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1913—2008

A Biographical Memoir by
LEON COHEN, MARLAN SCULLY,
AND ROBERT SCULLY

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Biographical Memoir

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THE LAMB SHIFT EXPERIMENT¹ was a landmark in 20th-century physics. Lamb devised an experiment that would be a crucial test of and provide the stimulus for renormalized quantum field theory. The experiments of Lamb and his students grounded quantum field theory in experimental reality and was instrumental in the emergence of quantum electrodynamics as the most accurate theory we have today. Willis Lamb received a Nobel Prize for this achievement and continued to make fundamental contributions in many fields. In the words of Schweber², “[Lamb] is one of the last physicists who could master the whole of physics.” Moreover, his contributions were both in experiment and theory and laid the foundation for new fields of research from nuclear physics (the Lamb-Mössbauer effect) to laser physics (the quantum theory of the laser) and laser spectroscopy (the Lamb dip).

Willis was born on July 12, 1913, in Los Angeles, California, to Willis Eugene Lamb from Minnesota and Marie Metcalf Lamb from Nebraska. His father was a telephone electrical engineer and his mother an alumna of Stanford University. Willis attended schools in or near Los Angeles until graduating from high school. While he excelled in his studies, especially those involving science, the picture of his school

years paralleled those of so many of his contemporaries. Willis rode a bike or walked the substantial distance of 2 miles to the various schools he attended. He studied Latin and the classics but preferred math and science to English and history. On the way home Willis and his brothers, John and Perry, often stopped off at the Los Angeles Public Library. Willis was born with a serious eye problem that would remain with him his whole life, preventing him from playing sports but not keeping him from becoming an avid reader.

In high school Willis was one of about 30 students who played simultaneously against the world-famous Russian chess master Alexander Alekhine. He was one of the few who won. In 1933 he played at the world's fair, taking second place in the fair's intercollegiate chess tournament. He then won the rapid-transit match in which one does not have the benefit of time to allow the plotting of the next move.

In 1930 Willis finished high school and enrolled at the University of California, Berkeley. At about \$60 per month for tuition and living expenses it was more affordable than Caltech or Stanford. At Berkeley he majored in chemistry. At the time the chemistry degree required no liberal arts classes, but one was required to learn scientific German. He graduated four years later with the highest honors.

In graduate school Willis chose to study theoretical physics. Although he had several offers, he remained at Berkeley so he could return home to Los Angeles frequently where the room and board were free. During the summers he traveled to different summer schools: in 1935 to Ann Arbor and during 1936-1938 to Stanford. It was at Ann Arbor where Lamb first met Robert Oppenheimer. According to Lamb, "One day he was coming down the stairs and I was going up the stairs; he stopped me and said, 'I understand you want to work with us.' In some way Oppenheimer was able to tell it was me without my having said anything to him. I was just

planning to show up in his classes and go on from there.” Such was a new beginning, with Lamb to become one of the 25 graduate students to eventually obtain degrees under Oppenheimer.

In graduate school Willis met many notable scientists, Enrico Fermi, Isaac Rabi, Edward Teller, and J. H. Van Vleck, to name a few. Lamb did not always have an interest in the same research subjects Oppenheimer was pursuing. He was mainly focused on aspects of quantum physics. As a graduate student he traveled widely, following his thesis adviser on a sort of annual migration from Berkeley to Caltech and making use of a desk at the Norman Bridge Laboratory in Pasadena. In 1938 Lamb got his Ph.D. for research, which he published with Leonard Schiff who was then a professor at Stanford.

His most famous early paper concerned what became known as the Lamb-Mössbauer effect. In 1939 he developed a theory of γ -ray emission following the resonant capture of slow neutrons by nuclei locked in a crystal lattice. After experimentally discovering recoilless γ -radiation, Mössbauer explained his observations by extending the work of Lamb to the case of γ -ray resonant absorption in crystals and discussed the Debye-Waller factors and the condition for recoilless radiation events. Lamb anticipated recoil free nuclear transitions long before they were observed.

In 1939 Willis married Ursula Schaefer, a German expatriate from Berlin, and moved to Columbia as an instructor of physics. Ursula had become a refugee after distributing pamphlets denouncing the Nazis and was forced to flee Germany. Marrying a German at the onset of World War II was not without problems. First, Lamb was forced to hand over his shortwave radio. He was also forbidden to walk on beaches. The government feared that he might contact German submarines.

World War II was on when Lamb got a call from Oppenheimer, who invited him to join the growing team in New Mexico. He was somewhat aware of what was going on with the hushed project at Los Alamos, and he chose instead to contribute to the war effort by conducting research in radar. It turned out to be a good decision.

During the War, Willis worked on radar at Columbia. The microwave expertise he developed there, together with his excellent understanding of quantum mechanics, allowed him to carry out his famous Lamb shift measurements in hydrogen. The essence of the Lamb shift is the small but important energy difference between the $2S$ and $2P$ levels in hydrogen atoms. According to the relativistic wave equation of Dirac these levels³ have exactly the same energy and hence something new was needed. The experiment consisted of observing directly, for the first time, the microwave induced transitions from the $2S$ to the $2P$ state. In fact, due to the virtual emission and reabsorption of photons, or alternatively due to vacuum fluctuations as we discuss below, the electron is not really a point particle. It is smeared out a bit and the $2S$ level is around 1000 MHz higher in energy (less tightly bound) than is an electron in the $2P$ level.

As mentioned earlier, attempts in the 1930s to calculate such vacuum-induced radiative corrections were frustrated as they predicted infinite level shifts. However, the beautiful experiments of Lamb and Retherford provided the stimulus for renormalized quantum field theory that has been so successful in providing excellent agreement with measurement.

On Lamb's 65th birthday, Freeman Dyson wrote, "Those years, when the Lamb shift was the central theme of physics, were golden years for all the physicists of my generation. You were the first to see that this tiny shift, so elusive and hard

to measure, would clarify in a fundamental way our thinking about particles and fields.”

Shortly after the experimental results were announced, in 1947, Bethe published in the *Physical Review* a simple nonrelativistic calculation in good qualitative agreement with experiment. It used the suggestion of Kramers, for subtracting off infinities. This was extended by Kroll, and Lamb, and French, and Weisskopf to a full relativistic theory in quantitative agreement with experiments. These fully relativistic QED (Quantum Electrodynamics) calculations provided a more satisfactory and quantitative treatment of the effect.

It should be emphasized that Lamb's previous studies of deviations from Coulomb's law led him to do his famous experiment. The notion that the $2S_{1/2}$ and $2P_{1/2}$ levels were slightly shifted was “in the air” in the 1930s and 1940s. Several workers had suggested that there seemed to be such a shift, but why waste time chasing down experimental dirt effects?

Lamb knew of the confusion surrounding these previous experimental studies, but he also knew why this was an important experimental issue. In a 1946 progress report on his experiments he says,

The hydrogen atom is the simplest one in existence, and the only one for which essentially exact theoretical calculations can be made on the basis of the fairly well confirmed Coulomb law of interaction and the Dirac equation for an electron. Such refinements as the motion of the proton and magnetic interaction with the spin of the proton are taken into account in rather good approximate fashion. Nevertheless, the experimental situation at present is such that the observed spectrum of the hydrogen atom does not provide a very critical test either of the theory or of the Coulomb's law of interaction between two point charges. A critical test would be obtained from a measurement of the fine structure of the $\eta = 2$ quantum state.

We have in Professor Lamb's famous experimental-theoretical accomplishments an excellent example of how a master marshals his resources and tools to outstanding advantage.

First of all he had a long interest (beginning with his thesis research) in deviations from Coulomb's law. He knew atomic spectroscopy and was aware of the possible existence of a $2S-2P$ level shift. He knew microwave engineering from his radar work and figured out how to use these new tools to do precision spectroscopy on the $2S$ state of hydrogen.

Lamb received the Nobel Prize for his work in 1955. The presentation speech was by Prof. I. Waller, who said,⁴

It does not often happen that experimental discoveries exert an influence on physics as strong and invigorating as did your work. Your discoveries led to a re-evaluation and a reshaping of the theory of the interaction of electrons and electromagnetic radiation, thus initiating a development of utmost importance to many of the basic concepts of physics, a development the end of which is not yet in sight.

Willis described his relation with Oppenheimer as "strong," and he had the highest regard for him. However, Oppenheimer was not always easy to get along with; witness the story Lamb tells of meeting Max Born, Oppenheimer's thesis adviser. Lamb introduced himself to Born as his "grandson," to which Born replied, "not likely." Willis explained that Born was his grandfather since Oppenheimer was his thesis father. Born, who had his own problems with Oppenheimer, then said: "Well, I wouldn't brag about that."

After his beautiful experimental and theoretical work, Lamb was awarded tenure at Columbia but only as an assistant professor. According to Norman Ramsey, Rabi thought he was hiring the next Paul Dirac when in fact he was hiring a young Enrico Fermi.

In the early 1950s Willis and Ursula moved to Stanford. Both repulsive and attractive forces figured in the move. Columbia finally promoted him to full professor in 1948, but they should have done so earlier. Willis always felt that Rabi could have been more supportive, although in the end they parted friends. Moving to Stanford was a semihome-

coming. There was a joint Berkeley-Stanford seminar led by Oppenheimer and Felix Bloch from Lamb's graduate school days. Willis had also spent several summers at Stanford and his thesis (on electromagnetic properties of nuclei) derived from a Stanford visit. In fact, it was at Stanford that Lamb first met Rabi. So it was understandable that with Bloch in residence, his good friend Leonard Schiff, who was also an Oppenheimer student, was able to lure him to Stanford. There he had excellent students, including Theodore Maiman, who built the first laser.

Unfortunately, Ursula could not find suitable employment in California, and their dissatisfaction resulted in leaving for Oxford University. The years at Oxford, 1956-1962, were very productive. Lamb pioneered the use of density matrix techniques to treat the atoms and molecules in lasers and masers. Their use is commonplace nowadays, but it was new then. It was at Oxford that he wrote his famous "Theory of Optical Masers" paper (1964) based on work begun at Stanford. It was followed by a series of papers published while he was at Oxford, Yale, and Arizona.

One consequence of this work was "Lamb dip"⁵ spectroscopy, which Willis would joke should not be confused with sheep dip. This was a powerful advance in spectroscopy because the radiative line widths of gas samples are usually masked by much larger Doppler broadening. The most important aspect of Lamb's theory, however, is the sound foundation it provides for laser physics.

At Oxford, Willis was the Wykeham Professor of Physics. He enjoyed his time there, but he couldn't do experiments. He was chair professor of theoretical physics but didn't have any (not one!) doctoral students. In some ways there was a mismatch between Lamb and Oxford. Nonetheless, Willis always spoke fondly of his time in the U.K.; but when he got an offer from Yale, they left Oxford. The Yale physics

department in the 1960s was excellent by any measure. The university hired Columbia physicist Vernon Hughes who hired Lamb and the physics community nicknamed Yale “Columbia on the Housatonic” (river). Other luminaries were Lars Onsager, Gregory Breit, and John Bardeen who was there on sabbatical.

Willis had received the Nobel Prize only a few years before and had been elected to membership in the National Academy of Sciences in 1954; he was in his prime. He had large experimental and theoretical efforts and was teaching a popular course in advanced quantum mechanics. During this period, he finished and published his classic laser theory paper, which is his most highly cited paper. Willis Lamb was a transformational hire. People and labs were moved to make room for his efforts. If he moved into your space, you were said to have been Lamb shifted. If you were displaced by someone who was displaced by Lamb, it was said that you experienced a second-order Lamb shift.

He had a razor wit that he would apply to students and colleagues equally, for example,

Student: Professor Lamb, I would like to work with you.

Lamb: Sorry, I don't take first year students.

Student: But I have special qualifications.

Lamb: Then I would be interested since I have so few qualifications myself.

The student got the job—Willis's prized chutzpah.

As an example of Willis's baiting professorial colleagues:

Lamb to a senior professor (from Oxford): This is our new paper on the quantum theory of the laser. There are some mistakes in it but none of them will bother you; they are all conceptual.

He cared deeply for his students, often calling them his children. He would spend long hours with his students solving a problem and long days writing up the solution. He found important positions for his people at, for example, Yale, MIT, and Bell Labs, among others, and he took an active role in mentoring them through to tenure. For example, he advised one of his protégés who wanted to move west not to leave until he was promoted and could move there as a full professor. Willis was always generous with and protective of his students, but he had a bit of a temper.

Yale was Lamb's second golden era. However, Ursula still didn't have a faculty position. He was unhappy about that and had serious midlife problems that were causing him to strain his Yale moorings. Arizona was just around the bend. The move to Arizona was, as in the case of Stanford, a combination of attractive and repulsive forces. In order to put into perspective this very human side of Willis's life, we mention a few more things about his wife, Ursula.

Ursula Schaefer was the granddaughter of August Heinrich Hoffmann, who wrote the lyrics of what became the German National Anthem, "Deutschland Über Alles." As Ursula explained, Hoffmann was writing for Austria, but his lyrics were later appropriated by the Nazis. The irony is that Ursula was very much against the Nazi movement and was forced to leave Germany because of her opposition. Willis was supportive of Ursula's political views and deeply devoted to her. Nevertheless, at some point in the late 1960s they separated. When they reunited a few years later, Willis was more determined than ever to help make Ursula's career the success that he knew that it should be. The problem was the glass ceiling that she constantly ran into. The University of Arizona succeeded in recruiting Willis to its faculty by first offering Ursula a faculty position in its history department

with whose interests her expertise in colonial Spanish history was very much in keeping.

Peter Franken's paraphrased tribute⁶ to Willis on the occasion of his 65th birthday is on target.

Around 1972 I was approached by Marlan Scully, who had fairly recently gone to the University of Arizona from MIT, about the possibility of succeeding Aden Meinel as director of the Optical Sciences Center. I was flattered by the suggestion ...[and] ... we decided to go. An offer was also outstanding then to Willis and Ursula, as well as to Bill Wing, Stu Ryan, and Keith MacAdam—the whole Yale flock. So I had some work cut out for me to persuade Willis that this could finally be a sensible Lamb shift. It really wasn't too hard to sell, particularly since Marlan, Steve Jacobs, and others had done a lot of the preparation.

Lamb's research interests in those days focused on a combination of laser physics, statistical mechanics, and quantum mechanics. For example, he worked on aspects of laser gyros and other applications of his classic laser theory and was also involved in the application of the quantum theory of the laser techniques to the foundations of statistical mechanics. Furthermore, it was at this time that he wrote the *Laser Physics* textbook (1974) with Sargent and Scully.

He was also interested in many aspects of quantum mechanics, for example, the issue of gauge in quantum mechanics as concerns the interaction Hamilton used in his original level-shift papers. There he gives a discussion pointing out that the electric field treatment worked better than the vector potential treatment when applied in a naive fashion. But this is strange since the two differ essentially by a gauge transformation. It was often stated that it was curious that although gauge invariance is well established in quantum mechanics, in this famous problem there seemed to be a difficulty at a very elementary level. This problem was among the problems that Willis and his coworkers sorted out during those years.

He also focused on the questions of the foundations of quantum mechanics and in particular the interface between the classical and quantum world. On the one hand he was interested in ways of motivating and developing the Schrödinger equation and on the other hand he was interested in the philosophy of quantum mechanics, especially the quantum theory of radiation. As was noted in the beginning of this biography, Willis was one of the founders of modern quantum electrodynamics. However, he often felt that the textbook approach to the subject didn't serve the students well. For example, he did not believe that the picture of the photon as a fuzzy ball was useful and wrote articles in which he emphasized that many of the phenomena thought to imply and motivate the existence of photons, such as the photoelectric effect, could in the main be explained with a semiclassical theory of light and a quantum theory of matter. The photon issue became something of a touchy point with Willis. He jokingly, and sometimes not so jokingly, would often insist that people should have to have a license to use the word "photon" and he would not hand out very many written licenses. An exception was, for example, Ivo Birula, who got a license signed by Willis Lamb and Marlan Scully.

An interesting final development in Willis's career and life style was his strong connection with Germany in general and the University of Ulm in particular. There he took a Humboldt many years running in the group of Prof. Wolfgang Schleich, who was a grand-student of Willis's. There was a lot of good fun and camaraderie between Willis and the Ulm group. He would show up early in the morning and work until late in the day, always interacting with people and making useful observations and contributions.

It is fitting then, that we should conclude with the words of the famous Viennese physicist Victor Weisskopf:⁷

We have too few people of your kind around. Physics is full of specialists, experts and mathematical virtuosos. You are one of the few who are different. You must go on helping all of us to make physics become what it really should be, a deeper insight into nature. I could have said that your physics is like physics was in the old days. In truth however, physics never was what it was supposed to be in the old days except in the minds of very few and some of them still exist and you belong to them.

NOTES

1. *Physical Review*. 72, 241 (1947)
2. S. S. Schweber. "QED and the Men who Made It," Princeton Press (1994), p. 209.
3. More correctly the $2S_{1/2}$ and $2P_{1/2}$ levels where $\frac{1}{2}$ refers to the (total) angular momentum state of the bound electron.
4. I. Waller. Nobel Prize in Physics 1955, in: Nobel Lectures, Physics 1942-1962. Amsterdam, Elsevier, 1964. http://nobelprize.org/nobel_prizes/physics/laureates/1955/press.html
5. The Lamb dip refers to the interesting fact that gas laser oscillator, like the HeNe laser, have less gain when the light and the atoms are tuned to exact resonance (of the atomic Doppler broadened line). This surprised people, including Lamb, who knew other radiation emitters, such as microwave oscillators, have maximum gain when tuned to resonance. See *Physical Review*. 134, 1429 (1964).
6. P. Franken. "On Knowing Willis" in: W. E. Lamb, Jr., a Festschrift, edited by D. ter Haar, and M. O. Scully, North Holland, Amsterdam, 1978.
7. V. Weisskopf. "Personal Letter" in: W. E. Lamb, Jr., a Festschrift, edited by D. ter Haar, and M. O. Scully, North Holland, Amsterdam, 1978.

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