The first observation of the nuclear Barnett effect

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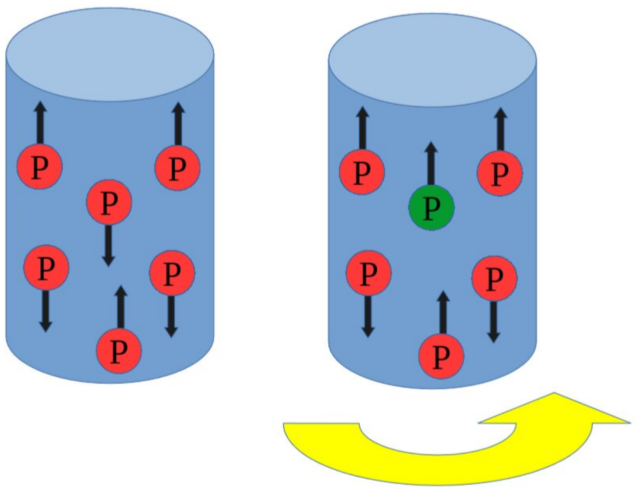

Figure representing the main idea behind the experiment. Credit: Mohsen Arabgol.

The electronic Barnett effect, first observed by Samuel Barnett in 1915, is the magnetization of an uncharged body as it is spun on its long axis. This is caused by a coupling between the angular momentum of the electronic spins and the rotation of the rod.

Using a different method from that employed by Barnett, two researchers at NYU observed an alternative version of this effect called the nuclear Barnett effect, which results from the magnetization of protons rather than electrons. Their study, published in *Physical Review Letters* (*PRL*), led to the first experimental observation of this effect.

"I was a graduate student at NYU where a group of colleagues were involved in a project related to brain imaging," Mohsen Arabgol, one of the researchers who carried out the study, told Phys.org. The fundamental idea behind the project was polarizing the brain molecules by inducing rotation using the Barnett effect and then applying the MRI-type imaging. I became interested and decided to work on the detection of the nuclear Barnett effect as my Ph.D. dissertation."

Initially, Arabgol and his supervisor Tycho Sleator wanted to drive rotation of the body used in their experiments by transferring the orbital angular momentum of light into the sample. They soon realized that this technique didn't really work, and thus decided to employ a more promising method using a mechanical spinner to drive rotation.

"The mechanical spinner allowed us to spin a larger sample of water up to speeds close to 15,000 revolutions per second, and finally, we were able to demonstrate the nuclear Barnett effect," Arabgol said.

In their experiments, Arabgol and Sleator used a commercial spinner turbine to rotate a sample of water up to very high speeds. They also used a non-standard nuclear magnetic resonance (NMR) machine that is designed to operate at low frequencies. This is in stark contrast with commercial NMR systems, which operate in high frequency.

"In our experiment, we were looking for a change in the NMR signal that was inversely proportional to the NMR frequency," Arabgol said. "So ironically, we wanted a low-frequency NMR apparatus, and we had to design and assemble the parts ourselves. To put this into numbers, we ended up working with an apparatus that was operating in less than 1 MHz, and we started searching for a few (1 to 3) percent change in the signal. If we wanted to use a standard apparatus, we had to search for a change in the signal few orders of magnitude smaller, which is impossible due to the variety of noises."

The NMR technique employed by Arabgol and Sleator, called CPMG-Add, works by processing a series of very weak signals (or echoes). The resulting signal was strong enough to be easily detected by the researchers' setup, to the point that the achieved rotational speeds changed it by a significant amount.

"As far as I can say, the beauty of this experiment was not finding an extraordinary technique or utilizing a novel apparatus, but finding the very narrow combination of many parameters in the experiment and running the whole experiment with the highest level of care and awareness about the variety of available noises," Arabgol said. "Our most interesting observation was that it is, in fact, possible to magnetize protons just by rotating a sample. That was quite exciting, since the electronic counterpart of this effect had been observed almost 100 years ago and we were not sure if it was possible to do the same thing for protons, especially seeing as the same effect is nearly 700 times smaller in protons compared to electrons."

Arabgol and Sleator were the first to magnetize protons, attaining a reliable observation of the nuclear Barnett effect. Another interesting aspect of their study is that the magnetization they observed has nothing to do with magnetic fields. This is particularly noteworthy, as researchers have so far typically magnetized objects by applying a magnetic field to them. The study carried out by Arabgol and Sleator, however, proves that there are, in fact, other mechanisms that can induce magnetization without necessarily creating a magnetic field.

From a theoretical standpoint, these observations enhance the current understanding of the relationship between magnetization and rotation. From a practical standpoint, they could aid the development of ultra-low-frequency NMR systems by introducing a new technique for inducing magnetization that does not require magnets.

"We conducted our experiment for liquids," Arabgol said. "A very logical next step would be to validate the results for solids. Measuring the Barnett effect for solids would be much harder using the same technique. As we explained before, the effect is so small that only a very narrow combination of parameters eventually worked, and unfortunately, it is nearly impossible to find such a combination for solids. It is noteworthy, however, that ours is merely one approach to tackle this problem. Other techniques (e.g. SQUID-based methods) might be more promising."

More information: Mohsen Arabgol et al. Observation of the Nuclear Barnett Effect, *Physical Review Letters* (2019). DOI: 10.1103/PhysRevLett.122.177202

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