F61: Nuclear Magnetic Resonance

T. Gierlich und A. Impertro

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Outline

Introduction

- **Nuclear:** Interaction of the nuclear spin...
- **Magnetic:** ...with magnetic fields
- **Resonance:** $\rightarrow$ resonant interaction
- **Spectroscopy:** Resolve the different signal components

Applications

- Non-destructive detection of substances in a sample
- Determination of molecular structures and dynamics
- Multidimensional imaging

Theoretical Concepts - Working Principle

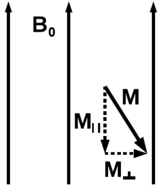

Figure: Magnetization

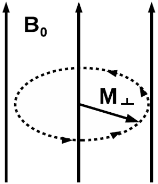

Figure: Larmor-Precession of $M_\perp$

- Nuclei with spin J have a magnetic moment μ
- Minimal energy $\rightarrow$ Dipole aligned parallel to B-field
- Ensemble of many nuclei: Measurable magnetization $\vec{M}$
- Ground state $\rightarrow M_\perp = 0$

- Excited states have a component $M_\perp \neq 0$
- $M_\perp$ precesses around the field lines with the Larmor frequency

$$\omega_L = \gamma B_0 \tag{1}$$

- ω_L can be measured!

Theoretical Concepts - Working Principle

How can we create an excited state ?

- An oscillating B-Field $\vec{B}_1$ rotates the magnetization $\vec{M}$ by an angle

$$\alpha = \gamma B_1 \Delta t \tag{2}$$

- By choosing Δt, we can create:
  - A perpendicular magnetization (90°-Pulse)
  - An anti-parallel magnetization (180°-Pulse)

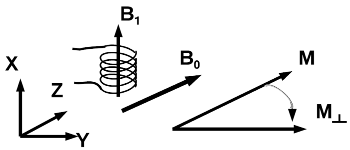

Figure: Rotation of M due to a HF-Pulse

Theory of Relaxation

Excited states decay into the Ground State on a characteristic timescale.
The decay is of exponential nature and described in the *Bloch equations:*

$$\frac{dM_\perp(t)}{dt} = -\frac{M_\perp(t)}{T_2} \tag{3}$$

$$\frac{dM_\parallel(t)}{dt} = -\frac{M_\parallel(t) - M_0}{T_1} \tag{4}$$

- T_2: Spin-Lattice Relaxation
- T_1: Spin-Spin Relaxation

T_2-Measurement: Spin Echo

Spin-Echo principle

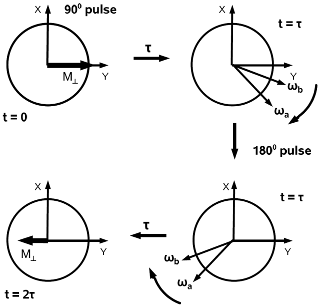

Figure: Principle of the spin-echo method

Pulse sequence

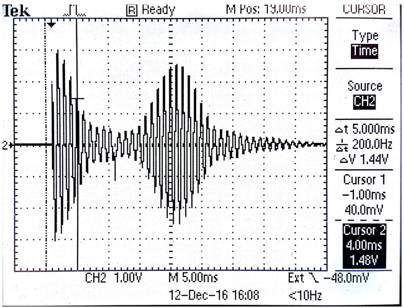

Figure: Spin-Echo measurement with $\tau = 10ms$

- **Disadvantage**: Dephasing for long measurement times!

T_1-Measurement: Spin Echo

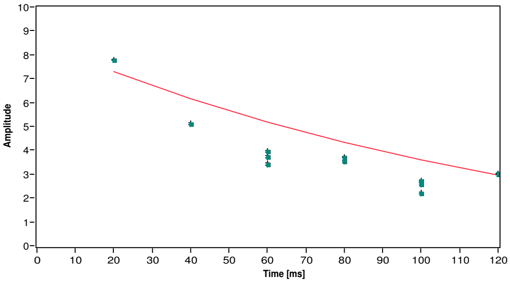

Figure: T2-Messung Probe 1 mit Fit.

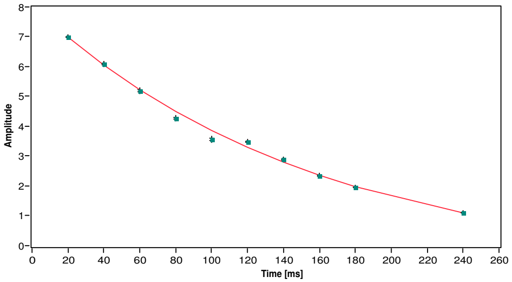

Figure: T2-Messung Probe 3 mit Fit.

T_2-Measurement: Carr-Purcell Sequence

Improve dephasing problem of spin-echo method:

- Inject a 180°-Pulse on odd multiples of a time τ.
- The system is phase coherent on even multiples of a time τ.

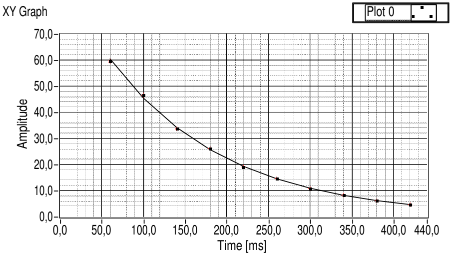

Figure: T2-Messung über Carr-Purcell Probe 1 mit Fit.

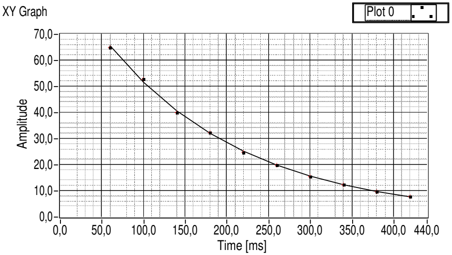

Figure: T2-Messung über Carr-Purcell Probe 3 mit Fit.

T_1-Measurement: Spin Echo

Spin-Echo, but start with a $180°$-Pulse (Anti-parallel Magnetization)

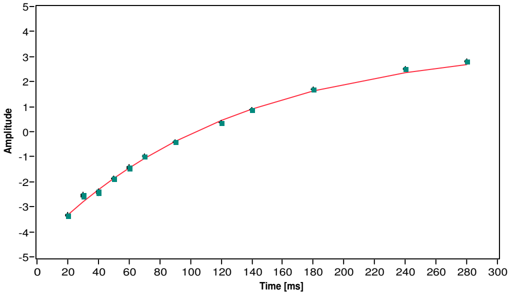

Figure: T1-Messung Probe 1 mit Fit.

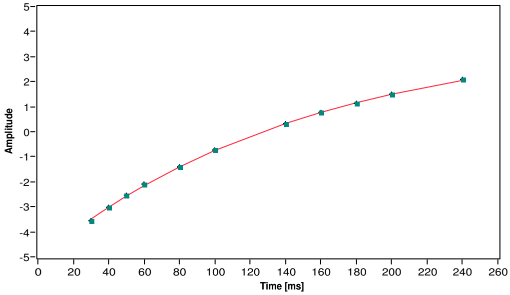

Figure: T1-Messung Probe 3 mit Fit.

Relaxation Times: Evaluation

Table: Relaxation times: Measured values

Zeit Methode	T_1 $[\mathrm{ms}]$ Spin-Echo	T_2 $[\mathrm{ms}]$ Spin-Echo	T_2 $[\mathrm{ms}]$ Carr-Purcell
Probe 1 (Gd 1:500)	$(125,5 \pm 0,6)$	$(119,5 \pm 0,5)$	$(140,1 \pm 0,4)$
Probe 3 (Gd 1:600)	$(150,5 \pm 1,2)$	$(139,3 \pm 0,8)$	$(166,9 \pm 0,4)$