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Physics Department

PHYS-403: Experimental Physics-II

ESR: A Report of Electron-Spin-Resonance Experiment

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ABSTRACT

In ESR experiment, two parts have been conducted. The first part was allocated to obtain the relation between the voltage and the resonance frequency of electrons. Where results yielded that at the resonance level voltage decreases dramatically. On the other hand, the second part pf the experiment was allocated to determine the g-factor of a DPPH sample. Where the analysis yielded that the g-factor of DPPH is 1.899 which within the literature value by 5% of error. This report states and analyze the findings of ESR experiment of both ports, respectively.

Contents

1 INTRODUCTION

1.1 Objectives

For such experiment there was two main parts. Part one was about Resonance absorption of a passive RF oscillator circuit and one objective was targeted:
1. Measuring the voltage U1 at the coil of the RF oscillator circuit as a function of the frequency with inductive coupling to a passive oscillator circuit.

While part two was about Electron spin resonance at DPPH and two main objectives were targeted:
1. Determining the resonance magnetic field B_0 as function of the selected frequency ν .
2. Determining the g-factor of DPPH.

1.2 Theory of Part.1

Electron resonance spin is a method for inspecting materials that have unpaired electrons, i.e., metal complexes and organic radicals. Unlike NMR, in ESR the spins of electrons are studied while their the spins of atomic nuclei are the ones of interest. In this experiment the ESR is detected on a DPPH sample. Where the sample is positioned in a way to absorb energy between an oscillator and an empty RF coil. These two components are related by the following equation:
$\nu_0 = \frac{1}{2\pi}\sqrt{L_2 C_2}$. Notice that varying the capacitance impact the resonance frequency itself. Once that the oscillator is excited with ν_0 it becomes damped and the voltage (U_1)decreases. Therefore our task now is to measure U_1 considering Ohm's law on a resistance of 56 Ω.

1.3 Theory of Part.2

It is known that every electron has a magnetic moment and spin quantum number (S $=\frac{1}{2}$) with magnetic components $m_s = \pm\frac{1}{2}$. In the In the presence of an external magnetic field with strength B_0 , the electron's magnetic moment aligns itself either anti-parallel ($m_s = -\frac{1}{2}$) or parallel ($m_s = +\frac{1}{2}$) to the field, each alignment having a specific energy due to the Zeeman effect: $E = m_s g_0 \mu_B B_0$. The separation of the lower and upper energies is $\Delta E = g_e \mu_B B_0$ for the unpaired electrons. What is more important is that unpaired electron can change its spin by either absorbing ot emitting radiation of $h\nu$ energy where that states the **resonance condition** $\Delta E = h\nu$. Such condition leads to the **fundamental equation** of ESR: $h\nu = g_e \mu_B B_0$. This equation permits a large number of combinations of frequency and magnetic field values by either fixing the frequency of the incident photon and varying the magnetic field or vice versa.

2 EXPERIMENTAL SET-UP

2.1 Procedure of Part.1

Mainly, the set-up for the first part consists of five components (see Figure.1):
1. Oscillator
2. Potentiometer
3. Coils (15 - 130 MHz)
4. Capacitor
5. Oscilloscope

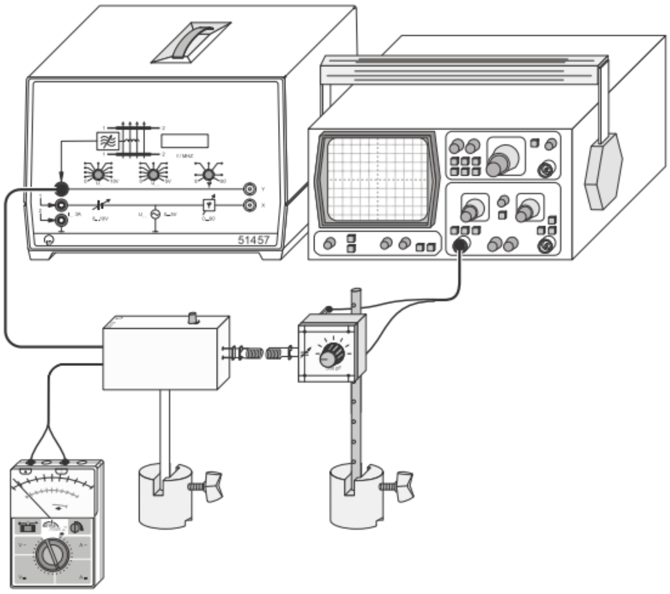

Figure 1: ESR set-up for the first part of the experiment

In this part we were varying the frequencies along the range of frequencies of each coil (small, medium & large) while observing the signal on the oscilloscope. Once a peak signal occurred (means a resonance between the passive and the active oscillators circulates) we record the current there which will allow us, at the end, to obtain the voltages at which the resonance occur between both signals. Moreover, we have collected data for different capacitance.

2.2 Procedure of Part.2

Similarly to the set-up of the first part, second part consists of five components (see Figure.2):

1. Oscillator
2. Potentiometer
3. Coils (75 - 130 MHz)
4. Helmholtz coils
5. Oscilloscope

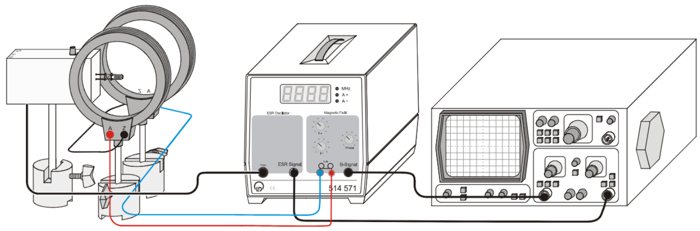

Figure 2: ESR set-up for the second part of the experiment

In this part, we have replace the capacitor with a Helmholtz coils which is going to generate a magnetic field (0 - 4 mT). Such field is going to be emitted on a DPPH sample which already inserted inside the Plug-in HF coils. Once the resonance condition (stated in introduction) is fulfilled, the sample absorbs energy and the oscillating circuit is loaded. Based on that we will be able to obtain the **g-factor** of the DPPH sample which is characteristic quantity of the electron binding the chemical structure.

3 RESULTS & DISCUSSION

The following table (Table.1) represents the collected data (frequency, voltage & current) for three scales of capacitance for the medium-size coil (30-75 MHz).

coil 2 (30 - 75 MHz)								
	c 1/6			c 2/6			c 3/6	
freq.	U1	I1 (μa)	freq.	U1	I1 (μa)	freq.	U1	I1 (μa)
46	3.75	67	43	3.77	67.3	39	3.5616	63.6
49	3.58	64	46	3.82	68.3	44	3.7184	66.4
52	3.65	65.2	49	3.58	63.9	49	3.6512	65.2
55	3.30	59	52	3.6848	65.8	54	3.584	64
58	2.63	47	55	3.36	60	59	2.688	48
60.7	3.00	53.6	58	2.688	48	64	3.6288	64.8
63	3.57	63.7	61	3.024	54	69	3.5336	63.1
66	3.60	64.2	64	3.584	64			
			67	3.5448	63.3			

Figure 3: ν and U_1 collected for Part.1

3.1 Results of Part.1

After plotting the collected data of the voltages with their corresponding frequencies we were able to notice that at resonance levels the voltage records the lowest values. Such result can be noticed in all the three scales of capacitance as can be seen in Figure.1,2 and 3.

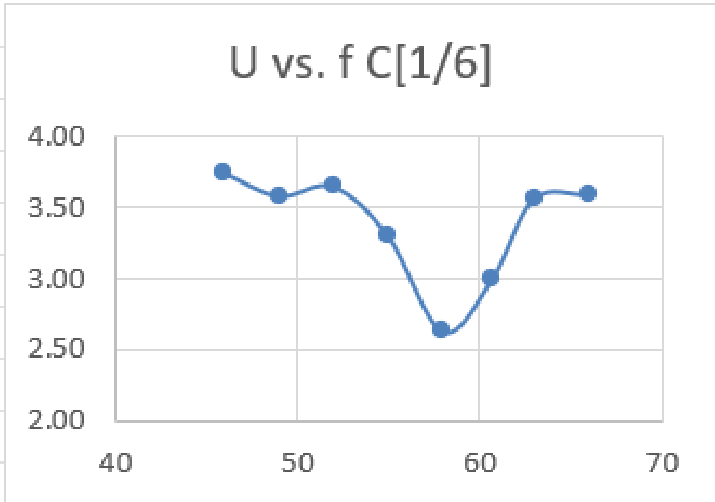

Figure 4: The **U** vs. **f** at 1/6 scale of capacitance

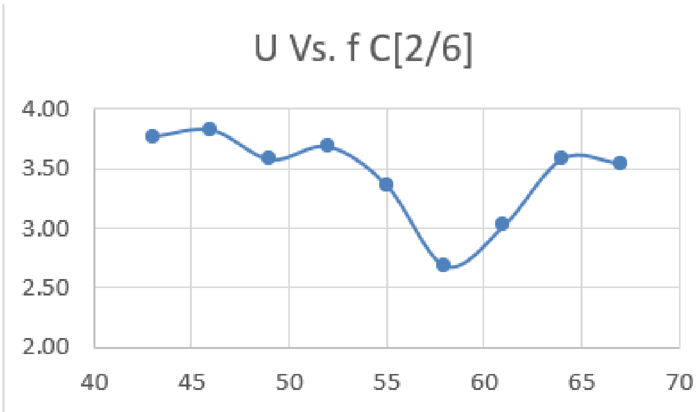

Figure 5: The **U** vs. **f** at 2/6 scale of capacitance

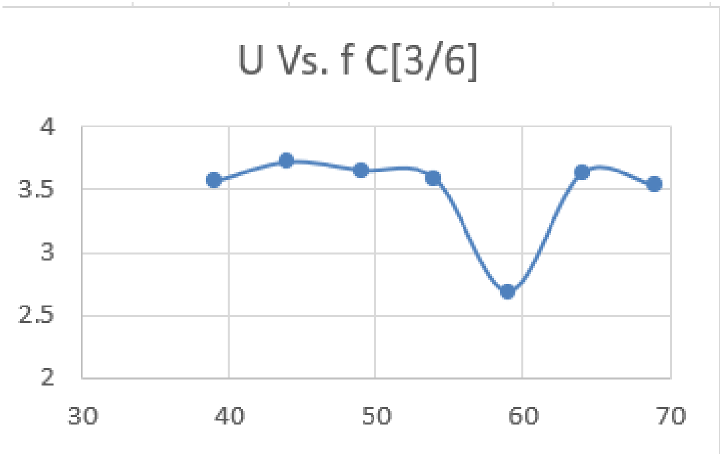

Figure 6: The **U** vs. **f** at 3/6 scale of capacitance

3.2 Results of Part.2

For the second part of the experiment we have measure the current for the spectrum of frequencies of the three coils. Table.2 represents the data collected:

MID		
Table.1		
f (MHz)	I_DC (A)	Coil
15	0.13	BIG
20	0.18	BIG
25	0.23	BIG
30	0.28	BIG
30.3	0.28	midium
35	0.3	midium
40	0.36	midium
45	0.4	midium
50	0.45	midium
55	0.5	midium
60	0.54	midium
65	0.58	midium
70	0.63	midium
75	0.67	small
80	0.71	small
85	0.75	small
90	0.8	small
95	0.85	small
100	0.89	small
105	0.94	small

Figure 7: Table.2: Measured current for each frequency point

For the data in Table.2 we can easily obtain the values of the magnetic field as a function of frequency, see Figure.8. Where B_0 obtained using the following equation:

$B_0 = \mu_0(\frac{4}{5})^{\frac{3}{2}}\frac{n}{r}I$; Notice that $\mu_0 = 4\pi 10^{-7}$, n = 320 turns, r = 6.8 cm and I is the current at each frequency point.

Table.2 for MID	
f (MHz)	B0 (mT)
15	0.55
20	0.77
25	0.97
30	1.18
35	1.27
40	1.52
45	1.69
50	1.90
55	2.12
60	2.28
65	2.45
70	2.67
75	2.84
80	3.00
85	3.17
90	3.39
95	3.60
100	3.77
105	3.98

Figure 8: The magnetic field B_0 as a function of frequency

Plotting the data represented in Figure.8 yields:

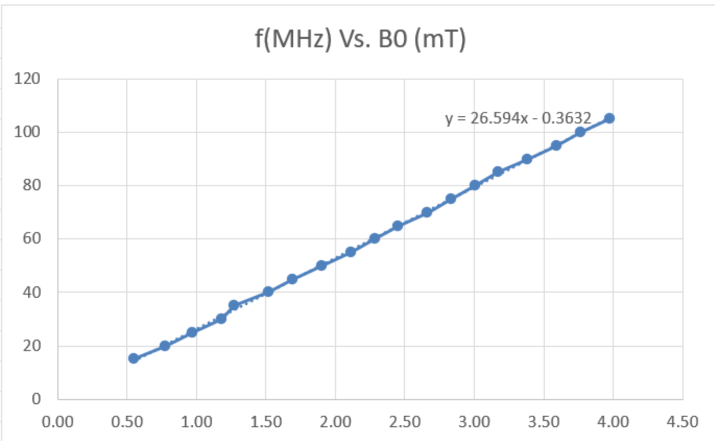

Figure 9: The plot of $B_0 Vs.f$

Finally, we are able to obtain the **g-factor** making use of the resonance conditon equation and the slope (the slope equal $\frac{f}{B_0}$) of the $B_0 Vs.f$ plot. As can be seen from the plot, the slope $\frac{f}{B_0} = 26.594$ Thus:
$\mathbf{g} = \frac{hf}{\mu_B B_0} = \frac{6.625 \cdot 10^{-34}}{9.273 \cdot 10^{-24}} 26.594 \cdot 10^9 = \mathbf{1.899}$.

4 Error Analysis

Litruture states the g-factor for DPPH as 2.0036 which is far from what have been obtained by **5.2%** which is an acceptable range of error. Also, the error analysis of LINEST function yields the following errors (see Figure.10):

slope	Intercept
26.5938	-0.3632283
Error in slope	**Error in intercept**
0.149	0.373

Figure 10: LINEST error analysis

This analysis suggests that the fitting of the curve is within a reasonable range of standard error.

Possible ssources of error are:

1. The size of the data collected.
2. The points at which the measurements have been collected.

5 CONCLUSION

In conclusion, ESR experiment has revealed several valuable concepts about electron resonance. First, we have noticed how at resonance level voltage across circuit decreased significantly. Second, we have testify how resonance of electrons can have a hand in the process of materials characterization through the g-factor. Our results was within an acceptable range of error ($< 5\%$) which yields an excellent accurate measurements. All in all, I found ESR experiment fruitful and valuable.