

Alfred Guillou Redfield

Alfred Guillou Redfield died on 24 July 2019 in Alameda, California. He was a major figure in the development of nuclear magnetic resonance (NMR) and its applications to problems in solid-state physics and biophysics.

Al was born in Milton, Massachusetts, on 11 March 1929 and raised in Cambridge and Woods Hole, where his father, the eminent oceanographer Alfred Clarence Redfield, worked at the Oceanographic Institution. The younger Al graduated from Harvard University in 1950 with a BA in physics and received his MS in 1952 and PhD in 1953, both in physics, from the University of Illinois at Urbana-Champaign. His thesis focused on experimental Hall effect measurements of electron mobilities in photoconductors and the associated theory. His thesis adviser was Robert Maurer, but the publications from his thesis work list Al as the sole author.

For postdoctoral research, Al returned to Harvard. There his interests shifted to magnetic resonance, most likely because of his interactions with Charles Slichter at Illinois and with Nicolaas Bloembergen, John Van Vleck, and others at Harvard. Al's 1955 *Physical Review* paper entitled "Nuclear magnetic resonance saturation and rotary saturation in solids" was a major conceptual breakthrough. In it, he focused on NMR signals from a coupled many-spin system in a solid that is subjected to continuous RF irradiation near the NMR frequency. He showed that the signals could be understood by applying principles of quantum statistical mechanics and thermodynamics to the spin system in a frame of reference that rotates around the static field direction at the frequency of the RF field.

Al's 1955 paper introduced ideas about spin temperature in the rotating frame, dipolar spin order, and spin locking that were essential for many developments in NMR of solids over the next

50 years. Without those concepts, NMR techniques that are widely used in studies of the structure and dynamics of biological and nonbiological materials would be inconceivable. In his book *Principles of Magnetic Resonance*, Slichter called Al's article "one of the most important papers ever written on magnetic resonance."

After taking a position in 1955 at the IBM Watson Laboratory at Columbia University, Al published his next big contribution: a general theory for the rates of relaxation of an out-of-equilibrium spin system in response to randomly fluctuating interactions with surrounding degrees of freedom. Using a quantum mechanical density matrix formalism, he showed that the approach to equilibrium can generally be described by a relaxation rate matrix, with elements that depend on spectral densities of the fluctuating interactions. The formalism, often referred to as Redfield theory, was published in the *IBM Journal of Research and Development* in 1957. In NMR of condensed matter, Redfield theory is commonly used to extract rates and amplitudes of molecular motions from linewidths and spin relaxation times.

Although Redfield theory was originally motivated by phenomena in magnetic resonance, it has broad applicability in condensed-matter physics and physical chemistry. Al's 1957 paper still receives about 50 citations per year, most recently in papers on topics as diverse as electron transfer in photosynthesis, light propagation in quantum dot lasers, and effects of magnetic fields on electrical currents in graphene.

Al was also a creative experimentalist. His work at Watson Lab included measurements of spin-lattice relaxation in metals at very low temperatures, measurements and analyses of spin relaxation in solids driven by translational diffusion, and the first demonstration of NMR as a method for characterizing the vortex lattice in a type II superconductor. Al also developed an indirect detection method for rare spin species that was an intellectual ancestor of contemporary indirect detection methods in NMR.

In 1969, during a sabbatical with Daniel Koshland at the University of California, Berkeley, Al began applying NMR to biological problems. In 1972 he joined the faculty of Brandeis University,



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where he remained for the rest of his career. Among his many contributions to biomolecular NMR are early studies of electron transfer in cytochrome c, the introduction of frequency-selective composite RF pulses for exciting hydrogen-1 NMR signals of biomolecular solutes without interference from much stronger solvent signals, and studies of tRNA structure by NMR-detected hydrogen-deuterium exchange. They also include an early ^1H -detected two-dimensional NMR technique for observing ^{15}N - ^1H chemical shift correlations, closely related to 2D techniques that are now a mainstay of biomolecular NMR.

For his outstanding achievements, Al received many honors. They include the International Society of Magnetic Resonance's ISMAR Prize in 1995 and the Max Delbruck Prize in Biological Physics from the American Physical Society in 2006.

Al was a modest man who did not like to call attention to himself. He was a scientist's scientist, with phenomenal mathematical and theoretical abilities, outstanding experimental skills, an exceptionally broad knowledge of physics and biology, and a love for research. He was universally respected and is deeply missed.

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