Helium-3 magnetometers for high fields

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While low magnetic fields ($< 10^{-2}$ T) can be measured extremely precisely (ca. 10^{-13}) by SQUID or SERF, nuclear magnetic resonance offers the highest precision at high fields. Furthermore, it can be shown that the highest metrological accuracy is reached for continuous measurements of frequencies. Therefore one needs a sample with long coherence times, as it is the case for motionally averaged signals of gases. A state that requires only a few millibar of the gas, hence requires hyperpolarization of the nuclear spins even at high fields. Helium-3 is the ideal candidate for this purpose, because it can be hyperpolarized (either by metastability optical pumping [1] or using the PAMP-effect [2]), shows only minimal interactions with the environment and its gyromagnetic ratio has been determined independently using Penning-traps [3]. Another requirement to obtain such extremely long lasting signals (T_2^* times in the order of 100 - 200 s) is to keep the sample in suitable containers to minimize susceptibility and relaxation effects [4], ideally this even allows for absolute field measurements.
While hyperpolarized ^{3}He at low pressures offers extreme precision magnetometry ($< 10^{-12}$), we recently also produced high pressure (up to 50 bar) ^{3}He samples for applications in which optical polarization is cumbersome. Such thermally polarized samples can serve as very simple magnetometers and may be used over a very broad temperature range (1-300 K).
Taken together, ^{3}He-magnetometers have the potential to become the new standard for high precision magnetometry at high magnetic fields.

[1] A. Nikiel, P. Blümler, W. Heil, et al., Ultrasensitive ^{3}He magnetometer for measurements of high magnetic fields, Eur. Phys. J. D **68**:330, 1-12 (2014).
[2] A. Maul, P. Blümler, P.-J. Nacher, E. Otten, G. Tastevin, W. Heil, Nuclear hyperpolarization of ^{3}He by magnetized plasmas, Phys. Rev. A **98**, 063405 (2018).
[3] A. Schneider, B. Sikora, S. Dickopf, et al., Direct measurement of the $^3He^+$ magnetic moments, Nature **606**, 878–883 (2022).
[4] A. Maul, P. Blümler, W. Heil, et al., Spherical Fused Silica Cells Filled with Pure Helium for NMR-Magnetometry, Rev. Sci. Instr. **87**, 015103 (2016).