

TU DRESDEN

ADVANCED PRACTICAL COURSE

LAB REPORT

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}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 μ . The proportionality factor is called the *gyromagnetic ratio* γ . 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 μ_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}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 ω_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 ω_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

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 was wrapped one has to sold it onto contacts of a stick, which provides a mechanism to tune the measured frequency to find the resonance frequency. One has to be carefully

2.2

2.3

3 Data Analysis

4 Discussion and conclusions

References

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