

TU DRESDEN

ADVANCED PRACTICAL COURSE

LAB REPORT

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# Nuclear Magnetic Resonance

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# 1 Introduction

## 1.1 Motivation

*Nuclear Magnetic Resonance* is a physical phenomenon that can be observed while placing an ensemble of nuclei into a static magnetic field and stimulate it with a high-frequent alternating field. A necessary condition for this effect is that the atoms of the sample have a *nuclear spin* different from zero. It is the central concept that is used for *NMR-Spectroscopy*, a standard methodology for the investigation of the structure and interaction of complex molecules and solid state bodies by measuring local magnetic fields, and the *magnetic resonance tomography* which is an imaging technique used in clinical diagnostics for describing the morphologic and physiologic build-up of tissues and organs. For all of those applications some important parameters of particular physical compensation-processes, the so called *relaxation times*  $T_1$  and  $T_2$  need to be quantified. In the following experiment exactly those material-characteristic observables are determined for an ensemble of  $^{57}\text{Fe}$ -nuclei. But at first some basic knowledge.

## 1.2 Nuclear Zeeman-Effect

Every quantum mechanic angular momentum - especially every spin - is correlated with a magnetic moment  $\mu$ . The proportionality factor is called the *gyromagnetic ratio*  $\gamma$ . So the intrinsic magnetic momentum matching to the nuclear spin  $\vec{I}$  considered in the experiment is given by:

$$\vec{\mu} = \gamma \vec{I} \quad (1)$$

$$\gamma = g_I \frac{\mu_N}{\hbar} \stackrel{^{57}\text{Fe}}{=} 0.8661 \cdot 10^7 \text{ T}^{-1} \text{ s}^{-1} \quad (2)$$

Where  $\mu_N$  is the *nuclear magneton* and  $g_I$  is the Landé-factor which both are core-specific parameters. If those magnetic moments are placed in a static magnetic field  $\vec{B} = B\vec{e}_z$  then the Hamiltonian of the system and its Eigenvalues to the Eigenstates of the spin-operator  $|I, m_I\rangle$  are given by:

$$\mathcal{H} = -\vec{\mu}\vec{B} \stackrel{(1)}{=} -\gamma \mathcal{I}_z B \quad (3)$$

$$\langle \mathcal{H} \rangle = \langle I, m_I | \mathcal{H} | I, m_I \rangle = -\gamma B \langle I, m_I | \mathcal{I}_z | I, m_I \rangle = -\gamma B \hbar m_I \equiv E_{m_I} \quad (4)$$

Where the Eigenvalues of the Spin-operator for given spin-quantumnumber  $I$  and magnetic quantum number  $m_I = -I, \dots, I$  were used. So the outer magnetic field annuls the  $2I + 1$ -fold degeneration of the energystates. The nuclear spin-quantum-number of  $^{57}\text{Fe}$  is  $I = 1/2$  so there are two additional energystates with a energydifference:

$$\Delta E = \hbar \gamma B = \hbar \omega_L \quad (5)$$

As equation (5) suggests, there may occur optical transitions between the terms which lead to an emission of photons with the angular frequency  $\omega_L$ . One finds that this frequency is equivalent to the *Larmor-Frequency* that describes the precession of a magnetic moment around the z-axis caused by the torsional moment  $\vec{M} = \vec{\mu} \times \vec{B}$  in a magnetic field. The classical description of this process leads to the same result as quantum mechanics do. If we consider the ensemble of  $N$  nuclei as canonical, then the number of spins in the state  $|s, m_I\rangle$  in the thermodynamic equilibrium is given by the Boltzman-statistics:

$$N(m_I) = N \cdot \frac{e^{-\frac{E_{m_I}}{k_B T}}}{Z} = N \cdot \frac{e^{-\frac{\hbar \gamma B m_I}{k_B T}}}{Z} \quad (6)$$

Where  $Z = \text{const.}$  is the canonical partition function and  $T$  is the absolute temperature of the environment. This implies that the spins prefer to be polarised not uniformly but in the direction

of the B-field so this leads to a mean magnetic moment  $\langle \vec{\mu} \rangle \neq 0$ . This leads to an observable macroscopic magnetisation in the volume  $V$ :

$$\vec{M} = \frac{d\vec{\mu}}{dV} \cong \frac{N}{V} \langle \vec{\mu} \rangle \neq 0 \quad (7)$$

These changes in magnetisation are used to induce voltages that can be measured.

### 1.3 Nuclear Magnetic Resonance

If the spins are just inside of a static magnetic field along the z-axis then they precess around this axis with an angular frequency of  $\omega_L$ . In the next step an alternating magnetic field  $\vec{B}_{RF} = B_{RF} \sin(\omega t) \vec{e}_x$  is applied to the spins additionally. If we consider *resonance* of the Larmor-precession and the radio-frequency field, i.e.  $\omega = \omega_L$ , then we can rotate the magnetisation around the x-axis by an angle of  $\alpha = \gamma B_{RF} t$  where t is the time the RF-field is applied.

## 2 Experimental procedure

The following task had to be done:

**2.1:** Preparation of a radio frequency resonant circuit with the insertion of an iron powder probe in a cryostat

**2.2:** Find the nuclear spin resonance by varying the NMR-pulse frequency while recording a spectrum of the  $^{57}\text{Fe}$  nuclear spin ensemble and calculation of the local magnetic field

**2.3:** Optimization of the pulse sequence by recording a rotation angle curve

**2.4.2:** Find the spin-spin- and spin-lattice relaxation constants  $T_2$  and  $T_1$ .

### 2.1 Preparation of a high frequency resonant circuit

First one has to prepare a copper coil with a diameter big enough to hold an iron powder assay. After the coil is wrapped one has to solder it onto the contacts of a stick, which provides a mechanism to tune the measured frequency to find the resonance frequency. While soldering one has to be careful to make sure, that one does not take too much tin, because the resistances of tin and copper are different. In the same way the soldered point should connect the contact and the coil directly, otherwise this could influence the results while tuning to the resonance frequency.

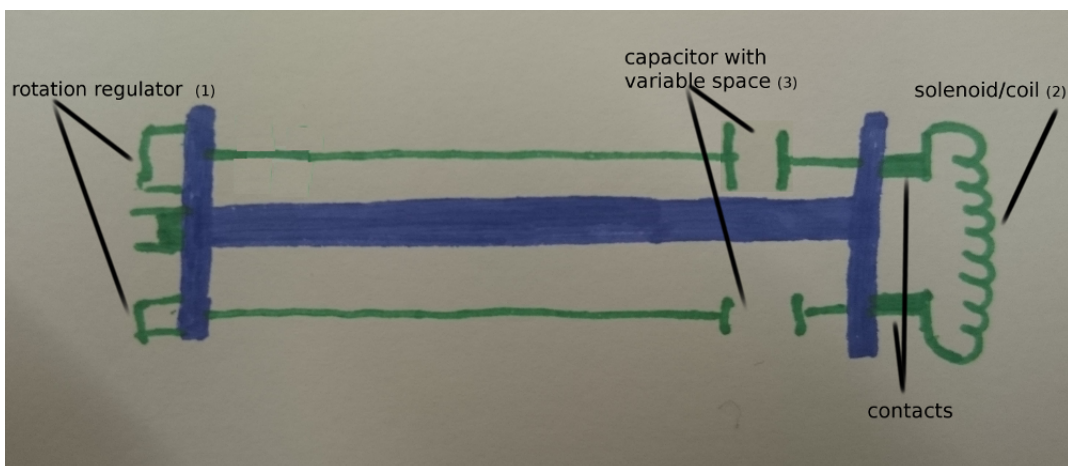
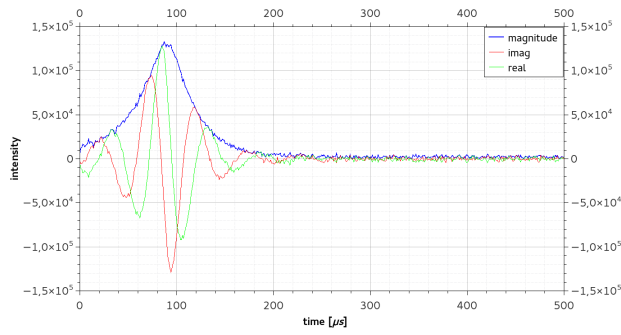
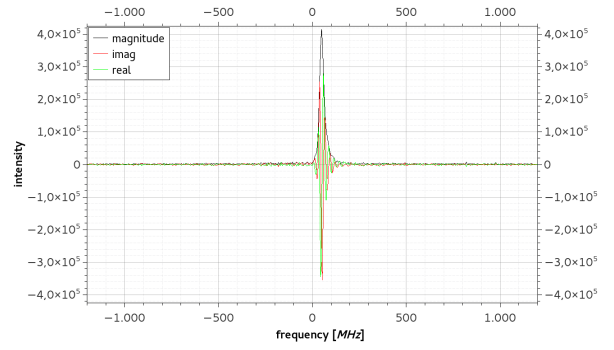


Figure 1: basic sketch of a probe with a coil on it

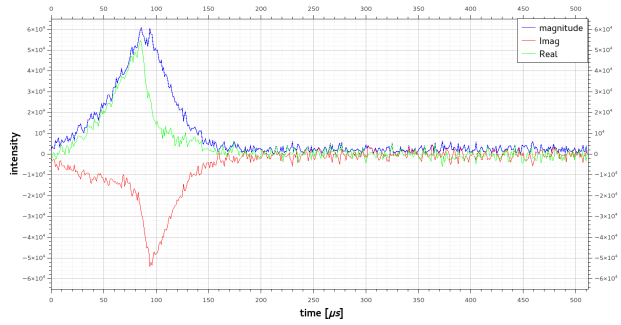
The rotation regulator (1.1) varies the space between the capacitor's plates (1.3) so one can tune the frequency of the solenoid (1.2).



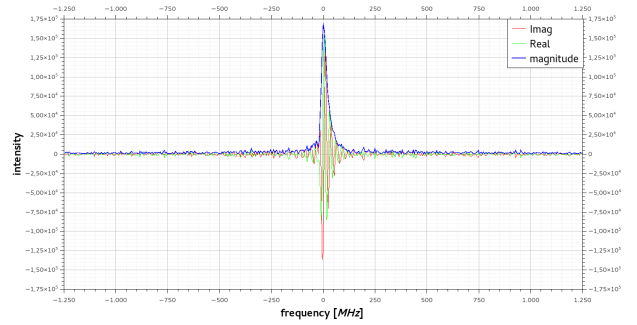
(a) intensity below resonance frequency in time domain



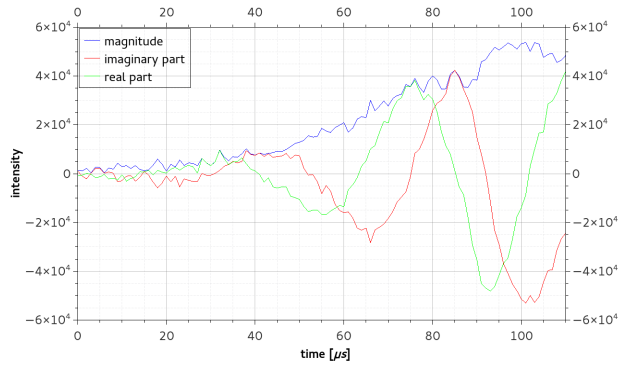
(b) intensity below resonance frequency in fourier space



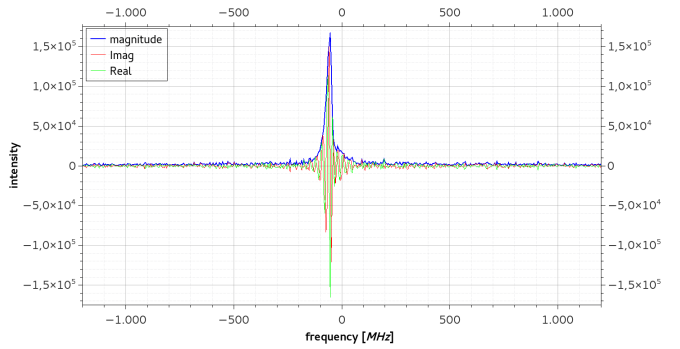
(c) intensity at resonance frequency in time domain



(d) intensity at resonance frequency in fourier space



(e) intensity below resonance frequency in time domain



(f) intensity below resonance frequency in fourier space

Figure 2: Different spectra below, at and above the resonance frequency

## 2.2 Finding of the nuclear spin resonance by varying the pulse frequency

2(a)

## 2.3 Optimization of the pulse sequence by recording a roation angle curve

## 2.4 Finding of $T_1$ and $T_2$

### 2.4.1 Spin-Lattice relaxation constant

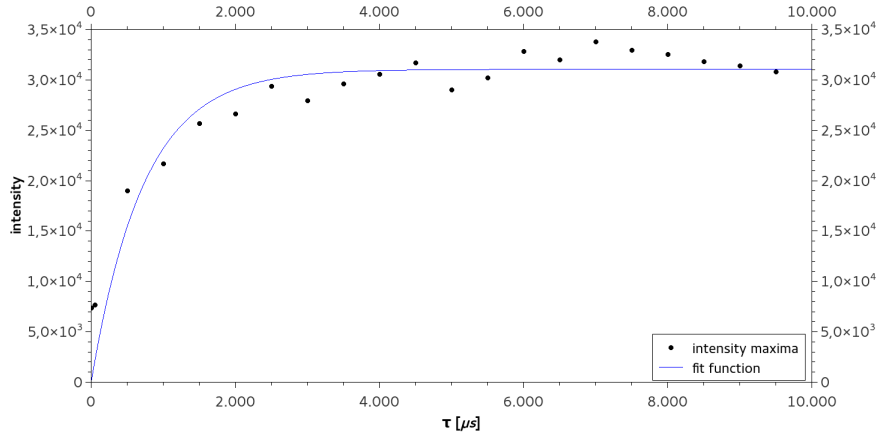


Figure 3: fit of a spin

### 2.4.2 Spin-Spin relaxation constant

## 3 Data Analysis

## 4 Discussion and conclusions

## References

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