Photosynth Res
DOI 10.1007/s11120-014-0013-9

HISTORICAL CORNER

Stories and photographs of William A. Arnold (1904–2001), a pioneer of photosynthesis and a wonderful friend

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Received: 19 April 2014 / Accepted: 29 April 2014

Abstract William A. Arnold discovered many phenomena in photosynthesis. In 1932, together with Robert Emerson, he provided the first experimental data that led to the concept of a large antenna and a few reaction centers (photosynthetic unit); in 1935, he obtained the minimum quantum requirement of 8–10 for the evolution of one O_2 molecule; in 1951, together with Bernard L. Strehler, he discovered delayed fluorescence (also known as delayed light emission) in photosynthetic systems; and in 1956, together with Helen Sherwood, he discovered thermoluminescence in plants. He is also known for providing a solid-state picture of photosynthesis. Much has been written about him and his research, including many articles in a special issue of Photosynthesis Research (Govindjee et al. (eds.) 1996); and a biography of Arnold, by Govindjee and Srivastava (William Archibald Arnold (1904–2001), 2014), in the Biographical Memoirs of the US National Academy of Sciences, (Washington, DC). Our article here offers a glimpse into the everyday life, through stories and photographs, of this remarkable scientist.

Keywords William A. Arnold · Delayed fluorescence · Nuclear fission · Photosynthetic unit · Photosynthesis · Thermoluminescence

This historical paper was read, edited and approved for publication in the Historical Corner of Photosynthesis Research by Elizabeth Arnold and Helen Herron, daughters of William A. Arnold, Jane F. Hill, a historian of science, and George C. Papageorgiou, an expert on Photosynthesis and Related Processes. Papageorgiou wrote *"I really enjoyed reading this "Historical Corner" paper by Choules and Govindjee. William (Bill) Arnold 's personality emerges as I have always imagined it: An inventive, influential, highly likable photophysicist, with lasting discoveries, and at the same time, a warm human being and a family man. He lived and worked at a time when the center of gravity of world science was shifting from Europe to the United States, from the Nobel-laureate Otto Warburg in Germany to Robert Emerson and his contemporaries in the USA. Authors stand to be congratulated."*

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Introduction

This article is coauthored by Lucinda (Cindy) Choules, daughter of Elizabeth Arnold, and grand-daughter of William (Bill) Arnold, and by Govindjee, who has done extensive research in the areas of Arnold's discoveries (particularly Delayed Fluorescence and Thermoluminescence). It contains stories told by William A. Arnold to Lucinda. William Arnold's daughter, Elizabeth Arnold, also provided stories. Since it is the nature of a story to change a little each time it is retold, these stories are not to be taken as absolute fact. Rather, these stories are presented in order to offer a glimpse into the life of this accomplished biophysicist. Historical autobiographical text from the article that Arnold wrote himself at the invitation of, and edited by, Govindjee (Arnold 1991) provides the backdrop for these stories. For a complete background, we refer the readers to many articles on Arnold in Govindjee et al. (1996) and those cited in Govindjee and Srivastava (2014).

We begin this paper by showing a portrait of William A. Arnold (see Fig. 1).

Published online: 27 May 2014

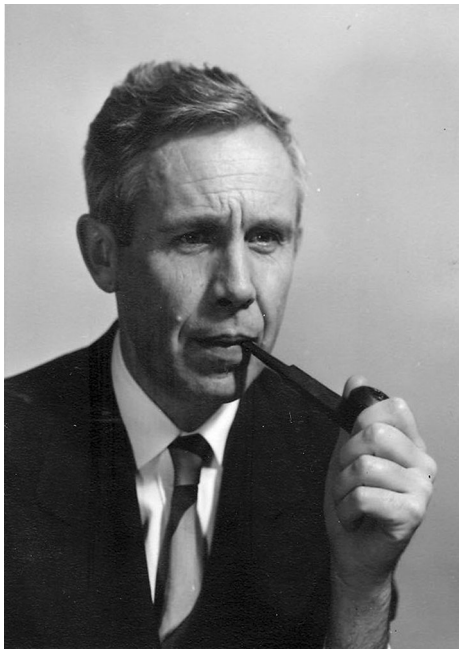

Fig. 1 Portrait of William Archibald Arnold used in his obituary by the Oak Ridger Newspaper, Oak Ridge, TN. Monday October 29, 2001, p 4A

Astronomy to biophysics

William Archibald Arnold (1904–2001) was raised on a 200 acre farm in Oregon. This rural upbringing nurtured his fascination with the sciences. His "favorite subject" in school was math and by the eighth grade, he had already set up and run most of the experiments, listed in his friends' high school physics book. On clear nights, young Arnold spent many hours gazing up at the beautiful array of stars over his farm, dreaming of one day becoming an astronomer (see Arnold 1991). However, this dream would not be realized as his amazing math abilities, inventive and inquisitive mind, and a chance class scheduling conflict led him down the road to biophysics instead.

William Arnold was a quiet but engaging young man and was known to his colleagues as simply "Bill". As an undergraduate at Cal Tech, Pasadena, California, he was unable to take Biology due to a scheduling conflict; therefore, he decided to take Plant Physiology (taught by Robert Emerson) instead. Robert (Bob) Emerson was working on photosynthesis experiments that were labor intensive as they involved the manipulation of light beams. Bill suggested that neon lights might be more suitable for the experiments planned by Robert Emerson (Emerson and Arnold 1932a, b; see Arnold 1991). Emerson allowed Bill to set up the neon lights, the experiments were successful, and the concept of Photosynthetic Unit was born (see Gaffron and Wohl 1936; Arnold 1991; Myers 1994; Govindjee and Bjorn 2012). [See Rabinowitch (1961) for a Biographical Memoir of Emerson; also see Govindjee (2004).]

In 1931, Bill Arnold graduated with a B.S. degree from Cal Tech. Robert Emerson asked Bill to stay on as his lab assistant for a few months, until he was accepted to a Masters program. This "short" assistantship lasted more than a year, and their research together resulted in two highly cited and influential research papers on the concept of the "Photosynthetic Unit".

At the conclusion of their research, Robert Emerson encouraged Bill to apply to Harvard. William A. Arnold was accepted at Harvard in 1932, where he worked as a Research Assistant in the Physiology department. Bill conducted and participated in multiple research projects at Harvard, resulting in several high-impact publications on photosynthesis (Arnold and Kohn 1934; Arnold and Winsor 1934; Stier et al. 1934; Arnold 1935a, b) and on UV effects (Oster and Arnold 1934; Blank and Arnold 1935a, b; see a later paper by Holt et al. 1951).

William Arnolds' Harvard doctoral thesis (Arnold 1935a) explored different reactions in photosynthesis. But some of his ideas were, perhaps, too far ahead of their time for some of his fellow students: during a lecture by him about his work on photosynthesis, Bill could see a young lady upfront fidgeting a lot. When he finished his talk, she raised her hand and when he called on her she stood up and said: "*Is there anyone on God's green Earth that believes anything you just said–besides you*?" Bill simply replied: "*Well maybe not, but perhaps someday they will*."

Further, while in college, he and some of his fellow students were working on a project, and in order to get the desired effect they needed a nitrogen-fixing bacterium, which was not available in the lab. William Arnold amazed his colleagues by isolating one to work with in order to finish the experiment. When later asked where he got this mysterious bacterium, he smiled and replied "*I went outside, grabbed a handful of dirt and then grew it on a nitrogen rich medium*."

Marriage

William Arnold married Jean Tompkins in 1929. They put off having children initially as many of the Fellowships of that day stated "no dependents" as part of the selection criteria (Herron 1996). They later had two daughters, Elizabeth and Helen. Elizabeth was born in Pacific Grove, California, in May 1937, while Bill was working for C. B. Van Neil (known to friends as Kees; see Barker and Hungate 1990) at Hopkins Marine Station (Herron 1996). Helen was born in California in July 1940, a year after they returned from Copenhagen (Herron 1996). Jean was a good

Fig. 2 Ten-month-old Elizabeth Arnold on kiddie bike, in front of Hopkins Marine station, where William Arnold worked (1936–1938). Photo taken by Jean Arnold in 1938, a few months prior to leaving for Copenhagen

Fig. 3 Bill and Jean Arnold. Photo taken at daughter Elizabeth's wedding, by George Lew Choules

match for Bill as her writing skills complemented his research skills. They were a happy couple and their marriage lasted for life.

Figure 2 shows a photo of Elizabeth, Lucinda's mother, when Elizabeth was 10 months old. And Fig. 3 shows Jean and Bill at the time of Elizabeth's wedding.

Copenhagen, coining of the term "nuclear fission"

In 1938, William Arnold accepted a fellowship in Copenhagen, and moved his family, including one-year-old Elizabeth, to Denmark, where he would work in Niels Bohr's Lab. He began his fellowship working on Geiger counter windows in Hilde Levy's lab. Later, he had the opportunity to work with Otto Frisch on deuterium in Frisch's lab, in an effort to discover if hydrogen bacteria could use deuterium. William Arnold was in Otto Frisch's laboratory the day they discovered nuclear fission. While William Arnold did not make this discovery, or help with the research leading to the discovery, he did name the discovery. Arnold (1991) wrote: "He [Frisch] said to me, 'You work in a microbiological lab. What do you call the process in which one bacterium divides into two?' I answered, 'binary fission'. He wanted to know if you could use the word fission alone and I said you could. Later that day when he sent the famous telegram to Bohr, who was in the United States, he used the word 'fission' in quotation marks." Dr. Bohr removed the quotation marks and "nuclear fission" became the accepted term.

Return to USA, appointment at Stanford

In 1939, with war in Europe imminent, the "Rockefeller Office in Paris" sent Bill Arnold a letter advising him to leave and return to America. Bill and his family made immediate arrangements to return home by sea. While waiting for the boat, Elizabeth remembers watching Nazi patrols goose-stepping nearby. In August 1939, the Arnolds arrived at their home in California. Robert Emerson and Charleton Lewis (1942) had made an action spectrum of photosynthesis in *Chroococcus*, a cyanobacterium (then called a blue-green alga), and had found that phycocyanin (excitation by orange light) was very efficient in photosynthesis. At the suggestion of Emerson, Arnold, in the 1940s, did experiments showing that energy absorbed by phycocyanin was transferred efficiently to chlorophyll *a* (see Arnold 1991, p. 77). This observation was later explained by Arnold and J. Robert Oppenheimer in terms of one of the first theories for excitation energy migration and excitation energy transfer in photosynthesis (see Arnold and Oppenheimer 1950).

In 1941, William Arnold was offered the job of Assistant Professor of Biophysics at Stanford University. However, shortly after this appointment, he received a letter from the Office of Scientific Research and Development, which was working on anti-aircraft-fire studies with Princeton University, asking for his help on their project. Since this work was for the military, Stanford reluctantly allowed him to go.

War research and his shooting ability

At Fortress Monroe, in New Jersey, where the Princeton project was conducted, Bill was put in charge of optical

light testing of range finders. When he had fixed some of the problems with the range finders, the military staff he was working with suggested that he go out on the test range and shoot at the targets himself (*they likely thought this civilian scientist, with no military training, would miss every target and they would have a laugh at his expense*). Bill agreed to shoot at the targets, as he was eager to see if the changes he had made to the equipment worked. When he returned from the test range, both men were standing up, with a look of amazement on their faces; one of them shook his hand and said, "*You hit every single one*!"

In 1942, the Princeton project was reorganized and William Arnold was sent to work for Eastman Kodak. According to Elizabeth Arnold, "One day while William Arnold was eating at the Kodak cafeteria, some young guys at a table next to him were trying to make each other sick by talking about worms and guts. When they noticed Bill sitting near them, they all looked over at him. Bill smiled and said, "*I'm not sure you want to play this game with me Fellas, I just graduated from a Biology lab*."

Eastman Kodak Company was later given the task of assembling physicists for a secret, Government-sponsored nuclear project in Oak Ridge, Tennessee. We know now that this secret project was the Manhattan Project. In 1944, Bill Arnold was sent by Kodak to Oak Ridge to be part of this classified project. Upon arriving in Oak Ridge, he was sent to work at a nuclear facility called Y-12, working with the huge mass spectrometers that separated isotopes of uranium. His job was to work on insulator problems. Later, he also worked at another nuclear research facility called X-10. Figure 4 shows women working in front of the Y-12 mass spectrometers.

Fig. 4 Women working in front of the Mass Spectrometers. From *Oak Ridge: The City That Changed The World,* The Delmar Company, Knoxville, TN, 1976

Y-12 mass spectrometers

The story below is not supported by some people, including a few Arnold family members, as *they do not think that anyone in Oak Ridge would dare to say the word "isotope" before the war ended*. However, there is an interview online with one of the "calutron" girls who stated that someone joked that they might be "splitting the atom" when they were socializing off the clock (Stenstrom 2013). Since Lucinda's grandfather Bill told her the following story multiple times, it is included here (also see a web site for Atomic Heritage Foundation 2013).

At the Y-12 facility, isotopes were separated by adjusting dials on huge magnetized panels. Men were in short supply across America due to the War, so women were enlisted for this particular task. Most of these women were teenagers from nearby farms or cities. None of these workers had any idea why they were doing this job–just that it was important for the War effort. One day a young male physicist, who had a crush on one of the girls who was working on the panels, walked up to her and stated, "*Wow you are doing the best job of separating isotopes of everyone*." Lucinda can't recall if her grandfather stated if the girl fainted or ran away crying when she was told this, but either way, this news came as quite a shock to her.

Life in Oak Ridge

Life in Oak Ridge (which was also referred to as the Secret City) was quite different: Bill's daughters Elizabeth and Helen grew up behind a locked gate as the entire town of Oak Ridge was transformed into a military base locked away from nearby Knoxville, TN. There were no sidewalks, and the orange mud could be hip deep at places. Children were not allowed outside the gates without a parent until, at age 12, they were given a much coveted pass to go through the gates alone. But the gates came down just before Elizabeth's 12th birthday, and she is still disappointed that she never got her pass.

Figure 5 shows the Arnolds at a Christmas Dinner in Oak Ridge, and Fig. 6 shows young scientist Elizabeth helping her father in the lab.

Two stories as told by Elizabeth Arnold

> One day, early in the morning while it was still dark, my father and I were driving to a local fishing spot. When we had just passed the front gate of Oak Ridge, a flaming meteor passed right in front of the car, then crashed into a nearby mountain and disintegrated. *For my Dad, who loved astronomy, it was a marvelous way to start this trip.*

Fig. 5 A photograph of the Arnolds at a Christmas dinner in Oak Ridge with a couple of neighbor boys dining with them; looking at us are :William Arnold, Helen Arnold, one of the boys, mother of young boys, Florence Tompkins (Jean's mother), and Elizabeth Arnold. Photo taken by Jean Arnold, 1950

Fig. 6 A photo of young Elizabeth Arnold helping her dad in his lab

Fig. 7 A photograph of William Arnold at home, on his way out to go smoke a pipe and dream up new experiments. Photo taken by Lucinda Choules, 1999

> One day at the Y-12 facility, a huge magnet had to be moved. Dad called maintenance and asked for a crew of men to move the magnet; they replied, *"OK we will tell the chief"*. A few minutes later, one very large man (named chief) showed up and moved the magnet by himself, amazing the nearby scientists.

After the war, Bill resumed his research in Biology in the newly-formed Oak Ridge National Laboratory (ORNL) and he remained in Oak Ridge for the rest of his life. Figure 7 is a photograph of Bill Arnold in his usual form, dreaming up new experiments.

Part of the old X-10 facility has today been turned into a museum. Bill Arnold and Lucinda visited this museum in 1998 (see Fig. 8). During their visit to the museum, he stated: "*it was a bit weird that his work-place had been turned into a museum while he was still alive*." Then he kidded "*Should I complain*?" Lucinda laughed, and he stated "*I guess this is just what happens when you live this long.*" Figure 8 is a photograph taken at the X-10 museum.

Epilogue

Even at 91, Bill Arnold would get up every morning, walk downstairs to the basement, and work on new experiments. He was truly a man who never stopped learning (see Fig. 9). He even tried out modern day computers and the internet, and marveled at photos of Mars and other planets, since his love of astronomy had not faded.

Fig. 8 A photograph of William Arnold at X-10 museum by Lucinda Choules, 1998

Fig. 9 A photograph of William Arnold in his basement library at home by Lucinda Choules, 1996

Arnold's discoveries included: the concept of the photosynthetic unit (Emerson and Arnold 1932a, b); minimum quantum requirement of 8–10 for the evolution of one oxygen molecule (Arnold 1935a, b, 1949); delayed fluorescence in photosynthetic systems (Strehler and Arnold 1951; Arnold and Davidson 1954, 1963; Arnold and Thompson 1955; also see Arnold 1955, 1957, 1966, 1972, 1977, 1986; Arnold and Azzi 1971a); thermoluminescence in plants (Arnold and Sherwood 1956; also see Arnold 1986); electroluminescence in plants (Arnold and Azzi 1971a, b, 1977). Lastly, he provided the solid-state picture of photosynthesis (see Arnold and Clayton 1960; Clayton and Arnold 1961; Arnold 1965, 1976; Arnold and Azzi 1968; Arnold and Maclay 1958; Arnold and Sherwood 1959). In addition, Arnold worked on other things, such as muscles (Arnold et al. 1958; Arnold 1961); estimating bacteriochlorophyll concentration (Van Niel and Arnold 1938); excitation energy transfer (Arnold and Meek 1956); making a recording Warburg apparatus (Arnold et al. 1951); and studying photochemical activity of single chloroplasts (Arnold et al. 1974). For further information on Bill Arnold's research, see Govindjee et al. (1996) and Govindjee and Srivastava (2014). To learn about the discoveries of some of the other pioneers of photosynthesis, see Govindjee et al. (eds.) (2005) and Hill (2012).

Govindjee has been personally involved with research on all aspects of what Bill had discovered, including the minimum quantum requirement for oxygen evolution (see, e.g., the controversy over it between Emerson and Otto Warburg, as described by Nickelsen and Govindjee (2011). Govindjee is, however, especially proud of publishing with Arnold the current theory of thermoluminescence (Devault, Govindjee and Arnold 1983; also see DeVault and Govindjee 1990; and Rose et al. 2008); further, Govindjee is quite happy that Bill agreed to coauthor the paper (DeVault, Govindjee and Arnold 1983) supporting the theory that Govindjee and DeVault had arrived at, which was different from Arnold's own earlier theory (Arnold 1965). Thermoluminescence in plants, one of Arnold's major discoveries, has been reviewed by many others including Sane and Rutherford (1986), Demeter and Govindjee (1989), Inoue (1996), Vass and Govindjee (1996) and Ducruet and Vass (2009); Vass (2003) has provided a wonderful historical treatment that includes many photographs.

Further, Govindjee remembers all the exciting experiments he and his coworkers have performed on "delayed fluorescence", also discovered by Arnold, expanding its meaning and value beyond the original observations (see, e.g., Jursinic and Govindjee 1977; Jursinic et al. 1978; Wong et al. 1978; and reviews by Govindjee and Jursinic 1979, and Jursinic 1986). This delayed fluorescence, also called delayed light emission (DLE), has been reviewed in depth by Lavorel (1975); it is still being used extensively to probe Photosystem II (see, e.g., Goltsev et al. 2009). For information on prompt fluorescence, in contrast to delayed fluorescence, see Govindjee et al. (eds.) (1986), Papageorgiou and Govindjee (eds.) (2004), and Papageorgiou et al. (2007). The discoveries by Arnold are fully alive and form the modern technology to understand the basics of photosynthesis!

William A. Arnold was a member of the National Academy of Sciences. He published more than 40 top research articles, mostly discoveries, between 1932 and 1991.

To Lucinda, he was her fascinating and wonderful Grandpa Bill, and to Govindjee, he was just the most

Fig. 10 A 2014 photograph of the authors of this historical corner article on William A. Arnold. *Left*: Lucinda Choules; photo taken by Jennifer A. Edwards at SFASU,Texas; Lucinda is holding a slide rule that belonged to her grandfather Bill Arnold. *Right*: Govindjee; photo taken by Rajni Govindjee; Govindjee is standing next to little red mangrove (*Rhizophora mangle;* see Feller 1995) in Key Largo, Florida

wonderful human being, a scientist of the highest caliber, and a co-student of Robert Emerson.

We end this Tribute to Bill Arnold by showing a 2014 photograph of the authors (see Fig. 10).

Acknowledgments We thank Elizabeth Arnold, mother of Lucinda Choules, for sharing her stories about her father for this article, helping us with timelines, and providing Figs. 1, 2, and 4. We are thankful to Helen Herron, Elizabeth Arnold, Jane F. Hill, and George C. Papageorgiou for reading this manuscript, and for their valuable suggestions for improving it.

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