Ultrasensitive magnetometer proposed based on compass needle

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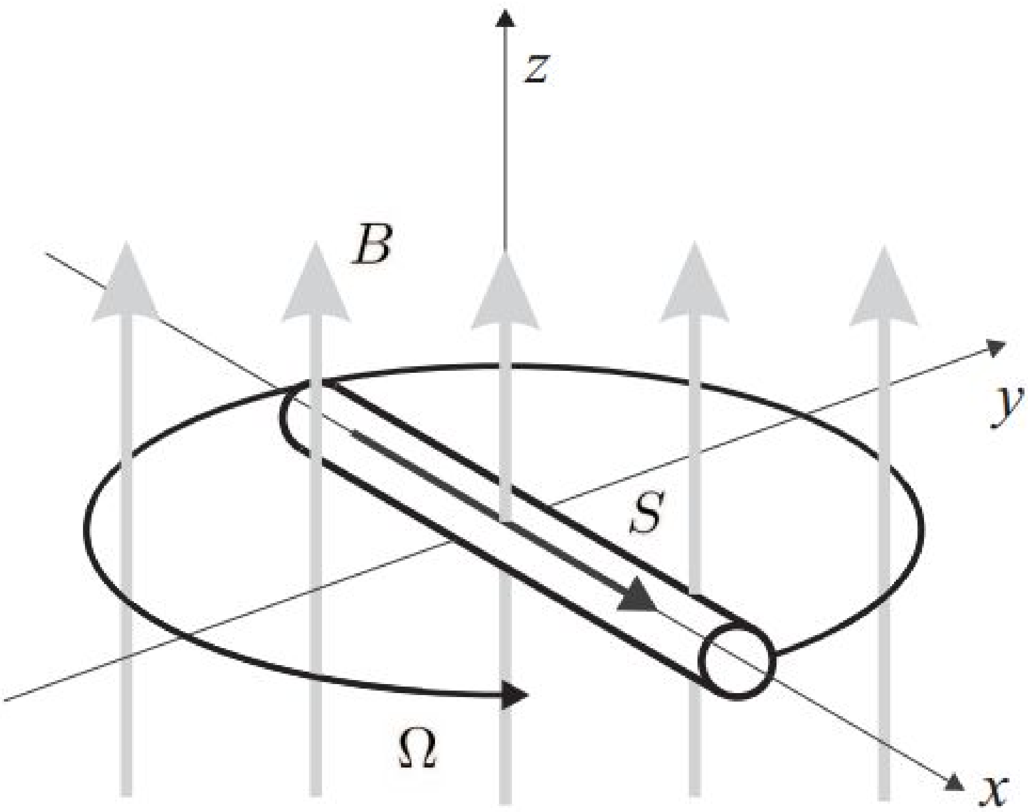

A ferromagnetic needle with spin S = N~ along its long axis precesses at a frequency Ω in a magnetic field B ≪ B*. Credit: arXiv:1602.02818 [quant-ph]

(Phys.org)—A team of researchers with members from several institutions in the U.S. and one in Germany has proposed the idea of using an extremely small compass needle to build an ultrasensitive magnetometer. In their paper published in *Physical Review Letters*, the team describes their idea and the possibility of such a device actually being built.

Current magnetometers are very sensitive, able to detect levels of magnetism that are approximately a trillion times less than that of the Earth's magnetic field. They achieve this feat by taking advantage of the wobble that occurs when an atom is placed in a magnetic field—such magnetometers are made by placing cells of atomic gas in a magnetic field, the wobbles of the atoms are averaged to arrive at a single measurement. In this new effort, the researchers suggest that a new way to measure magnetic fields could be perhaps as much as 1000 times more sensitive.

The idea behind the still theoretically magnetometer comes from the way a compass needle works—instead of wobbling when exposed to a magnetic field, it simply lines up—at least when viewed from a distance. The researchers have shown that such needles do actually wobble like atoms, when they are very small and placed in a very weak magnetic field. They envision a very tiny needle made of cobalt with all of its atoms aligned in a single direction. When the needed is placed in a weak magnetic field, the angular momentum of the rotation of the needle would be a lot smaller than its intrinsic spin angular momentum, which means it would precess, very much like single atoms do. Measuring the precess then would offer a means of measuring the level of magnetism.

Constructing such a magnetometer they acknowledge, would be challenging. The team believes their needle would be approximately 10 micrometers long, with a radius of 1 micrometer. The trick would be in isolating such a needle from external noise. It would have to be held at a very low temperature, somehow protected from detecting the Earth's magnetic field, and be held without being touched, perhaps levitated by a superconductor. Measuring the precess would be tricky was well, likely requiring a super-conducting quantum interference device, which would likely also be the limiting factor in the final product.

More information: Derek F. Jackson Kimball et al. Precessing Ferromagnetic Needle Magnetometer, *Physical Review Letters* (2016). DOI: 10.1103/PhysRevLett.116.190801 , On *Arxiv*: arxiv.org/abs/1602.02818

ABSTRACT
A ferromagnetic needle is predicted to precess about the magnetic field axis at a Larmor frequency Ω under conditions where its intrinsic spin dominates over its rotational angular momentum, $N\hbar \gg I\Omega$ (I is the moment of inertia of the needle about the precession axis and N is the number of polarized spins in the needle). In this regime the needle behaves as a gyroscope with spin $N\hbar$ maintained along the easy axis of the needle by the crystalline and shape anisotropy. A precessing ferromagnetic needle is a correlated system of N spins which can be used to measure magnetic fields for long times. In principle, by taking advantage of rapid averaging of quantum uncertainty, the sensitivity of a precessing needle magnetometer can far surpass that of magnetometers based on spin precession of atoms in the gas phase. Under conditions where noise from coupling to the environment is subdominant, the scaling with measurement time t of the quantum- and detection-limited magnetometric sensitivity is t−3/2. The phenomenon of ferromagnetic needle precession may be of particular interest for precision measurements testing fundamental physics.