Albert W. Frenkel

1919–2015

BY GOVINDJEE AND SUSANNA FRENKEL

Albert Frenkel was the fourth and youngest child of Selma (Baerwald) and Arthur Frenkel. He was born during the Spartacist rebellion, and the attending doctor had to be guaranteed his safety after Al's birth. Al was raised in an upper-class environment, with visits to the huge house of his grandfather Hermann Frenkel—next door to the family house of one of the fathers of rocket science, Werner von Braun. From Germany, the family moved to Switzerland in the 1920s to escape the rise of the Nazis. Al began collecting wild-flowers in Switzerland and pressing them; this collection is now part of the Jepson Herbaria at the University of California (UC), Berkeley.

Al graduated from the Bismarck Gymnasium in Berlin in 1936, but he had a rough time at the Nazi-controlled elite high school. As a Jew, he was pushed around at school. To avoid being picked up, he would ride his bike to get around instead of taking public transportation.

In April 1937, at age 17, Al left Germany. Eager to leave behind the rigidity of German life, he eventually made his way to New York City and then San Francisco. He applied to UC Berkeley and wrote his admission essay on Marie Curie. He received two years of college credit for his Gymnasium education and received his BA in plant physiology with highest honors in 1939. His senior and PhD theses were on studies of enzyme systems in photosynthesis by means of radioactive tracers, carbon monoxide, and ultraviolet light. Al obtained his PhD in botany in 1942, at the age of 23 (see http://ucjeps.berkeley.edu/history/botanyatberkeley/). His degrees from UC Berkeley were under his original name, Wolfgang Hans Albert Frenkel, which he changed to Albert W. Frenkel upon becoming a U.S. citizen in 1944.

A photograph of Albert Frenkel in Berlin. Source: Archives of the Frenkel family.

Albert Frenkel at the University of Minnesota. Source: Archives of the Frenkel family.

As a graduate student, Al 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, Al 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 and attended the function at the State Department when Kamen was awarded the Fermi Prize in 1996.

After graduation, Al went to work with Robert Emerson at Caltech, studying "artificial rubber." He was then drafted into the U.S Army, first stationed at Fort Hood and then sent to Oak Ridge National Laboratory, 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.

In 1947, Al was hired as an assistant professor in the Department of Botany at the University of Minnesota, and in 1948 he met his wife, Goldie (Schwartz); they were married in Grand Forks, North Dakota.

Al was a member of the University of Minnesota faculty until retiring as a professor of botany and plant physiology in 1988. He served as chair of the Botany Department from 1971 to 1975. The Albert Frenkel Reading Room in the Biological Sciences Building was named in recognition of his many contributions to the life sciences and his support of university libraries. At the dedication of this room, he was lauded as a "much-loved teacher, scholar, and adviser."

It was in 1954 that Albert Frenkel did research with 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, Al did research at the Hopkins Marine Station (working with the greatest microbiologist of his time, Cornelis van Niel), Stanford University (1967–1968), and the Marine Biology Laboratory at Woods Hole National Laboratory (first in 1948, then again in 1957).

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In his 1993 "Recollections" in the journal *Photosynthesis Research,* Al did a fantastic job in bringing before us his research life, his discoveries, and his associations, showing 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 to show his journey in science from graduate student in the 1940s until retirement in the 1980s.

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 the surface of cells (Rothstein et al., 1948), perhaps a follow-up of what went on during World War II.

1950s

Photoreduction in algae
Hans Gaffron had discovered photoreduction in some algae; Al soon thereafter discovered it in several other algae and extended this area of research, 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, Al coauthored a major and highly authoritative review on photosynthesis with Allan Brown, editor-in-chief of *Plant Physiology* from 1958 to 1963 (see Brown and Frenkel, 1953a,b).

Discovery of photophosphorylation
As mentioned earlier, Al 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 invited to write a review on this topic (Frenkel, 1959b).

Structural aspects
Al began looking at structural aspects of photosynthesis with Donald D. 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 the 1950s were reviewed after a decade with a new unique perspective (Frenkel and Cost, 1966).

Free radicals
With Jim Bolton, Al 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 then known about chromatophores (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.

The finale

Al ended his writing career by covering Fritz Lipman's contributions (Frenkel, 1985) as well as his own (Frenkel, 1993).

Personal attributes

Al Frenkel was a good-natured and kind person. He would spend hours telling stories of the past, including the controversy between the 1931 Nobel laureate Otto Warburg and Robert Emerson about the minimum quantum requirement of oxygen evolution (see Hill and Govindjee, 2014).

Al was not only a dedicated scientist, but he was also 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.

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, and by daughter Susanna Frenkel (coauthor of this tribute), sons David and Joseph Frenkel, and four grandchildren.

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