Experiment 28

Electron spin resonance

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1 Motivation

The motivation of this experiment is to measure the g-factor of free electrons in diphenylpikrylhydracil using the effect of electron spin resonance.

2 Theory

Quantum particles like electrons possess a measureable angular momentum even if the ground angular momentum of the atomic shell they are in is zero or if they are free. This is called the electron spin. The spin obeys the laws of quantum mechanics wich state that angular momentums are not continuous, but discrete values. Since electrons are charged, their angular momentums induce magnetic moments. The quantization of those magnetic moments can be derived from the wave function of an one-electron atom

$$\psi_{n,l,m}(r,\vartheta,\varphi) = R_{n,l}(r)\theta_{l,m}(\vartheta)\phi(\varphi) = \frac{R_{n,l}(r)\theta_{l,m}\mathrm{e}^{im\varphi}}{\sqrt{2\pi}}, \tag{1}$$

which leads to the following equation for the z-component of the magnetic moment

$$\mu_z = -\frac{1}{2}\frac{e_0}{m_0}m\hbar = \mu_\mathrm{B}m \tag{2}$$

with the elementary charge e_0, the electron mass m_0, the reduced planck constant $\hbar$, the Bohr magneton μ_B and the magnetic quantum number m. When put into a homogenous magnetic field $\vec{B}$ along the z-axis the angular momentums split into $2l+1$ discrete directions which are described m, showing its relation with the azimuthal quantum number l. Those directions also correspond to energy levels of equal distance. This is called the Zeeman effect.

As it is observed in the Stern-Gerlach experiment the electron spin splits into two energy levels which can be described by the spin quantum number $s = \frac{1}{2}$ and its direction quantum number $m_S = \pm\frac{1}{2}$. But when plugged into (2) a factor g needs to be added to match the measured results.

This g-factor can be measured by putting free electrons into a homogenous magnetic field, casuing them to split into two energy levels which differ by

$$\mathit{\Delta} E = g\mu_\mathrm{B}B. \tag{3}$$

This difference in energy is now given to the system in form of electromagnetic waves leading to electrons with lower energy changing their direction. Since this is not a stable state the electrons dispense the energy in complex ways to get back to the lower energy level. This whole process is called electron spin resonance and with the energy of the used radiation, the following connection can be found:

$$h\nu = g\mu_\mathrm{B}B. \tag{4}$$

This is also depicted in figure 1. The homogenous magnetic field is created by a Helmholtz coil, for which the magnetic field correlates with the used current:

$$B(I) = \frac{8\mu_0 nI}{\sqrt{125}\cdot r}. \tag{5}$$

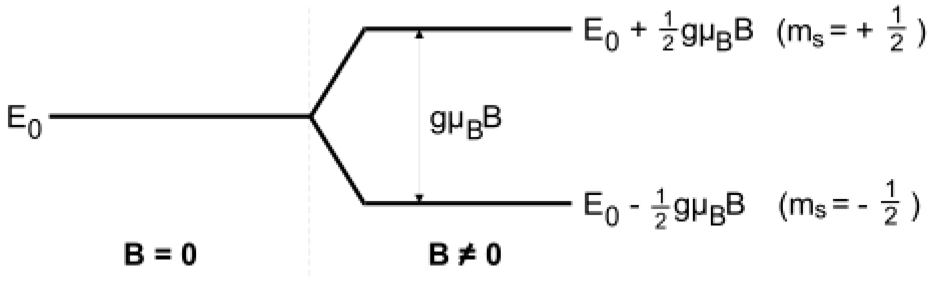

Figure 1: Graphic representation of electron spin resonance.[1]

3 Execution

First of all the circuit depicted in figure 2 needs to be set up.

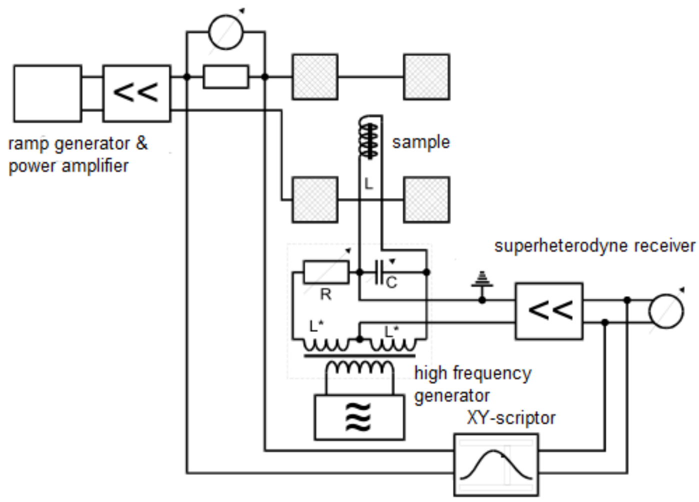

Figure 2: Circuit for electron spin resonance measurements.[1]

This circuit consists of a rampg generator and power amplifier which generates a triangular current used for the homogenous magnetic field and the x-axis of the XY-scriptor. In addition to that there is a high frequency generator connected to a bridge circuit with the sample inside one of its coils. This high frequency signal is then amplified, filtered and rectified by a superheterodyne receiver, and connected to the y-input of the XY-scriptor. The frequency ν_e for the bridge circuit needs to be set. Since the measured signal is amplified by a superheterodyne receiver with a fixed amplifying frequency of $\nu_{\mathrm{ZF}} = 552\,\mathrm{kHz}$ it needs to be modulated with an oscillator frequency so that the condition

$$\nu_{\mathrm{OSC}} + \nu_{\mathrm{ZF}} = \nu_e \tag{6}$$

is met. With the frequencies set, the bridge circuit needs to be adjusted so that the measured volatages are minimal. This is alternated with increasing the amplification on the superheterodyne receiver. When the voltage is minimal while apmlification is set to maximum, resonance curves as seen in figure 3 should appear on the XY-scriptor. If this is not the case, the offset on the ramp generator needs to be varied until resonance curves appear.

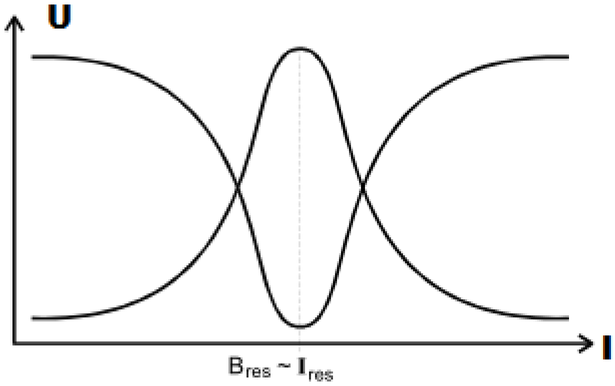

Figure 3: Example for a resonance curve.[1]

The range of currents generated by the ramp generator is determined with a power meter. It is equal to the length of the curve produced by the scriptor. By measuring the length at which the resonance spot is seen, the according current can be calculated. To cancel out errors induced by earth's magnetic field, the resonance curve is measured with the helmholtz coils both parallel and antiparallel to earth's magnetic field. This measurement is done for four signal frequencies ν_e.

4 Evaluation

To determine the g-factor, formula (4) can be converted to

$$g = \frac{h\nu}{\mu_{\mathrm{B}} B}, \tag{7}$$

with the Planck constant $h = 6.626 \times 10^{-34}\,\mathrm{J\,s}$ [4] and the Bohr magneton $\mu_{\mathrm{B}} = 927.4 \times 10^{-26}\,\frac{\mathrm{J}}{\mathrm{T}}$ [2]. The used frequencies and currents as well as the strength of the homogenous magnetic field, which was calculated using (5), with $n = 156$ and $r = 0.1\,\mathrm{m}$, are shown in table 1.

Table 1: The determined g-factor for different frequencies ν_e.

ν_e / MHz	I / mA	B / mT	g
29.448	719.5	1.01	2.08
29.448	606.6	0.85	2.47
23.888	562.3	0.79	2.16
23.888	481.5	0.68	2.53
19.448	380.4	0.53	2.60
19.448	370.4	0.52	2.67
14.798	473.1	0.66	1.59
14.798	460.5	0.65	1.64

The average value for the g-factor is $g = 2.22 \pm 0.15$.

5 Discussion

The calculated g-factor is 2.22 ± 0.15 and its deviation from the literature value 2.002 [3] is 10.89 %. This deviation is probably mosty due to mode interference voltages which cannot be canceled out completely, especially in the low voltage range of the measurement. Another source of error is the XY-scriptor, because the position of the resonance point had to be measured by hand with a ruler, making it rather unprecise. But despite this the deviation is low enough to validate the literature value and the theory of electron spin resonance with adequate precision.

References

[1] TU Dortmund. *Instructions for the experiment 28.* 2018.

[2] National Institute of Standards and Technology. *Bohr magneton.* URL: `https://physics.nist.gov/cgi-bin/cuu/Value?mub%7Csearch_for=bohr+magneton` (visited on 11/19/2018).

[3] National Institute of Standards and Technology. *Electron g factor.* URL: `https://physics.nist.gov/cgi-bin/cuu/Value?gem` (visited on 11/21/2018).

[4] National Institute of Standards and Technology. *Planck constant.* URL: `https://physics.nist.gov/cgi-bin/cuu/Value?h%7Csearch_for=h` (visited on 11/19/2018).