Spin-Dependent Sensors

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Physics possibilities with Spin-based quantum sensors:

Precision experiments can detect extremely subtle energy shifts at energy scales ~10^{-26} eV

Tests of fundamental physics, complimentary to large-scale detectors and colliders

- Symmetry violating electromagnetic moments aligned with particle spins
- Exotic spin-dependent forces
- Coupling of spins to ultralight bosonic dark matter fields
- Changes to the local environment that affect spins

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Quantum sensors for high precision measurements of spin-dependent interactions

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ABSTRACT

The applications of spin-based quantum sensors to measurements probing fundamental physics are surveyed. Experimental methods and technologies developed for quantum information science have rapidly advanced in recent years, and these tools enable increasingly precise control and measurement of spin dynamics. Theories of beyond-the-Standard-Model physics predict, for example, symmetry violating electromagnetic moments aligned with particle spins, exotic spin-dependent forces, coupling of spins to ultralight bosonic dark matter fields, and changes to the local environment that affect spins. Spin-based quantum sensors can be used to search for these myriad phenomena, and offer a methodology for tests of fundamental physics that is complementary to particle colliders and large scale particle detectors. Areas of technological development that can significantly enhance the sensitivity of spin-based quantum sensors to new physics are highlighted.

1 Executive Summary

There are disparate profound mysteries in fundamental physics, ranging from the nature of dark matter and dark energy to the origin of the matter-antimatter asymmetry of the

Overview

1. New physics may break symmetries of the Standard Model: Novel responses of Standard Model spins to other Standard Model fields
    a. EDM searches
2. New physics may directly affect the spin: e.g. via an interaction between a new field and the spin
    a. Searches for exotic spin-dependent interactions with (co)magnetometry
    b. Spin-based sensor networks
    c. Magnetic resonance searches for ultralight bosonic dark matter searches
3. Spins as sensors of changes to the environment: the environment of the spin may be affected by the new physics
    a. Spin-based sensors as dark matter particle detectors

Priorities

- Enhance number of polarized spins N
  - Shot-noise limited sensitivities proportional to 1/sqrt(N)
  - Optical pumping and other quantum control techniques
- Increase spin-coherence times τ
  - Scales as 1/sqrt (τ)
- Develop new techniques and schemes, e.g.
  - quantum back-action evasion and rapid averaging of qu uncertainty in highly correlated spin systems (e.g. ferromagnets)
  - New systems, e.g. non-centrosymmetric crystals, polyatomic molecules, and deformed nuclei
  - Better control of systematic errors and spurious technical noise,
    - comagnetometers and quantum sensor networks
  - increase the bandwidth
  - speed up the scanning rate of dark matter haloscope searches
  - spin-based sensors at smaller length scales to probe higher mass exotic bosons