LIFE ON EARTH THROUGH PHOTOSYNTHESIS

Dialogues on key discoveries and the people behind them

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Fatti non foste a viver come bruti,
ma per seguir virtute e canoscenza.
(Dante Alighieri, 1265–1321)

The aim of science is not to open the door to infinite wisdom,
but to set a limit to infinite error.
(Bertolt Brecht, 1898–1956)

Leo Szilard once announced to his friend Hans Bethe
that he was thinking of keeping a diary:
"I don't intend to publish it: I am merely going to record
the facts for the information of God".
"Don't you think God knows the facts?" Bethe asked.
"Yes," said Szilard. "He knows the facts, but he does not know this version of the facts".
*(Freeman Dyson, *15 December 1923)*

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To Anna and Uta with thanks
for their support
and endless dialogues
on solar energy.

Since 2003 we have been discussing, creating, deleting, recreating dialogues for a staged-reading format of a book on milestones of photosynthesis research – and the people behind it. And often we interrupted the seemingly impossible task. Thanks to reading the 2006 book *Science on Stage: From Doctor Faustus to Copenhagen* by Kirsten Shepherd-Barr, however, our ideas became more structured. Her profound analysis of the still young tradition of science-in-theater helped us to go ahead. This we want to acknowledge right at the beginning. We also thank Janina Möbius for her lasting advice on how to merge theatrical form and scientific content. We are grateful to Giovanni Venturoli and Paola Turina (University of Bologna), Martin Plato (Free University Berlin), Wolfgang Lubitz (Max Planck Institute for Chemical Energy Conversion, Mülheim/Ruhr) and Alexey Semenov (Lomonosov State University Moscow) for their critical and constructive comments on several parts of the manuscript. Their encouragement was indispensable for us to continue. We thank Anton Savitsky and Birgit Deckers (Max Planck Institute for Chemical Energy Conversion, Mülheim/Ruhr) for their expert help in preparing the artwork for the figures.

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Summary

Photosynthesis is the most important process for Life on Earth. It provides all the oxygen we breathe, all the food we eat and all the fossil fuels we burn for our civilization. Understanding the underlying physical, chemical and biological principles of photosynthetic solar-energy conversion and sustainable storage – and ultimately copying them for "artificial" photosynthesis devices – is among the grand challenges of the cultural world under the threat of global climate change. The book describes milestone discoveries in photosynthesis research, ranging from the times of alchemy to present-day molecular biology, biophysics and biochemistry. It is written in the format of "Science-on-Stage" with dialogues between different characters related to research achievements in their historical and political context. It is composed of 13 Scenes, a Prologue, an Intermezzo and an Epilogue.

The Prologue is setting the stage for the follow-up Scenes with their discussions about essential discoveries, interspersing them with memoirs of the scientists involved, history of the ground-breaking work done in the respective time periods, their specific politics and consequences for society at large. Those social aspects are even more accented in the Intermezzo and Epilogue with reflections on how to bridge the gap between the two cultures, science and humanities. Whenever felt necessary, some technicalities of the photosynthetic processes are also given within the Scenes for a better understanding of the discussions. This is further supported by a Glossary and a Bibliography that is recommended for further reading. Each Scene stages "The Chorus", as in classical Greek theater and in many contemporary plays. It summarizes accepted scientific background knowledge, voices general ideas on progress and responsibility in science, and reminds of most important contributions of a multitude of researchers in the field. The Chorus consists of seven members, all experts in contemporary photosynthesis research.

Dialogues as the format of writing about controversial topics in science and humanities have been the traditional way of Renaissance Europe to express new ideas – and to defend them against traditional views. But this tradition practically disappeared from

the scientific literature since the Age of Enlightenment. It was, however, reanimated after World War II, leading to a modern generation of Science-on-stage plays, often well received by a broad public.

The book describes not only eminent discoveries but also tells illuminating stories on the people behind them. Complicated characters are involved in intense competition; extremes of euphoria in case of success alternate with bottomless disappointment in case of failure. Stories are told of the researchers' greatest strength and – in not so rare cases – of their human weakness. They are told to experts and laymen alike, to teachers and students, to undergraduates, postdoctoral researchers and professors, in short to anybody from the educated public. The hope is that even if the details of photosynthesis may be obscure to many readers and audiences, the life stories of the protagonists and the implications of their discoveries and ideas become accessible.

The book appears at the right time for the United Nations "International Year of Light and Light-based Technologies, 2015", this observance "that aims to raise awareness of the achievements of light science, its applications, and its importance to humankind to provide solutions to worldwide challenges in energy, education, agriculture, communications and health".

Contents

Foreword

To write a book on the history of photosynthesis research and to do this in the form of dialogues for (staged) reading in the still young Science-in-theater tradition, apparently needs some explanations for the motivation behind this endeavor.

No doubt: Photosynthesis is the most important process for Life on Earth. It provides all the oxygen we breathe, all the food we eat and all the fossil fuels we burn for our civilization. Understanding the underlying physical, chemical and biological principles of photosynthetic solar energy conversion – and ultimately copying them for "artificial" photosynthesis – is among the grand challenges of the cultural and intellectual world. In fact, understanding photosynthesis affects all parts of human societies in all parts of the globe. It may turn our life around by means of current and future top research strategies for a sustaining renewable energy supply.

The largest impact of photosynthesis is due to green plants, algae and cyanobacteria, in whose two interconnected reaction-center protein complexes, photosystems I and photosystems II (PS I and PS II) the light-driven electron-transfer reactions occur. They ultimately lead to the assimilation of carbon dioxid, CO_2, to carbohydrates like glucose sugar, $C_6H_{12}O_6$, for which water (H_2O), serves as electron donor. Oxygen (O_2) is released as a by-product of this reaction, thereby stabilizing the CO_2/O_2 composition of the Earth's atmosphere. Thus, the net reaction of oxygenic photosynthesis can be summarized to $6\ CO_2 + 6\ H_2O \rightarrow C_6H_{12}O_6 + 6\ O_2$. This looks rather simple, but it isn't: For the reaction to proceed, light energy is needed as well as chlorophylls and other cofactor molecules embedded in protein complexes to serve as biocatalysts ("enzymes"). The molecular basis of their biological function is still far from being completely understood, not to speak of employing this knowledge to copy the process for producing "solar fuels".

But why did we choose "dialogues" as the format of writing about a scientific subject? In the sciences and humanities of Renaissance Europe, the traditional way of expressing new ideas and controversies – and defending them against traditional views – was the

dialogue format, notably used by Galileo Galilee (1564–1642) in his *Dialogue on the Two Chief World Systems, Ptolemaic and Copernican* and Robert Boyle (1627–1691) in his *The Sceptical Chymist: or Chymico-Physical Doubts & Paradoxes*. But the tradition of dialogues practically disappeared from the scientific literature since the Age of Enlightenment. It was, however, reanimated after World War II, leading to a modern generation of Science-on-stage plays. They became rather successful, at least in academic circles and other parts of the cultural intelligentsia. This encouraged us to adopt the dialogue format to describe a kaleidoscope of discoveries in photosynthesis – and to tell stories of the people behind them. These people often present inherently dramatic material: Complicated characters are involved in intense competition; extremes of euphoria in case of success alternate with bottomless disappointment in case of failure. Not surprisingly, also in photosynthesis research the key discoveries were often controversially discussed in the community, and sometime such controversies developed into enduring antagonism rather than getting on well with one another. We are telling stories on the researchers in the historic context, on their scientific greatness and – in not so rare cases – on their human weakness. Ungrudging admiration between scientific competitors is quite frequent, but frequent are also clandestine intrigues and defamation. Even scientific fraud is not so uncommon as one would like it to be, and it happened indeed also in photosynthesis research. Particularly embarrassing are the stories related to the discrimination of Jewish scientists in Nazi Germany, and the history of Dahlem, the "Berlin Oxford" of the Kaiser-Wilhelm Gesellschaft, is full of them. We tell these stories to experts and laymen alike, hoping to keep them interested during listening (or reading).

In Science-in-theater plays the wide formal spectrum of styles is amazing. Often, they reflect straight realism or documentary theater, or they are reminiscent of Brechtian epic theater. Prominent examples are Bertolt Brecht's *The Life of Galileo,* or the much-vaunted *Copenhagen* by Michael Frayn, or *Oxygen* by Carl Djerassi & Roald Hoffmann. With characters that act halfway between the real world and the supernatural, oscillating between vastly different time periods. It is not only science itself – be it physics, mathematics, biology or chemistry – also the history of science has become a vital source for new plays.

Several studies in theater arts – as the one by Kirsten Shepherd-Barr, Princeton University Press, 2006 – have pointed out that there seems to be an impulse of the science playwrights to call on the audience's imagination more than is usually done in the theater. Probably, their aim is not just getting a story across, but presenting a set of facts and ideas that can be quite complicated – and abstract – to explain. And to do this without the technical illusion and animation capabilities of science films and TV documentaries – which have become a popular art genre – but leave very little room for the audience's imagination.

Photosynthesis is the subject where both of us authors are doing active research since many years. Our publications are mainly placed in professional journals aiming at a highly specialized scientific readership. But this time, in the *Dialogues* on photosynthesis, our aim is to disseminate the essentials of photosynthesis research to a broad reader-

ship, not only from the sciences, but also from the humanities. We address the book to all educated persons; those, for example, who are interested in the urgent problems of menacing climate change. And who are interested in the chances for renewable energy supply by natural and artificial photosynthesis.

The phenomenon "photosynthesis" is being studied in vastly different fields of science, ranging from condensed-matter physics and chemistry, photochemistry, biophysics and biochemistry, physiology and botany as well as long-time ecology. We restrict ourselves to milestone-discoveries in photosynthesis research, often honoured by Nobel Prizes, and we devote individual Scenes to them. The selection of "milestones" has been made in accordance with the principle that they should be illustrative for an important scientific breakthrough or a fundamental new idea. An extra Scene is dedicated to spectroscopy in photosynthesis research because many of the new fundamental insights into the complex problems have been gained by spectroscopy in all its varieties. It allows one to visualize the molecular structure via the interaction between the molecules and electromagnetic radiation. However, one has to realize that spectroscopy provides only an indirect and highly encrypted picture of the molecules and their motion, a sort of "shadows" of the real bodies, such as a protein. To make the molecular structure of the protein machinery "visible" for us, we need modern quantum theory and large-scale computers to transform the shadows into real bodies.

The book is divided into a Prologue, 13 Scenes, an Intermezzo, and an Epilogue – and all this at intermixed locations and times. Each Scene has an appropriate quotation at the beginning, reflecting the essence of what will be discussed. The quotations should resemble the posters and projections of slogans and conclusions that are typically used as stylistic device in Brechtian epic theater and other modern stagings. For example: "The aim of science is not to open the door to infinite wisdom, but to set a limit to infinite error". (Bertolt Brecht).

Specifically, each Scene stages "The Chorus" – as in classical Greek theater and in many contemporary plays. The Chorus summarizes accepted background knowledge, general ideas and the contributions of a multitude of researchers in the field. Being part of the dialogues, the Chorus immensely reduces the number of acting characters of the story. Still, many individual characters remain, in fact almost 40, who are actively involved in the play, one way or the other. The Chorus is composed of seven chorus members, each of them an expert (*koryphaios*) in photosynthesis research. The Chorus provides different levels of information and reflections. This means that there exists a hierarchy of statements: The Chorus (*unisono*) makes general statements about the scientific background – and indisputable facts of the issue. Individual chorus members provide selected additional information – based on their own expertise in specific areas. But sometimes the individual character behind a chorus member steps out of the Chorus – to give his personal opinion on the subject discussed.

The challenge for every science playwrite is to keep the proper balance between hardcore scientific discovery to be described – and the human being behind it. In popular cases of conflict – like the competition of Galileo Galilei and Johannes Kepler in im-

proving the telescope for measuring the skies, or of Werner Heisenberg and Niels Bohr in hiding the truth about their 1941 meeting in Copenhagen to discuss Nazi-Germany's nuclear bomb project. In such cases the educated audience might not fully understand the science behind the change of paradigm, but can easily comprehend the events and people involved in the scientific competition. This situation would also apply to Charles Darwin's research on evolution – as part of a science-on-stage play. But will it also apply to Otto Warburg's conflict with James Franck on the maximum efficiency of photosynthesis? Or to Peter Mitchell's discovery of the chemiosmotic theory of ATP formation in photosynthesis and his priority conflict with Robert Williams? Our hope is that even if the details of photosynthesis research may be obscure to many readers and audiences, the life stories of our protagonists and the implications of their discoveries and ideas becomed accessible. At least, that's what we hope.

The book starts off with a Prologue setting the stage of what is intended by the authors and how it will be structured. It is followed by Scenes with discussions about essential discoveries in Science related to photosynthesis, Memoirs of the scientists involved, History of the discoveries in the respective time periods as well as specific Politics and Consequences for Society at large. Those aspects are accented in the Intermezzo and Epilogue. Whenever felt necessary, some Technicalities of the photosynthetic processes are also given within the Scenes for a better understanding of the dialogues. This is further supported by an extended Glossary as well as a Bibliography recommended for further reading.

In conventional discourses on purely scientific issues, the arguments normally follow a linear, if not chronological pathway. This is no longer the case in our *Dialogues* when, occasionally, personal associations and digressions take over and go astray. Since we are not interested in describing a linear dramatic development – neither of the characters of the play nor of the time course of scientific achievements, we have composed interweaving Scenes, both from historical and contemporary times, going back and forth as the protagonists' flow of thoughts demands. Flashbacks alternate with flashforwards as the story develops – such narrative devices are often employed in postmodern literature, theater, film and television. Don't worry! Remember what Antoine de Saint-Exupéry was saying: "If you want to build a ship, don't start by collecting wood, cutting out planks and assigning the work to do, but rather raise the people's longing for the endless immensity of the sea".

Finally our Disclaimer:

All persons in the Dialogues are real, but all dialogues are fictitious.

Some of the dialogues are based on recorded interviews or written documents suited for being cited – most often they are not. But we believe that our individual dialogue partners, from knowing them either personally or from historical writings, could have expressed similar ideas, of course with other words. We stress the point of an "all dialogues fictitious" disclaimer. Freedom of literature *versus* rights of individuals – we make the point that in our work of fiction, individuals who are portrayed will accept fictitious

statements they make. As long as these statements do not interfere with their privacy – or are getting defamatory. This was observed, we assure.

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