

Albert W. Frenkel (1919–2015): photosynthesis research pioneer, much-loved teacher, and scholar

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Abstract Albert W. Frenkel, a pioneer in photosynthesis research, and discoverer of photophosphorylation in photosynthetic bacteria, is remembered here by two of us: Govindjee (historical corner editor of photosynthesis research) and Susanna Frenkel (SF; Albert Frenkel's daughter, who provided most of the family information).

Keywords Photophosphorylation · Allan Brown · Robert Emerson · Albert Frenkel · Hans Gaffron · Martin Kamen · Fritz Lipman · Cornelis van Niel

Early life

Albert Frenkel was the 4th and the youngest child of Selma (Baerwald) and Arthur Frenkel. The time of his birth was unique; it was during the Spartacist rebellion¹ and the attending doctor had to be guaranteed his safety after Albert's birth. Members of his family were quite prominent: his grandfather, on his father's side, Hermann Frenkel (grandmother: Henrietta Pinkus) was Director of a private banking house of Jaquier & Securius bank, Privy commercial councilor, a noted art collector, and founding

member of the German Film company UFA (Universum Film-Aktien Gesellschaft). On the other hand, his other grandfather (on his mother's side) Dr. Hermann Baerwald (grandmother: Emma Sandberg) was Director of the Academy Philantropin in Frankfurt am Main.

Albert was raised in an upper-class environment with visits to his grandfather Hermann Frenkel in his huge house, which was next door to the family house of Werner von Braun.²

From Germany, the family moved to Switzerland in the 1920s to escape the rise of the Nazis; the family failed to become Swiss citizens. The young Albert began collecting wildflowers in Switzerland and pressing them; this collection is now a part of the Jepson Herbaria at the University of California (UC) Berkeley. He returned to Germany before coming to USA.

Figure 1 shows a portrait of young Albert, when he was in Berlin.

Education

Frenkel graduated from the Bismarck Gymnasium in Berlin in 1936. He was introduced to chemistry by his cousin, Lise Baerwald, who was then working on her Ph.D at the University of Frankfurt. Throughout his life, Frenkel has

This tribute to Albert Frenkel was read by Robert E. Blankenship before its publication.

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¹ The Spartacists were radical socialists; they were founded, in 1915, by Rosa Luxemburg and Karl Liebknecht; the group was named after Spartacus who had led a revolt, in 73 BC, by slaves against the mighty Romans. In 1918, it became the German Communist party.

² Werner von Braun (1912–1977) was a German and later American aerospace engineer and space architect; he is one of the “fathers of Rocket Science”. Although in his early life, he was a member of the Nazi party, he seemed to have been accepted in USA, perhaps, because his science overshadowed everything else.



Fig. 1 A photograph of Albert Frenkel, in Berlin, taken by his father Arthur Frenkel, who was an accomplished photographer. Date unknown. *Source* Archives of the Frenkel family

been grateful to those who encouraged his scientific career (see extensive acknowledgment section in Frenkel 1993).

As told by Albert to one of us (SF), he did have a rough time at the Bismarck Gymnasium, an elite high school that was under Nazi control. He was pushed around at school as a Jew and there was concern that he could get picked up at any time. He would ride his bike to get around instead of taking public transportation in order to avoid being picked up.

In April, 1937, Frenkel left Germany; he was aided by his uncle Paul Baerwald, who was head of the Joint Distribution Committee, during 1932–1961. He left Germany by ship from Hamburg, Germany, taking a break in Northampton, UK, arriving in New York City; from there, he went to San Francisco, California, by train. Frenkel had applied to the University of California, Berkeley and wrote his admission essay on Marie Curie. He was only 17 when he came to USA and was eager to leave behind the rigidity of German life. He received two years college credit for his Gymnasium education. In 1939, Frenkel received his B.A. in Plant Physiology with highest honors—Phi Beta

Kappa. His senior thesis was: “*Studies of the enzyme systems in photosynthesis by means of radioactive tracers, carbon monoxide, and Ultra violet light*”.

He obtained his PhD in 1942, at the age of 23, in Botany at UC Berkeley (see <http://ucjeps.berkeley.edu/history/Botanyatberkeley/>). His PhD thesis was titled: “*Studies in the enzyme systems in photosynthesis by means of radioactive tracers, carbon monoxide, and ultra-violet light*”. His degrees from UC Berkeley were under his original name: Wolfgang Hans Albert Frenkel. He changed his name to Albert W. Frenkel when he became US citizen in 1944.

As a graduate student he had worked with Martin Kamen and Samuel Ruben when they were working at the Cyclotron in the Radiation Lab at Berkeley. The era of “Big Science” was being ushered in by Ernest Lawrence at Berkeley (see Kamen 1985). In addition to Andrew A. Benson, of Calvin-Benson cycle fame, Frenkel was one of the first to learn of Kamen and Ruben’s discovery of Carbon—14; he remained a friend of Kamen’s all his life; he was one of the few among those we know to have attended the function at the State Department when Kamen was awarded the Fermi Prize in 1996.

Academic life

After graduation, Frenkel went to work with Robert Emerson (who was later to be PhD advisor of one of us, Govindjee), at Cal Tech, and this work was on “artificial rubber”. (See Govindjee 2004, for a historical article on Emerson.) Frenkel was then drafted into the U.S Army, first stationed at Ft Hood (for basic training), and then sent to Oak Ridge National Lab, where he worked for the Army Corps of Engineers. During this period, he worked at Rochester, New York, for the Manhattan Project as a technical sergeant. In addition, he worked for the U.S. Atomic Energy Commission.

From 1947 to 1988, Frenkel served on the faculty at University of Minnesota; he retired as a Professor of Botany/Plant Physiology from there. In 1947 he was hired as an Assistant Professor in the Department of Botany. In 1948 he met his wife Goldie (Schwartz) and they were married in Grand Forks, North Dakota.

It was in 1954 that Frenkel did research with the 1953 Nobel Prize winner Fritz Lipmann at Harvard Medical School and Massachusetts General Hospital. And it is this work that led to the discovery of photophosphorylation in photosynthetic bacteria (Frenkel 1954).

In addition, Frenkel had also done research at Harvard Medical School and Massachusetts General Hospital (1954); Hopkins Marine Station (worked with the greatest microbiologist of his time, Cornelis van Niel, while he was at UC Berkeley, as well as at another time later), Stanford University



Fig. 2 A photograph of Albert Frenkel taken at the University of Minnesota. Date unknown. *Source* Archives of the Frenkel family

(1967–1968); and Marine Biology Laboratory at Woods Hole National Laboratory (first in 1948, then again in 1957).

Frenkel served as chair of the Botany Department from 1971 to 1975. Students and faculty of University of Minnesota would always remember him since there is “The Albert Frenkel Reading Room” in the Biological Sciences Building at the University of Minnesota; it was named in recognition of his many contributions to the Life Sciences and his support of University Libraries, including his role as department chair from 1971 to 1975. At the dedication of this room, he was lauded as a “*Much-loved teacher, scholar, and advisor.*”

Figure 2 shows a photograph of Albert Frenkel when he was at University of Minnesota.

Research

Frenkel (1993) has done a fantastic job in bringing before us his research life, his discoveries, his associations, and how and when he did what. We refer the reader to this wonderful story. Here, we present a glimpse of his research areas in chronological order for the readers to see his

journey in science from the 1940s (when he was a graduate student) till 1980s (when he retired).

1940s

Path of carbon in photosynthesis

Long before anyone else, Frenkel (1941) and Ruben et al. (1942) presented one of the earliest measurements on intermediates in plant cells using radioactive tracers. This was followed by looking at what uranium did on surface of cells (Rothstein et al. 1948), perhaps a follow-up of what went on during the World War II.

1950s

Photoreduction in algae

Hans Gaffron had discovered photoreduction in some algae, and Frenkel soon thereafter discovered it in several other algae, and extended this area, which is now becoming quite important for biofuel and bioenergy. (See Frenkel et al. 1950; Frenkel and Rieger 1951; Frenkel 1952; and Frenkel and Lewin 1954.)

Major review

In 1953, Frenkel coauthored a major and highly authoritative review on photosynthesis with Allan Brown; interestingly, it was published in two different “Annual Reviews” (Brown and Frenkel 1953a, 1953b).

Discovery of photophosphorylation

As mentioned earlier, Frenkel discovered photophosphorylation in bacterial photosynthesis (Frenkel 1954; see his full detailed paper: Frenkel 1956; also see Gest and Blankenship 2004, 2005).

Light-induced reduction of nucleotides in photosynthetic bacteria

Just as ATP is important, reducing power is equally important for photosynthetic bacteria. Frenkel (1958, 1959a) made one of the first measurements in this area. Soon thereafter, he was recognized to write a review on this topic (Frenkel 1959b).

Structural aspects

Frenkel began looking at structural aspects of photosynthesis with Hickman; this opened a new way of thinking for

him (see Frenkel and Hickman 1959; Hickman and Frenkel 1959).

Nitrogen fixation

Getting deeper into biochemistry and metabolism of photosynthetic bacteria, he studied nitrogen fixation (see Pratt and Frenkel 1959).

1960s

Structural aspects (continued)

Hickman and Frenkel (1965a, b) continued their detailed structural studies on photosynthetic bacteria extending them to several species.

New interest in a chlorophyll b mutant of barley

Highkin and Frenkel (1962) published their physiological studies on a barley mutant that would be used by others later for understanding the mechanism of protection against excess light by plants (see e.g., Gilmore et al. 2000).

Review of photophosphorylation

The discoveries in 1950s were reviewed after a decade with a new unique perspective (Frenkel and Cost 1966).

Free radicals

With Jim Bolton, Frenkel described free radicals in both chromatophores and chloroplasts (Cost et al. 1969).

1970s–1980s

Electron transport in bacterial chromatophores

Frenkel (1970) discussed the multiplicity of electron transport in bacterial photosynthesis and reviewed, in great depth, all that was known about chromatophores till then (Frenkel and Nelson 1971).

Mechanism of superoxide production

Jahnke and Frenkel (1975, 1978) and Frenkel et al. (1981) studied the mechanism of superoxide production in *in vitro* systems since he had earlier become interested in free radicals and their role in biology.

The finale

Frenkel ended his writing career by writing about Fritz Lipman's contributions (Frenkel 1985) as well as his own upon invitation by one of us (Frenkel 1993).

Personal attributes

Al Frenkel was a good natured and kind person. He would spend hours telling one of us (Govindjee) stories of the past including that of the controversy between the 1931 Nobel laureate Otto Warburg and Robert Emerson that both knew (for a discussion of this controversy that dealt with the minimum quantum requirement of oxygen evolution, see Hill and Govindjee 2014).

Frenkel was not only a dedicated scientist, but he was a very good father. Often on weekends, he would take his children (including the author SF) to work with him and they would wander around the old Botany Department building at the University of Minnesota, and the adjacent student union and the hospital.

As recalled by one of us (SF), his mind was very sharp even during the last years of his life; it was like an onion, and he remembered and told his family, in great details and clarity, about his early life.

Albert Frenkel was preceded in death by his sisters Doro Odenheimer, and Susanne Goltz, and his brother Paul Frenkel. He is survived by his wife Goldie Frenkel, daughter Susanna Frenkel (author of this Tribute), sons, David Frenkel & Joseph Frenkel, and four grandchildren.

Acknowledgments We have drawn information on Frenkel from family archives, from an article on him written by one of us (SF): https://en.wikipedia.org/wiki/Wikipedia_talk:Articles_for_creation/Albert_W._Frenkel and from Frenkel (1993).

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