28

Electron paramagnetic resonance

Kevin Mika
kevin.mika@tu-dortmund.de

Noah Krystiniak
noah.krystiniak@tu-dortmund.de

Execution: 17.10.2018

TU Dortmund – Faculty of Physics

Contents

1 Motivation

The motivation of this Experiment is to determine the magnetic moment caused by the Spin of a free electron. Diphenylpikrylhydrazyl is a sample which offers free electrons. Methods of high frequency spectroscopy are used for this purpose: The experimental conditions are varied until a resonance absorption of the electrons occur. With the resonance condition it is possible to determine the magnetic moment.

2 Theory

Electrons without orbital angular momentum still have a magnetic moment. From this it can be concluded that the electrons have a spin. The connection between orbital angular momentum and magnetic momentum in of quantum mechanics, based on the consideration that the wave function for an atom in the one-electron approximation can be represented as

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

leading to the expression

$$\mu_B = -\frac{e_0\hbar m}{2m_0} \tag{2}$$

which describes the relationship between magnetic and the angular momentum. $m\hbar$ is the angular momentum l and the product of the natural constants is called Bohr magneton μ_B.

2.1 Spin relative to an external magnetic field

If an external magnetic field is applied, the energy levels are split (Zeeman effect). In addition, a force

$$F_Z = \mu_{S,Z}\frac{\partial B_Z}{\partial Z} \tag{3}$$

acts on the magnetic moments, thus deflecting the beam. depending on the orientation of the moment relative to the external magnetic field. The spin quantum number is calculated as then according to

$$2s + 1 = 2 \tag{4}$$

This is due to the fact that the components of a vector are at most equal to their amount, the Orientation quantum number m only assume the following values:

$$m = 0, \pm 1, \pm 2, ..., \pm l \tag{5}$$

So there are only $2l + 1$ settings for the Orientation quantum number m, where l is the angular momentum. Therefore, the following relationship applies to the Z-component of the spin:

$$S_Z = m_s\hbar = \pm\frac{\hbar}{2}. \tag{6}$$

The magnetic moment μ of the spin is then

$$\mu_{S_z} = -\frac{g \cdot \mu_B}{2}. \tag{7}$$

g is referred to as the gyromagnetic ratio and may assume a value other than 1.

2.2 Electron paramagnetic resonance

The electron paramagnetic resonance method is used to determine the gyromagnetic ratio. With an external magnetic field, the simple energy levels are converted into two sub-levels, where the energy difference between the two levels is

$$\Delta E = g\mu_B B. \tag{8}$$

If now energy, which corresponds to the energy difference, is supplied to the system in form of light quanta, then 8 results to

$$h\nu = g\mu_B B. \tag{9}$$

The electrons are now able to go into the higher energy state and their spin is reversed. The sample to be investigated is wrapped in a coil which is connected to a bridge circuit

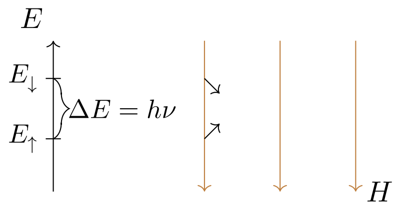

Figure 1: Energy levels $E_\downarrow$ and $E_\uparrow$ split by an external magnetic field H. ΔE can be modified by varying H.

and placed in a Helmholtz coil. The magnetic field of a Helmholtz coil can be determined with

$$B(I) = \frac{8\mu_0 n I}{\sqrt{125} \cdot r} \tag{10}$$

where μ_0 is the Vacuum permeability. A high-frequency voltage is applied to the bridge circuit. The coil in which the sample is located serves to supply energy, while the Helmholtz coil generates the external, homogeneous magnetic field.

3 Execution

The first step is to set up the apparatus according to Figure **??**. The frequency of the supply voltage for the bridge circuit should meet the condition

$$\nu_{OSC} + \nu_{ZF} = \nu_e. \tag{11}$$

While $\nu_{ZF} = 552\,\mathrm{Hz}$, ν_{OSC} can be set to fixed values and ν_e can be adjusted accordingly. The superheterodyne receiver is adjusted by slowly increasing the ZF-amplifier until a voltage is visible. The preamplifier is then set up so that the output voltage becomes maximum. Then the bridge is adjusted. Then this process is repeated until the maximum ZF-gain is reached. Then the ramp generator is switched on. A resonance curve should

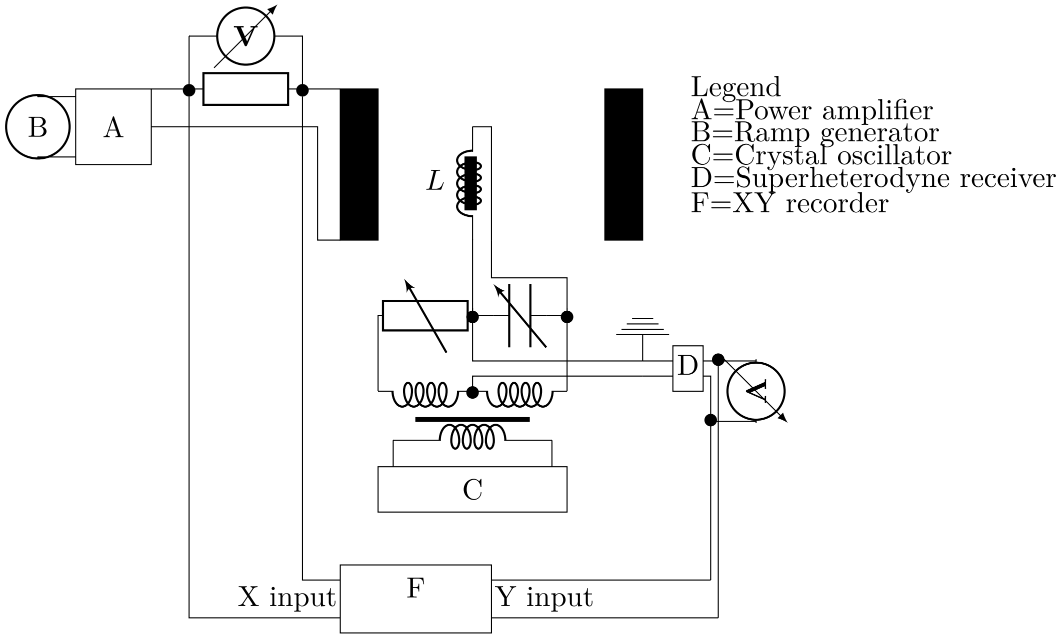

Figure 2: Measurement setup of the electron spin resonance method. The Helmholtz coil generates an external field proportional to the fed-in ramp voltage. The change of the complex resistance of the coil with the sample leads to a change of the bridge voltage, which is fed with a high frequency voltage.

now be visible, which is recorded by the XY recorder. The required current for the resonance can be read from the drawing and thus the gyromagnetic ratio of the sample can be determined according to the formula 9. The magnetic field can be determined with formula 10.

4 Evaluation

Formula 9 can be converted to g:

$$g = \frac{h\nu}{B\mu_B} \tag{12}$$

with $h = 6.626070040 \cdot 10^{-34}\,\mathrm{J\,s}$ and $\mu_B = 927.4009994 \cdot 10^{-26}\,\mathrm{J/T}$. The values can be taken from Table **??**. The error is determined by the Gaussian distribution, since both h and μ_B have errors:

$$\Delta g = \sqrt{\frac{\partial g}{\partial h} + \frac{\partial g}{\partial \mu_B}} \tag{13}$$

The average value is as follows:

Table 1: Gyromagnetic ratio determined for different frequencies ν_e according to the electron spin resonance method. x is the position of the resonance current on the XY recorder, B is the magnetic field of the Helmholtz coil and the gyromagnetic ratio g and the error Δg.

ν_e / MHz	x / cm	B / mT	g / Hz s	Δg
29,448	15,5	0,22	9,68	0,00
29,448	14,0	0,20	10,71	0,00
23,888	11,4	0,16	10,67	0,00
23,888	12,8	0,18	9,51	0,00
14,798	7,4	0,10	10,19	0,00
14,798	8,4	0,12	8,97	0,00
19,448	10,4	0,15	9,52	0,00
19,448	9,0	0,13	11,01	0,00