Long coherence of electron spins coupled to a nuclear spin bath

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Overview

GaAs quantum dot using Carr-Purcell-Meiboom-Gill echo sequence:

\[ T_2 > 200 \, \mu s \]
**Hyperfine Interaction:**

- interaction of the electron spin with the nuclear spins
- Overhauser field \( B_N \propto \frac{1}{\sqrt{N}} \)
- \( B_N^z \) directly changes the precession frequency of the electron spin by \( g\mu_B B_N \)
- Orientation and magnitude of \( B_N \) change over time
→ electron spin picks up a random phase

\[
T_2^* = \frac{\hbar}{g\mu_B \sqrt{2\langle(B_N^z)^2\rangle}} \approx 10\text{ns}
\]

But nuclear spins evolve much slower than electron spins...
Hahn-Echo (Petta et al.) $\rightarrow T_2 \approx 1\mu s @ 100mT$:

random contributions of $B_N$ to the electron spin precession before and after the spin reversal approximately cancel out.
Petta et al. \( \rightarrow T_2 \approx 1 \mu s \) @ 100mT

**But:**

- theory predicts revivals of several \( \mu s \)
  \( \rightarrow \) initial decay is due to coherent Lamor precessions of the nuclei

- theory predicts longer coherence time at higher magnetic fields

- improvement with better controlled pulses

- improvement with advanced pulse cycles
**Experiment:**

- GaAs double quantum dot with QPC

→ measure the singlet-state probability
revival peaks when $\tau/2$ is a multiple of the three Lamor precession frequencies of the nuclei.

$T_2 \approx 30\mu\text{s} @ 700\text{mT}$

(including compensation of drifts)
Repeated measurements of the echo signal:

- **unoptimized**: position of the maximum of the echo signal fluctuates on a timescale typical for nuclear fluctuations

- **optimization**: only the width of the maximum fluctuates

\[ T_2 \approx 30\mu s \text{ @ } 700mT \]

(including compensation of drifts)
Carr-Purcell-Meiboom-Gill echo:

n-fold repetition of the Hahn-echo
$T_2 > 200\mu$s

(without compensation of drifts)