The Dawn of Ultrasonics and the Palace of Science

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Ultrasonics research in the United States began in a secretive private laboratory built in the mansion of the investment banker Alfred Lee Loomis.

Inaudible sound is an oxymoron, so perhaps it is no surprise that the idea of sound with frequencies above human hearing was not well-defined until the early 1800s. Such sound was initially called either "supersonics" or "ultrasonics," with the latter eventually winning out. Ultrasonics came into the modern era after the collision of the Titanic with an iceberg in 1912 and the coming advent of submarine warfare. The beginning of the twentieth century launched a new and urgent need for underwater sensor technology for the detection of underwater objects. In this historical overview, we look back at the founders of modern ultrasonics through vignettes of a most interesting set of scientists.

Finding the Subs: Paul Langevin and Robert William Boyle

A few weeks after the sinking of the Titanic, Lewis Fry Richardson (inventor of fractals) applied for a patent on ultrasonic echo-ranging underwater, but the technology to produce high-intensity ultrasound at the time was simply insufficient. Just three years later, however, a young Russian electrical engineer working in France, Constantin Chilowsky, proposed a plan for submarine detection based on Richardson's echo-ranging concept. The French government asked Paul Langevin (**Figure 1, *left***), then in Paris, for an evaluation of the idea. Langevin was a well-known physicist with expertise in magnetic phenomena and piezoelectricity. Chilowsky and Langevin initiated a project in Langevin's laboratories, made some progress, and applied for a patent in 1915, but their working relationship was rocky and Chilowsky soon left the project.

The test program was then transferred to the Toulon naval base in southern France. Langevin was responsible for a key invention in the pursuit of high-intensity ultrasonics. Although his initial single-crystal quartz piezoelectric transducers were encouraging, the voltages required to drive them were too high for practical use. In addition, finding quartz specimens of the size required in quantity was also impractical. Langevin then devised a steel-quartz-steel sandwich transducer, where the resonance was determined by the overall thickness of the whole assembly, not the quartz crystal. In the first tests, single pieces of very large quartz crystals were cemented between the steel plates with a diameter of 20 cm.

There was a synergism to be had among the research expertise of the Allies. The British were pioneers in underwater listening devices (i.e., hydrophones), whereas the French excelled in generating high-intensity ultrasound. In 1916, a joint French-British effort was initiated under the direction of the British Board of Invention and Research (BBIR) and Lord Ernest Rutherford, who had received the Nobel Prize in physics eight years earlier. Research on submarine detection was given a high priority and progressed rapidly, largely due to Langevin and to the development

https://doi.org/10.1121/AT.2019.15.4.38

Figure 1. Left: *photo of Paul Langevin (1872–1946), taken from a group photo after a luncheon in honor of Albert Einstein convened by Langevin at his home in Paris, 1920. Photo courtesy of the Welcome Collection under the Creative Commons license with attribution.* ***Right:*** *Robert William Boyle (1883–1955). Photo courtesy of the Wikimedia Creative Commons license with attribution.*

of practical transducers by Robert William Boyle (a former Rutherford student; **Figure 1, *right***). The British-French joint effort was brilliantly successful in just two years, and early versions of the technology were being installed on Royal Navy warships (HMS *Antrim* and then HMS *Osprey*) just after World War I came to an end.

Boyle played the primary role for the British effort on the active sound detection project, producing a prototype for testing at sea by mid-1917. Boyle used composites of quartz mosaics (as shown in **Figure 2**), alleviating the need for large quartz crystals, and produced the first practical underwater active-sound detection in the world. To maintain secrecy, no mention of ultrasound or quartz was made; the made-up word ASDIC (from Anti-Submarine Division) was used, which eventually became known as "sonar" (for "sound navigation and ranging" in analogy with "radar").

Beyond his direct work on sonar, Boyle was the first to observe acoustic cavitation from the ultrasonic irradiation of liquids, a point rather important to the chemical and physical effects of ultrasound and likewise to the underwater propagation of high-intensity ultrasound. Boyle (1928) is also notable for having written the first major review on ultrasonics, which, unfortunately, was published in a journal that went bankrupt soon after. Thus, Boyle's review had rather limited impact.

By way of background, Langevin completed college at the École Normale Supérieure, went to Cambridge to study with J. J. Thomson, and returned to the Sorbonne, obtaining his PhD in 1902 under the supervision of Pierre Curie, codiscoverer of piezoelectricity, future Nobel Laureate, and husband of Marie Curie. In 1904, Langevin was appointed to the Collège de France (Paris), where among his doctoral students were future Nobelists Irene Joliot-Curie (daughter of Pierre and Marie) and Louis de Broglie. After World War I, Langevin, along with some French entrepreneurs, succeeded in commercializing marine ultrasonics and produced a depth-sounding instrument that was installed on many ships during the 1920s. In 1940, capping his many successes, Langevin received the Copley Medal of the Royal Society (the oldest surviving scientific award in the world). Langevin was politi-

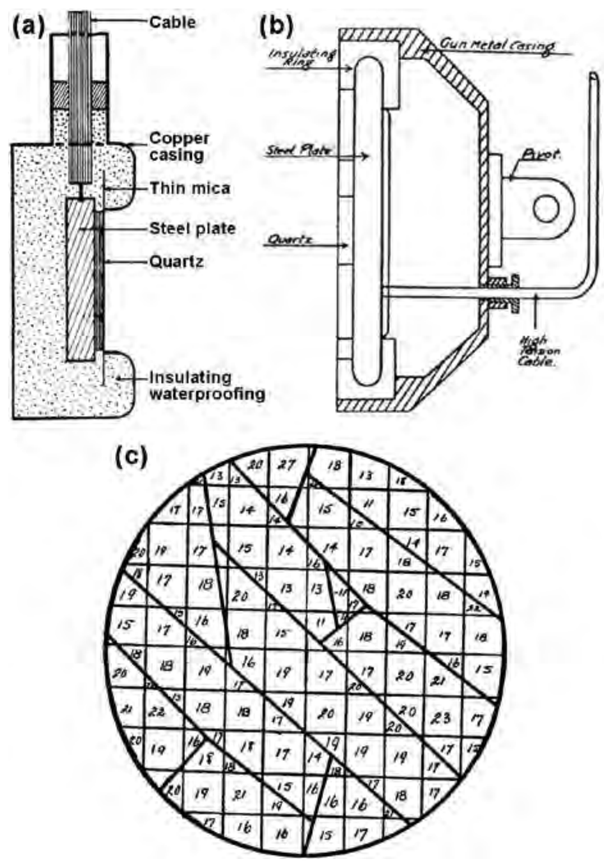

Figure 2. a and b: *Cross-sectional views of two forms of quartz transducers designed by Boyle, recorded in British Board of Invention and Research (BBIR) document 38164/17.* ***c:*** *Both transducers have a mosaic of quartz elements as shown, thereby obviating the need to use large single crystals. These transducers (50 cm^2 at 75 kHz) in October 1917 transmitted signals nearly a mile in open ocean.*

cally active as a notable anti-fascist, which resulted in house arrest by the Vichy government for most of World War II.

By comparison, Boyle had come across the pond in 1909, following his PhD mentor Rutherford. Boyle was born in Newfoundland and educated in Montreal at McGill University, receiving the first PhD in physics from McGill University studying radioactivity. Boyle returned to Canada in 1912 to start the physics program at the University of Alberta (Edmonton, AB, Canada) where he shifted to the new field of ultrasonics. With the advent of World War I, Boyle volunteered and joined the BBIR back in England. In 1919, Boyle returned to Alberta where he became dean of applied science and was elected two years later to the Royal Society of Canada. Boyle was a major contributor to the development of Canadian science as director of physics for 20 years at the National Research Council.

The Prankster of Baltimore: Robert Williams Wood

Among those to whom Langevin displayed his work at Toulon was Robert W. Wood, professor of physics at Johns Hopkins University (Baltimore, MD; **Figure 3**). Wood had been asked to assist the US armed services shortly after the entry of the United States into World War I. He participated in antisubmarine projects and was present at a June 1917 meeting in Washington with the French-British delegation where Langevin's work was reported.

Figure 3. *Robert W. Wood (1868–1955) posing in front of a spinning mercury telescope mirror that he built in the barn of his Long Island summer home. Photo taken in ~1915. Photo courtesy of the American Institute of Physics (AIP) Emilio Segre Visual Archive.*

Wood had previously contributed importantly to the early concepts of acoustics and shock waves. Visualization of acoustic phenomena was limited in 1900, so to better illustrate the wave properties of sound, Wood photographed (using spatial differences in refractive index) the actual wave fronts of sound waves and demonstrated vividly all the phenomena of reflected and refracted waves. These photographs received wide attention, brought Wood international acclaim, and resulted in an invitation to lecture before the Royal Society.

Commissioned as major in the army, Wood gained permission to devote particular attention to Langevin's work. As he later wrote (Wood, 1939, p. 35), "It was my good fortune during the war to be associated for a brief time with Prof. Langevin during his remarkable developments. At the arsenal at Toulon I witnessed many of the experiments with the high power generators...the narrow beam of supersonic waves shot across the tank causing the formation of millions of minute air bubbles and killing small fish which occasionally swam into the beam. If the hand was held in the water near the plate an almost insupportable pain was felt, which gave one the impression that the bones were being heated." This observation of Langevin's work lay dormant in Wood's mind for a decade but reemerged during his interactions later with Alfred Loomis, discussed below in **The Last Amateur Scientist and the Palace of Science: Alfred Lee Loomis**.

A member of a prominent New England clan, Wood was the son of a physician well-known for his work in Hawai'i. From childhood on, Wood had an intense interest in all sorts of scientific phenomena, which he must have found a relief from the rule-bound schooling he mostly had to endure. He was flunked out twice from the Roxbury Latin School (Boston, MA) before being admitted to Harvard University (Cambridge, MA) where he earned a bachelor's degree in chemistry in 1891 despite poor marks in languages and mathematics. After a brief stint in graduate school at Johns Hopkins University, where he became most interested in the physics of optics, Wood moved, in 1892, to the University of Chicago (Chicago, IL). Wood eventually completed his doctoral dissertation, but the academic rules had changed and he was never officially awarded his PhD. He then worked for Heinrich Rubens in Berlin on infrared optics. Wood returned to the United States as an instructor at the University of Wisconsin (Madison) where his career blossomed quickly. In 1901, Wood was appointed full professor of experimental physics at Johns Hopkins University after a physics professor had died unexpectedly young (Dieke, 1956).

Wood was an inveterate prankster. As a student, his landlady was, in his opinion, rather too interested in his comings and goings. So on a rainy day with muddy streets, he took his shoes off and created "a trail of footprints in his room starting at the window, up the wall, across the ceiling and down the other wall. The reactions of the landlady are not recorded" (Dieke, 1956, p. 333). He apparently had no mercy on landladies because in Paris, his proprietor kept a pet tortoise in the garden. Wood bought a series of tortoises of various sizes and exchanged them every few days in order of increasing size, making it appear that the tortoise was growing at an amazing rate. When the landlady told Wood about this, he suggested that she should go to the press. At this point, Wood reexchanged the tortoises in decreasing size, reversing the process!

Even as professor of physics at Johns Hopkins University, there are stories of his entertaining the crowds at football games during halftime by a display of boomerang throwing. Wood developed a bit of a reputation in Baltimore where he was known to cough loudly, sputter, and spit into puddles on the streets of Baltimore while surreptitiously dropping in a small piece of sodium metal. The resulting ball of flame must have truly spooked those passing nearby!

While at Johns Hopkins University, Wood and his family would spend the summers on an old farm on Long Island, NY, where he apparently introduced the Hawaiian surfboard to the Long Island beaches (Dieke, 1956). Out of his own pocket, Wood set up an improvised laboratory in an old barn, the crown jewel of which was a 40-foot grating spectrograph, probably the largest then in existence and certainly capable of better results than anyone had ever seen before. The light guides were constructed from sewer pipe. During the long months between summers when the instrument was not used, the optical path would become cluttered with spider webs. "Wood's method of cleaning the tube has become a classic. He put the family cat in one end and closed the end so that the cat, in order to escape, had to run through the whole length of the tube, ridding it very effectively of all spider webs" (Dieke, 1956, p. 330).

An interesting spin-off from Wood's summer home on Long Island came from friendship with a neighbor, the famous Florenz Ziegfeld, producer of the most spectacular stage shows on Broadway that swarmed with chorus girls in resplendent costumes. Wood was well aware that many substances fluoresce brightly under ultraviolet light, and the possibility of interesting stage effects was not lost on him, especially because he had invented the ultraviolet (UV) filter still used today for producing "black light." Many of Wood's ideas on lighting tricks with UV found their way to Ziegfeld's stage (Dieke, 1956).

Wood was a man of many skills and hobbies. He was a prolific author, especially for his time, publishing some 300 scientific papers and *the* classic textbook on physical optics (Wood, 1911). He also wrote fiction, coauthoring two science fiction novels with Arthur C. Train (a well-known writer of courtroom thrillers): *The Man Who Rocked the Earth* in 1915 and its sequel *The Moon Maker* in 1916; the former was rather notable for describing an atomic detonation 30 years before the first atomic bomb. Wood also authored and illustrated children's books including *How to Tell the Birds from the Flowers* (1907).

This irrepressible practical joker was to become the world's dominant research scientist in optics and spectroscopy and a pioneer of infrared (IR) and UV photography. Wood was a fellow of most of the world's major academies and winner of *many* international awards. Indeed, in his honor, the Optical Society of America offers the R. W. Wood Prize for outstanding discovery or invention.

The Last Amateur Scientist and the Palace of Science: Alfred Lee Loomis

During his time in the Army during World War I, Wood made the acquaintance of Alfred Lee Loomis (**Figure 4**) at the Aberdeen Proving Grounds, where Loomis had invented the "Loomis chronograph" for measuring the velocity of artillery shells. Loomis was a New York finance banker whose lifelong hobby had been physics and chemistry. Loomis led a fascinating and complex life, well beyond our scope here. For those interested, I recommend highly the excellent biography of Loomis by Conant (2002).

Both Wood and Loomis came from respected New England families, both had successful physicians as fathers, and both were passionately interested in science. They met again in 1924 on respective family summer visits to eastern Long Island. Although Wood was almost 20 years senior, his lack of pretension and his laboratory in the barn were considerably more attractive to Loomis than the alternative of time spent with his aunts. This began a symbiosis that lasted many years:

Figure 4. Alfred Lee Loomis (1887–1975) in the laboratories at Tower House (Tuxedo Park, NY). Einstein dubbed it the "palace of science." The apparatus is the high-voltage oscillator used to drive a quartz piezoelectric transducer to produce intense ultrasound. Photo courtesy of the Smithsonian Institution Archives, image #SIA2008-5428.

Wood acted as Loomis's private physics tutor and Loomis became Wood's financial patron.

Loomis was looking for a science project to fund, and Wood told him about Langevin's experiments with ultrasonics and the killing of fish. Because Langevin was really focused only on submarine detection and other marine applications, this new field offered a wide range for research in physics, chemistry, and biology. Loomis was enthusiastic and together they made a trip to the research laboratory of General Electric and purchased two huge "pilotron" amplifying vacuum tubes that were similar to the high-frequency oscillators then used in radio broadcasting, stepping up the voltage from the usual 2 kV to 50 kV. The resulting generator was used to drive thick quartz transducers with an ultrasonic output of 2 kW over the range of 100 to 700 kHz, specs that would be a state-of-the-art rig even today! This apparatus was first built in Loomis's garage in Tuxedo Park (40 miles north of New York City and from which the black-tie formal dress gained its name). The space was too small, so Loomis bought a huge stone mansion nearby perched on the summit of one of the foothills of the Ramapo Mountains.

Loomis, with suggestions from Wood, transformed this "Tower House" (**Figure 5**) into a private laboratory deluxe, with rooms for guests or collaborators, a complete machine shop with a mechanic, and a dozen large and small research labs. The 40-foot spectrograph in Wood's Long Island barn was transferred and refurbished where it saw heavy use by Loomis and other scientists under Loomis's aegis. As Wood put it, in these more hospitable surroundings, it "required no pussycat as housemaid" (Conant, 2002, p. 49).

Loomis, who wished to meet the celebrated European physicists and visit their laboratories, asked Wood to go abroad with him to make introductions. The pair made two trips together, in the summers of 1926 and 1928. Thereafter, Tower House became a center for visiting scientists of the highest order from Europe or the United States, with symposia and visits from Einstein, Bohr, Fermi, Franck, Heisenberg, and many others.

In 1927, Wood and Loomis published the first paper from the Loomis Laboratory, a truly pioneering piece of work entitled "The Physical and Biological Effects of High-frequency Sound-waves of Great Intensity" in Wood's favorite journal, *Philosophical Magazine* (more formally titled *The London, Edinburgh, and Dublin Philosophical Magazine and Journal*

Figure 5. *The palace of science, Tower House (Alfred Loomis's laboratory in Tuxedo Park, NY) was used from 1926 until 1940, when Loomis set up the MIT Radiation Laboratory. Tower House is at present pretty much unchanged on the outside and functions as an apartment complex. Photo courtesy of the New York Public Library, Astor, Lenox and Tilden Foundations.*

of Science). In this paper, using the apparatus built in the Tower House (**Figure 6**), they reported

- acoustic radiation pressures sufficient to support a weight of 150 g;
- the burning of skin or wood when pressed against an ultrasonically vibrating rod;
- the ultrasonic etching and drilling of glass plates pressed against a vibrating rod;
- the internal heating of liquids and solids;
- the formations of emulsions and fogs;
- the flocculation of solid particles suspended in a liquid;
- numerous biological effects, including rupturing red blood cells, killing microbes, and harmful to lethal effects on small fish, frogs, and mice; and
- preliminary observations on the effects of ultrasound on crystallization.

These results, the first reported on the physical and biological effects of ultrasound, still represent a modern-day litany of ultrasonic research (Hinman and Suslick, 2017)! They deferred reports on the chemical effects to work soon published by Loomis and William T. Richards, discussed below in **The Chemical Consequences of Ultrasound: William T. Richards**. In 1929, Loomis and Woods went on to receive a patent on the use of ultrasound "for forming emulsions and the like."

After completing their pioneering work together on ultrasonics, Wood did not continue research on ultrasonics but instead returned to optics and spectroscopy, sometimes with Loomis as coauthor. Loomis, however, continued to be interested and published several other papers over the next few years on the bioeffects of ultrasound, ranging from bacteria to fruit flies. Wood did eventually publish the first monograph on ultrasonics, recounting his earlier work and other developments (Wood, 1939).

The discovery of light emission during ultrasonic irradiation of liquids, oddly enough, was not made by Loomis, Wood, or Richards, despite Wood's unsurpassed expertise in optics. Indeed, the first observation of sonoluminescence had to wait another 10 years (Frenzel and Schultes, 1934). Personally, I am not displeased that Wood missed that opportunity; he was the world master of spectroscopy, and there would have been nothing left to discover for those of us working 50 years later (Suslick and Flint, 1987; Suslick et al., 2018)!

Loomis had made a substantial fortune (together with his brother-in-law Landon K. Thorne) financing the largest public utilities and electrifying rural America. Realizing that the stock market was in a speculative bubble, over a few months in early 1929, Loomis and Thorne sold their securities and converted everything into cash and long-term treasury bonds. After the Great Crash (October 1929) and reinvestment during the Depression, Loomis became one of the 10 richest men in America.

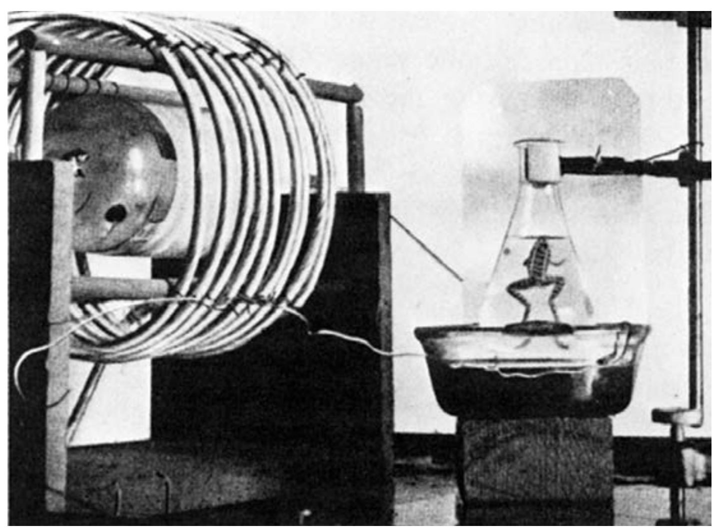

Figure 6. *Apparatus for early experiments with intense ultrasound. The large coil is a transformer to increase the voltage from the 2-kW oscillator up to 50 kV at 100 to 700 kHz, and the leads from it are connected to a 1-cm-thick quartz plate immersed in oil beneath the flask containing the frog (Wood and Loomis, 1927).*

Luis Alvarez (Nobel Laureate, close friend of Loomis, and writer of Loomis's obituary) called Loomis the "last great amateur of science" (Alvarez, 1983), not in the modern sense of a "dabbler" but rather in the original French meaning "one who loves." Loomis was never a mere dilettante but indeed became master of any endeavor he pursued. As a scientist, Loomis held 10 patents ranging from racing car toys to centrifuge microscopes to high-speed chronographs to long-range navigation (LORAN); he was coauthor of 32 scientific papers (including 5 in *Science* and 2 in *Nature*) and sponsor of another 48 from collaborators in his laboratory.

Loomis was, indeed, a quiet giant in the technological advances in the first half of the twentieth century. In addition to his adventures in high-intensity ultrasonics at Tuxedo Park, he was a pioneer in ultrafast chronography, an early developer of the electroencephalograph (EEG), and inventor of LORAN (the predecessor to GPS). Moreover, he funded the first cyclotron at University of California, Berkeley, and founded the MIT Radiation Laboratory, (Rad Lab; where airborne radar and radar-controlled antiaircraft artillery were developed). Loomis made contacts between physicists and Secretary of War Henry Stimson, who just happened to be Loomis's favorite cousin. The Manhattan Project was remarkable for the lack of administrative roadblocks, a fact that Alvarez attributed "to the mutual trust and respect that Secretary of War Stimson and Loomis had. Loomis was in effect Stimson's minister without portfolio to the scientific leadership of the Manhattan District — his old friends Lawrence, Compton, Fermi, and Robert Oppenheimer" (Alvarez, 1983, p. 33).

Despite his avoidance of publicity, Loomis did receive honorary degrees from Yale University (New Haven, CT); the University of California, Berkeley; and Wesleyan University (Middletown, CT); and in 1940, at the tender age of 53, he was elected to the National Academy of Sciences. In 1948, for his efforts in the development of radar, Loomis received both the US Presidential Medal of Merit (the highest civilian award) and from Britain the King's Medal for Service in the Cause of Freedom. Lee DuBridge (director of the Rad Lab and then president of Caltech, Pasadena, CA) later commented, "Radar won the war; the atom bomb ended it." Loomis was integral to the success of both. Alfred Lee Loomis was the most important scientist of the twentieth century who almost no one has ever heard of. And from all accounts, Loomis wanted it that way.

Figure 7. *William T. Richards (1900–1940), coauthor with Loomis of the first paper on sonochemistry in 1927. Photo courtesy of the Conant (2002) family.*

The Chemical Consequences of Ultrasound: William T. Richards

In the same year as the Wood-Loomis paper, Loomis published a second paper specifically on the chemical effects of ultrasound, this time with William T. Richards (**Figure 7**; Richards and Loomis, 1927). They had discovered that high-intensity ultrasound increased the rates of three classes of chemical reactions (initiation of detonation of an explosive, a hydrolysis reaction, and a clock reaction) and also reported other physical effects, including degassing of liquids.

At that time, Richards was a young assistant professor of chemistry at Princeton University (Princeton, NJ). Richards was the son of the first American Nobelist in Chemistry (Theodore W. Richards, Harvard University), had earned his PhD at Harvard University (under his father's tutelage), and was the brother-in-law of James B. Conant, later president of Harvard University. Richards kept his position at Loomis Laboratory until his death but had to resign from Princeton University due to depression and illness, traits than unfortunately ran strong in the Richards family (Conant, 2002).

Over the next 12 years, Richards went on to publish 19 additional papers on various aspects at the interface between physical chemistry and physical acoustics, most dealing with gas-phase measurements. In an overview based on an address to the Acoustical Society of America (ASA; Richards, 1938, p. 305), Richards noted, "I have been told by every mathematical physicist I know that the analysis of cavitation is a task beyond the ability of present day mathematics." A rather forceful statement to be made in front of the ASA, given that Lord Rayleigh had already analyzed the problem of bubble collapse, albeit in the context of propeller-generated cavitation, in 1917 (Rayleigh, 1917). Rayleigh made accurate predictions of enormous pressures during cavitation but did not extrapolate them to the extreme temperatures created in the collapsing gas phase, which turns out to be the origin of most sonochemistry (Noltingk and Neppiras, 1950; Suslick et al., 2018). Indeed, in his very last scientific paper a year later (a massive review of "supersonic phenomena"), Richards stated that one of the possible results of cavitation "is the large pressure which Rayleigh has shown to accompany the collapse of bubbles. It might be argued that pressure surges from this cause are sufficiently great to cause the adiabatic temperature changes required. This explanation is improbable for several reasons..." (Richards, 1939, p. 53). Richards favored an electrical discharge mechanism, a hypothesis that did not stand the test of time (Suslick et al., 2018).

The announcement of the death of Richards appeared on February 1, 1940, in the *Daily Princetonian*: "William T. Richards, former University scientist, was discovered dead yesterday with his wrists slashed in the bathtub of his New York City apartment, an apparent suicide. Police refused to disclose the contents of a note found beside the tub" (Anonymous, 1940).

The story does not quite end there, however, because a murder mystery, *Brain Waves and Death*, was published posthumously under the pseudonym "Willard Rich" a few weeks later. The book was a very thinly veiled roman à clef of the Loomis Laboratory, and Loomis felt much betrayed. Loomis and Conant were apparently able to purchase and destroy most copies, and today copies of the book are scarce, with the least expensive being $1,000.00 (plus shipping!). There is a much fuller description of Richard's book and a suppressed short story ("The Uranium Bomb," an accurate description, disguised as a science fiction story, of the secret Fermi-Szilard plan that initiated the Manhattan Project) in Conant's superb *Tuxedo Park* (2002).

Figure 8. *Albert Szent-Györgyi (1893–1986) was the first to report ultrasonic cleavage of polymers. Photo taken in 1917. Photo courtesy of the Wikimedia Creative Commons license with attribution.*

Another Dionysian: Albert Szent-Györgyi

Only a few years after the pioneering work of Loomis with Wood and with Richards, a very brief note was published in 1933 in *Nature* by Albert Szent-Györgyi (pronounced "Saint Georgie"; **Figure 8**), describing the first depolymerization of polymers (Szent-Györgyi, 1933). This work remains strikingly relevant even today with rather active current research on the mechanochemistry of polymers, most often initiated by ultrasonic irradiation of polymer solutions (Suslick, 2014). Szent-Györgyi went on to win the 1937 Nobel Prize for his discovery of vitamin C and work on biological oxidation. Amusingly, Szent-Györgyi ends his *Nature* article, "For lack of funds, our investigation has been broken off."

Aside from this very early contribution to the chemical effects of ultrasound, I have brought up Szent-Györgyi for his philosophical insights into the origins of any new field of study. Szent-Györgyi, who tellingly observed that "a discovery must be, by definition, at variance with existing knowledge," divided scientists into two categories: the Apollonians and the Dionysians (Szent-Györgyi, 1972, p. 966). These classifications reflect extremes of two different approaches found in most human endeavors, e.g., science, literature, art, and music. "In science the Apollonian tends to develop established lines to perfection, while the Dionysian rather relies on intuition and is more likely to open new, unexpected alleys for research... Applying for a grant begins with writing a project. The Apollonian clearly sees the future lines of his research and has no difficulty... Not so the Dionysian, who knows only the direction in which he wants to go out into the unknown; he has no idea what he is going to find there... The future of mankind depends on the progress of science, and the progress of science depends on the support it can find. Support mostly takes the form of grants, and the present methods of distributing grants unduly favor the Apollonian" (Szent-Györgyi, 1972, p. 966).

The dawn of ultrasonics was well before regular government funding from the National Science Foundation, the National Institutes of Health, and the French National Center for Scientific Research. What I find especially interesting are the methods tapped by these Dionysian scientists: wartime crisis funding and "the facilities of a great private laboratory backed by a great private fortune" (Alvarez, 1983), rather different from modern funding modes. Loomis's wide-ranging and extraordinarily creative contributions, first in ultrasonics, are Dionysian in its finest form as was his ability to gather around him brilliant minds of similar proclivities.

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BioSketch

Kenneth S. Suslick is the Schmidt Research Professor of Chemistry at the University of Illinois at Urbana-Champaign. He received his BS from Caltech in 1974 and PhD from Stanford University in 1978, coming to the University of Illinois at Urbana-Champaign immediately thereafter. He has received the Helmholtz-Rayleigh Interdisciplinary Silver Medal (Acoustical Society of America), Centenary Prize and Stokes Medal (Royal Society of Chemistry), Materials Research Society Medal, Chemical Pioneer Award (American Institute of Chemists), and the Nobel Laureate Signature and Hildebrand Awards from the American Chemical Society. He received the Eastman Professorship at Oxford (UK) for 2018–2019. He is a Fellow of the National Academy of Inventors.