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Editorial

Celebrating the millennium – historical highlights of photosynthesis research, Part 2

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Abstract

This paper is an introduction to Part 2 of our celebrations of the historical highlights of photosynthesis research. Part 1 was published in October 2002 as Volume 73 of *Photosynthesis Research.* After a brief introduction, we recognize two giants in the field: Cornelis B. van Niel (for anoxygenic photosynthesis), and Robert Hill (for oxygenic photosynthesis). This is followed by recognition of a 1960 book by Hans Gaffron, and a multi-authored book edited by W. Ruhland and André Pirson, and inclusion in the appendix of a list of selected books. Our celebration is enhanced by the inclusion of beautiful paintings of cells by Antoinette Ryter. After introducing all the historical papers contained in this volume, we honor Louis N. M. Duysens, one of the greatest biophysicists of our time, and finally we dedicate this volume to a great scientist, humanist and peacemaker: Eugene I. Rabinowitch.

'Annihilating all that's made
To a green thought in a green shade'
– Andrew Marvell (1621–1678), The Garden

In continuation of Part 1 celebrating the millennium

This volume is the second in a series that was originally intended to consist of a single journal issue but which, because of the enthusiastic response, has been expanded to three parts. Part 1 contained an editorial (Govindjee and Gest 2002) that noted key discoveries in photosynthesis research from its roots in the early 18th century to the application of spectroscopy, molecular genetics and crystallography in the late 20th century. Some of these key discoveries were featured in historical and personal minireviews of Part 1, and this style continues in Part 2. For paid members of ISPR (International Society of Photosynthesis Research), Part 1 is available free at http://www.photosynthesisresearch.org .

Jonathan Swift's oft-quoted satire of Gulliver's travels (Swift 1726) includes the sentence,

> And he [the King of Brobdingnag] gave it for his opinion, that whoever could make two ears of corn, or two blades of grass to grow upon a spot of ground where only one grew before, would deserve better of mankind, and do more essential service to his country, than the whole race of politicians put together.

In a discussion of 'Science and Food Production,' Max Perutz (1989) noted this passage by Swift and remarked:

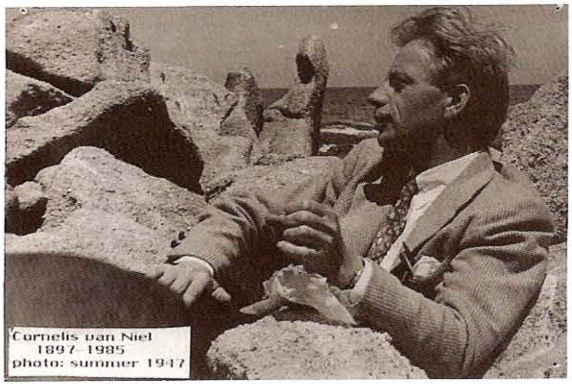


Figure 1. Cornelis B. van Niel (1897–1985) pioneered studies on the physiology of purple sulfur photosynthetic bacteria in the 1930s. These led him to formulate a 'comparative biochemical water-cleavage hypothesis' to explain the absence of oxygen production in bacterial photosynthesis (van Niel 1941; see Gest 1993 for a detailed discussion and evaluation). Although some of the early concepts had to be superceded by new information, this hypothesis contributed to the understanding that photosynthesis is a light-driven redox process (Blankenship 2002, see pp. 30–31). In 1944, van Niel published an extensive study on characteristics (general physiology and pigments) of nonsulfur purple species that later became major experimental organisms for research on anoxygenic photosynthesis.

> Yet I have seen no monuments erected to Norman Borlaug, the American who developed high-yielding wheat, nor to Douglas Bell, the Englishman who developed high-yielding barley... Science has revolutionized agriculture, doubling the world's grain production from 1950 to 1971, but can it continue to feed the world's growing population without unacceptable damage to the environment?

These words ring true today, when photosynthesis researchers, farmers and environmentalists continue to face these and new challenges.

Cornelis B. van Niel *(1897–1985)* and Robin Hill (1899–1991)

After World War II, interest in photosynthetic bacteria as 'model' experimental systems was greatly stimulated by C.B. van Niel (Figure 1; see R.E. Hungate 1986). His research on the general properties and physiology of these organisms led to a focus on the comparative biochemistry of oxygenic and anoxygenic photosyntheses. With this as a background, 1945–1960 can now be seen as a fertile period of 'synthesis,' accelerated by important fundamental discoveries and new concepts. For example, discovery of photophosphorylation (by Dan[1] Arnon and coworkers and Al[1] Frenkel, both in 1954; André Jagendorf 2002) and the 1960 formulation of the 'Z scheme' of oxygenic photosynthesis by Robert Hill and Fay Bendall (see Figure 1 in David Walker 2002a for a photograph of Robin[1] Hill; and Walker 2002b for the discovery of the Z-scheme). The prophecy of the two light reactions in oxygenic photosynthesis, one oxidizing a cytochrome, and another reducing it was made in 1956 by Eugene I. Rabinowitch (1901–1973) (see front cover of this issue).

Books in the early 1960s

In 1960, Hans Gaffron summarized photosynthesis in a 274-page review (with 624 references) (see Peter Homann, this issue, for his photograph and a tribute to him). In the same year, Volume 5 (Parts 1 and 2) of 'Encyclopedia of Plant Physiology' (Ruhland 1960, subeditor André Pirson) was published, as one of the most comprehensive surveys of knowledge of photosynthesis in the 20th century. It was an interesting volume entitled 'The Assimilation of Carbon Dioxide.' Within the same chapter, sometimes sections were in two languages: German and English. (For a list of books on photosynthesis since 1924, see Appendix.) The articles in this Encyclopedia, written by a cast of prominent scientists, totaled 1,881 pages and is a rich source of references to the history of research on all aspects of photosynthesis. Among the contributors were Daniel I. Arnon (chloroplast as complete unit for photosynthesis), Sam[1] Aronoff (chemistry of chlorophylls), James A. Bassham & Melvin Calvin (carbon fixation), Kenneth A. Clendening (Hill reaction), James Franck (chlorophyll fluorescence), C. Stacy French (chlorophylls *in vitro* and *in vivo*), Howard Gest and Martin Kamen (photosynthetic bacteria), T. W. Goodwin (carotenoids), Francis T. Haxo (chromoproteins of algae), Erich Kessler (oxygen evolution; influence of oxygen on photosynthesis), Bessel Kok (efficiency of photosynthesis), Helge Larsen (chemosynthesis), Robert Livingston (photochemistry), Walter E. Loomis (history of photosynthesis of green plants), Jack Myers (algal culture), André Pirson (Mineral factors in photosynthesis), E. Steemen Nielsen (CO_2 uptake in plants), Jan B. Thomas (chloroplast structure), R. van der Veen (induction of photosynthesis), and Horst. T. Witt (flashing light experiments on photosynthesis). Several of these and many other scientists are featured in articles in the historical issues of *Photosynthesis Research* (Part 1, Part 2, and in Part 3, still to come).

The pathway of carbon assimilation (variously called reductive pentose cycle, photosynthetic carbon reduction cycle, or Calvin–Benson–Bassham cycle) in photosynthesis was essentially completed by 1960 (Andy Benson 2002; James Al Bassham, this issue), and it was discussed by Gaffron (1960) as well as by Bassham and Calvin in Ruhland's 1960 Encyclopedia. However, neither Gaffron (1960), nor authors in Ruhland (1960) could have discussed the two-light reaction two-pigment system concept (see Govindjee 2000; Jack Myers 2002), since it was just beginning to become known; it was established essentially on the basis of the 1957–1958 work of Robert Emerson to whom we dedicated Part 1 of the historical issues. It was first discussed in the volume on 'Light and Life,' edited by McElroy and Glass (1961). By 1963, the concept of the two light reactions and the two pigment systems, and the Z-scheme of Robin[1] Hill were firmly established, as is evident from several papers in the volume 'Photosynthetic Mechanisms of Green Plants,' organized by Bessel Kok and André Jagendorf at the Airlie House in Warrenton, Virginia (1963), and in the Colloquium 'La Photosynthèse' held at Gif-sur-Yvette, France, in July 1962, the President of the conference being René Wurmser (see CNRS 1963). (Photographs of the participants appear in de Kouchkovsky 2002.)

In the 1960s, few could predict the enormous impact that new research techniques and inventions would have on the study of photosynthetic mechanisms. The workhorses of research at that time were manometric measurements of CO_2 and O_2 exchange, spectrophotometry of photopigments and chromoproteins, and paper chromatography; research with radioactive tracers had still not blossomed to its full potential. In retrospect, the research was laborious and time-consuming. Even the determination of a steady state absorption spectrum of photopigments in a cell extract was an undertaking of hours. However, the age of computers and automation of sampling and sample processing was dawning.

A recent review of the early history of computing science by Brian Hayes (2002) reminds us that the first disk drive was built in 1956, and was 2 feet (61 cm) in diameter. Hayes notes that contemporary disk drives are only 3.5 inches (9 cm) in diameter: 'Thus the surface area of the disks has shrunk by a factor of almost 800 while their information capacity has increased 24,000 times.' A current disk can hold hundreds of gigabytes! Hayes's perspective: 'Here in the palm of one hand is space for a whole intellectual universe – all the words that can enter a human mind in a lifetime of reading.' The challenge now is to analyze and interpret the vast amount of data that we can now collect quickly and store in a small space. Two obvious examples are to determine in the context of a living cell the significance of one-dimensional genome sequences, and three-dimensional protein structures, both of which are stored as bytes in computer files.

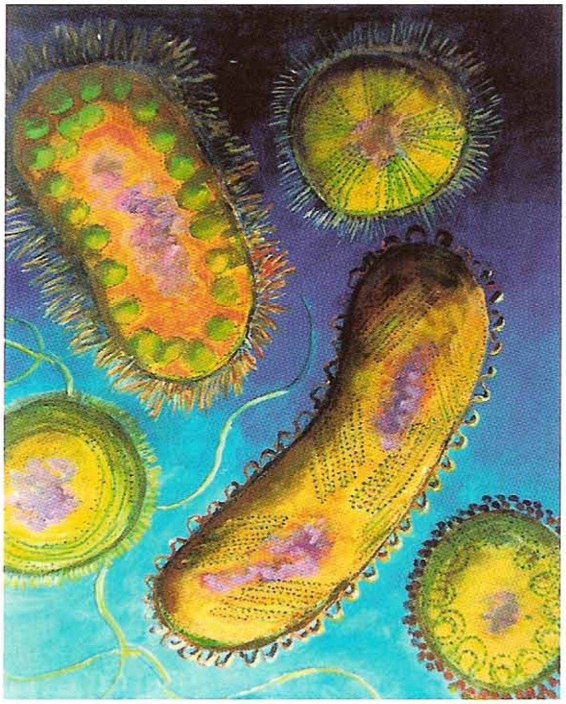
Artists among scientists

Many scientists are endowed with artistic talents. We provide here just a few examples of those we know personally. Martin Kamen played the viola; Shmuel Malkin plays the piano; René Delosme plays the organ; and Bill[1] Rutherford plays blues guitar. Photos of Delosme (playing organ) and Shmuel Malkin (playing piano) are shown in Delosme's paper (this issue). Rutherford's photo appears in the paper of Imre Vass (this issue). Kazuhiko Shibata, son of the famous Sieho, was a great painter. One of his paintings is shown in Ogawa's paper (this issue). A painting by Al[1] Bassham appears in this issue in his minireview. Images of rural Japan, painted by Seikichi Izawa (1926–1997), are available at http://www.art.net/studios/visual/Rei/Sei/i ndex.html.

Figure 2 shows colored photographs of paintings of algal cells and photosynthetic bacteria by Antoinette Ryter (for details, see the legend to Figure 2). The cells in the paintings were not meant to identify particular organisms. The paintings are artistic impressions, based on many studies that illustrate prominent features of phototrophs.

The content of Part 2

Part 2 of the historical issues of *Photosynthesis Research* resembles Part 1 (Govindjee and Gest 2002) in the sense that it includes various aspects of anoxygenic photosynthesis as well as oxygenic photosynthesis. Figure 3 shows two of us (HG and JTB) with Carl Bauer, who are all engaged in work on anoxygenic photosynthetic bacteria. Figure 4 shows the oxygenic arm of the editorial team (G) with other scientists (Kenneth Sauer, Achim Trebst, André Jagendorf and



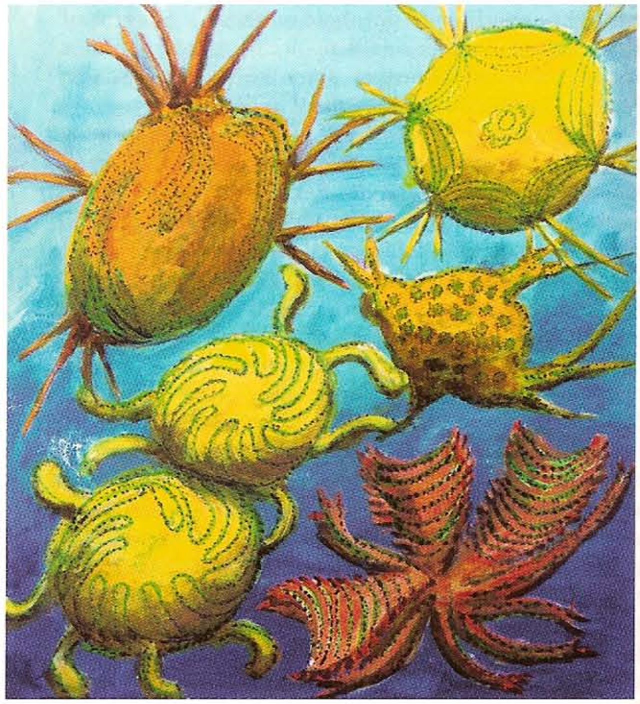


Figure 2. Paintings of photosynthetic bacteria (left) and unicellular algae (right) by Antoinette Ryter. The paintings are artistic interpretations of electron microscope observations, based on her extensive experience. The paintings are based on many studies that illustrate prominent features of phototrophs. They are great examples of art in science. Antoinette Ryter is Professeur Honoraire à l'Institut Pasteur (Paris, France), where she was Head of the Laboratory for Electron Microscopy (Department of Biology) from 1964 to 1989. The 'Ryter–Kellenberger' procedure for fixation of sections for electron microscopy has been widely used since its description (see Ryter et al. 1958). Photographs reproduced with her permission.

Figure 3. Two of the editors, Howard Gest (middle) and Tom Beatty (right), along with their colleague Carl Bauer (left). This photograph was taken in 1992 when Beatty spent six months of a sabbatical in Bauer's laboratory.

Figure 4. From left to right: Kenneth Sauer, Govindjee, Achim Trebst, André Jagendorf and Andrew Benson, gathered together in January 2002, at the Western Photosynthesis Conference, held at Asilomar, California. Here, they discussed the various highlights of discoveries on the role of manganese in oxygen evolution, the two-light reactions in photosynthesis, protection of plants by carotenoids and tocopherols, photophosphorylation, and carbon fixation, respectively.

Andy[1] Benson) who are engaged in various aspects of oxygenic photosynthesis research.

In this issue, the great diversity in contemporary photosynthetic bacteria is discussed by Mike[1] Madigan; Radhey Gupta describes an approach for using sequence data to investigate evolutionary patterns and relationships among contemporary organisms. Although several approaches have been used to evaluate the evolutionary pathways of photosynthesis, they seem to be converging on a consensus that includes horizontal gene transfer as a significant factor.

The history of chloroplast molecular biology and genomics is discussed by Masahiro Sugiura and Laurie[1] Bogorad. Chloroplast structures are reviewed by Andrew Staehelin, and the catalytic activities of photosynthetic proteins and pigments by Fevzi Daldal, Meenal Deshmukh and Roger Prince (membrane anchored cytochromes), Pierre Joliot and Anne Joliot (excitation energy transfer among Photosystem II units), Sakae Katoh (plastocyanin), Slava[1] Klimov (pheophytin in Photosystem II), Terry Meyer and Mike[1] Cusanovich (electron transfer proteins in bacteria), Bill[1] Parson (primary photochemistry of bacterial reaction centers), Mike[1] Seibert and Mike[1] Wasielewski (primary photochemistry of Photosystem II). Advances in methodology are described by Per-Åke Albertsson (separation of membranes), René Delosme (photoaccoustics), Teruo Ogawa (chlorophyll protein complexes), Kimiyuki Satoh (Photosystem II reaction center) and Imre Vass (thermoluminescence).

The responses of photosynthetic organisms to changes in light intensity and wavelength have been studied for more than 100 years, and notable advances are reviewed by Nicole Tandeau de Marsac (phycobilisomes), Arthur Grossman (chromatic adaptation), Judy[1] Armitage and Klaas Hellingwerf (phototaxis), Noam Adir, Hagit Zer, Susana Shochat and Itzhak Ohad (photoinhibition), and Barbara Demming-Adams (photoprotection).

A basic difference between oxygenic and anoxygenic photosynthetic processes centers on the oxygen-evolving complex of Photosystem 2 (PS 2), which is reviewed by Pierre Joliot (period 4 oscillations), and Gernot Renger (oxygen evolution).

Carbon metabolism is described by Al[1] Bassham (carbon fixation), Bill[1] Ogren (photorespiration), John Ormerod (reductive citric acid cycle in bacteria), David Walker (CO_2 fixation in intact chloroplasts), Clanton Black and Barry Osmond (Crassulacean acid metabolism), while hydrogen metabolism is described by Peter Homann (hydrogen metabolism of algae).

As in Part 1, some authors have provided interesting historical summaries of photosynthesis research in prominent laboratories and specific countries. Among these are Leo Vernon (Kettering Research Labs), Agepati S. Raghavendra, Prafullachandra Vishnu (Raj[1]) Sane and Prasanna Mohanty (India), Ting-Yun Kuang, Chunhe Xu, Liang-Bi Li and Yun-Kang Shen (China), George Papageorgiou (Greece), Alexander Krasnovsky, Jr. (Soviet Union and Russia), Alex[1] Borisov (biophysics in Russia), Olga Belyaeva (chlorophyll biosynthesis in Russsia and Byelorussia) and Tony[1] Larkum (tribute to Henrik Lundegårdh, Sweden).

Although research on oxygenic and anoxygenic photosyntheses has usually been pursued by groups specializing in one of these two areas, this research has been complementary and mutually beneficial. Such research cross-fertilization between similar disciplines in the oxygenic and anoxygenic fields was accompanied by advances that were spurred onward by new interdisciplinary approaches to long-standing questions. For example, the 3-D structures of pigment-protein membrane complexes have provided valuable insights into the interpretation of spectroscopic data, and allowed the formulation of catalytic models that can be tested experimentally. A major breakthrough came when the crystal structure of the reaction center of the photosynthetic bacteria was solved by Hartmut Michel, Johann Deisenhofer, Robert Huber and their coworkers in Martinsried, Germany. The award of the 1988 Nobel Prize in Chemistry to Michel, Deisenhofer and Huber was applauded by the entire photosynthesis community. (For a complete list, and web addresses, of Nobel Prizes awarded for photosynthesis-related topics, see Govindjee and Krogmann 2002.) The structural biologists benefited from the primary sequence data provided by gene sequencing, and site-directed mutagenesis has proven to be a powerful tool for testing of functional models that arise from considerations of structures. The rapidly growing areas of genomics and bioinformatics have resulted in a surfeit of information, requiring new approaches for data management and analysis. Applications of BLAST[2] and other sequence analysis tools to the burgeoning databases is now a standard procedure for the predictive identification of protein homologues. Transformation of the huge numbers of primary sequences to 3-D structures and catalytic activities of individual molecules, as well as the integration of the key players into metabolic and regulatory networks, presents a formidable challenge for the future.

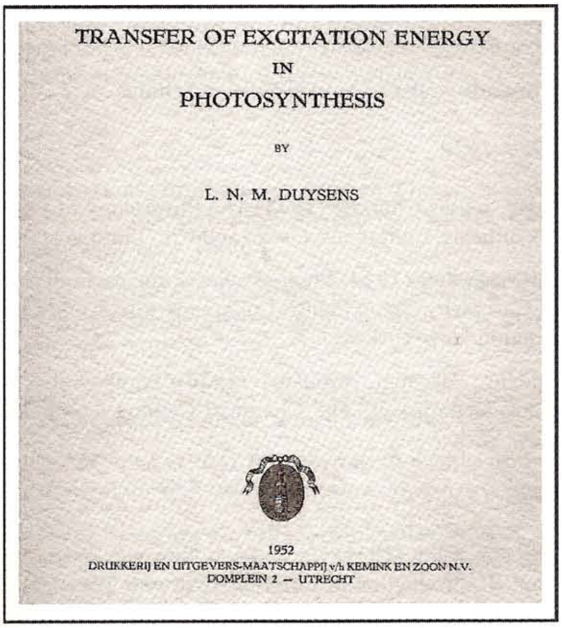
Research is now speeded up by ultrafast computer searches of primary databases; the literature and the *lingua franca* of computers have facilitated international group research efforts. Although the rapid processing of voluminous data by computers opens new doors, the immediate future of photosynthesis research, and biology in general, still appears to depend on the ability to design, carry out and interpret incisive experiments – regardless of whether such experiments are done on populations *in situ*, cells *in vivo*, biochemical preparations *in vitro*, or using information *in silico*.

Dedication

In the Editorial of Part 1 of the special history issues, we honored Martin Kamen (co-discoverer of radiocarbon-14), and dedicated the issue to Robert Emerson (discoverer of the 'photosynthetic unit' and the enhancement effect that led to the two light reactions two photosystems concept of oxygenic photosynthesis). In Part 2, we honor Louis N.M. Duysens and dedicate this issue to Eugene I. Rabinowitch.

A photograph of Louis Nico Marie Duysens is shown in Figure 5A. Lou's[1] 1952 PhD thesis at the State University at Utrecht, The Netherlands, is a classic (see Figure 5B). In addition to the establishment of excitation energy transfer from accessory pigments to (bacterio) chlorophyll (also see Dutton 1997), and discovery of two types of chlorophyll *a* in red algae, it includes the first observation of a small absorption change that he attributed to a pigment 'P,' currently known as reaction center P_{870} (see Rod[1]Clayton 2002). Lou established one of the most important centers in the world for research on 'Biophysics of Photosynthesis.' His 1961 paper with Jan Amesz (Duysens et al. 1961; see Duysens 1989) is the cornerstone evidence for the series scheme of photosynthesis, predicted in its bare bones by Eugene Rabinowitch in 1956 (see his quotation on the cover of this issue).

A portrait of Eugene I. Rabinowitch is shown in Figure 6. His biography and publication list are available at http://library.albany.edu/speccoll/findaids/ger075.htm#bio. One of us (G), who obtained his PhD with Eugene in 1960, honored him with a special issue of the *Biophysical Journal* in July 1972 (Govindjee 1972), nine months before his death. [See Bannister (1972) for the life and contributions of Eugene; Govindjee and Rabinowitch (1960) for the discovery



TRANSFER OF EXCITATION ENERGY
IN
PHOTOSYNTHESIS

BY

L. N. M. DUYSENS

1952
DRUKKERIJ EN UITGEVERS-MAATSCHAPPIJ v/h KEMINK EN ZOON N.V.
DOMPLEIN 2 – UTRECHT

Figure 5. Top: Louis N. M. Duysens (left) and one of us (G). Photograph was taken in 1989. *Bottom:* Cover page of the classical doctoral thesis of L.N.M. Duysens that was given to one of us (G) when he visited Lou at his home in Oegstgeest on August 27, 1989.

that different forms of chlorophyll *a* are in two different photosystems; and Govindjee et al. (1960) for the discovery of the two-light effect in chlorophyll *a* fluorescence.] Govindjee, Rajni Govindjee, Roderick K. Clayton, Christian Sybesma, Farrington Daniels, Gregorio Weber and Jerome L. Rosenberg honored him with the following words:

> A man who inspired a generation of photobiologists with his enthusiasm, innovative ideas, and penetrating thoughts. Eugene is not only a distinguished scientist and a creative teacher, but also a central figure of great influence on the understanding of photosynthesis over three decades, a poet, and above all, a humanist deeply concerned with peace among all mankind. Very few have achieved his broad wisdom and insight into the affairs of men. We dedicate this special issue with great respect, affection and admiration to him.

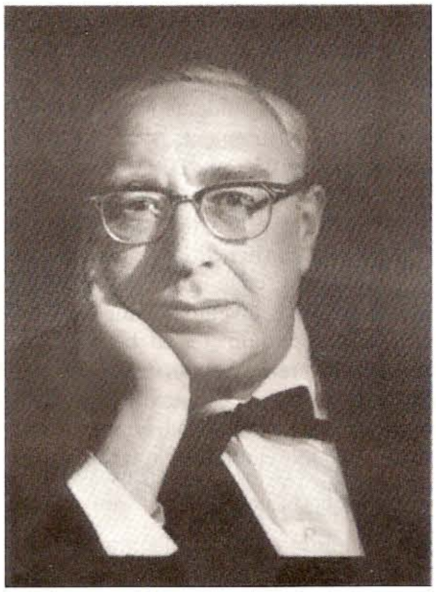


Figure 6. Eugene I. Rabinowitch (1901–1973), to whom we dedicate this historical issue (reproduced from Govindjee 1972).

After Eugene's death in May 1973, the recipient of the 1995 Nobel Peace Prize, Sir Joseph Rotblat, wrote (see Rotblat 2000):

> Eugene Rabinowitch was a man of many facets: a scientist and a teacher; a classics scholar and a modern philosopher; a poet and a man of letters; a journalist and an editor; a sociologist and a politician. But his main characteristic was simply as a human being, with a warm heart, filled with love and tenderness, not only for his family and friends, but for the whole of mankind. This love for humanity, and his profound belief in the potential of science to ensure a happy life for all, were the guidelines throughout his whole life, the philosophy on which all his activities were based.

Eugene Rabinowitch's research group in Urbana studied mainly the storage of light energy in chemical systems and the chemistry of chlorophylls, the goal being to find a chemical system that would solve the 'energy problem' facing the world. In addition, he guided his graduate students to make some of the first biophysical measurements of the primary events in photosynthesis (see Brody 2002; Govindjee 2003): the quantum yield of chlorophyll *a* fluorescence, the lifetime of this fluorescence, the 'sieve effect' and 'selective scattering.' Earlier, Eugene was known as the co-discoverer of the 'cage effect' in photochemistry (with James Franck), inventor of the first difference absorption spectrophotometer to be used in photochemistry, discoverer of photo-oxidation of chlorophyll *in vitro*, and of the 'photovoltaic effect.' He is, however, best known to the photosynthesis community as the author of the authoritative treatise 'Photosynthesis' in Volume 1 (1945), Volume 2 (Part 1) (1951) and Volume 2 (Part 2) (1956).

We end this Editorial by welcoming the readers to look forward to Part 3 of these issues, which will be edited by John Allen and two of us (G and JTB).

Acknowledgments

Govindjee and Howard Gest thank the National Science Foundation (Grant SES 00-92507) for crucial support in the planning of these special issues. Our special thanks go to Ellen Girmscheid in the Editorial Department at Kluwer Academic Publishers for her outstanding contribution to the success of this issue. We are particularly thankful to Loan (Kelly[1]) Nguyen, an undergraduate student at the University of Illinois at Urbana, Illinois, for her painstaking work in scanning many of the figures used in these issues, and for organizing the mailing of papers to the Netherlands. Without the support of Jacco Flipsen (Kluwer Academic Publishers), David Knaff (Editor-in-Chief of *Photosynthesis Research*) and the office of the Department of Plant Biology (Evan DeLucia, Head), we could not have produced these special issues.

Govindjee is grateful to Jeff Haas and his excellent staff at the University of Illinois for the maintenance of computer facilities for on-line editing of manuscripts, and for the scanning of photographs. He also thanks Sanjay Govindjee and Morten Christiansen for similar facilities provided to him in Lafayette (California) and Ithaca (New York), respectively.

Tom Beatty thanks the Canadian Institutes of Health Research for funding that freed him from experimental work to yield the time to contribute to this issue.

The paper was read and approved by David Krogmann. We are most grateful to John Allen for editing this Editorial.

Notes

[1] In these historical issues, we had requested authors to include first (or given) names as well. Many authors have done that; some have used initials, but many including the editors have even used nicknames in the text.

[2] BLAST (Basic Local Alignment Search Tool) is a set of similarity search programs designed to explore all of the available sequence databases regardless of whether the query is protein or DNA (from: http://www.ncbi.nlm.nih.gov/BLAST/blast_overview.html).

Appendix – list of books, Editors' choice

1920–1929

Bose, Jagdis Chunder (**1924**) The Physiology of Photosynthesis. Longmans, Green and Co., London

Stiles, Walter (**1924**) Photosynthesis: the assimilation of Carbon by Green Plants, Longmans, Green and Co., London/New York

Spoehr, Herman Augustus (**1926**) Photosynthesis. Book Department, The Chemical Catalog Company, New York

1930–1939

Shibata, Keita (**1931**) Carbon and Nitrogen Assimilation. (Reproduction of Original Text with Translation by Howard Gest and Robert K. Togasaki, 1975.) Japan Science Press, Tokyo

1940–1949

Baly, Edward Charles C. (**1940**) Photosynthesis. Methuen & Co., London

Rabinowitch, Eugene (**1945**) Photosynthesis and Related Processes, Vol I. Interscience Publishers, New York

Calvin, Melvin (**1949**) The Path of Carbon in Photosynthesis. University of Notre Dame, Notre Dame, Indiana

1950–1959

Rabinowitch, Eugene (**1951**) Photosynthesis and Related Processes, Vol II (Part 1). Interscience Publishers, New York

Hill, Robert and Whittingham, Charles P. (**1955**) Photosynthesis. Wiley, London/Methuen, New York

Rabinowitch, Eugene (**1956**) Photosynthesis and Related Processes, Vol II (Part 2). Interscience Publishers, New York

Bassham, James Alan and Calvin, Melvin (**1957**) The Path of Carbon in Photosynthesis. Prentice-Hall, Englewood Cliffs, New Jersey

Terrien, H., Truffaut, G. and Carles, J. (**1957**) Light, Vegetation and Chlorophyll. (Translated by Madge E. Thompson.) Philosophical Library, New York

1960–1969

Gaffron, Hans (**1960**) Energy Storage: Photosynthesis. In Steward, F.C. (ed) Plant Physiology, Vol IB. Academic Press, New York

Calvin, Melvin and Bassham, James Al (**1962**) The Photosynthesis of Carbon Compounds. W.A Benjamin, New York

Kamen, Martin David (**1963**) Primary Processes in Photosynthesis. Academic Press, New York

Lascelles, June (**1964**) Tetrapyrrole Biosynthesis and Its Regulation. W.A. Benjamin, New York

Clayton, Roderick K. (**1965**) Molecular Physics in Photosynthesis. Blaisdell Publishing Company, New York

Rosenberg, Jerome Laib (**1965**) Photosynthesis, the Basic Process of Food-Making in Green Plants. Holt, Rinehart and Winston, New York

Thomas, J. B. (**1965**) Primary Photoprocesses in Biology. John Wiley and Sons, New York

Fogg, Gordon Elliott (**1968**) Photosynthesis. American Elsevier Publishing, New York

Robertson, R. N. (**1968**) Protons, Electrons, Phosphorylation and Active Transport. Cambridge University Press, London

Heath, Oscar Victor Sayer (**1969**) The Physiological Aspects of Photosynthesis. Stanford University Press, Stanford, California

Rabinowitch, Eugene and Govindjee (**1969**) Photosynthesis. John Wiley & Sons, New York

1970–1979

Zelitch Israel (**1971**) Photosynthesis, Photorespiration, and Plant Productivity. New York, Academic Press

Krogmann, David W. (**1973**) The Biochemistry of Green Plants. Prentice Hall, Engelwood Cliffs, New Jersey

Lascelles, June (**1973**) Microbial Photosynthesis. Dowden, Hutchinson & Ross, Stroudsburg, Pennsylvania

Whittingham, Charles Percival (**1974**) The Mechanism of Photosynthesis. E. Arnold, London

Gregory, Richard P. F. (**1977**) Biochemistry of Photosynthesis. Wiley, London/New York

Hall, David Oakley and Rao, Krishna K. (**1977**, 1981, 1987, 1994 et seq.) Photosynthesis. E. Arnold, London

1980–1989

Clayton, Roderick K. (**1980**) Photosynthesis: Physical Mechanisms and Chemical Patterns. Cambridge University Press, New York

Halliwell, Barry (**1981**, 1984) Chloroplast Metabolism: the Structure and Function of Chloroplasts in Green Leaf Cells. Clarendon Press, Oxford/Oxford University Press, New York

Tribe, M. and Whittaker, P. (**1982**) Chloroplasts and Mitochondria, second edition, Studies in Biology, No 31. Edward Arnold, London

Edwards, Gerald Elmo and Walker, David (**1983**) C3, C4: Mechanisms, and Cellular and Environmental Regulation, of Photosynthesis. Blackwell Scientific Publications, Oxford

Kirk, John Thomas Osmond (**1983**) Light and Photosynthesis in Aquatic Ecosystems. Cambridge University Press, Cambridge, UK

Hoober, Kenneth (**1984**) Chloroplasts. Plenum Press, New York

Bell, L.N. (**1985**) Energetics of the Photosynthesizing Plant Cell. Harwood Academic Publishers, New York

Lawlor, David W. (**1987**) Photosynthesis: Metabolism, Control, and Physiology. Longman Scientific & Technical Harlow, UK/Wiley, New York

MacColl, Robert and Guard-Friar, Deborah (**1987**) Phycobiliproteins. CRC Press, Boca Raton, Florida

Gregory, Richard P. F. (**1989**) Photosynthesis. Blackie, Glasgow, UK (distributed in USA by Chapman & Hall, New York)

Rowan, Kingsley S. (**1989**) Photosynthetic Pigments of Algae. Cambridge University Press, Cambridge, UK

1990–1999

Walker, David Alan (**1992**) Energy, Plants & Man, 2nd edition. Oxygraphics, Brighton, UK

Lawlor, David W. (**1993**) Photosynthesis: Molecular, Cellular and Environmental Processes, Longman Scientific & Technical, Harlow, UK

Gillham, Nicholas W. (**1994**) Organelle Genes and Genomes. Oxford University Press, Oxford

Falkowski, Paul G. and Raven, John A. (**1997**) Aquatic Photosynthesis. Blackwell Science, Malden, Massachusetts, USA

Wild, Aloysius and Ball, R. (**1997**) Photosynthetic Unit and Photosystems – History of Research and Current Views (Relationship of Structure and Function). Backhuys Publishers, Leiden, The Netherlands

2000–2002

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