ESR Experiments

Ibraheem Al-Yousef

Second Lab Report for PHYS403

Partners: Moayad M. Ekhwan & Umar Al-huwaymel

December 1, 2022

Abstract

This document reports on two Electron Spin Resonance (ESR) experiments: (i) Determining the magnetic field as a function of the resonance frequency. (ii) Resonance Absorption of a Passive RF Oscillator circuit.

Introduction

Electron spin resonance (ESR) is a powerful spectroscopic technique used to study the structure and dynamics of molecules. It is based on the interaction between the spin of an unpaired electron and an external magnetic field. ESR is used to study a wide range of phenomena, including the structure of molecules, the dynamics of chemical reactions, and the properties of materials.

The technique is based on the fact that an unpaired electron has a spin, which can be either "up" or "down". When an external magnetic field is applied, the electron's spin can be aligned with the field, or it can be opposed to it. When the electron's spin is aligned with the field, it is said to be in the "spin-up" state. When the electron's spin is opposed to the field, it is said to be in the "spin-down" state.

When an electron is in the spin-up state, it absorbs energy from the external magnetic field. This energy is then released as a photon, which can be detected by an ESR spectrometer. By measuring the energy of the photon, the spin state of the electron can be determined.

The ESR technique can be used to study a wide range of phenomena. For example, it can be used to study the structure of molecules, the dynamics of chemical reactions, and the properties of materials. It can also be used to study the magnetic properties of materials, such as ferromagnets and antiferromagnets.

Every electron has a magnetic moment and spin quantum number $s = \frac{1}{2}$, with magnetic components $m_\mathrm{s} = +\frac{1}{2}$ or $m_\mathrm{s} = -\frac{1}{2}$. In the presence of an external magnetic field with strength B_0 , the electron's magnetic moment aligns itself either parallel ($m_\mathrm{s} = +\frac{1}{2}$) or anti-parallel ($m_\mathrm{s} = -\frac{1}{2}$) to the field, each alignment having a specific energy due to the Zeeman effect, and it is shown by:

$$E = m_s g_e \mu_\mathrm{B} B_0$$

where:

- g_e is the electron g-factor. $g_e = 2.0023$ for free electrons.
- μ_B is the Bohr magneton.

What we are interested in, is the separation between the two energy states due the external magnetic field, $\Delta E = g_e \mu_\mathrm{B} B_0$. This implies the proportional relation between the external magnetic field and the separation, which we shall verify in this report, as well as the literature value of the g-factor.

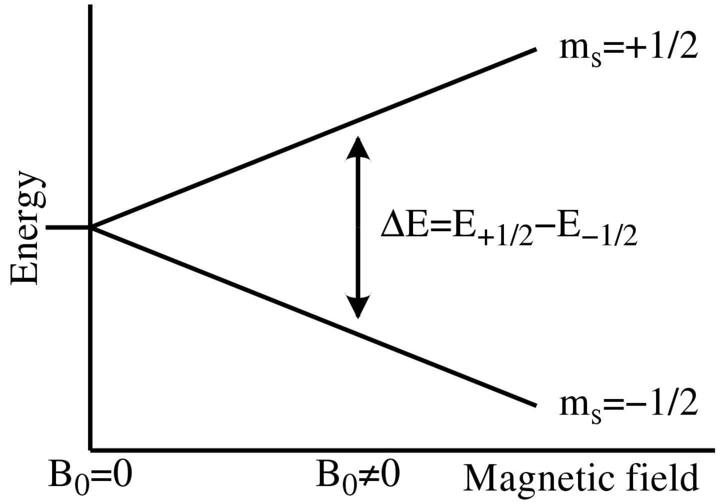

Figure 1: Illustration of the splitting dependence on B_0

Moreover, using a passive oscillator circuit, the resonance frequency of the passive oscillator is related to the capacitance of the coil:

$$\nu_0 = \frac{1}{2\pi\sqrt{L_2 C_2}}$$

Which means if the active oscillator circuit is excited with the resonance frequency ν_0, it is damped and the voltage $U1$ at the RF coil decreases. Which we shall verify in the second experiment.

1 Determining the magnetic field as a function of the resonance frequency.

1.1 Experimental Setup

- 1 ESR basic unit
- 1 pair of Helmholtz coils
- 1 ESR control unit
- 1 DPHH sample

1.2 Results & Discussion

After carrying out the experiment, here are the results:

$\frac{\nu}{\text{MHz}}$	$\frac{I}{\text{A}}$
15.	0.136
20.	0.173
25.	0.209
30.	0.261
30.	0.265
35.	0.289
40.	0.347
45.	0.383
50.	0.436
55.	0.483
60.	0.514
65.	0.569
75.	0.659
80.	0.672
85.	0.738
90.	0.79
95.	0.82
100.	0.861
105.	0.908
110.	0.947
115.	1.002

$\xRightarrow{B_0=4.23\,I}$

$\frac{\nu}{\text{MHz}}$	$\frac{B_0}{\text{mT}}$
15.	0.57528
20.	0.73179
25.	0.88407
30.	1.10403
30.	1.12095
35.	1.22247
40.	1.46781
45.	1.62009
50.	1.84428
55.	2.04309
60.	2.17422
65.	2.40687
75.	2.78757
80.	2.84256
85.	3.12174
90.	3.3417
95.	3.4686
100.	3.64203
105.	3.84084
110.	4.00581
115.	4.23846

Table 1: The resonance magnetic field values B_0 computed from the measures current I.

The magnetic field B of the Helmholtz coils can be calculated from the current I through each coil:

$$B_0 = \mu_0 \cdot \left(\frac{4}{5}\right)^{3/2} \cdot \frac{n}{r} \cdot I \xRightarrow[r=6.8cm]{n=320} B_0 = 4.23\,I$$

where n is the number of turns per coil, r is the radius of the coil, $\mu_0 = 4\pi 10^{-7}$. Now that we obtained the resonance frequency, we can relate it to the g-factor as the following:

$$E = h\nu = m_s g_e \mu_\text{B} B_0 \implies g_e = \frac{h\nu}{\mu_\text{B} B_0}$$

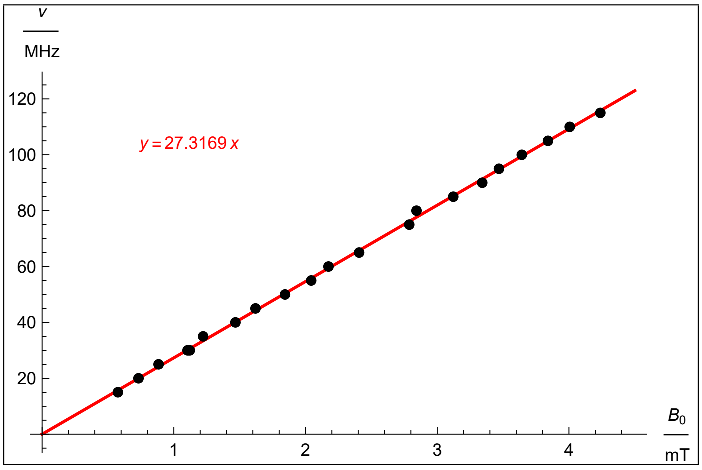

Figure 2: ν Vs B_0. The slope of this plot represents $\frac{\nu}{B_0} = 27.32$

Therefore, we can obtain the g-factor by substituting the slope of the plot:

$$g_e = \frac{h\nu}{\mu_\text{B} B_0} = 1.952 \pm 0.01$$

And when we compare it to the literature value of 2.0036, we obtain this difference:

$$\%Error = 2.6\%$$

2 Resonance Absorption of a Passive RF Oscillator circuit

2.1 Experimental Setup

- 1 ESR basic unit
- 1 passive oscillator circuit
- 1 ESR control unit
- 1 amperemeter, DC, I $\leq$ 1 mA

2.2 Results & Discussion

After carrying out the experiment, here are the results:

$\frac{\nu}{\text{MHz}}$	$\frac{U1}{\text{V}}$	$\frac{U2}{\text{V}}$
43.	4.676	0.7
44.	4.7208	0.77
45.	4.7488	0.85
46.	4.7432	0.94
47.	4.6928	1.12
48.	4.6368	1.38
49.	4.4184	1.75
50.	3.7576	2.37
50.9	1.8592	2.54
52.4	3.0184	2.42
53.	3.8864	2.08
54.	4.6144	1.55
55.	5.0736	1.24
56.	5.3424	1.
57.	5.5216	0.85
58.	5.656	0.71
59.	5.7512	0.66
60.	5.8128	0.58

Table 3: The voltages at scale mark 1/6 of the capacitor

$\frac{\nu}{\text{MHz}}$	$\frac{U1}{\text{V}}$	$\frac{U2}{\text{V}}$
25.	3.5056	0.72
26.	3.5672	0.74
27.	3.6288	0.77
28.	3.696	0.82
29.	3.7408	0.88
30.	3.8024	1.03
31.	3.8528	1.24
32.	3.808	1.71
33.	3.3152	2.63
33.5	2.24	3.18
35.	3.472	2.05
36.	4.0376	1.21
37.	4.228	0.83
38.	4.2728	0.55
39.	4.3288	0.41
40.	4.4128	0.33

Table 4: The voltage at scale mark 2/6 of the capacitor

The voltage $U1$ is obtained directly from the ESR unit by using the amperemeter. Then it was converted to voltages using ohm's law:

$$U1 = I \cdot 56\, k\Omega$$

The voltage $U2$ was obtained directly from the oscilloscope through the passive oscillator circuit. The objective now is to find the resonance frequency at different capacitance, which we will be able to observe by investigating the plot of the data:

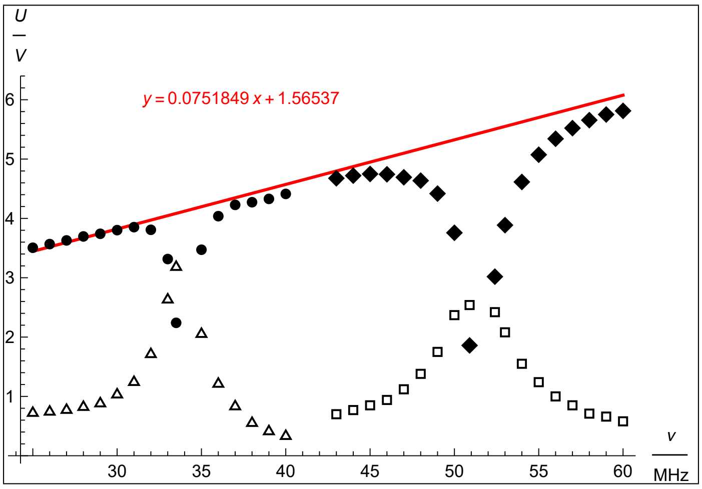

Figure 3: The voltages $U1$ and $U2$ at different frequencies. The red line represent the voltage $U1$ without the passive oscillator

Knowing earlier, that at the resonance, the passive oscillator circuit will be damped. Therefore, we must investigate the plot where we find peaks (or valleys). By doing so, we can find two resonance frequencies. The resonance frequency at 1/6 mark of the capacitor, let's call it $C_1 = 50.9\,MHz$. And $C_2 = 33.5\,MHz$.

3 Conclusion

In conclusion, ESR is a powerful spectroscopic technique used to study the structure and dynamics of molecules. It is based on the interaction between the spin of an unpaired electron and an external magnetic field. ESR is used to study a wide range of phenomena, including the structure of molecules, the dynamics of chemical reactions, and the properties of materials. It is also used in industry to detect impurities in materials, to measure the purity of pharmaceuticals, and to detect the presence of certain metals in food.

In this report, we were able to verify the proportional relationship between the external magnetic field and the resonance frequency, and find the g-factor of the DPHH material. Moreover, we were able to show the relationship between the inductive coupling to a passive oscillator circuit and the resonance frequency, and we measured the resonance frequency by investigating the peaks and the valleys of the voltages across the passive oscillator and the ESR unit.