Phys. Perspect. 12 (2010) 180–189

1422-6944/10/020180-10
DOI 10.1007/s00016-009-0011-z

Physics in Perspective

Robert Vivian Pound and the Discovery of Nuclear Magnetic Resonance in Condensed Matter

Ursula Pavlish*

This paper is based upon five interviews I conducted with Robert Vivian Pound in 2006–2007 and covers his childhood interest in radios, his time at the Massachusetts Institute of Technology Radiation Laboratory during the Second World War, his work on the discovery of nuclear magnetic resonance in condensed matter, his travels as a professor at Harvard University, and his social interactions with other physicists.

Key words: Nicolaas Bloembergen; Felix Bloch; William W. Hansen; Martin Packard; Robert V. Pound; Edward M. Purcell; I. I. Rabi; John T. Tate; Henry C. Torrey; John H. Van Vleck; Harvard University; Massachusetts Institute of Technology; MIT Radiation Laboratory; Stanford University; University of Buffalo; Nobel Prize in Physics; molecular beams; nuclear magnetic resonance; history of physics.

As a student of physics and history of science I became particularly attracted to the history of nuclear magnetic resonance (NMR) from its beginnings in molecular-beam physics to its present ubiquity in chemistry, materials science, and medicine.

The first detection of NMR in condensed matter occurred just weeks after the end of the Second World War, independently and nearly simultaneously by two teams of physicists on opposite coasts of the United States. Of the six physicists comprising the two teams—Felix Bloch, William W. Hansen, and Martin Packard at Stanford University, and Edward M. Purcell, Henry C. Torrey, and Robert V. Pound at Harvard University and the Massachusetts Institute of Technology (MIT)—only Pound is still living. I met and interviewed him five times during the academic year 2006–2007 at the Cadbury Commons nursing home, north of the Harvard campus. I provide excerpts of my interviews below, especially as they pertain to the early history of NMR.

* Ursula Pavlish lives in Pécs, Hungary. She graduated with a degree in physics from Princeton University in 2005 and then studied history of science at Harvard University for one year. She has conducted interviews with more than twenty-five physicists and astronomers.

Fig. 1. Robert V. Pound (b. 1919) in the control room on the second floor of Jefferson Physical Laboratory at Harvard University in January 1960 recording data for the Pound-Repka experiment to measure the gravitational red shift. *Credit*: American Institute of Physics Emilio Segrè Visual Archives.

Robert Vivian Pound (figure 1) was born in Ridgeway, Ontario, on May 16, 1919, and at the age of three moved with his parents to Buffalo, New York, where he got his start in science through amateur radio at the age of twelve.[1] He would go daily after school to an amateur radio shop called "Dimac" on the street where he lived. That early experience contributed to his work on NMR. For example, he used the same special radio receiver at the Massachusetts Institute of Technology Radiation Laboratory (MIT Rad Lab) and in the NMR experiments.

Pound: The Halicrafters radio receiver was a familiar thing to me because I was an amateur radio person who invested much of my youth in that.

> That is why I became what I became; that is how I learned about electronics. (I 3, p. 3*)

Pound became known as an electronics guru, which was true, but he is also regarded as a very accomplished physicist.

> **Pound:** I was very grateful to him [George Pake] once because he wrote me a long letter to tell me how much he appreciated me as a physicist and not as an electronics expert. (I 1, p. 9)

Pound received his B.A. degree in physics in 1941 at the University of Buffalo where his father, Vivian Ellsworth Pound, was Professor of Physics. He then moved to Boston, where he obtained a position as a research physicist at the Submarine Signal Company through one of his brothers-in-law who was chief of radar development there.[2] The company was then developing pulsed radar in analogy to sonar, its specialty before the war for the detection and location of submarines. Pound recalled that one day when the *Queen Mary* left Boston Harbor he and other physicists used 50-centimeter radar to follow it eight miles out to sea.

> **Pound:** It was impressive that the *Queen Mary* came in and docked down at the army base in South Boston. It was an image that was a large part of our horizon when we looked out of our windows there, from Atlantic Avenue. It was quite illegal to mention it in the newspapers. (I 2, p. 14)

A year later, in 1942, Pound moved to the MIT Rad Lab, where the work there on radar during the Second World War contributed directly to the discovery of NMR in condensed matter, both in terms of the equipment and techniques used, and socially by bringing professional physicists together in a tight-knit collaboration.

> **Pound:** The whole radar program is almost identical to the NMR problem. Namely, in both cases you apply a driving signal and look for its aftereffects. In the case of radar, you look for echoes, backscatter from whatever it is that is out there. And in NMR you activate it by applying a large RF [radiofrequency] signal, and it may have a persistence in response which you can see later. (I 2, p. 15)

Similarly, the physicists recognized the importance of signal-to-noise ratios, and Pound transplanted the diode crystals used in the radar systems at the MIT Rad Lab into the first NMR experiment. The magnets were quite special, unlike the oscilloscopes they used.

* Interview 3, page 3; I use this notation throughout.

Pound: The equipment we used in the NMR experiment were just common parts of an electronics laboratory that you would have had at that time. (I 3, p. 8)

They carried out their experiments in a run-down shed adjacent to Jefferson Physical Laboratory, home of the Harvard Physics Department, using some of Harvard's and some of MIT's equipment, while working under a contract from the US Navy. They should have begun by using pulsed radar techniques but instead used continuous-wave radar techniques, because these were what they had used at the MIT Rad Lab.

The social atmosphere at the Rad Lab also contributed to the discovery of NMR, since Pound got to know I. I. Rabi, Jerrold Zacharias, Norman F. Ramsey, Robert H. Dicke, Edward M. Purcell, Henry C. Torrey, John H. Van Vleck, and other leading physicists there.

Pound: It [physics] is a social phenomenon. I have often emphasized the fact that the MIT Radiation Lab had a tremendous impact on the future of physics because so many people became such close collaborators and friends during that period. They would never have met each other [otherwise]. As Purcell pointed out, he had no concept of magnetic resonance before getting into the MIT Radiation Lab. (I 5, p. 23)

Just after the war, when physicists had not yet moved back into academia, they were still in their offices at the Rad Lab writing books that would be published in the MIT Rad Lab series.

Pound: My book is called *Microwave Mixers*.[3] That is the thing which you [use to] convert microwaves into ordinary radio frequencies, that could be amplified by conventional technology. (I 2, p. 18)

During the early 1940s, Pound and his colleagues went for lunch daily to a delicatessen in Central Square, where he would be served his favorite Boston Cream Pie with ice cream for the same price as that day's 40-cent Special. Pound called this "The Waitress Effect." The delicatessan also made its own molasses bread, which he regularly took home to his wife Betty.

One day on the way to lunch Ed Purcell asked Pound and his officemate Henry Torrey, who had worked on magnetic resonance in molecular beams in Rabi's laboratory at Columbia University in the 1930s, if they were interested in working together to detect NMR in condensed matter. Torrey's experience and work with Rabi, Ramsey, and Zacharias at Columbia were now vital.

Pound: We were happy that we did not have to do the kind of high-vacuum work and so forth that the molecular-beam people had to do. That is why this was a great simplification of the whole game. The idea of magnetic resonance was already well established by those molecular-beam experiments. (I 2, p. 10)

The discovery of NMR was not a conventional one.[4]

> **Pound:** [It] was something entirely predictable, and if it had not been the way it is, if it had not worked, it would have been completely our fault because everything about it was calculable. All we did was dig it out of the noise. It was just as it should be. Sure enough, it was there.
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> …
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> As Ed [Purcell] has sometimes said, if we had not been able to find [NMR in condensed matter] that would have been a catastrophe, because everything was clearly calculable, and there is no way it could have failed. Now the only way it could have failed was by what is called saturation; overpowered by the RF field, so the absorption can be wiped out by being saturated. We knew enough about it; we kept it at a level so that it could not do that. … We were pretty clear about what we were doing. (I 1, pp. 20, 23)

Thus, for example, they chose paraffin as their first sample because, first, paraffin is rich in protons and protons have the largest magnetic moment; second, paraffin absorbs very little electromagnetic radiation: it is an extremely good dielectric; and third, paraffin was easily obtainable: Purcell picked some up from a nearby general store "on Massachusetts Avenue, a block or so above the corner of Martin Street and Mass Avenue." (I 1, p. 14) They worked at a feverish pace.

> **Pound:** We used to do that kind of thing—work all night. We not only did that in that case [of NMR], but we were quite used to it during the war years in the Radiation Lab. (I 1, p. 21)

Before Pound and Purcell sent their manuscripts to *The Physical Review* for publication, they showed them to John H. Van Vleck.

> **Pound:** Van knew all about what we were doing. He was a major reference with a background in the area that Purcell and I were up to…. [Van's] subject was essentially the knowledge of ions in paramagnetic media. So, NMR was sort of the epitome of that kind of thing. And so Van was the person who knew the most about paramagnetism in materials. (I 5, pp. 8–9)

Van Vleck also knew John T. Tate, Managing Editor of *The Physical Review*, well from his years at the University of Minnesota (1923–1928) and thus could recommend the research of Pound and his colleagues to Tate. The initial detection of NMR was only the beginning.

> **Pound:** We discovered that quantitative aspects to study were things like relaxation times and line widths.
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> …
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> When I started studying nuclear magnetic resonance in crystals, and in solids and so forth, I began studying line shapes and structures. I soon realized that the nuclear quadrupole moment could be exploited. (I 1, p. 23)

One mode of thought dominated.

> **Pound:** We were used to thinking in terms of Fourier Transforms of the signals we were applying in time, and looking at the frequency distributions and so forth. It is just like a lot of the kind of thing we did anyway, not just to do with magnetic resonance, but with radio reception, microwave signal reception. (I 3, p. 8)

The discovery of NMR spread throughout the physics community. For example, Erwin L. Hahn, who later conceived spin echoes, had worked with Purcell and Pound at Harvard learning how to do NMR in condensed matter and then went to graduate school at the University of Illinois. And in 1946 Nicolaas Bloembergen came from Utrecht, The Netherlands, to join Purcell (figure 2) and Pound. Two years later, they published their definitive paper, which became known as the BPP paper,[5] on the complexities of NMR.

Back in December 1945, on the West Coast, Felix Bloch, William W. Hansen, and Martin Packard detected NMR in condensed matter independently and almost simultaneously using a slightly different method.[6] Later, after both teams had published their results, Bloch approached Pound at a cocktail party at the home of physicist J.B.H. Cooper on 72nd Street in New York City, asking if the Harvard group would like to file a joint patent on NMR with the Stanford group. Pound and his coworkers declined to do so, and in fact could not have done so, because the two groups had not collaborated in making the discovery of NMR in condensed matter. According to Pound, it is even possible that Rabi had told the Stanford group of the Harvard group's achievement and this helped Bloch's team to the discovery. In any case, the leaders of the two teams, Bloch and Purcell, shared the Nobel Prize in Physics for 1952 "for their development of new methods

Fig. 2. Edward M. Purcell (1912–1997, *left*) and Nicolaas Bloembergen (b. 1920). *Credit*: American Institute of Physics Emilio Segrè Visual Archives.

Fig. 3. William W. Hansen (1909–1949, *left*) and Felix Bloch (1905–1983) in their laboratory at Stanford University in 1947. *Credit*: Anderson/Stanford News and Publications Service.

for nuclear magnetic precision measurements and discoveries in connection therewith."[7]

Pound speaks well of the members of the competing Stanford team. He credits Bloch and Luis Alvarez for their measurement of the magnetic moment of the neutron before the war,[8] and believes that Hansen (figure 3) received insufficient credit for his work leading to the detection of NMR in condensed matter.

> **Pound:** If anybody had invented the whole subject, it was Hansen…. Hansen came to MIT [in the fall of 1941] and gave lectures for about three years on the foundations of magnetic resonance and in technical aspects of solid-state physics. (I 5, p. 20)

Pound has a fond recollection of Hansen's lectures.

Most of my interviews were focused on nuclear magnetic resonance, but in one I asked Pound about his and Glen Rebka's gravitational-redshift experiments.[9] He recalled that he went down in mineshafts and up in the Empire State Building in search of a good location for them before settling on a shaft in Jefferson Physical Laboratory.

Pound has had a full life as an experimental physicist. While never formally receiving a Ph.D. degree, he invented a device called The Pound Box*; he did experiments on a nuclear-spin system at negative temperature;[10] and he invented "frequency locking."

* This was a microwave cavity of about a liter in volume.

Immediately after the war, Pound was elected to the prestigious Harvard Society of Fellows which, he recalled, was like a fraternity with scholars in such diverse fields as Irish history and literature, botany, English, and physics who came together socially in the evenings. Then, in 1948, he was appointed as an assistant professor at Harvard, where he spent his entire career. The first course he taught was on signal-to-noise, building on books in the MIT Rad Lab series such as *Threshold Signals* and *Vacuum Tube Amplifiers*.[11] He served as chair of the Harvard Physics Department for eight years, occasionally having to deal with eccentric behavior, for example, when one of the laboratory teaching assistants painted the NMR magnets in bright colors and named them after the wives of Henry VIII. He recalled that he was known among the Harvard faculty for his opposition to Harvard's core curriculum.

Pound traveled widely, spending a year at Oxford University as a Fulbright Scholar in 1950–1951 and sabbatical and other leaves at other European and American universities. Earlier, in the summer of 1948, he and his wife Betty went to a metallurgy conference in Paris. John and Abigail Van Vleck were also there, and the two couples would cross the Seine together from the Van Vlecks' hotel on the Right Bank to the Pounds' hotel, D'Isly, on the Left Bank. They also saw a French movie in Paris together, "Les Enfants du Paradis" ("Children of Paradise"), that they had enjoyed in a shortened version in the U.S. Pound took a photograph from the window of their hotel room of the street below, which showed no cars, only a man pushing a cart full of fruit and vegetables. When he returned to Paris in the 1970s, he again took a photograph from the same window, which now showed many cars on the street below. He hung the two photographs side-by-side in his home in Arlington (Cambridge's neighboring suburb), symbolizing how much the world had changed in the intervening three decades.

> **Pound:** I have always felt that it was a little bit unfortunate that the world bases all of its history on political and military frontiers and so forth, whereas such a formative aspect of the history of the world should be based on the advances of technology…. People do not recognize how much various technical advances have changed the world. (I 5, p. 15)

Pound had hoped that his work on NMR would get him into the field of nuclear physics, the most prestigious field of physics after the war, but that did not pan out.

> **Pound:** So many of them [nuclear moments] had already been observed in other ways by the time it [NMR] came along, that there was never much effort made to extend it into that use as a particular application…. [Instead, NMR] revealed all kinds of things about the interactions among nuclei and of the nuclei with their surroundings in materials. So that is what dominated the applications for many years. (I 3, pp. 10–11)

Later, when NMR found an increasing number of applications in medicine, the letter "N" was dropped and the technique was renamed magnetic resonance imaging, or MRI, and as such has become known worldwide.

During one of my last visits to Cadbury Commons, a pianist performed Mozart's A-minor Sonata for its elderly residents. Pound was seated in the front row. Other people hummed along with the music; some moved their fingers as if playing a piano; still others tapped their hands on their knees. I sensed that Pound could not enjoy the performance as others did, which was confirmed when he left the room during the slow, sad, second movement. Pound's wife Betty, a niece of the renowned Danish composer Carl Nielsen, is a gifted pianist. Their house in Arlington, which was designed by Bauhaus architect Karl Coke and an associate, was built as a homage to music: the living room has a special corner to accommodate their 5-foot 6-inch Steinway piano. They used to invite scientists for musical evenings. Physicists Otto Robert Frisch, Victor Weisskopf, and others would play the Steinway during their visits, but Pound recalled that his wife Betty was never satisfied with the quality of their performances. Once, on a return visit to Frisch's home in Cambridge, England, Pound met Frisch's aunt, Lise Meitner, there.

Pound remembers people fondly, and he is a good conversationalist. He eases smoothly from one story into another, from anecdotes to technical explanations. He does not repeat himself much; his thoughts, however, sometimes take him down avenues related only obliquely to his scientific work.

I got the impression that Pound pursued his research—on NMR, the gravitational redshift, and much more—aggressively, but that he did not wholly center his soul on his physics. It might be said that his colleagues, his secretaries, and others who were involved in his research projects formed the backbone of his scientific universe. He was known as an extraordinarily precocious and gifted experimental physicist, but he does not speak about his experiments or scientific instruments with anything like the love he manifests for the uniqueness and timeless worth of the people in his life. He and his wife read *The New Yorker* "religiously," he said, and they used to talk about the articles in it even before they were married.

On one of my visits, when I told Pound that I am fascinated not only by scientific facts but also by scientific stories—that stories were what attracted me to physics in the first place—he replied, with a twinkle in his eyes, "Good, good, good."

Acknowledgment

I thank Roger H. Stuewer for his thoughtful and careful editorial work on my article.

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Ferencesek u. 20
7624 Pecs, Hungary
e-mail: Ursula.pavish@gmail.com