Università degli Studi di Padova

Dipartimento di Fisica e Astronomia Galileo Galilei

PULSED NUCLEAR MAGNETIC RESONANCE: SPIN ECHOES

Laboratory Report

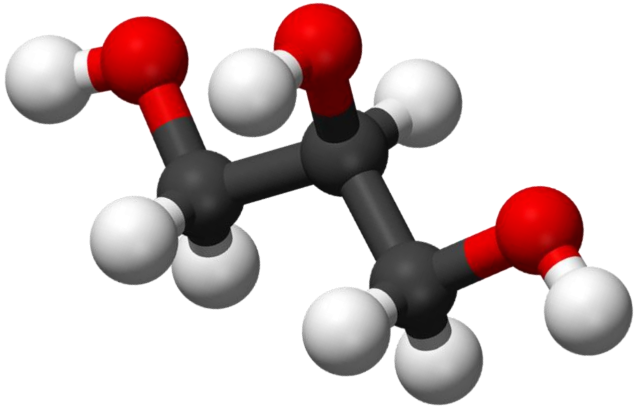
May 16 2025

Introduction to Quantum Hardware

Prof. Caterina Braggio
Prof. Carmelo Mordini

Alessandro Miotto

Experimental parameters

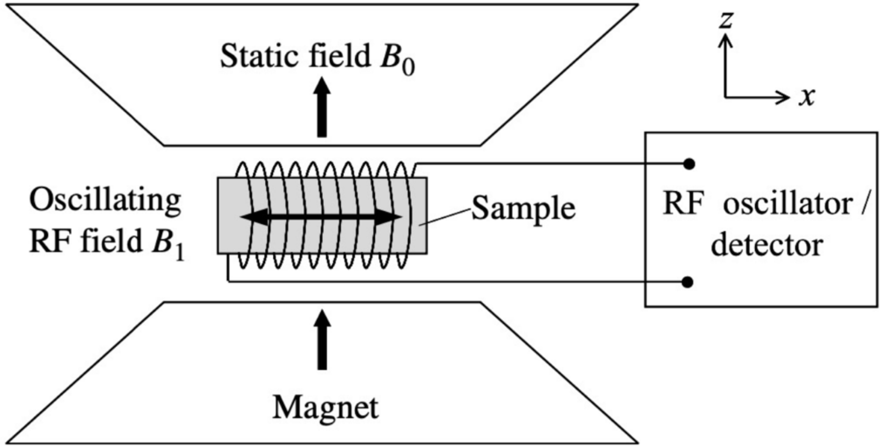


Sample: glicerine $C_3H_8O_3$

molar mass: 92.09382 g/mol
density: 1.26 g/cm^3

cylindrical container:

- **height:** 19 mm
- **radius:** 4.5 mm



Electromagnet: BE 15

current: $I = 8.129$ A
magnetic field: $B_0 = 0.526$ T

Larmor frequency:

$\omega_L = \gamma B_0 = 22.39$ MHz

$\gamma = 42.58$ MHz/T

Spin-lattice relaxation T_1

The longitudinal nuclear magnetic moment returns to thermodynamic equilibrium through a relaxation process. In fluids, $T_1 \simeq \mathcal{O}(1\ \mathrm{s})$

$$M_z(t) = M_0(1 - e^{-t/T_1})$$

Spin-spin relaxation T_2

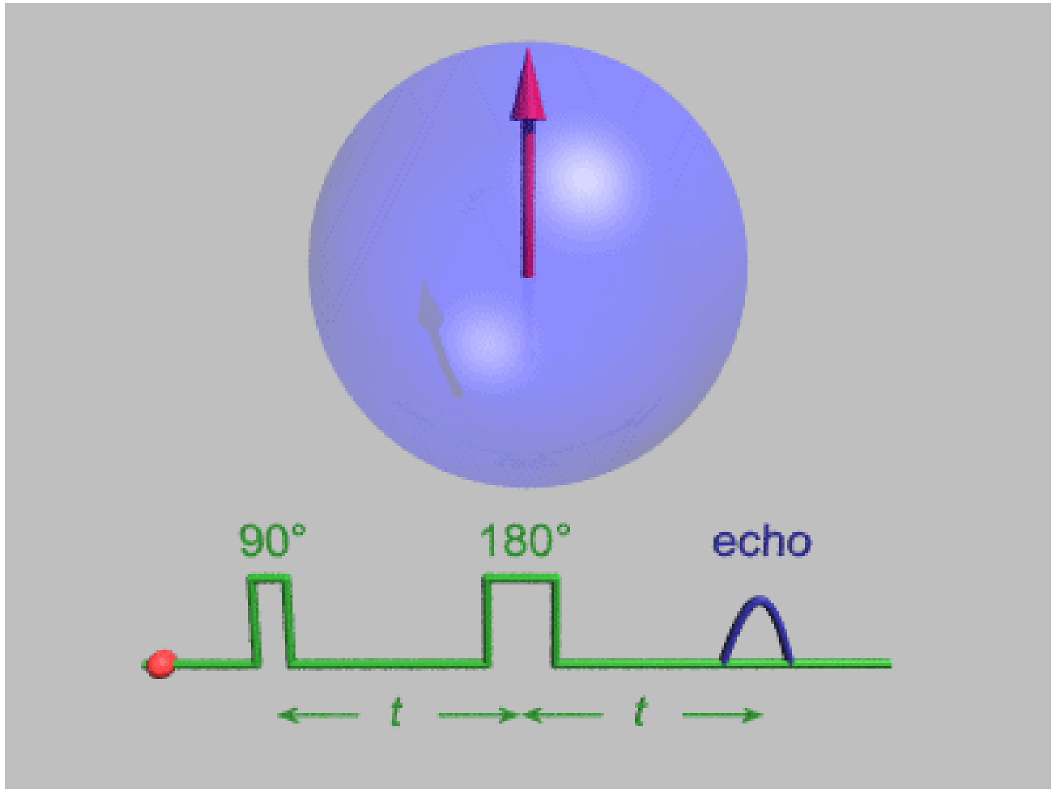
The transverse component of the nuclear magnetic moment relaxes due to dipole-dipole interaction with neighboring spins. In fluids, $T_2 \simeq \mathcal{O}(10\ \mathrm{ms})$

$$M_{xy}(t) = M_0 e^{-t/T_2}$$

FREE INDUCTION DECAY

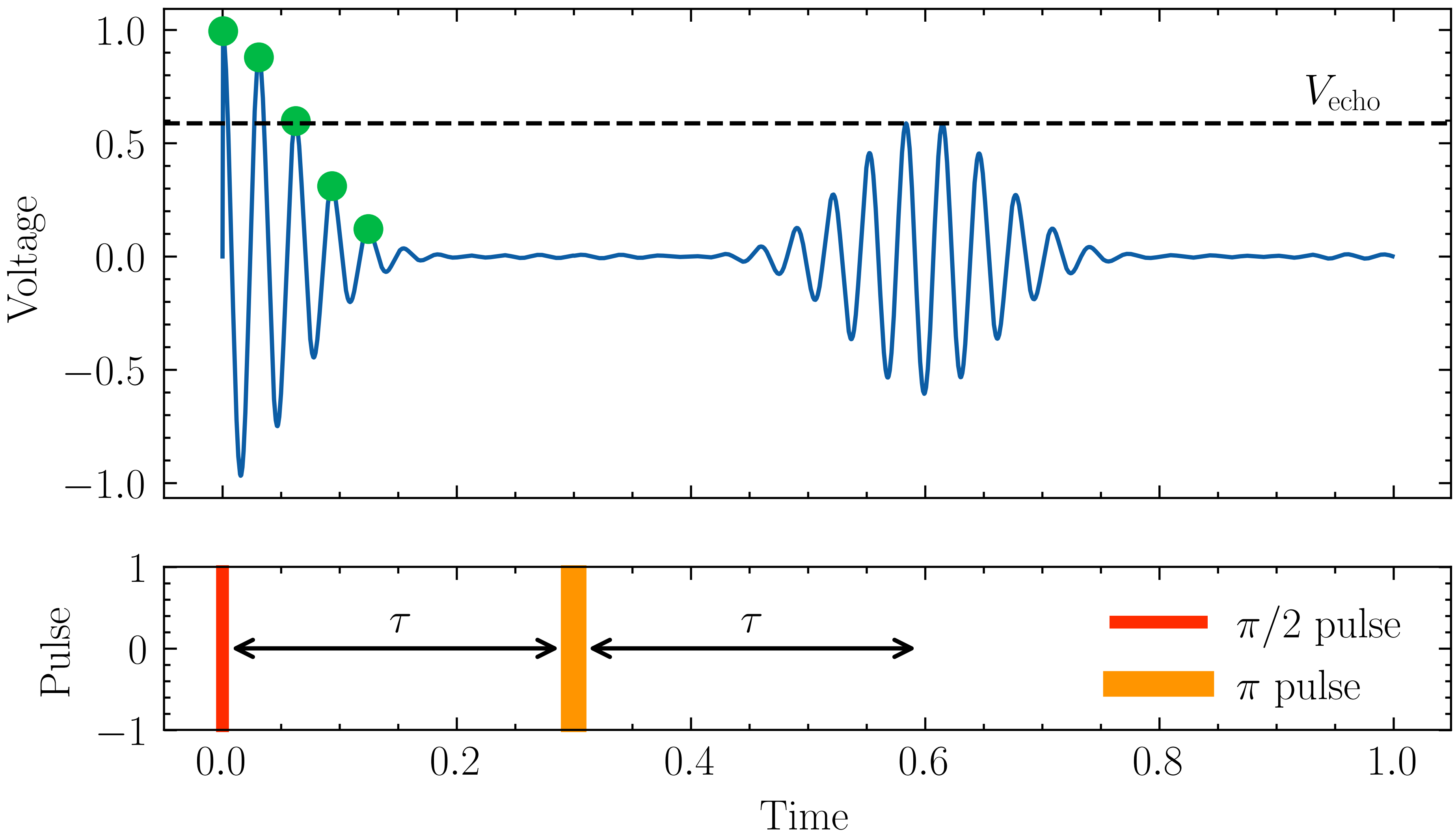
Inhomogeneties in the external magnetic field ΔB_0 can increase the relaxation time T_2:

$$\frac{1}{T_2^*} = \frac{1}{T_2} + \frac{1}{T_1} + \gamma\Delta B_0 \approx \frac{1}{T_2} + \gamma\Delta B_0$$

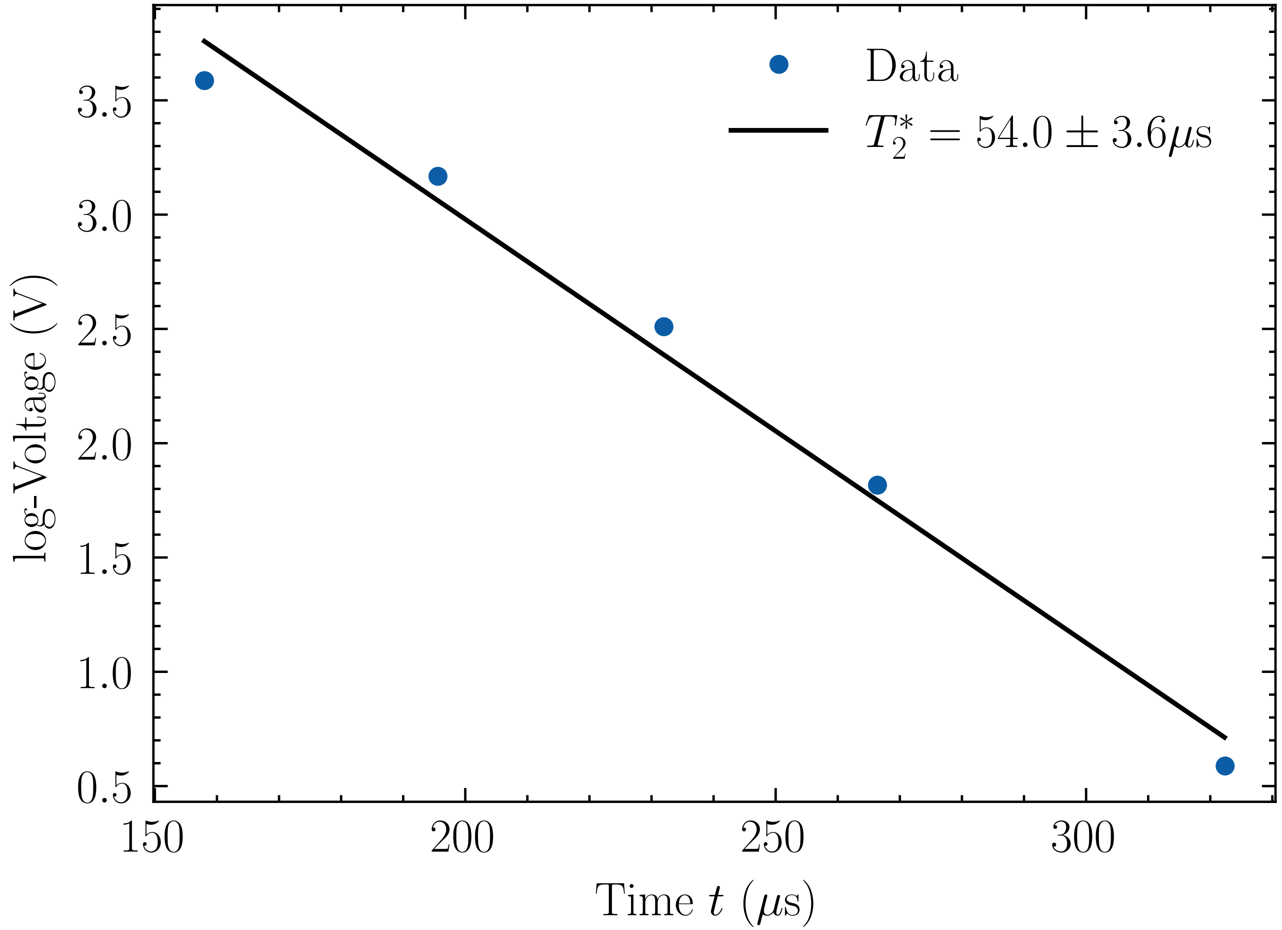


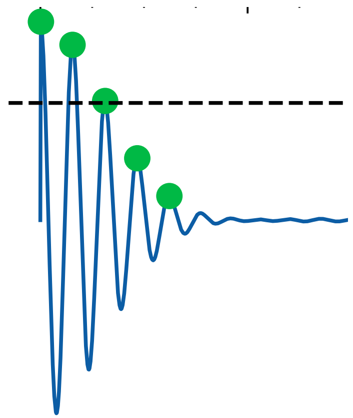
A spin echo (also known as a Hahn echo) is a sequence of pulses that can reverse the effects of magnetic field inhomogeneities

Numerical simulation



Experimental results: free induction decay





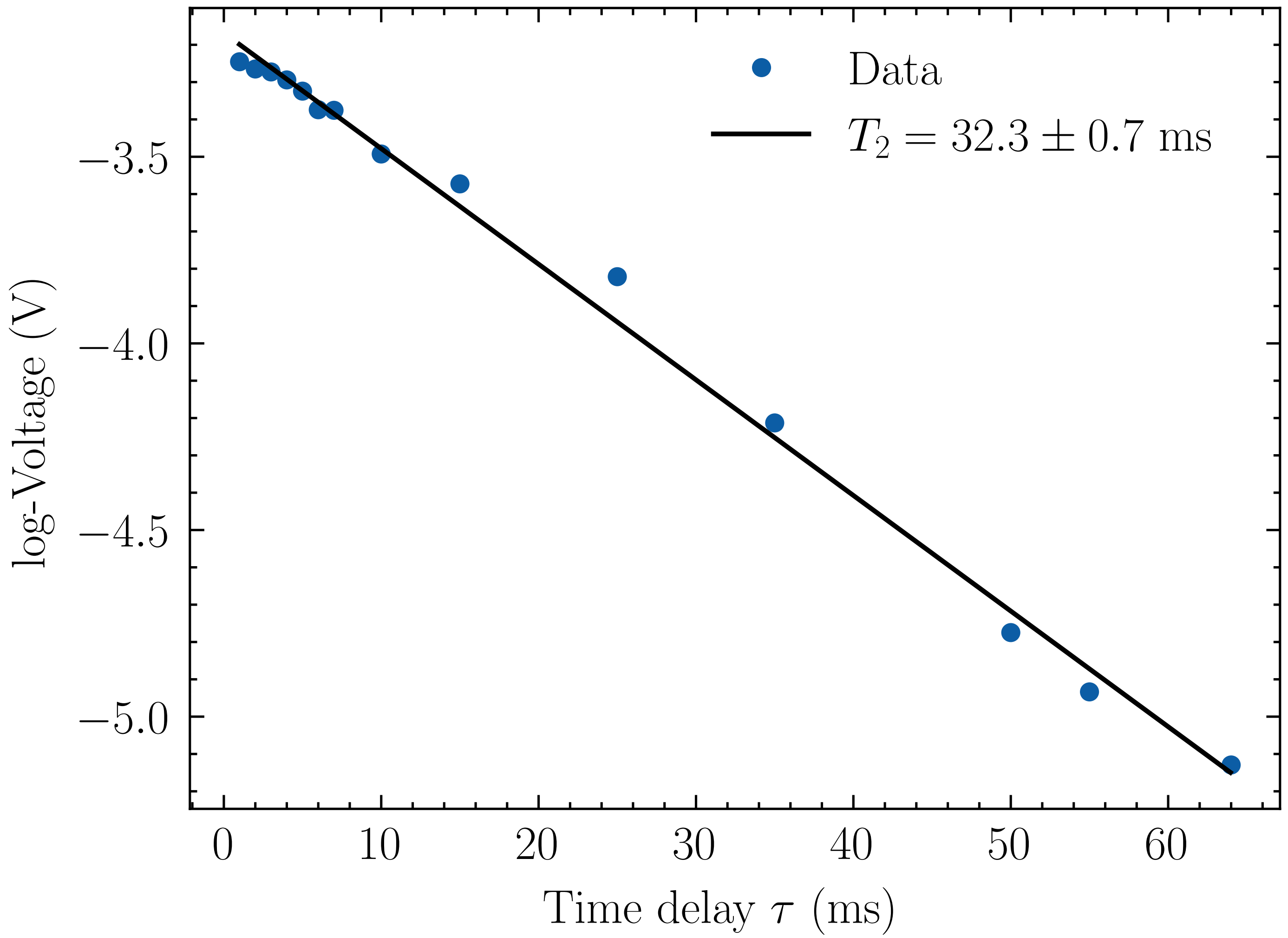
t (μs)	V (V)
158.0	36.10
195.6	23.75
232.0	12.30
266.4	6.15
322.4	1.80

$$V(t) = V_0 e^{-t/T_2^*}$$

$$\log V(t) = \frac{1}{T_2^*} t + \log V_0$$

$$\boxed{T_2^* = 54.0 \pm 3.6\ \mu s}$$

Experimental results: echo



τ (ms)	V_{echo} (V)
1.0	36.00
2.0	37.10
3.0	37.90
4.0	38.20
5.0	38.95
6.0	34.25
7.0	34.20
10.0	30.42
15.0	28.08
25.0	21.90
35.0	14.80
50.0	8.44
55.0	7.20
64.0	5.92

$$\boxed{T_2^* = 32.3 \pm 0.7 \text{ ms}}$$

Experimental results

$$\frac{1}{T_2^*} \approx \frac{1}{T_2} + \gamma \Delta B_0$$

$$\boxed{\Delta B_0 = 4.34 \pm 0.15\ \mathrm{G}}$$

$\mathrm{B_0} = 0.526\ \mathrm{T}$
$\Delta B_0/B_0 = 8.2 \times 10^{-4}$

$\mathbf{B_0}$ (T)	$\mathbf{\Delta B_0/B_0}$	**Gap** (mm)
0.1	1×10^{-4}	30
0.5	1×10^{-4}	50
0.5	5×10^{-4}	80
1.0	1×10^{-4}	30

BE 15 electromagnet datasheet