public.asu.edu/~laserweb/woodbury/woodbury.htm
http://www.biology.lsa.umich.edu/people/faculty/cyocum.html

Kindergarten to grade 12 (K-12) educational sites

http://photoscience.la.asu.edu/photosyn/education/learn.html
http://www.life.uiuc.edu/govindjee/photoweb/WWWoverview.html
http://school.discovery.com/homeworkhelp/worldbook/atozscience/p/428180.html
http://photoscience.la.asu.edu/photosyn/study.html
http://www.photosynthesiseducation.bigstep.com/
http://www.life.uiuc.edu/govindjee/Psed_index.htm
http://www.pbs.org/ktca/newtons/9/phytosy.html
http://www.life.uiuc.edu/cheeseman/JC.software.html
http://www.nap.edu/readingroom/books/nses/html/photo6e.html
http://www.sciencemadesimple.com/leaves.html
http://set.lanl.gov:80/programs/tops/tops9799/curriculum/lightyears/carbo.htm
(http://naio.kcc.hawaii.edu/chemistry/default.html)
http://www.chem.uidaho.edu/~honors/redox.html

Experiments on the Web

http://www.uswcl.ars.ag.gov/exper/lghtseed.htm
http://quest.arc.nasa.gov/smore/teachers/act1.html
http://web.ukonline.co.uk/webwise/spinneret/plants/psfac2.htm
http://web.ukonline.co.uk/webwise/spinneret/plants/psfac1.htm
http://www.accessexcellence.org/AE/AEC/AEF/1996/morishita_pictures.html
http://askeric.org/cgi-bin/printlessons.cgi/Virtual/Lessons/Science/Botany/BOT0046.html
http://koning.ecsu.ctstateu.edu/Plant_Biology/pstranslab.html
http://department.stthomas.edu/BIOL/COURSES/Biology201/201LAB/LEAF_DISK.HTM
http://saps1.plantsci.cam.ac.uk/worksheets/disc.htm

http://www.iit.edu/∼smile/bi9614.html
http://www.nyu.edu/classes/murfin/secmethodsboard/messages/308.html
http://www.accessexcellence.com/AE/AEC/AEF/1996/linhares_lab.html
http://www.accessexcellence.com/AE/AEC/AEF/1995/culler_photo.html
http://filebox.vt.edu/users/kpotter/sharma/labexerciseonphotosynthesis.htm
http://www.iit.edu/∼smile/bi9201.html
http://www.mrwatkins.com/labs/biolabs/Photosynthesis.html
http://botany.miningco.com/science/botany/library/weekly/aa092000c.htm
http://www.science-projects.com/APPhotosynth0.htm
http://www.chem.hope.edu/labscape/catofp/chromato/tlc/tlc.htm
http://photoscience.la.asu.edu/photosyn/education/experiments/protein_exp/cover.htm
http://www.biology.duke.edu/chlamy/strains/projects.html

Books and journals

Books

http://www.wkap.nl/series.htm/AIPH
http://photoscience.la.asu.edu/photosyn/books/advances.html
http://www.blackwell-science.com/∼cgilib/bookpage.bin?File=3245
http://photoscience.la.asu.edu/photosyn/books/newbook.html
http://www.elsevier.nl/gej-ng/29/50/show/
http://www.molecadv.com/
http://www.cup.org/ObjectBuilder/ObjectBuilder.iwx?processName=productPage&product_id=0521430364&origin=redirect
http://www.cup.org/Titles/57/052157000X.html
http://www.life.uiuc.edu/govindjee/photoweb/4books.html
http://www.worldscientific.com/books/lifesci/3609.html
http://www.life.uiuc.edu/govindjee/photoweb/4books.html
http://www1.oup.co.uk/bin/readcat?Version=900797103&title=Plant+Biochemistry+and+Molecular+Biology&TOB=209439&H1=185927&H2=209114&H3=209115&H4=209205&count=1&style=full
http://www.life.uiuc.edu/govindjee/photoweb/4books.html
http://photoscience.la.asu.edu/photosyn/books/probebk.html
http://www.portlandpress.co.uk/books/isbn/1855780976.htm
http://photoscience.la.asu.edu/photosyn/books/walkerbk.html
http://www.oxygraphics.co.uk
http://photoscience.la.asu.edu/photosyn/books.html
http://www.life.uiuc.edu/govindjee/photoweb/2books.html
http://www.life.uiuc.edu/govindjee/books.html

Journals

http://link.springer.de/link/service/journals/00203/
http://www.publish.csiro.au/journals/ajpp/
http://pubs.acs.org/journals/biochem.html
http://www.elsevier.nl/gej-ng/29/50/show/
http://www.biophysj.org/
http://www.cell.com/
http://www.elsevier.nl/febs/show/
http://pubs.acs.org/journals/jacsat/index.html
http://www.jbc.org/
http://www.elsevier.com/inca/publications/store/5/0/4/0/9/2/
http://pubs.acs.org/journals/jpchax/index.html
http://www.nature.com/nature/
http://www.pol-us.net/PAPHome/
http://kapis.www.wkap.nl/journalhome.htm/0166-8595
http://www.ueb.cas.cz/ps/ps.htm
http://kapis.www.wkap.nl/journalhome.htm/0167-4412
http://www.plantphysiol.org/
http://www.pnas.org/
http://www.proteinscience.org/
http://www.sciencemag.org/

Societies and organizations

http://www.photosynthesisresearch.org/
http://www.acs.org/
http://www.ashs.org/
http://www.kumc.edu/POL/
http://www.aspp.org/
http://www.biophysics.org/biophys/society/biohome.htm
http://www.chemistry.mcmaster.ca/∼iaps/
http://www.carotenoid.uconn.edu/main.html
http://www.nacos.com/jspp/jspp01.html
http://www.psaalgae.org/

Related sites

http://www.arabidopsis.org/home.html
http://www.biology.duke.edu/chlamy/
http://www-cyanosite.bio.purdue.edu/index.html
http://www-cyanosite.bio.purdue.edu/cybib/cybibhome.html
http://photoscience.la.asu.edu/photosyn/links.html

Searching

http://www.google.com
http://www.yahoo.com
http://www.lycos.com/
http://www.altavista.com
http://www.hotbot.com
http://www.askjeeves.com
http://www.yahooligans.com/
http://www.nbci.com
http://www.goto.com
http://www.directhit.com
http://www.excite.com
http://www.searchenginewatch.com/

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http://www.arpa.gov/
http://www.w3.org/History/1989/proposal.html
http://www.sciam.com/2001/0501issue/0501berners-lee.html
http://www.bell-labs.com/user/zhwang/vcerf.html
http://www.wired.com/wired/archive//2.10/jim.clark_pr.html
http://www.internetvalley.com/intval.html
http://www.isoc.org/internet-history/brief.html
http://www.wired.com/wired/archive//5.03/ff_father_pr.html
http://wwwinfo.cern.ch/pdp/ns/ben/TCPHIST.html
http://www.w3.org/History.html
http://www.wired.com/wired/archive//2.10/mosaic_pr.html
http://www.wired.com/wired/archive//3.06/xanadu_pr.html

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Bernes-Lee T, Fischetti M and Dertouzos DL (1999) Weaving the Web: The Original Design and Ultimate Destiny of the World Wide Web by Its Inventor. Harper, San Francisco

Bernes-Lee T, Hendler J and Lassila O (2001) The semantic web. Sci Am 284: 34–43. Also available on line at http://www.sciam.com/2001/0501issue/0501berners-lee.html [12 June 2001]

Cerf V (1993) How the Internet came to be. http://www.bell-labs.com/user/zhwang/vcerf.html [5 March 2001]

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Leiner BM, Cerf VG, Clark DD, Kahn RE, Kleinrock L, Lynch DC, Postel J, Roberts LG and Wolff S (2000) A brief history of the internet. http://www.isoc.org/internet-history/brief.html [16 March 2001]

Orr LA and Govindjee (1998) Photosynthesis and the World Wide Web. In: Garab G (ed) Photosynthesis: Mechanisms and Effects, Vol V, pp 4387–4392. Kluwer Academic Publishers, Dordrecht, The Netherlands

Schwartz EI (1997) The father of the web. Wired http://www.wired.com/wired/archive//5.03/ff_father_pr.html [16 March 2001]

Segal B (1995) A short history of Internet protocols at CERN. http://wwwinfo.cern.ch/pdp/ns/ben/TCPHIST.html [17 March 2001]

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Wolf G (1994) The (second phase of the) revolution has begun. Wired http://www.wired.com/wired/archive//2.10/mosaic_pr.html [17 March 2001]

Wolf G (1995) The curse of Xandu. Wired http://www.wired.com/wired/archive//3.06/xanadu_pr.html [10 March 2001]