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This Week's Citation Classic

Carr H Y & Purcell E M. Effects of diffusion on free precession in nuclear magnetic resonance experiments. *Phys. Rev.* **94**:630-8, 1954.
[Dept. Physics, Rutgers Univ., New Brunswick, NJ and Lyman Lab. Physics, Harvard Univ., Cambridge, MA]

Nuclear magnetic resonance (NMR) free precession concepts, techniques, and experimental results were reported, including: a 180°-90° pulse method ('inversion-recovery') for measuring longitudinal relaxation; a many-pulse sequence ('Carr-Purcell') for partially eliminating the artificial transverse decay caused by diffusion; and the intentional application of field gradients for observing spatial effects (diffusion and bulk flow). [The *SCI*® indicates that this paper has been cited in over 1,045 publications since 1961.]

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"In the fall of 1949 at Harvard University, I began reading about nuclear magnetic resonance (NMR) under the guidance of E.M. Purcell. In early November, Purcell read E.L. Hahn's historic abstract[1] about the fascinating phenomenon of 'spin echoes.' Purcell suggested that I try to understand this effect.

"During Christmas recess I traveled to a student conference at the University of Illinois where a group of students from Harvard, many of us veterans, lobbied for a conference resolution asking Congress to use US food surpluses to help alleviate world famine. Amid this political activity, I made a visit to the physics building where Hahn showed me his laboratory—a cramped hallway at the top of a high stairwell. There for the first time I saw spin echoes and learned about their discovery.

"Hahn had explained his echoes using a model involving only equatorial components. Purcell suggested using a three-dimensional model, and this greatly simplified the understanding of the relatively complicated echoes associated with Hahn's *equal* pulses. It was during lunch one day in the spring of 1950 that I realized the explanation could be simplified even more by using two *unequal* 90° and 180° pulses, and indeed a sequence consisting of a 90° pulse followed by a series of 180° pulses. As I built my own pulse apparatus that spring, I therefore incorporated independently variable pulse gates. By the end of the summer of 1950, we had seen our own echoes at Harvard.

"The 1954 paper—drafts of which were written in a cabin on a Cache Lake-island in Ontario's Algonquin Park—included work done both at Harvard and using, in 1952-1953, Henry Torrey's excellent new magnet at Rutgers University. In addition to the work listed in the above abstract, the 1954 paper included an explanation of the effect of a 180° pulse in partially eliminating the artificial decay caused by diffusion in an inhomogeneous magnetic field, as well as a random walk model for relaxation. Not all of the 1952 Harvard thesis work[2]—e.g., the spinning of the sample to reduce field inhomogeneity effects—was included in the 1954 paper. The absolute value of the water self-diffusion coefficient D reported in the paper was measured at Rutgers using 'anti-Helmholtz' coils to obtain the nearly uniform gradient, while at Harvard only relative values of D were observed using long parallel wires to obtain the gradient. To the best of my knowledge, this was the first use of *intentionally applied* gradients to obtain spatial information.

"The extensive citation of this 1954 paper is undoubtedly due both to its very simple explanation of important basic phenomena, and to the exceedingly extensive—indeed, beyond all our expectations—applications of free precession techniques, especially when coupled with fast computer technology.

"Relatively recently I have personally enjoyed using[3] some of these techniques to study liquid-vapor critical phenomena, and I have especially admired their use by others in the study of solid ^{3}He, superfluid ^{3}He, and high resolution studies in solids,[4] as well as the clinical applications of NMR imaging."[5]

1. **Hahn E L.** Spin echoes. *Bull. Amer. Phys. Soc.* **24**:13, 1949.
2. **Carr H Y.** *Free precession techniques in nuclear magnetic resonance.* PhD thesis. Cambridge, MA: Harvard University, 1952.
3. **Hayes C E & Carr H Y.** NMR measurement of the liquid-vapor critical exponents β and β_1. *Phys. Rev. Lett.* **39**:1558-61, 1977.
4. **Abragam A & Goldman M.** *Nuclear magnetism: order and disorder.* Oxford: Clarendon, 1982. p. 53-272.
5. **Pykett I L.** NMR imaging in medicine. *Sci. Amer.* **246**(5): 78-88, 1982.