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Praktikumsprotokoll V28

Elektronenspin-Resonanz

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1 Objective

The purpose of this experiment is to determine the magnetic moment of a free electron. To implement this the electronspin-resonance is used.

2 Theory

In quantum mechanics the status of particles is described by a wave function.

$$\psi_{n,l,m}(r,\theta,\phi) = R_{n,l}(r) \cdot \Theta_{l,m}(\theta) \cdot \Phi_m(\phi)$$

Thereby r is the radial part, Θ discribes the polar angle and Φ is the part of the azimuth angle. N, l, m are quantum numbers. N is the principal quantum number and describes the energy level. L is the number of the orbital angular momentum. M characterises the orientation of the system and can take the values 2l+1.

The current density is defined by

$$S = \frac{\hbar}{2im_0} \cdot (\psi * \nabla\psi - \psi\nabla\psi*).$$

It results of moving electrons on the shell of an atom which implies a magnetic moment

$$\mu_z = \mu_b \cdot m,$$

with μ_b the Bohr magneton. Figure 1 shows the geometric thoughts to deduce the magentic moment.

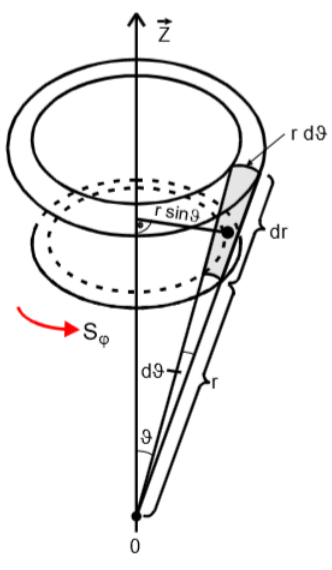

Figure 1: derivation of the magnetic moment [1]

In a homogeneous magnetic field the magnetic momentum of the electron shell is connected to the outer magnetic field. The quantization of the direction leads to the zeeman-effect, which describes the split of the energy levels in the outer magnetic field. It is shown in figure 2.

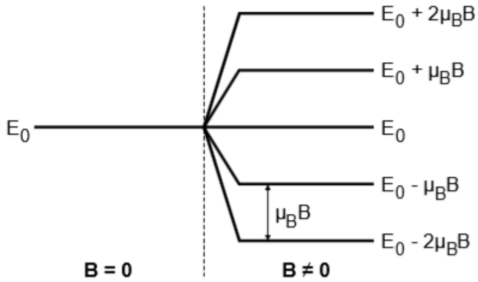

Figure 2: Split of the energy niveau [1]

A split of an electron without orbital angular momentum is not expected. In the Stern-Gerlach-experiment the split of the electron into two resulting beams in a inhomogeneous magnetic field leads to the postulate of the existence of another angular moment, which is called spin. The electron is a fermion and has the spin $|S| = 1/2$. The z-component of the magnetic moment is able to take two directions which are determined by the quantum number $m_s \in [-1/2, 1/2]$. The relation between spin and related magnetic moment is often expressed in the unit of the bohr magneton

$$\mu_{sz} = -g m_s \mu_B.$$

The energy difference between two niveaus

$$\Delta E = g \mu_B B$$

is needed to get the electrons into a higher energy level. G the gyromagnetic relation or Landé-factor.

In thermal equilibrium the two energy levels are filled according to the Boltzmann-statistic. By a large number of electrons the upper level is less filled than the lower one. The Energy ΔE is given to the system by inserting high frequenzy HF-quantum. Because of this elctrons are able to go from the lower level to the upper. Therefore the electrons' spin is flipped. This methode of transporting electrons into a higher level of energy by flipping the spin is called the electronspin-resonance.

3 Experimental setup

The experimental setup is presented in figure 3. As a sample Diphenylpikrylhydeazyl

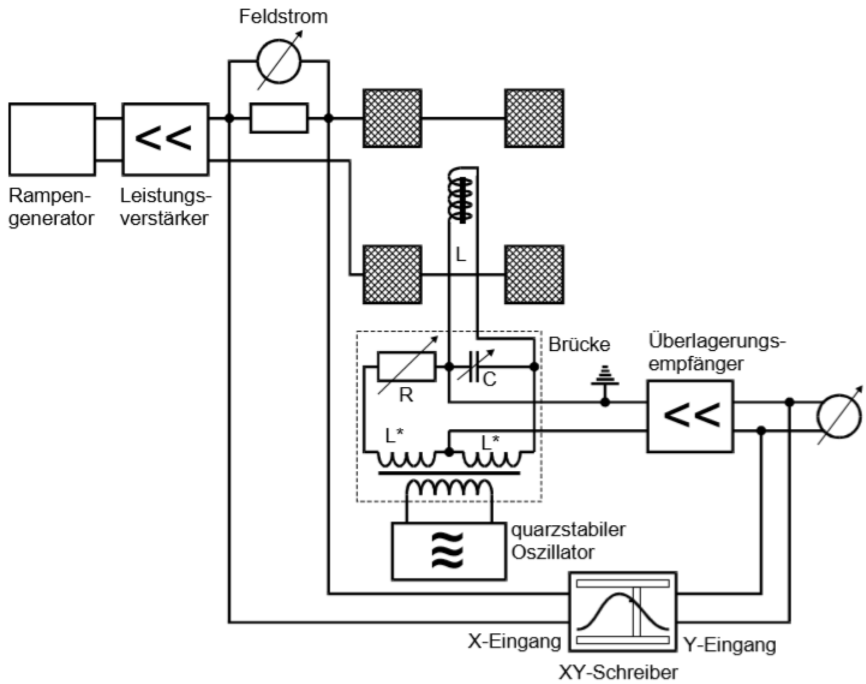

Figure 3: construction of the experiment [1]

with its chemical structure of one free electron is used. This sample is located in the HF-coil. The coil is supplied with current of a quarstable HF-generator and connected with them over a bridge circuit. The variable elements R, C_{grob} and C_{fein} are needed to adjust the bridge voltage. Through an overlap receiver the interference voltage is suppressed and the bridge voltage amplified.
The first amplifier enhances the input signal and also suppresses the interference voltage. Because of the voltage generated by the Oszillograph the two signals overlab. The following HF-amplifier supplies the highest part of amplification and inhibition of the unwanted frequencies. The voltage with frequencies near the signal-frequency ν_e can not be inhibated completely. To measure the alternating voltage it has to get commutated by the Demodulator. An amplifier circuit is shown in figure 4.

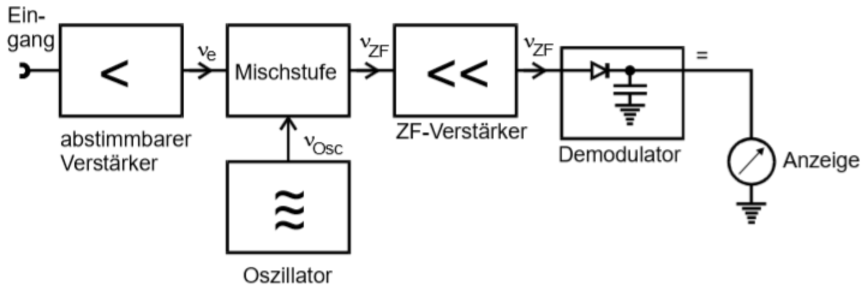

Figure 4: circuit of the overlay intensifier [1]

The electricity of the field coil is changing by manual interaction. Because of this the sample is located in a changing homogeneous magnetic field which effects the Zeeman-split. A change of the complex resistance on an arm of the bridge results in a reached response field intensity. An other result is the high frequency bridge voltage which is addes by in a voltage amplifier. With the XY-writer the resonance-curves can are drawn.
The theoretical curve with the resonance point is presented in figure 5

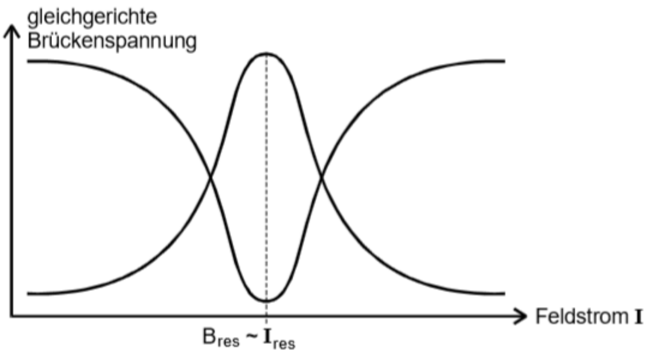

Figure 5: theoretical resonace curve [1]

4 Provision

First the bridge circuit has to be synchronized and the amplifier equipment must be set to the signal-frequency ν_e. The Oszillator-frequence ν_{osz} has to be adjust to

$$\nu_e = \nu_{osz} + \nu_{ZF}$$

The ZF-amplifier has to get minimized and the preamplifier maximized. After that the bridge ist going to synchronized by adjust C_{grob}, C_{fein} and R to get a minimized signal. Next we had to adjust the voltage to the point where the resonance curves can be seen. Then the resonance curves are drawn by the XY-writer. If the resonace point is not located in the magnetic field it is necessary to move the measuring range by the outer magnetic field. To calculate zhe magnetic field the formula

$$B(r) = \frac{8}{\sqrt{125}} v_0 \frac{n}{r} I \tag{1}$$

is used with n = 156 and r = 0.1m. The measurement is repeated for four frequencies and for each frequency two times, parallel and antiparallel to the earth's magnetic field. For the second measurement the polarity of the magnetic field is reversed.

5 Results

5.1 Determination of the resonance points

The resonance points can be taken from the resonance curves, which were drawn by the XY-plotter. These are atteched in the appendix. With the calibration of the x-axis every cm is linear propotional to 50 mA, which is used for the data of the table 1 .
The values of the parallel orientation are placed in every first line of each frequency, the values of the antiparallel orientation in the second.

Table 1: Distance and related currents of the resoncance points

ν_{e} / MHz	x / cm	I / mA	B / µT
14,798	8,3	415	582
	7,2	360	505
19,448	11,0	550	771
	10,0	500	701
23,888	12,6	630	884
	11,5	575	807
29,448	15,7	785	1101
	14,5	725	1017

The magnetic field is calculated with equation 1.

5.2 Determinaton of the Landé g-factor and the earth's magnetic field

The earths's magnetic field can be calculated with

$$B_{earth} = \frac{1}{2}(B_p - B_a).$$

In result the values of the magnetic field are listed in table 2

Table 2: Values of the magnetic field

ν_e / MHz	B_{erd} / µT
14,798	38,5
19,448	35,0
23,888	38,5
29,448	42,0

The mean value, which can be estimated with

$$\bar{x} = \frac{1}{n} \sum x_n \tag{2}$$

and

$$\sigma = \frac{1}{\sqrt{n}} \sqrt{\frac{\sum (x_n - \bar{x})^2}{n-1}}, \tag{3}$$

is

$$\bar{B}_{earth} = 38,75 \pm 1,24.$$

The Lande g-factor can be calculated with

$$g = \frac{h\nu_e}{B\mu_b}.$$

In result the eight g-factors for each frequency and orientation are listed in table 3

Table 3: Values of the g-factor

ν_e / MHz	x / cm	g
14,798	8,3	1,82
	7,2	2,09
19,448	11,0	1,80
	10,0	1,98
23,888	12,6	1,93
	11,5	2,12
29,448	15,7	1,59
	14,5	1,72

The mean value of the g-factor is calculated with 2 and 3. It amounts of

$$\bar{g} = 1,88 \pm 0,06.$$

6 Discussion

All of the results are presented and compared to their theoretical value in table 4.

Table 4: Comparison between measures and theoretical value

	Measures	Theoretical value	Deviation in percent
B_{earth}	38,75±1,24 μT	44 [2] μT	11,93 %
g	1,88±0,06	1,761 [3]	6,76 %

Eventhough the deviation in percent is with 6,67% for the g-factor and 11,93% for the earth's magnetic field small, there are some sources of error in the implentimantation aswell as in the analysis of the resonance curves. The adjustment of the bridge voltage was imprecised because it was not possible to regulate the voltage close to zero. At some point the resonance curve was hard to find and additionally the drawing with the XY-plotter made the resonance point even more flatter. By analysing the curves by hand it was, especially for the 23,888 MHz frequency, difficult to get exact values of the coordinate paper.
Nevertheless the generated results are close to the theoretical values despite of some inaccuracies in the implentimantation and analysis by hand.

References

[1] TU Dortmund. *Versuchsanleitung V28*. URL: `http://129.217.224.2/HOMEPAGE/PHYSIKER/BACHELOR/FP/SKRIPT/ESR.pdf` (visited on 11/05/2018).

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