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Ultrasensitive magnetometer using a single atom

CHRISTOF WUNDERLICH, University of Siegen

Precision sensing, and in particular high precision magnetometry, is a central goal of research into quantum technologies. The precision, and thus the sensitivity of magnetometry scales as $1/\sqrt{T_2}$ with the phase coherence time T_2 of the sensing system. Typical quantum sensing protocols prolong T_2 of the quantum states used for sensing by using dynamical decoupling (DD), that is, applying a continuous or pulsed electromagnetic driving field. In the case of pulsed DD, the required repetition rate of pulses – with each pulse having a well defined pulse area – is proportional to the frequency of the field to be detected with high sensitivity, thus effectively limiting the frequency range of the sensor. To achieve a long coherence time T_2 using continuous DD, the amplitude of the driving field has to be kept highly stable for time T_2, another technologically challenging problem. Here, we implement a decoupling scheme using two continuous decoupling fields in an atomic 4-level scheme. Thus, the coherence time is no longer limited by fluctuations of the amplitude of the decoupling fields. Instead, T_2 is determined by the frequency stability of the driving fields which is straight forward to maintain with high precision using, for instance, a commercial atomic clock. Using a single trapped $^{171}\mathrm{Yb}^{+}$ ion as a sensor, we experimentally attain a sensitivity of 4.6 pT $/\sqrt{\mathrm{Hz}}$, to our knowledge the best sensitivity so far realized with a single atom [1]. The detected magnetic field is an alternating-current (AC) magnetic field near 14 MHz. Based on the principle demonstrated here, this unprecedented sensitivity together with its tuneability from direct-current to the gigahertz range could be used for magnetic imaging in as of yet inaccessible parameter regimes.

[1] I. Baumgart, J.M. Cai, A. Retzker, M.B. Plenio, C. Wunderlich, Phys. Rev. Lett. **116**, 240801 (2016).