Observation of the Barnett Field in Solid by Nuclear Magnetic Resonance

How do we generate magnetic fields? Although the most conventional way is applying a current to an electric wire, there exists a completely different principle: when a material body is rotated, a magnetic field appears on the rotating body. In 1910's, S. J. Barnett found rotation-induced magnetization of magnets, which is interpreted, in modern physics, as the Barnett effect for the electron spin of a magnet [1]. The magnetization was first discussed phenomenologically by introducing an emergent field, a Barnett field B_Ω in a rotating object. Then, the microscopic mechanism of the field was rigorously formulated in terms of relativistic quantum mechanics [2]. The Barnett field can be written as $B_\Omega=\Omega/\gamma$, where Ω and γ are an angular velocity of rotation and a gyromagnetic ratio, respectively.

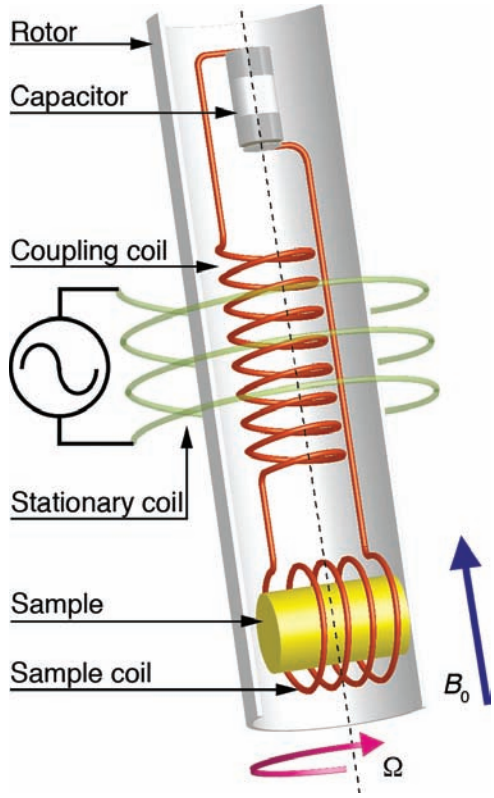

Fig. 1: An illustration of the experimental assembly.

To measure the Barnett field by the NMR method, the detection has to be done on the same rotating frame as the body. The reason for this is that, if there is relative motion between a signal detector and a body (signal emitter), an extrinsic NMR frequency shift arises from the relative motion (the rotational Doppler effect). To overcome the difficulty, we developed a new detection method in NMR, and directly measured the Barnett field [3].

Figure 1 shows a schematic illustration of the experimental assembly. The assembly comprises two components: the stationary coil placed along external field B_0 and connected to an NMR spectrometer, and a high-speed rotor consisting of a cylindrical capsule in which a specially arranged tuning circuit is installed. This circuit is composed of two small coils and a small capacitor. One of the two coils is arranged parallel to the stationary coil to establish a coupling by a mutual inductance between the tuning circuit and the stationary coil (coupling coil). The other, the sample coil, holds a sample inside. The RF field in the coupling coil is transmitted to the sample coil and generates an oscillating RF field to induce an NMR signal. Under this configuration, the sample coil rotates at exactly the

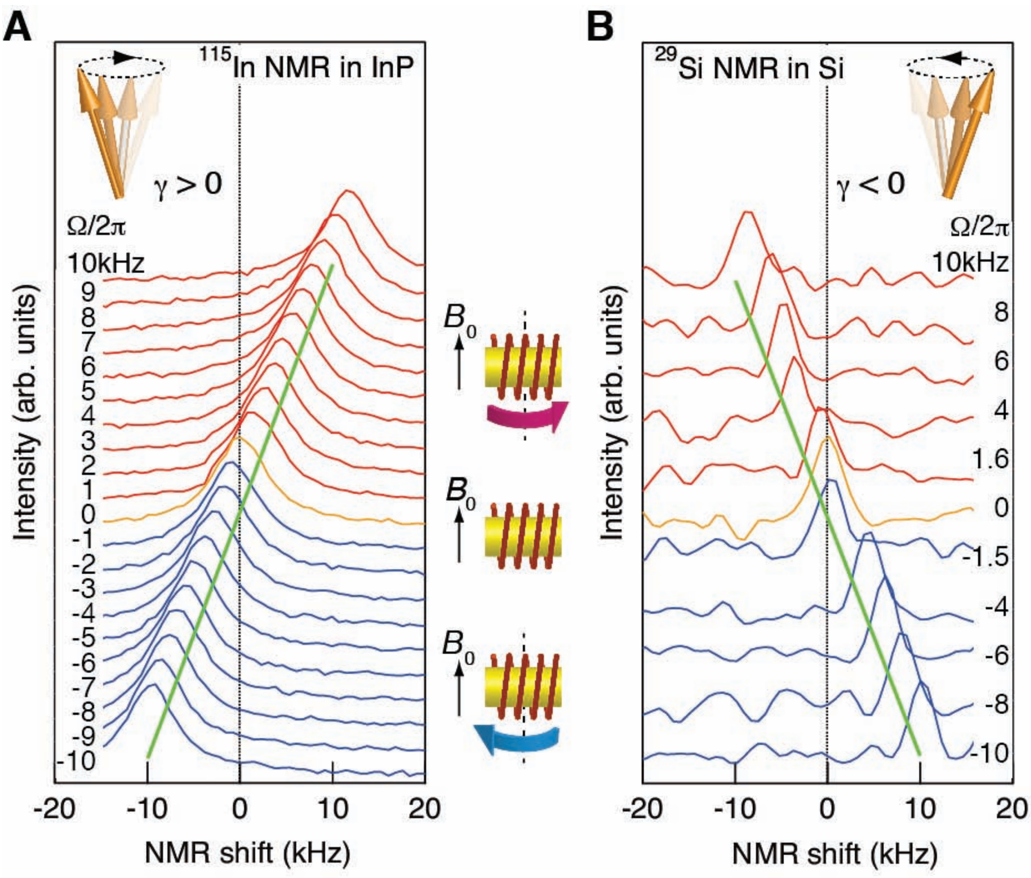

Fig. 2: NMR spectra for positive and negative gyromagnetic ratios. Spectra for (A) ^{115}In and (B) ^{29}Si NMR obtained at various angular velocities.

same angular velocity as the sample. The rotor is put inside the stationary coil and, during measurements, it is rotated up to $|\Omega/2\pi|=10$ kHz.

In Fig. 2A, we plot the ^{115}In NMR spectra in InP at various values of Ω. The NMR frequency increases linearly with Ω. By reversing the rotation direction, the direction of the NMR shift is also reversed; thus, the sign of B_Ω is reversed. The sign of γ of ^{115}In is known to be positive. Next we measured the NMR shifts for nuclei with negative γ. From the NMR spectra for ^{29}Si in Fig. 2B, the direction of the NMR shift is clearly opposite to that for ^{115}In, indicating that the emergent Barnett field is opposite in direction to that for ^{115}In. These results mean that the Barnett field depends on both the rotation direction and the sign of the gyromagnetic ratio. It is direct evidence for the Barnett field.

References

[1] S. J. Barnett, Phys. Rev. 6, 239 (1915).
[2] M. Matsuo, et al. Phys. Rev. B 87, 115301 (2013).
[3] H. Chudo et al., Appl. Phys. Eepress 7, 063004 (2014).