Advanced Physics Lab SS19

# Experiment: Nuclear spin

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**Abstract**

# Contents

# 1 Theory

The contents of this chapter are, if not otherwise specified, derived from the guide to the experiment [1]

## 1.1 Spin and nuclear spin

The spin or intrinsic angular momentum of a elementary particle is an intrinsic property of particles from the family of the fermions. Members of this family, such as protons, neutrons and electrons all have a spin of $s = \frac{1}{2}$. The spin can be explained semi classically, as rotation of the particle around its own 'centre of mass', with fixed frequency and variable axis of rotation. However, this illustration only makes sense in finite-size particles, of course. Just as with the angular momentum, not all three spin components can be defined at the same time, but only the amount and projection on a freely selectable 'quantization axis'. The possible spin quantum numbers are

$$\left|\vec{S}\right| = \hbar\sqrt{S\,(S+1)}$$

with $S = 0, \frac{1}{2}, 1, ...$ and Planck's constant $\hbar$. Atomic nuclei are also assigned a spin, the nuclear spin, which is defined with the nuclear spin number $I$, analogue to the spin:

$$\left|\vec{I}\right| = \hbar\sqrt{I\,(I+1)}$$

The nuclear spin number is also quantified in its direction. Analogue to the electron spin, the projection of the nuclear spin can also assume certain states as , e.g. with the z-axis as the quantization axis $I_z = m_I\hbar$ with $-I \leq m_I \leq +I$. In total there would be $2I+1$ different states for $I_z$. Protons or the nucleus of $^{19}F$ both have a nuclear spin number of $I = \frac{1}{2}$. So both have only two possible states: $m_I = \pm\frac{1}{2}$. They can only align parallel or antiparallel with the quantization axis in the experiment.

## 1.2 Magnetic momentum

The spin of a quantum mechanical particle is connected to a magnetic dipole momentum $\vec{\mu}$, the ratio of both is described as the gyromagnetic ratio $\gamma$.

$$\vec{\mu} = \gamma\vec{I} \qquad \text{with} \quad \gamma = \frac{g_I\mu_K}{\hbar}$$

The constant $g_I$ is the nuclear g factor, which is to be calculated during the exam. $g_I$ has no dimension and is unique for each nucleus. The second constant $\mu_K$ is the nuclear magneton, which is computed analogue to the Bohr magneton:

$$\mu_K = \frac{e\hbar}{2m_p}$$

The difference between those two is that for the Bohr magneton the elecron mass is used and for the nuclear magneton the proton mass. In the ground state of atomic nuclei, the nucleons are arranged according to the Pauli principle so that each orbital is occupied by two protons or neutrons of opposite spins. If now a eu-nucleus (with an even number of protons and an uneven number of neutrons) or if an ue-nucleus (where the even and uneven nucleons are reversed) is present, an unpaired nucleon remains. This leads to an half-digit total spin. For a uu-nucleus two unpaired nucleons remain resulting in an integer total spin. In a ee-nucleus all nucleons are paired, therefore the total spin is zero. Examples for ee-nuclei are $^{16}_{8}O$ and $^{12}_{6}C$. Therefore it is possible to measure the spin of hydrogen $I = \frac{1}{2}$ utilizing glycol ($C_2H_6O_2$) and water ($H_2O$) samples. For the $^{9}_{19}F$ nucleus with 9 protons and 10 neutrons the total spin is also $I = \frac{1}{2}$.

## 1.3 Interaction with magnetic fields and radiation (nuclear magnetic resonance)

## 2 Conduct of the Experiment

In the beginning of the experiment it had to be checked if the magnetic field inside the setup is homogeneously distributed. For this a Hall-Sensor was used with which the field strength can be measured. Here by the sensor was slowly put into the field and depending on place the strength of the field was recorded. After conforming the uniformity of the field, a position in the middle of the homogeneous part was chosen to place the probes into.

With this set the experiment was set up like in figure **??** described. The measurement was started with Glycol at a depth of 2 cm and a constant magnetic field of 425 mT. With this set, the corresponding frequency of the nuclear magnetic resonance (NMR) oscillator was set by looking for the absorption peaks in the oscilloscope. After learning that it would be easier to find the rough position with a fixed frequency it became much easier to locate the peaks. The fine positioning was still done by modifying the frequency. By setting all peaks equidistant to one another the correct resonance frequency could be found. After this two underground samples were made, one without the $H_1$ probe inside the field and by setting wrong combinations of magnetic field and oscillation. The $H_1$ probe was used for all background as well as for the calibration between the change in frequency and the change in position on the oscilloscope. The reason for using $H_1$ is that it has the least amount of disturbances. It is so to speak our standard candle. With the position - frequency calibration done the actually measurements were started anew. For different combinations of magnetic field and frequency with equidistant absorption lines, the CSV files were taken. After doing this for $H_1$ and Glycol the Hall-Sensor broke and another one had to be used. This one had the problem that it was strongly influenced by the temperature. This showed by the slowly decrease in measured field strength. The first value measured around the depth of 2 cm was noted.

After finishing this way the $^{19}F$ probe the Lock in Method was used to decrease the background noise. After building the setup of figure **??** a suitable resonance frequency was chosen. Here a slow shifting of the absorption peaks was noted, most likely duo to the heating of the magnets. After waiting for them to be warmed up the shifting stopped and the first measurement with the Lock in Method could be started. Here a new calibration of position and frequency was made by shifting the positions of the differentiated absorption signal.

Duo to some problems with the measurement of the magnetic field some measurements to the influence of the Hall-Sensor were made. One with the sawtooth voltage and one without it. With these and the voltage and ampere used to create the magnetic field, the accuracy of measurement with the new Hall-Sensor can be determined more closely.

# 3 List of tables

## List of Tables

# 4 List of Figures

## List of Figures

# 5 Bibliograpy

## References

[1] *Versuchsanleitung: Fortgeschrittenen Praktikum Teil 1 Kernspin.*

# 6 Appendix