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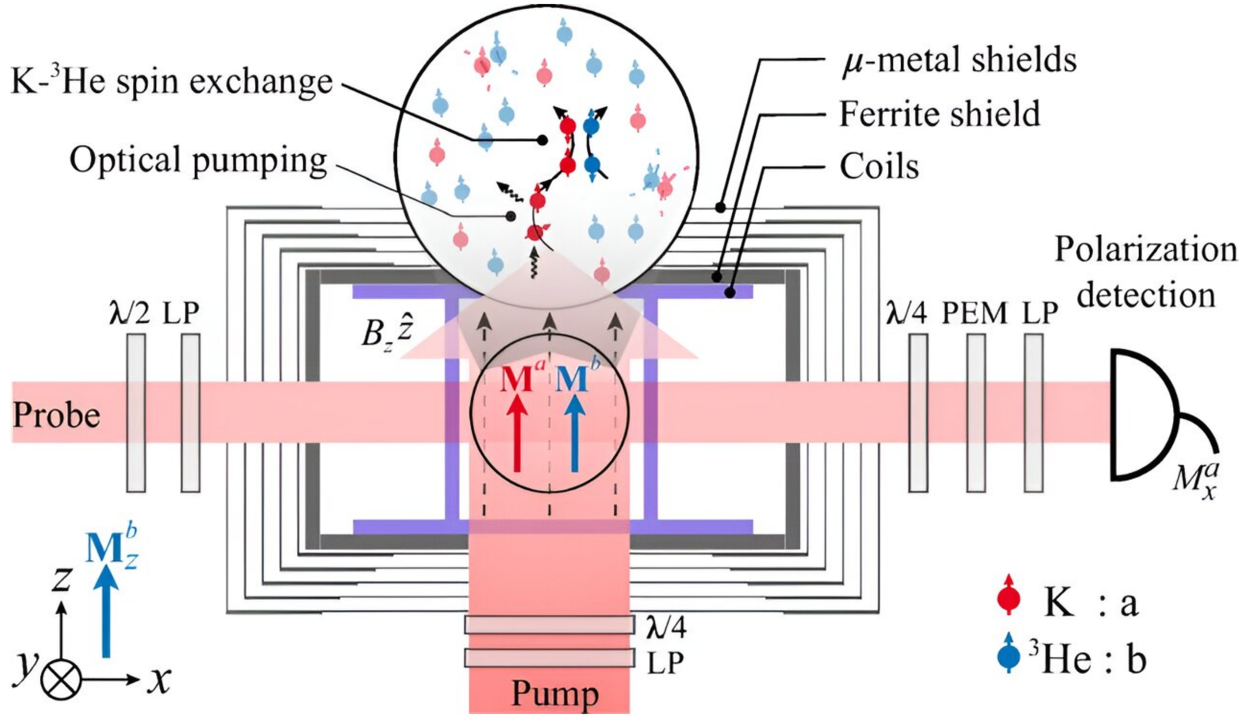
Research team develops atomic comagnetometer that suppresses noise by two orders of magnitude

August 27 2024



Schematic of magnetic noise self-compensation experiment. Alkali-metal and noble-gas atoms are initially polarized along □□. Alkali spins are probed along □□. The spin-exchange coupling leads to an effective field experienced by alkali spins. The noble-gas response to magnetic noise interferes with the alkali-metal response via the effective field. The magnetic noise is self-compensated when such interference is destructive. LP, linearly polarizer; □□/4, quarter-wave plate; PEM, photoelastic modulator. Credit: *Physical Review Letters* (2024). DOI: 10.1103/PhysRevLett.133.023202

A research team has discovered the Fano resonance interference effect between mixed atomic spins. They proposed a novel magnetic noise suppression technique, reducing magnetic noise interference by at least two orders of magnitude. The study was published in *Physical Review Letters*. The team was led by Prof. Peng Xinhua and Associate Prof. Jiang Min from the University of Science and Technology of China (USTC) of the Chinese Academy of Sciences (CAS)

In the past few decades, exotic spin interactions beyond the standard model of particle physics have attracted widespread attention in the field of precision measurement. These exotic spin interactions cover many frontier areas, such as searching for spin-dark matter particle interactions, the fifth force, etc. In these precision experiments, exotic interactions are equivalent to magnetic fields acting on spins, and extremely weak magnetic field measurement techniques provide a new means for testing such weak magnetic field signals.

However, the magnetic field signals in these studies are extremely weak and often masked by noise backgrounds, especially susceptible to interference such as magnetic noise. Although atomic comagnetometers can use two different spins to reduce the effects of magnetic field drift and fluctuations, previous atomic comagnetometers have only been effective for low-frequency magnetic noise (less than 1Hz), which severely hinders the experimental search for exotic spin interactions in a vast unexplored parameter space.

The research team has developed a magnetic noise suppression method based on magnetic noise self-compensation effects, and experimentally verified it in a mixed system of potassium (K) and ^{3}He gases. In this system, K polarized by lasers served as a means of polarization and readout for the nuclear spin of ^{3}He, achieving their polarization through spin-exchange collisions.

In previous experiments, the bias magnetic field was typically set to be equal in magnitude but opposite in direction to the equivalent field produced by He atoms. The nuclear spin of He could adiabatically follow the external low-frequency magnetic noise, thereby achieving suppression effects. Researchers found that while changing the magnitude of the bias field, effective suppression of higher frequency magnetic noise can be achieved by adjusting the angle between the detection direction and the external specific frequency magnetic noise.

Moreover, this approach provided a complete and accurate theoretical explanation for the experimental phenomenon from a new perspective of Fabry-Perot resonance interference cancelation. Researchers have demonstrated the suppression of magnetic noise from near direct current to up to 200Hz using the self-compensation effect of magnetic noise, with the suppression multiples all exceeding two orders of magnitude.

This work further indicated that, if the sensitivity of magnetic detection was limited, utilizing this self-compensation effect of magnetic noise was expected to enhance the sensitivity to pseudomagnetic fields by an order of magnitude. In other words, it reached a level of $0.1 fT/Hz^{1/2}$ over a broader frequency range. The study will benefit areas such as dark matter detection and exotic spin interactions in fundamental physics research.

More information: Yushu Qin et al, New Classes of Magnetic Noise Self-Compensation Effects in Atomic Comagnetometer, *Physical Review Letters* (2024). DOI: 10.1103/PhysRevLett.133.023202

Provided by University of Science and Technology of China

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