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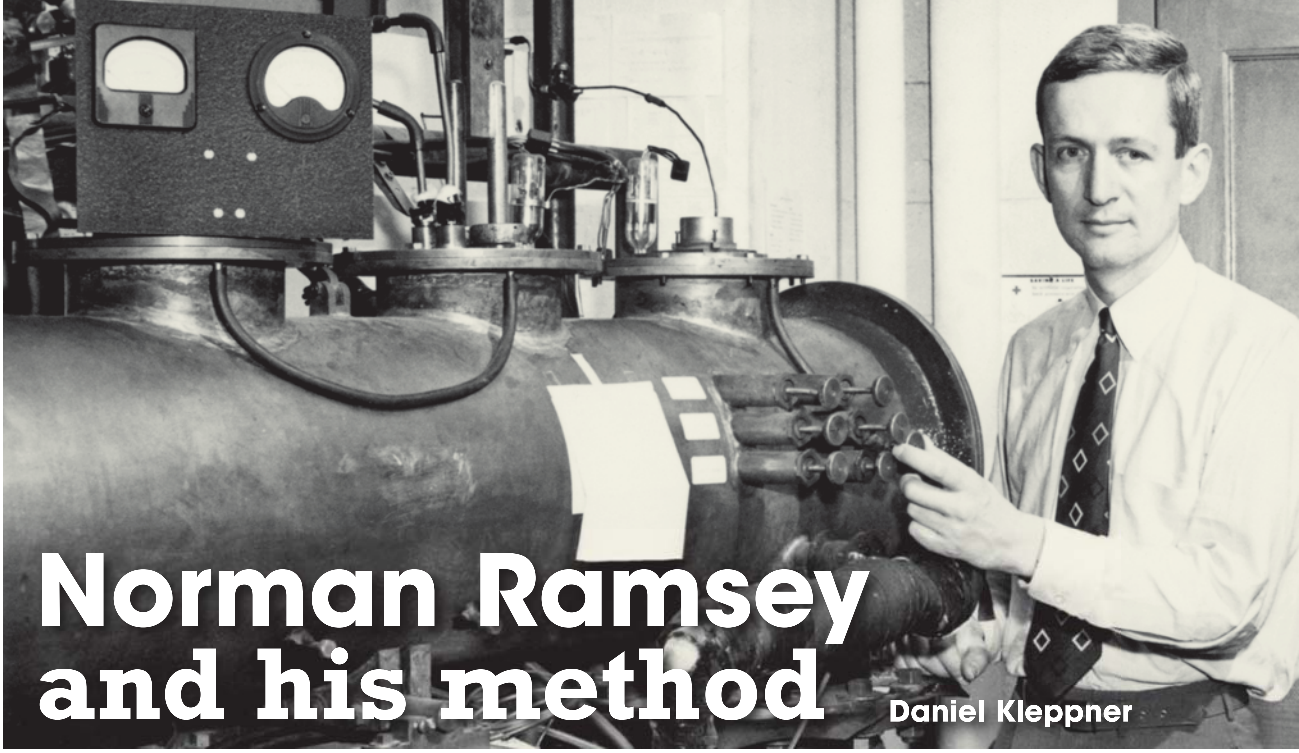

Norman Ramsey and his method

Daniel Kleppner

While searching for a way to boost the resolution of an atomic spectrometer, Ramsey hit on a simple solution: Replace a single oscillating magnetic field with two separated ones.

History does not often permit pinpointing the genesis of a prize-winning idea. But in the case of Norman Ramsey's invention of the separated oscillatory fields method—which was cited in his 1989 Nobel Prize award (see PHYSICS TODAY, December 1989, page 17)—the story formed one of the many anecdotes with which Norman regaled his students and colleagues.[1]

Early days at Columbia

The story calls for some background: Norman was very much of a novice when he bounced into I. I. Rabi's research group at Columbia University in the fall of 1937. Having graduated from Columbia in 1935 with a degree in mathematics, he returned from Cambridge University, where he had studied physics for all of two years. He plunged into the research and was on hand a few months later when Rabi invented molecular-beam magnetic resonance. The first resonance experiments were on the lithium fluoride molecule, which gave beautiful spectra, and on molecular hydrogen and deuterium, whose signals were so ugly that no one knew what to make of them. The messy problem of hydrogen and deuterium was turned over to Norman while the others in the group pursued more productive research.

At the heart of Rabi's apparatus is a uniform magnetic field containing a short coil through which atoms or molecules pass. The coil is excited by an RF oscillator, and if the frequency is correct, the nuclear spin of an atom flips as the atom passes through. Working alone, Norman discovered that by vastly reducing the power to the coil, he could obtain meaningful data. Furthermore, the spectrum of the deuterium molecule contained a major surprise: unambiguous evidence that the deuteron is not spherical.[2] That discovery was a major scientific achievement for Rabi's group.

The width of the spectral lines in Rabi's resonance method is fixed by the molecules' time of flight through the coil: The longer the time, the sharper the line. The group subsequently reported results from using a coil that had been extended from 2.5 cm to 13.5 cm, with a corresponding decrease in linewidth and increase in spectral resolution.[3] That early experience seems to have given Norman a taste for high-resolution spectroscopy and precision measurements.

Design problems

In 1947 Norman joined the Harvard University faculty and set up a laboratory. In designing his new molecular-beam magnetic resonance apparatus, he naturally sought to maximize the spectral resolution by making the radio frequency coil, and hence the apparatus itself, as long as possible. In molecular-beam magnetic resonance, the frequencies of the spectral lines depend primarily on the strength of the applied magnetic field. Consequently, to achieve extremely narrow spectral lines, the magnetic field must itself be extremely uniform. Achieving that uniformity becomes increasingly difficult as the length is increased.

While struggling with the problem, Norman recalled a curious fact that had stuck in his mind since his undergraduate days at Cambridge. An instructor, P. I. Dee, had pointed out that the Michelson stellar interferometer had a spatial resolution almost twice as high as a perfect telescope mirror

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whose diameter is the length of the interferometer. He recalled Dee suggesting that if the resolution of your telescope is not quite high enough to determine whether an object is a single or a double star, simply paint the middle of the mirror black. The image will be dimmer but almost twice as sharp.

After "two or three days of thinking," Norman discovered an analogy with his apparatus. If he used a short coil to apply an oscillating field as the atoms enter the magnetic field and a second short coil to apply an oscillating field as they exited the magnetic field, the spectral line would be almost twice as sharp as if the oscillating field were applied over the entire path using a single long coil. The photo on page 25 shows Norman in Harvard University's molecular-beam laboratory in 1952 standing next to the apparatus that first employed his new resonance method. (For a simple description of the method, see his July 1980 PHYSICS TODAY article reprinted in this issue on page 36. A technical description is in his journal articles and classic text cited in reference 4.)

Joy in a factor of two

Norman was elated to have discovered a factor-of-two increase in resolution. It took him a few days to realize that this was merely one of many advantages of his new method. Just as the quality of the mirror that is blackened in Dee's hypothetical telescope is unimportant, the need for uniformity of the magnetic field between the two oscillating fields is considerably reduced. That advantage was crucial for Norman's new machine. Furthermore, the single-coil method is limited to coil lengths that are short compared to the wavelength of the oscillating field and thus precludes observing microwave transitions precisely. The separated oscillatory fields method overcame that limitation and immediately opened the way to the creation of the cesium atomic clock. The cesium clock quickly became the workhorse for frequency standards.

Today the factor of two in intrinsic resolution seems negligible compared with the factors of hundreds or thousands that have been achieved using the Ramsey method. Also, the method has played ubiquitous roles in extending coherent spectroscopy from radio frequencies to the optical frequency regime. As described by Serge Haroche, Michel Brune, and Jean-Michel Raimond on page 27 of this issue, the Ramsey method continues to greatly influence atomic physics and is found in one form or another in most high-precision measurements, advanced atomic clocks, and experiments on atom entanglement and cavity quantum electrodynamics.

References

1. Norman also retold the account in an oral history interview: N. Ramsey, interview by U. Pavlish (4 December 2006), Niels Bohr Library and Archives, American Institute of Physics, College Park, MD, http://www.aip.org/history/ohilist/31413_3.html.
2. J. M. B. Kellogg, I. I. Rabi, N. F. Ramsey Jr, J. R. Zacharias, *Phys. Rev.* **55**, 318 (1939).
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4. N. F. Ramsey, *Phys. Rev.* **76**, 996 (1949); *Phys. Rev.* **78**, 695 (1950); *Molecular Beams*, Clarendon Press, Oxford, UK (1956). ■