



Shmuel Malkin (1934–2017)

Listening to photosynthesis and making music

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Abstract

We present here the life and work of Shmuel Malkin (1934–2017), an accomplished scientist and a gifted musician who touched the lives of many around the world. His early scientific work addressed the dynamics of light harvesting and electron transport in photosynthesis. Later, he used photoacoustic and photothermal methodologies to explore all aspects of photosynthesis. As a musician, Shmuel played the piano often for family and friends but after his formal retirement, he produced a body of original musical compositions, many of which were performed publicly. Throughout his life, Shmuel was a caring and deeply thoughtful man, respected and loved by colleagues, family, and friends. This tribute presents a summary of Shmuel's work as well as remembrances written by his wife, Nava Malkin, their son, Eyal Malkinson, and many of his colleagues: Michael Havaux from France; Sandra and Marcel Jansen from Ireland; David Cahen, Marvin Edelmann, Joop and Onnie de Graaf, Jonathan Gressel, Uri Pick, Yona Siderer, and Elisha Tel-Or from Israel; Ulrich Schreiber from Germany; James Barber and Alison Telfer from the UK; Govindjee, Stephen Herbert and Thomas Sharkey from the USA. Minnie Ho and Iris Malkin of the USA wrote contributions about Shmuel's music.

Keywords Bessel Kok · Hebrew University · Photoacoustic · Photosynthesis · Research Institute for Advanced Studies · Weizmann Institute of Science

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Introduction

Shmuel Malkin was born in Israel on August 31, 1934, and passed away in Israel on March 3, 2017. He began his scientific career earning an MS degree in Chemistry and Physical Chemistry from the Hebrew University of Jerusalem in 1957 and continued for a Ph.D. in Chemistry under Ernst Fischer at the Hebrew University of Jerusalem and the Weizmann Institute of Science in Rehovot, Israel. Shmuel completed his Ph.D. in 1963. After postdoctoral research with Bessel Kok at the Research Institute for Advanced Studies in Baltimore, MD (see Myers 1987; Govindjee and Renger 1993), Shmuel returned to the Weizmann Institute in 1966 as a research scientist and continued his scientific work there until his retirement. Shmuel was promoted to be a professor in 1975; he chaired the Department of Biochemistry from 1984 to 1987, and retired as the Joseph Meyerhoff Professor of Biochemistry in 2003. Figure 1 shows a 2016 portrait of Shmuel Malkin, and Fig. 2 shows him doing an experiment in 1954.

While based at the Weizmann Institute, Shmuel traveled widely to work with colleagues in Europe, North America,

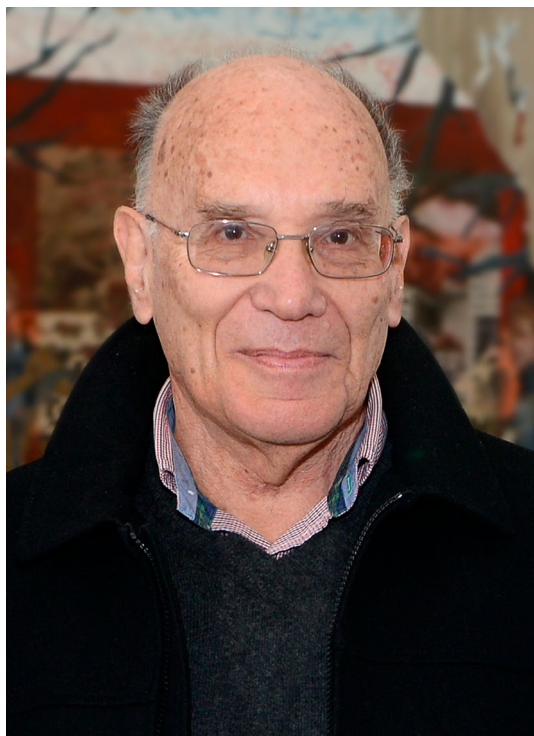


Fig. 1 Shmuel Malkin, ca. 2016. Source: Archives of the Weizmann Institute; courtesy of Namma Chomski-Pesso, Nava Malkin and Marvin Edelmann



Fig. 2 Shmuel Malkin as a chemistry student working with Dalia Parizki at the Hebrew University of Jerusalem in 1954

Japan and Sri Lanka. He was best known for his use of photoacoustics and other heat-detecting technologies to understand the dynamics of energy flow in photosynthesis. Shmuel was also an accomplished pianist and a composer. After retirement, he produced a burst of original musical compositions, some of which he first drafted when he was a young man.

Photoacoustics

Shmuel Malkin's early work on photosynthesis focused on the dynamics of light harvesting and electron transport as revealed by chlorophyll (Chl) fluorescence (Malkin 1966, 1967; Malkin and Kok 1966; Malkin and Jones 1968). Later, Shmuel became interested in using the photoacoustic effect to study photosynthesis. The photoacoustic effect is the generation of a pressure wave in a sample when it absorbs a pulse of light. This pressure wave is caused by thermal expansion, photochemical volume change, photochemical gas evolution, or some combination of the three (reviewed in Tam 1986; Herbert et al. 2000; Delosme 2003). The photoacoustic effect was rarely exploited for study of photosynthetic samples until David Cahen suggested to Shmuel to explore it in photosynthetic membranes. In groundbreaking work, they showed that light absorption, energy stored in reduced electron carriers, and O₂ evolution by photosystem II (PS II) could all be readily quantified in photosynthetic samples using photoacoustics (Cahen et al. 1978; Bults et al. 1981). More studies of photosynthesis using photoacoustics followed these publications as a small group of researchers adopted and adapted photoacoustic methodologies for their work, often after a visit by Shmuel. Shmuel and colleagues also explored photothermal radiometry, in which the conversion of absorbed light to heat is detected by emission of thermal infrared light (Kanstad et al. 1983; Malkin et al. 1991; Drienaar et al. 1994). In the late 1980s, Shmuel visited David Mauzerall at Rockefeller University, where they and Ora Canaani showed that photoacoustic signals from single turnover flashes could be used to follow the S states of oxygen evolution in intact leaves (Canaani et al. 1988). Later, using an approach pioneered much earlier by William Parson (Callis et al. 1972; Arata and Parson 1981), Mauzerall and his research group devised an advanced, time-resolved photoacoustic system to make extensive measurements of the changes in enthalpy and molecular volume that occur with charge separation in photosystems (reviewed in Hou and Mauzerall 2011). Shmuel's last paper on photosynthesis described the use of Mauzerall's approach to follow flash-induced volume changes caused by primary charge separation in the reaction centers (RCs) of *Rhodobacter sphaeroides*. Shmuel and co-authors found that carotenoid triplet decay after the flash did not contribute significantly

to RC volume changes in the nanosecond time scale but that high concentrations of terbutryn, which binds to the Q_B site, altered both volume changes and energy storage in the RCs (see Nagy et al. 2015).

Shmuel's music

Contributed by Minnie Ho, Intel Corporation; minnieho@yahoo.com.

Shmuel Malkin began his musical studies at the age of 7, playing the recorder and the violin. Later, he studied composition and piano with Paul Ben-Haim (1897–1984), a German-born Israeli composer known for synthesizing Eastern and Western approaches in his music. Although Shmuel chose a career in science, he remained active in writing music in parallel with his scientific activities. After retiring from the Weizmann Institute in 2003, he began composing on a professional basis. In all, he published twenty-four pieces of music, mostly for small groups, from solo clarinet and solo piano to chamber orchestra and mixed choir. He was versatile with instrumentation, composing for ensembles of wind instruments (flute, oboe, clarinet, bassoon, saxophone quartet), brass (French horn), strings (guitar, harp, violin, viola, cello), piano, and most voice types (from bass to soprano). Several of his vocal compositions set works of Hebrew poets to music. These could be considered the equivalent of German “lieder”, or, since they often came in groups of two or three, as song cycles. One song cycle for mezzo-soprano and guitar was performed at the 11th annual Beverly Hills International Music Festival in 2014. Nearly all of Shmuel's pieces were performed and recorded. Most are available for listening by courtesy of the Israel Composers League (<http://shmuelmalkin.com/music.php>), of which Shmuel was a member.

Remembrances

We begin this section with personal remembrances by Nava Malkin, Shmuel's wife, and Eyal Malkinson, his son. Remembrances of colleagues follow, in alphabetical order.

Nava Malkin

Shmulik, as we called him, was born in Tel Aviv on August 31, 1934. In 1940, there were no paved roads in the city, so he had to make his way through the sand to get to his elementary school. It would have been fun, had the Italians not been bombing Israel at this time. Shmulik's worried parents, mother Dr. Sera Krasuchin, a dentist, and father Misha Malkin, who produced “kefir,” a traditional Russian dairy product, chose to send him to the school closest to home,

which happened to be “Bilu school,” a religious school for boys only. The 6-year-old child made every effort to fit in with his classmates and therefore he started introducing his secular family to religious Jewish customs. His parents had emigrated from Russia in the early 1930s and, being of a Socialist background, they did not identify with the religious community. It seems that his parents cooperated with the boy and even got pleasure from practicing candle lighting on Sabbath eve and attending Synagogue services on Saturday mornings. In time, Shmulik's music would find expression in the prayers he heard in the Synagogue. His musical talent was apparent early on and he began to study the recorder with a group of children at the first conservatory of music established in Tel Aviv. He excelled at this and so his teacher recommended that Shmulik study the piano; however, he only began these lessons at the age of 12. His teacher was Paul Ben-Haim (1897–1984), a composer who had fled Nazi Germany to settle in Israel. Those were wonderful years for Shmulik. His mentor devoted himself to the talented student and very quickly started to teach him composition.

Shmulik attended Tel Aviv's best high school and quickly proved himself in his studies, especially in chemistry. His parents allowed him to carry out chemical experiments in their backyard in Tel Aviv, where he put up a small lab. This lab had a sad ending after a failed experiment when the young experimenter barely escaped injury from a terrible explosion! Shmulik loved to study; he was a *bookworm*. He would borrow a book from the library, finish it on the way home, and quickly return for another one. He especially loved the Bible and would read it over and over. Knowing this, his friends often turned to him for help in finding the sources of quotations and their interpretation. Shmulik remembered in detail the many classics he read in his childhood. He especially admired Jules Verne and Charles Dickens and re-read their books many times. His children and grandchildren enjoyed hearing him read excerpts from these books. Often, when they wanted answers quickly, they took the short cut of using their “Saba” (grandfather) as a walking encyclopedia, much as his classmates had done long before.

In 1952, at the age of 18, Shmulik served in the Israeli military as part of an anti-aircraft unit. The next year, the Hebrew University accepted him for a special Master's Degree program. Here too, he excelled in chemistry and, upon returning to the army 4 years later, he served in a weapons development unit. Music was always a part of Shmulik. During his army service, he successfully wrote a string quartet and several songs that were aired on the radio. At the same time, he also volunteered to teach Hebrew to new immigrants arriving from Middle Eastern countries. Before leaving for the settlements to teach in the evenings, he would stop for a bite at the army camp dining room. This is where I first met him in 1959. It was love at first sight. I immediately knew that I wanted to spend my life with him. A year

later we started our family. Figure 3 shows a picture at our wedding, and Fig. 4 is that of our son Eyal and me with Bessel Kok.

Music and science played a dominant role in Shmulik's life—he was torn between the two but science prevailed. Shmulik was accepted by the Weizmann Institute of Science in 1959 and completed his Ph.D. there in 1963. Upon completion, he was awarded a postdoctoral research grant from the Charles F. Kettering Research Foundation in the USA. We moved to Baltimore, Maryland, for 2 years at the Research Institute for Advanced Studies (RIAS). There, Shmulik worked with Bessel Kok and they developed a close friendship. Bessel passed away a few years after our return to Israel. We were greatly saddened by his loss (see Myers 1987). He was very young, only 61 years old.

All of Shmulik's working life was spent at the Weizmann Institute. During his last days, when he was somehow able to manage the stairs at home, he asked us again and again to drive through the Weizmann campus. He loved seeing the lawns, the gardens and the trees, and repeatedly asked to bid farewell to the place he loved so much.



Fig. 3 Shmuel and Nava Malkin on their wedding day (April 5, 1960)



Fig. 4 Nava Malkin with young son Eyal and with Bessel Kok, USA, ca. 1966

Shmulik passed away at home on the 3rd of March, 2017, with all his family at his side. We were privileged to live with this special and wonderful man. Tranquil and unassuming, he was a source of stability and security for us. He never raised his voice. He resolved all problems congenially and with good judgment for both family and friends. At work, with endless devotion, he established a younger generation of scientists, many of whom remained in touch with him even when they lived far away. Shmulik was both spiritual and intellectual, with a deep interest in the world and the Jewish history, as well as in modern and classical literature and poetry. He was well known for his knowledge of the Bible. He combined his love of science and music in his scientific research in the area of *photoacoustics*. At home Shmulik always played chamber music, together with our children Eyal, Dafna, and Nurit, as well as with friends. After retirement, in 2003, he decided to delve into composition, which he did with his typical total devotion while maintaining his scientific responsibilities at the Weizmann Institute. He composed feverishly as though he could sense that he was working against the clock. He had a great desire to express the many ideas that were burning inside him. It was difficult for him to penetrate the milieu of the formal *avant-garde* music of the younger generation. Nevertheless, his achievements were very impressive. I think Shmulik's

music is remarkable in its unique style. He succeeded in being original and still remaining tonal. One can identify the influence of the liturgy from his past and of the composers he admired, especially Sergei Prokofiev and Béla Bartók. In 2012, Shmuel was awarded a prize in Japan for composing choir music to words from the “Mishna” in Hebrew, English and French, “Who is rich? He who is content with his lot.” In Los Angeles, USA, in 2014, he won a competition for songs that he had written when he was still a student.

An optimistic man, Shmulik felt fortunate in the life he led. He was always interesting to be with. I loved my life with him. At the end, when he could no longer read by himself, he asked the children to read to him and so he passed away with his family by his side listening to the texts he loved. May his memory be a blessing for us all.

Eyal Malkinson

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“...that there is none like him in the earth, a whole-hearted and an upright man, one that feareth God, and shuneth evil” (The Book of Job 1:8). That’s what my father was like, in the quiet modesty that so typified him throughout his life to the very end. A champion in solving crossword puzzles but a minimalist when it came to using words in everyday life, a talented strategist on the chessboard, always seeing ahead, carefully planning his moves but never placing himself in the center, a safe and secure harbor for all of us, never raising his tone, not letting his personal feelings distract him from the task at hand. Anyone that turned to him for help, whether family, friends, or colleagues, found a sympathetic ear and wise counsel (see Fig. 5 of Shmuel with his family).



Fig. 5 The Malkin family in 2000. From left, Eyal, Dafna, Nava, Nurit, and Shmuel

My father was the consummate scientist, always attentive to the tiniest details, conducting his work with rigor, clarity, and passion. He was particularly exemplified by his long years of research on the interaction between light, material, and plants—there he succeeded in melding his love for science and music. We cherished the special way in which he taught and explained all manner of things; whenever we came with a question we got a detailed, comprehensive response. He would begin with a piece of fresh paper and start to write with the special focused manner that only he had. Bit by bit, step by step, his handwritten notes would clearly illuminate the solution to the seemingly complicated question.

My father was very much attached to the Jewish tradition: Friday evening ‘Kiddush’, synagogue on holidays, fasting on ‘Yom Kippur’, always in his quiet manner, setting an example—never forcing, never imposing.

My dad used to play for me the first Prelude from the second book of Bach’s “The Well-Tempered Clavier” and I would look up to him and wish to be like him. It was the first piece that I ever learned by heart and, years after, every time I play it, I go back to being that 6-year-old boy who had a father who could accomplish anything. He taught me by personal example that one could do anything if one put one’s mind to it. We used to play music together: me on the cello and he on the piano, or the two of us on two pianos, or with four hands effortlessly (for him). Years later, when I had opportunities to play the piano part of the Brahms Sonata for piano and cello, as well as the Beethoven piano sonatas, I could hardly believe how modest he was when he would sight-read these difficult pieces, never making a big deal of it, as if everything just flowed from his fingers. He taught me how to sight-read scores without making an effort “just look ahead all the time” he said. Such was his attitude toward life. He looked ahead...with optimism (Fig. 6 shows Shmuel and I playing together).

I have a flood of memories of my Dad from my childhood: a spontaneous trip from Rehovot to Tel Aviv, I merely



Fig. 6 Eyal and Shmuel playing together in Malkin’s apartment, Rehovot

a 5-year-old kid, and he bringing along Mom's poppy cake. And that trip when we got lost in the woods near Baltimore. I remember the trees, the darkened landscape, and the noisy highway that we were unable to cross, and both of us laughing.

Dad had the courage to take his family with three small kids on a sabbatical in London, to buy our first car, a red Fiat 124 station wagon, and to drive it hundreds of miles around England and Scotland's roads with the steering wheel on the left-hand side and, to top it all, later traversing throughout Europe as if we were nomads driving from campground to campground, or even sleeping in the car. For all of us it was an era that made us who we are and shaped our perspective on life.

Dad was a great Grandpa to all his grandchildren, writing them poems and riddles and parables, teaching and helping them in all their classes through high school graduation and into their university years, always taking an interest in all they did.

He worked all his life at the Weizmann Institute doing research but music was there all the time, through composing or playing with others. It was important for him to bring all his songs and musical art work to the point of performance and he invested every bit of his energy to complete his musical work till his last breath.

Our father is no more. We are sad without him. The illness lurked on him and on us all and it shuffled the deck and our lives. In the last months, while the illness hit him cruelly, he never complained and never cried out. Everything was gone for him. He couldn't move, couldn't breathe, but even then he remained the same modest and quiet man, and as such he went from us, in his own home, embraced by all who loved him dearly. He shall live in each and every one of us forever.

James Barber

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Shmuel Malkin was not only a colleague, who visited and worked in my laboratory at Imperial College London several times, and I in his at the Weizmann Institute, but a very close friend. He was an exceptionally talented and creative scientist and musician and I am fortunate and proud that our friendship dates back to over 40 years. Because of our close relationship, my wife Lyn and I have seen his children and grandchildren grow up, as he did ours. His wife Nava is also a wonderful and creative person who is a talented musician and, recently, a filmmaker. They were a very close couple and my heart goes out to Nava and the extended Malkin family.

I first became aware of Shmuel in October 1967, when I joined Lou Duysen's lab in Leiden as a post-doc. Shmuel

had also been working there as a visitor, but had to leave in a hurry for Israel because of the Six Day War the previous June. After the war, he did not return to Leiden but continued his work at the Weizmann Institute and, consequently, we never met face to face at that time. An opportunity to meet him arose only in 1974, when the 3rd International Congress on Photosynthesis Research was held at the Weizmann Institute. I attended his lecture on the analysis of the Chl *a* fluorescence induction curve following the onset of illumination. It was an elegant analysis indicating that there was a substantial pool of electron acceptors between PS II and photosystem I (PS I). We briefly met on that occasion but I had already concluded that he was a "heavyweight" in photosynthesis research, and, of course, I was aware of his landmark papers with Bessel Kok (Malkin and Kok 1966; Malkin 1966). I met him on several occasions after that and was very pleased when he wrote to me in early 1977 about his intention to spend a sabbatical year in London at the Royal Institution with Professor Sir George Porter and that he would like to link up with me also. It was during this sabbatical year that I got to know Shmuel very well and became a close friend. He was able to use the equipment I had built to monitor prompt and millisecond delayed Chl *a* fluorescence and we wrote a wonderful paper together (Malkin and Barber 1978).

In 1980, I spent 3 months in Shmuel's Lab at the Weizmann Institute, and it was during that time that I and my family got to know Shmuel and his family well. They were extremely kind to us and the Barber family looks back on that time as being very special, so much so that we returned in 1983 for another working visit. Shmuel also came to work with me in London several times and it was always a joy to have him visit. He was very keen to use his time to do experiments, which he would analyze rigorously using basic physical and photochemical principles. Over the years we published several joint papers.

Shmuel and Nava got to love coming to London and used the opportunity to go to concerts and the theatre. They were addicted to the performing arts and London offered them endless possibilities. On these occasions, they usually stopped at our house, where they were most welcome. In July 2015, they came to London to attend a party to celebrate my 75th birthday and another to celebrate my 50 years of marriage to Lyn. They really were a part of our family. Just prior to this last visit, Lyn and I went to Israel to attend an event to celebrate his 80th birthday. Several of his Weizmann colleagues gave excellent scientific talks and I was honored to be included. And of course we visited with Shmuel and Nava and enjoyed each other's company (Fig. 7 shows my picture with Shmuel).

Shmuel Malkin was indeed a "heavyweight" of photosynthesis research but also a very modest man. Our field has lost a very exceptional and creative scientist.



Fig. 7 Shmuel Malkin (right) and Jim Barber traveling in Israel, 2015

David Cahen

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I am not sure if I would have stayed in scientific research without Shmuel Malkin. After getting my Ph.D. from Northwestern University in Evanston, Illinois, I returned on a postdoctoral fellowship to Israel just a month before the 1973 October war. The fellowship allowed me to choose to work with anyone at the Weizmann Institute and I wanted to get my feet wet in biophysics but I didn't really know what it was about. In the month-long confused period that followed the war, I got totally lost. A Ph.D. student of Shmuel's, Binah Silberstein, suggested that I talk to him. Waiving my special fellowship, I got the OK from the Institute to join Shmuel, who put me on a clearly defined project that, as he correctly assessed, I could handle. It was to determine the viability of algal chloroplasts by measuring the decay of their Chl *a* fluorescence, a joint project of Shmuel with Itzhak Ohad. At the time, I simply enjoyed doing the research. Only much later did I realize how wise Shmuel's choice had been. After just 1 year, for reasons I have never understood, I was given a chance to join the Weizmann faculty, but, unbeknown to me, I was one of the first to do so without a defined mentor. It was Shmuel who became my de facto mentor and remained so for a decade.

In October of 1975, I formally started my "tenure track" position with no lab, no office, and no budget. I read Allan Rosenzweig's semi-popular article on *Photoacoustic Spectroscopy of Solids* (Rosenzweig 1975) and, as chance favors

the prepared mind, in my case by my Chl fluorescence project with Shmuel, I ran to him with it, arguing that this could complement understanding of where the energy that chloroplasts absorb goes. I do not recall Shmuel's reaction, but suffice to say that, with no support from my department, I had access to all of Shmuel's equipment and technical personnel to try to do this experiment. Shmuel provided constructive advice on how to correct my (mostly rather stupid) mistakes, and I received help from a postdoctoral associate (later assistant professor) E. Itzhak Lerner. Our first results were published in Cahen et al. (1978) and Malkin and Cahen (1979), landmark papers on photoacoustic spectroscopy of chloroplast membranes that included a first theoretical framework for the data, the latter of which established Shmuel as the leading authority on photoacoustics of photosynthesis. The rest is history but some points deserve not to be forgotten. At that time, my department kicked me out of the temporary lab I had settled in and who but Shmuel came to the rescue, finding space in the catacombs (sub-basement) of the Biochemistry building, where my lab space remained for several years (a remarkable gesture, as this was before photoacoustics became a major part of his research!!).

The first photoacoustics conference was held in 1979 in Ames, Iowa, USA. Shmuel and I participated. As a special event, an evening piano recital was announced. That day, after the lectures ended, a grand piano was pushed onto the stage. The temptation was too much and Shmuel sat down to play. Quickly an "official" ran out on stage to tell him that only "real" pianists could use the instrument. When I listened that evening to the "real" pianist, I looked at Shmuel and saw him trying hard to appear as if he enjoyed the music.

Marvin Edelman

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I, together with Jonathan Gressel, paid a condolence visit to Shmuel's family. We both were aware of his love of music alongside his science. Shmuel composed music and occasionally gave a concert of his work to his scientific colleagues. He transmitted this love and ability on to his son and granddaughter. Shmuel was a scholar and a gentleman. He was mild mannered and measured in his approach to his fellow beings and in his scientific work. It was a distinct pleasure collaborating with him over the years on several aspects of photosynthesis.

Govindjee

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In the 1960s, the two possible models for the energetic interconnection between photosynthetic units (PSUs) were: (1) The “lake” model, where all the PSUs form one statistical entity in which a photon absorbed anywhere in the antenna could reach any open RC and be trapped there. Here, the lifetime of Chl *a* fluorescence is expected to be linearly dependent on the intensity of Chl *a* fluorescence (see e.g., Robinson 1967). (2) The “separate package” model, where the PSUs act as separate entities and a limited number of antenna molecules are attached to each RC. Here, when the RC is closed, Chl *a* fluorescence would live longer and fluorescence intensity would not be linearly dependent on lifetime of fluorescence. In 1968, Ted Mar (then my Ph.D. student), Gauri Singhal (a research associate) and I approached Henri Merkelo to build a new instrument with the hope of answering the above question. Merkelo, together with his associate S. R. Hartman and with full participation of Mar and Singhal, then built a new sensitive mode-locked laser system to make such measurements (Merkelo et al. 1969). It was not until later, however, when Jean-Marie Briantais came to work with me in Urbana, that we observed a linear relationship of the lifetime of fluorescence and fluorescence intensity in the green alga *Chlorella pyrenoidosa* (Briantais et al. 1972), supporting the lake model, as was shown in 1967 by L. A. Tummerman in Russia using a “phase fluorometer” (see de Kouchkovsky and Cerovic 2005). However, when Ismael Moya worked jointly with Briantais and me using pea and lettuce chloroplasts under different salts and different salt concentrations, we observed a non-linearity in the lifetime of Chl *a* fluorescence and its intensity (Moya et al. 1977). Here, we invoked the existence of “dead” fluorescence to explain our results! It was only after this time that Shmuel Malkin decided to come to work with me on a short visit in 1979 to find out the “truth” about it all, using essentially the same instrument as used by Briantais et al. (1972) but with a focus on using what Shmuel called “living leaves”. Using fresh leaves from many types of plants (peas, mustard, lettuce, pigweed, and spinach), Malkin et al. (1980) indeed showed a clear non-linearity between the lifetime of fluorescence and fluorescence intensity, during the fast (OJIP) and even slow (P to S) fluorescence induction transients, challenging the “truth” of the lake model in intact leaves. The concept of something in-between the lake and the separate package models, i.e. having variable connectivity between PSUs, must be the “truth”, as has been discussed before and after the 1979 experiments of Shmuel (see Stirbet 2013 for a review).

Shmuel and I had a great time together in 1979, including pleasant exposure to his musical talent. My graduate student Daniel Wong had also participated in our joint experiments, and he too liked working with Shmuel who was always kind and peace-loving and had a unique grin when talking and even when doing experiments. We miss you Shmuel.

Jonathan Gressel

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Most people think of Shmuel Malkin as an expert on photosynthesis but he was more than that; he was a complete photobiologist whose main work was on photosynthesis. As a colleague and a friend, I plugged into Shmuel’s deep knowledge of photobiology on more than one occasion. He was so easy to work with yet so meticulous. If he agreed with our data, I knew we had not generated an artifact. When one of my grad students was getting beyond my depth in developmental photobiology (photoinduced conidiation of *Trichoderma*), I quickly arranged with Shmuel to serve as a joint advisor. When one student was working on a weed resistant to PS II herbicides and another on a weed resistant to paraquat (methyl viologen), Shmuel graciously let us use his equipment and, more importantly, he was there to make sure we interpreted the data correctly. Thus, he took time off from his own research to be an invaluable co-author on seven publications. I knew that he was an avid musician throughout his scientific career but it was only after he retired that I learned he was composing music. Based on my perception of Shmuel as a scientist, I quickly imagined that Shmuel’s compositions would sound sort of like Bach. Was I ever wrong, as I discovered when I listened to his CD! He is sorely missed.

Michel Havaux

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I met Shmuel Malkin for the first time when I arrived in the late 1980s in his laboratory at the Weizmann Institute as a young postdoctoral researcher, right after obtaining my Ph.D. I remember what he told me on my arrival: “Michel, we have developed here a new biophysical method to study the processes of photosynthesis, and I would like you to see what you can do with it in the ecophysiology field, for example to characterize the photosynthetic responses of plants to environmental constraints” (transcribed from memory). This message is symptomatic of Shmuel Malkin’s vision of science: freedom and creativity. I enjoyed the complete freedom he gave me during my postdoctoral stay in his lab. I was quickly convinced and enthusiastic about the photoacoustic method that Shmuel was developing and, with the help of Ora Canaani, we applied this new technique to plants exposed to various environmental stress conditions. The photoacoustic set-up was placed in the basement of the Biochemistry building

to limit vibrations. I remember the long hours spent in the photoacoustic room, trying to get the least noisy signal possible, and unfortunately this was not always a small task. I learned a lot from my postdoctoral training with Shmuel, and I think that my stay in his laboratory, ‘listening to photosynthesis’, had a notable influence on the continuation of my scientific career. We were highly productive and our work was published in several journals (see Canaani et al. 1986; Havaux et al. 1986a, b, 1987a, b, c, d; Malkin et al. 1986b). Shmuel used to take regular sabbaticals abroad, and I had the chance to welcome him to Cadarache for a few months where we worked together on the monitoring of CO₂ and O₂ uptake in leaves using photoacoustic signals (see Havaux and Malkin 1998; Malkin and Havaux 2001). I remember Shmuel as a brilliant and creative biophysicist who combined rigor and originality, and I recognize the luck I had of starting my scientific path at his side.

Stephen Herbert

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I had the privilege of working with Shmuel when he visited my post-doctoral mentor David (Dave) Fork at the Plant Biology Department of the Carnegie Institution for Science in 1989. My work with Dave was on state transitions, photoinhibition, and other dynamics of photosynthesis in red algae. After a few minutes speaking with Shmuel, I determined that I should learn whatever I could from him about photoacoustics. The result was three papers on state transitions and PS I cyclic electron transport (Malkin et al. 1990; Herbert et al. 1990; Fork et al. 1991). During our work together, Shmuel would often come to the lab early to participate in experiments, suggesting improvements and explaining solutions to technical problems as they arose. Sometimes he would ask for specific measurements that he needed for the paper he was drafting. On these days, after the needed measurements were completed, Shmuel would quickly gather up the armloads of chart paper that we had produced and hurry upstairs to his office space, where he spent the rest of the day extracting numbers from the traces and writing out calculations all around them by hand. I will never forget the quickness of his step as he went off with the chart paper fluttering behind him. It was a physical manifestation of his passion for knowledge.

Shmuel took every opportunity to hear and play music during his visit to Carnegie. One morning, he mentioned to Dave that he would take the bus from Stanford to San Francisco that evening to hear a piano performance, returning late at night. I often rode the same bus and had occasionally seen passengers in the back of the bus bullied by



Fig. 8 Shmuel Malkin using a pistol to drive a high speed shutter in Bessel Kok's lab, ca. 1966

small groups of rough characters. Shmuel was not physically imposing and gentle in his manner. I was concerned he might be singled out for bullying and advised him to sit at the front of the bus, close to the driver, especially on his return trip. Shmuel smiled at this, looked to Dave, and asked mildly, “Do you have a pistol...?” Dave did not have a pistol available but Shmuel returned safely from the concert nonetheless. It was not until later that I learned Shmuel's comfort with a pistol allowed him to use one as part of an optical shutter during his research with Bessel Kok (Fig. 8).

My sharpest memories of Shmuel are of the times we encountered gaps in my knowledge of physics or chemistry. He took a special delight in filling these gaps, dropping what he was doing and seizing a piece of paper to draw out diagrams and equations as he explained. Despite my awkwardness during these explanations, Shmuel was always gracious. My memories of his passion for knowledge and his courtesy to all still inspire me.

Sandra and Marcel A. K. Jansen

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Shmuel's passing is a very sad loss! We were postgraduates at the Weizmann Institute during 1988–1993. Sandra, who worked with Shmuel, has very fond memories of being part of his research group. Marcel is indebted to Shmuel for contributions to his work (see Jansen et al. 1989) and career,

and especially for his friendship. Working with Shmuel on photoacoustics not only gave both of us a fantastic grounding in photosynthesis research, but also opened our eyes to the joys of home-built equipment.

Iris Malkin

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I had the pleasure of knowing Shmuel Malkin for the past 7 years. Even though we share the same last name, we are not family-related. What connected us was his beautiful music. I am a Mezzo-Soprano from Israel, now living in Los Angeles, and I was asked to perform two of Shmuel Malkin's songs for voice and piano at the Beverly Hills International Music Festival in 2010. After that performance, I got to meet Shmuel and his lovely wife Nava, a few times in Los Angeles and also in Israel. I always looked forward to those meetings. I got to know Shmuel's wonderful personality and his excitement about his music. He would always send me his new compositions and I learned quickly that he was always open to new challenges. He knew that I used to sing in a duo with a guitarist and so he composed two songs for voice and guitar, which I performed with guitarist Edward Trybek at the Beverly Hills International Music Festival in 2014. My performance of Shmuel's "Music for Two Poems" at this festival may be seen at https://www.youtube.com/watch?v=M3uOkI_MeRA. Yona Siderer was the author of the poems. I truly enjoyed performing Shmuel's songs. I feel that his musical language was very unique and I always enjoyed practicing and learning his compositions. I miss Shmuel now but I am glad to know that his music is here to stay and I look forward to performing his songs again in the future.

Autar Mattoo

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My association with the Weizmann Institute of Science, in what was then the Department of Plant Genetics, started in 1979 in the laboratory of Professor Marvin Edelman. I soon became aware of the top-notch scientists working in the Department of Biochemistry in the same Ullman building, headed by Professor Mordhay Avron. It was natural that I got introduced to Shmuel Malkin and his team. Shmuel was always ready to help with fluorescence experiments and discuss results from his laboratory, in particular the photoacoustic measurements. He would visit our lab whenever we sought his advice. Shmuel was gentle, helpful, a grand scholar and yet low key, and explained the workings and use of fluorescence and photochemistry

in the most memorable manner. I was highly impressed and he befriended our group. His thoughts and input are acknowledged in the highly cited paper on D1 protein turnover that resulted from our work (Mattoo et al. 1984). The first manuscript where Shmuel became a coauthor along with me was Greenberg et al. (1989), which showed for the first time that separate photosensitizers mediate degradation of the D1 protein (then referred to as the rapidly turning-over 32-kD protein). Our interaction continued till much later on, after I left Israel and joined USDA at Beltsville, MD. A few other papers followed: Jansen et al. (1993) and Babu et al. (1999).

Certainly, Shmuel Malkin made a mark in our research and became my teacher in photoacoustic and photosynthesis instrumentation and the science associated with them. I salute Professor Shmuel Malkin and feel blessed by meeting and working with him. Thank you Shmuel!

Uri Pick

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My acquaintance with Shmuel dates back to the early 1970s, when I joined the photosynthesis group at the Weizmann Institute as a young student for my Ph.D. with the late Mordhay Avron. Already then, and more so later in my career, I found myself sitting in Shmuel's modest office, seeking his advice and clarification on basic issues in science, especially those that I did not fully understand. Shmuel was the senior physical chemist in our group and for me he was the top authority in any subject involving spectroscopy, photochemistry and physical chemistry. Shmuel was always happy to help; he listened patiently to my questions and with his calm and clear wisdom, explained just about everything. At later times, when Shlomo Avital worked with him on properties of the carotenoids, a topic of my expertise, we often met to discuss Shlomo's interesting results.

We had the pleasure of hosting Shmuel when he visited me and my family several times abroad: in Utrecht (The Netherlands), in London (UK), where I stayed with our common friend Jim Barber, and then in Berkeley, California (USA). I had a special bonding with Shmuel and with Nava because of our love for music. It started at social meetings in the Malkins' home in Rehovot, where Shmuel played the piano with great talent and an emotional depth that could rival a professional pianist. He was often joined by Nava or by one of the guests they had invited to take part in the private concert. Later we met with Shmuel and Nava at numerous concerts in Tel Aviv and elsewhere in Israel. I particularly remember the enchanting musical event organized for Shmuel's 80th birthday and performed by family members.

Shmuel will stay in my heart as an original and dedicated scientist, a talented musician, an honest and sincere man and, above all, a very dear friend.

Ulrich Schreiber

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Shmuel was an exceptionally gifted scientist and a very gentle person. My memories of him date back to the late 1980s and early 1990s, when I spent some time in his lab in Rehovot and he in my lab in Würzburg. We had a common interest in biophysical measurements of photosynthesis that used fluorescence, luminescence, P700, photoacoustics, and photothermal signals. At that time, we in Würzburg had developed a new approach for computer-based deconvolution of pulse-modulated photoacoustic signals, differentiating between one photothermal component (energy storage) and two photobaric signals (O_2 evolution and what we took to be O_2 uptake). Shmuel was very much interested in this system and we had been planning to collaborate on its application. However, it soon turned out that the photobaric uptake signal was dominated by CO_2 solubilization driven by stroma alkalization and was strongly dependent on CO_2 concentration, which increased with enclosure of the leaf sample in the photoacoustic cuvette. This was not what we had hoped to find but we did publish some nice papers as a result of our collaboration (Malkin et al. 1991, 1994; Drienaar et al. 1994).

Thomas D. Sharkey

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This is a remembrance of a giant in the field of photosynthesis. Speaking on behalf of many who knew of his work but did not know him personally, this remembrance brings to life his great love of research on photosynthesis, his love of music, and, above all, his unassuming manner. I am confident that not only those who knew him, but everyone else interested in his many important insights that came from his work on photoacoustics, the so-called “lake model” of photosystems, and more, will appreciate reading this Tribute, and gain insight into the life of this wonderful human being, who walked among us, and touched the lives of many.

Yona Siderer

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On the 15th of February 2015, we celebrated Shmuel Malkin's 80th birthday with a scientific conference in his

honor, held at the Lopatie Conference Hall of the Weizmann Institute of Science, Israel. Many local and international scientists attended the conference. It was indeed a very rewarding event. An earlier personal gathering for his family and friends was held in the picturesque chamber music center in the Ein Kerem quarter in Jerusalem. The Malkin family played piano or two pianos with Shmuel and Nava and their children, Eyal and Nurit, and Tal, their singer granddaughter. It was a wonderful warm gathering. All this was just over 2 years ago—that is a good memory of Shmuel for the future (see Shmuel Malkin at a dinner in 2015; Fig. 9).

In 1974, I came to the Weizmann Institute of Science and its Feinberg Graduate School to start my doctoral studies and to find an advisor for my Ph.D. thesis. After talks with several physical chemists, Shmuel's description of his research on photosynthesis attracted me and he became my mentor and advisor. Our first research was mainly on the behavior of the oxygen evolving system in plants, using delayed luminescence and prompt fluorescence to follow salt effects.

Shmuel was not only a clever and a deep-thinking scientist but also a devoted teacher. He listened to us whenever we asked him anything and he devoted time not only to his students but also to the staff and all his colleagues. In his very modest office, which opened into the laboratory, he was there to instruct, to suggest and to advise where to find the tools, the colored glass filters, the metal supports, and whatever else was needed to plan, design, and perform an experiment in the darkened room for measuring light-induced effects on plants at the end of the corridor, on the second floor of the Ullmann building. Shmuel's patience with me, with other students, and with the staff was one of his virtues. It was great to work when he was with us.

When I felt that I would like to move on in my research and use electron spin resonance (ESR) to study the role of manganese in chloroplasts, Shmuel encouraged me, and gave me full independence that I really appreciated.



Fig. 9 Dinner at the home of the Malkins following Shmuel's 80th birthday conference, 2015. From left, Jim Barber, Sylvia Braslavsky, Shmuel Malkin, Yosepha Shahak, Daniel Farkas, Yona Siderer, and Lyn Barber

We talked with Professor Zeev Luz in the Department of Isotopes, located then in the Physics building, and later moved to the new Perlman building, which was actually closer to the Ullmann biochemistry building on the green campus of the Weizmann Institute. (For history, I note that the laboratory of Professor Chaim Weizmann in the Sieff building stands in between.) Together with Professor Luz and Dr. Raphael Poupko, we published our research on continuous light and dark induced changes of the manganese ESR signal and interpreted those as changes in the oxygen-evolving system (Siderer et al. 1977).

I recall the general good atmosphere in the Department of Biochemistry. On Friday mornings, we (Shmuel, David Cahen, Binah Zilberstein, Haim Hardt, Yosepha Shahak, Uri Pick, Elisha Tel-Or, Sonia Philosophe, Rachel Oren, myself, and a few others) would get together for our group seminar with Professors Mordechai (Mordhay) Avron (1931–1991), Zipora (Zippy) Gromet-Elchanan (Elhanan, 1931–2007), their students, and research staff. These seminars were very interesting and illuminating, and we learned what other colleagues were exploring. Shmuel's presentations were always insightful, adding theoretical aspects to the design of experiments or to the explanation of the results, while trying to penetrate into the mechanism of life.

During 1974–1979, we published our joint research (Malkin and Siderer 1974; Siderer et al. 1976; Siderer and Malkin 1979). Working under Shmuel's guidance was very interesting and very pleasant. I felt that I always trusted Shmuel, my teacher. I would also like to mention Shmuel's devoted technician, Mr. Shlomo Gershon (1928–2016), who passed away recently. Shlomo arrived early in the morning to the laboratory, prepared solutions, adjusted lamp stands, fixed tools and all sorts of supports for Shmuel and for us students. In order to design any new apparatus, Shmuel approached the division of research services, consulting the electronic unit staff and Mrs. Neomy Raz, the engineer, and the mechanical workshop members, where the cutting and the use of special tools for the right filter settings, selection of the proper tubes and syringes, injectors, stroboscopes, and other gadgets took place.

During my post-doc studies, first with Professor Charles (Chuck) G. Dismukes at Princeton University and then with Dr. Geoffrey Hind's group at the Brookhaven National Laboratory in Long Island, NY, Shmuel visited me. I appreciated Shmuel's consideration when I wanted to stop at local shops or watch a firemen's parade in a town during a drive to the South Fork of Long Island, all the way to the tip, overlooking the Atlantic Ocean. We passed through the little village where Albert Einstein had spent time after he left Europe. I could sense Shmuel's excitement seeing these places, in spite of his very quiet nature (see a 1981 photograph of Malkin with me (Yona); Fig. 10).



Fig. 10 Yona Siderer and Shmuel Malkin on Long Island, South Fork, 1981

Over the years, living not very far from Shmuel and Nava, I have had many wonderful opportunities to meet, host, and talk with them, always having rewarding conversations. During the last several years we found another route for collaboration, and this was music. Shmuel, the musician, had returned to musical composition after his retirement, in addition to his scientific work. Upon my request, Shmuel chose to write music for two of my more sensitive poems published in 1993. They are “If you are in a boat, on the sea”, and “The words I swallowed in me”. He composed special, beautiful music for these poems. First, Shmuel wrote a piano piece to accompany the singer but when a guitar was recommended, Shmuel took a few lessons for the arrangement of the role of a guitar. This was done in collaboration with Professor Reuven Seroussi at the Rubin Music Academy of Tel Aviv University. This act of taking lessons was very characteristic of Shmuel's serious approach to his creative work, both in science and in music. On the occasion of the inauguration of a new poetry book of mine, Avital Deri, a gifted alto singer, sang my words with Shmuel's music penetrating the hearts of the listeners at Tel Aviv House of the Writers, *Beit Hasofer*, in 2014. Shmuel also gave a lecture on his music composition at Haifa University on April 23, 2014. His musical work was performed there. About 7 years ago, Shmuel performed at the Tokyo Concert Hall in Tokyo,

Japan. Since I worked at the International Research Center for Japanese Studies in Kyoto at that time, Shmuel wrote to me and suggested that I attend the concert, but time and distance did not permit me to do so. Shmuel also produced a CD recording of his piano and chamber music.

With family and friends surrounding him, Shmuel passed away peacefully after a short illness. Let his memory be blessed—*Yehi Zichro Baruch*.

Elisha Tel-Or

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I got to know Shmuel Malkin at the outstanding Friday morning seminars held by Professor Mordechai Avron for his students, visitors and coworkers in the Biochemistry Department of the Weizmann Institute of Science. Shmuel's interests and his curiosity matched ideally with Professor Avron's. I recall Shmuel's involvement in the seminar as a sheer demonstration of wisdom, integrity, knowledge and competence. At the time, Shmuel was a member of the Organic Chemistry Department but his understanding and knowledge were so complementary to the Friday seminar participants that Professor Avron arranged for him to be reassigned as a staff member in the Biochemistry Department, together with his devoted technician Shlomo Gershon. Thus, Professor Malkin became an integral component of the research group led by Professor Avron and Dr. Zipora (Zippy) Elhanan. In turn, the connection between Shmuel and Professor Itzhak Ohad from The Hebrew University of Jerusalem became a very strong bridge for the Avron group to Ohad's deep interest in *Scenedesmus* photosynthesis.

As a M.Sc. and Ph.D. student of Professor Avron, I was involved in studies of cyanobacterial electron transport, mainly in *Phormidium luridum*, identifying the relationship between PS I, PS II, and the pigment phycocyanin. These studies led to a most interesting report and a mathematical model developed by Shmuel that was accepted for publication in *Biochimica et Biophysica Acta* (Tel-Or and Malkin 1977).

Beginning in 1974, my research interests became focused on N_2 -fixation by heterocystous cyanobacteria. Upon a return visit to Israel during a sabbatical in the USA, I suggested to Shmuel that we collaborate on the relationship between photosynthesis and N_2 -fixation in the aquatic fern *Azolla*. The idea was brought up during the International N_2 -Fixation Congress in Holland, where I discussed possible collaboration with Professor Kulasooriya, a leading expert in *Azolla* research from the University of Peradeniya in Sri Lanka. Shmuel and I applied for support from the USAID program and were awarded a 3-year grant to develop a practical device to quantitate N_2 -fixation by *Azolla* activity.

Mrs. Hanna Arad, a M.Sc. student in my laboratory joined Shmuel's junior colleague, Dr. Ora Canaani, in this project and all together we found that nitrogen fixation could be measured indirectly from photoacoustic signals. In time Professor Kulasooriya joined forces with Shmuel to conduct field studies, using a mobile analytical unit in flooded rice fields. It would be interesting if this idea could be developed further someday, carrying on Shmuel's scientific vision. The association of rice and *Azolla* still plays a major role in rice producing countries in the Far East and South Central America.

Alison Telfer

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I, like Jim Barber, knew Shmuel for nearly 40 years—as I was working in Jim's lab all that time. I had the pleasure to work with Shmuel on several of his visits and to publish two papers with him (Barber et al. 1989; Malkin et al. 1986a). On their last trip to the UK for Jim's 75th birthday, Shmuel and Nava were, as usual, very active. Shmuel was indignant that he was not allowed to drive a rental car because of his age but Nava told me she was secretly rather glad! Undeterred, they travelled around South West England by train, bus, and taxi. I am glad that my last memories of meeting Shmuel are of a happy, active person. We have lost a truly special colleague.

Conclusion

Shmuel Malkin leaves a rich legacy of science and music, students and colleagues, family and friends. He contributed to our knowledge of photosynthesis at a time when measurement and computational technologies were sophisticated enough to reveal the complexity of natural photosynthesis but not yet sophisticated enough to make the underlying mechanisms clear. In this challenging time, Shmuel was one of a cohort of disciplined minds that crafted the key hypotheses of photosynthesis research, many of which continue to guide experiments today. The use of photoacoustics to study photosynthesis, Shmuel's great technical contribution to the field, has decreased in recent years but photoacoustic methods still have much to offer, for example the ability to quantify light-induced volume changes in photoactive protein complexes. The use of photoacoustics in life sciences outside of photosynthesis research has expanded greatly of late owing to the emergence of live tissue imaging by photoacoustic tomography (reviewed in Wang and Yao 2016). Photoacoustic tomography generates images of soft tissue in living animals by intensive processing of photoacoustic signals using re-purposed ultrasound imaging systems. The

advantage of photoacoustic tomography over standard ultrasound imaging is that it detects the absorption spectra of different cell types, after labeling in some cases, and can also detect photochemistry. The rapid development and application of photoacoustic tomography to tissue imaging suggests that photoacoustics could be re-applied to photosynthesis research using the dramatically improved signal processing capabilities now available. Shmuel would no doubt have found this very interesting.

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