Electron Spin Resonance Investigation

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1 Introduction

1.1 Abstract

The aim of this investigation is to find the Landge g factor (defined below), by attempting to "flip" the orientation of the free radicals in a compound. The flip can be induced by exciting the radical to a higher energy level via a photon of energy hf. Thus, by using Helmholtz Coils we create an magnetic field that by varying the current, and use a Basic Unit to vary the photon frequency to attempt to create an electron resonance. From these measurements and the equations expanded upon below, we can calculate the g factor.

1.2 Background Information

This lab is an attempt to find a satisfactory measurement for the Lande g factor, where

$$g = \frac{\gamma}{e/2m} \tag{1}$$

Here, γ is the gyromagnetic ratio and e/m is the charge-to-mass ratio of an electron. By finding γ, we can attempt to find a value for the g factor.
When a free electron is affected by an external magnetic field B, its potential energy can be found through

$$E = -\mu \cdot B \tag{2}$$

where μ is the magnetic dipole moment of the electron. In turn, the dipole moment forms a relation with the gyromagnetic ratio and its angular momentum Sthrough

$$\mu = \gamma S \tag{3}$$

Combining the above two equations, we can consider the external magnetic field B to be in the z direction basis, yielding

$$E = \gamma S_z B_z \tag{4}$$

for which we can substitute $S_z = \pm\frac{\hbar}{2}$ for

$$E = \pm\frac{\hbar}{2}\gamma B_z \tag{5}$$

which corresponds to the two possible states of an electron. A photon incident on an electron may be absorbed if the electron is in the lower energy level, which will increase the energy of the electron up to the higher energy state. Thus, the energy of the photon would be the difference in energy between the two states, which is $E = \hbar\gamma B_z$.

As the energy of a photon is $E = hf$, where h is Planck's constant and f is the frequency of the photon, we can substitute that into the above equation for

$$h\nu = \hbar\gamma B_z \tag{6}$$

$$f = \frac{1}{2\pi}\gamma B_z \tag{7}$$

which shows that with knowledge about the magnetic field and the frequency of the photons, we can find γ and with it, the Lande g factor.

Q2 - Notice that the above equation is only linear in the case when the magnetic field is uniform. However since the magnetic field is produced by Helmholtz Coils, the equation is only linear in a local region near the axis of the coils.

1.3 Materials and Apparatus

1. Copper Coils in three sizes
2. DPPH free radical (in test tube)
3. ESR probe unit (basic unit)
4. ESR adapter
5. Two Helmholtz coils
6. Photon frequency counter
7. Oscilloscope
8. Ammeter
9. 1 Ω resistor
10. Power supplies (for adapter and Helmholtz coils)

1.4 Procedure

1. Connect the circuit as seen in Figure (4) in appendix, where the distance between the Helmholtz coils are the same as their radius.
2. Turn on the power supplies for the ESR adapter and the Helmholtz Coils, the ESR Basic Unit, and the Ammeter.
3. Turn on the Oscilloscope.
4. Adjusted the Basic unit until the Frequency counter returned a value (indicating a promising value). Then, adjusted the current so that the Oscilloscope presented a single peak, while making sure that current did not exceed 2 amps (AC).
5. Repeated step 4 for 5 different data points.
6. Repeated steps 2 to 4 for all three different coils.

2 Results and Analysis

Extra Measurements on the Helmholtz Coils:

1. Radius of Coils 0.0725 ± 0.0005 m.
2. Number of turns in the coils - 320

We summarize the measured values for each of the copper coils with their uncertainty below. During the data collection, when working with the medium copper coils, we made a slight change to the orientation of the coils, attempting to it perfectly vertical, for the medium copper coils, we also noticed that the frequency measurements had large fluctuations making the reading unclear (took multiple readings and averaged it.)

Q3 - When trying to align the current and frequency to create a single periodic peak, we notice that the width of the peak varied between trials. The physical meaning of the width of the peak means that there is a larger range of currents that creates a measurable resonance. Thus, when tuning the current and frequency, we ensured that the peak width was as small as possible.

Frequency (±0.001 Mz)	Current (±0.001 A)
70.119	1.132
86.158	1.129
73.292	0.955
77.022	1.003
83.508	1.082
119.29	1.547
92.121	1.194

Table 1: Frequency Measurement from the Basic Unit and the AC Current in the Coils for the Smallest Copper Coil

Frequency (±0.001 Mz)	Current (±0.001 A)
52.420	0.302
43.150	0.576
41.210	0.526
34.050	0.429
42.080	0.537
55.194	0.716
53.729	0.710

Table 2: Frequency Measurement from the Basic Unit and the AC Current in the Coils for the Medium Copper Coil

Frequency (±0.001 Mz)	Current (±0.001 A)
70.119	1.132
86.158	1.129
73.292	0.955
77.022	1.003
83.508	1.082
119.29	1.547
92.121	1.194

Table 3: Frequency Measurement from the Basic Unit and the AC Current in the Coils for the Largest Copper Coil

Since the current measurement in the coils was AC current, we divide by 2, to get an approximate "DC" current. Substituting the DC current measurement into,

$$B = \left(\frac{4}{5}\right)^{3/2} \frac{\mu_0 n I}{R} \tag{8}$$

where $n = 320$ is the number of coils in Helmholtz coils, $R = 0.0725 \pm 0.0005$m is the radius of the coils.

Plotting the frequency against the calculated magnetic field for each of the copper coils we get the following plots.

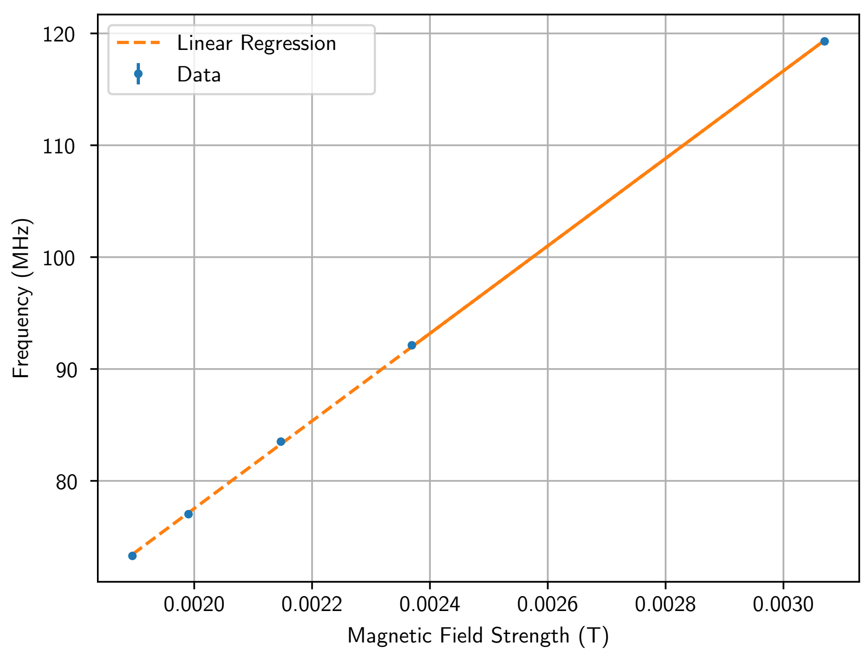

Figure 1: Frequency of Photons as a function of Magnetic Field Strength using the smallest coil. *Current error bars are present, however they are* ≈ 100 *times smaller.*

From `scipy.optimize` the line of best fit is,

$$y_{\text{Small}} = 39120B - 0.71$$

where the slope has uncertainty $m = 39120 \pm 11$ Mz/T, and the y-intercept $b = -0.71 \pm 0.02$ Hz.

Using Equation (7) we can calculate γ and substitute that into Equation (1) to find,

$$g = 2.36 \pm 0.02$$

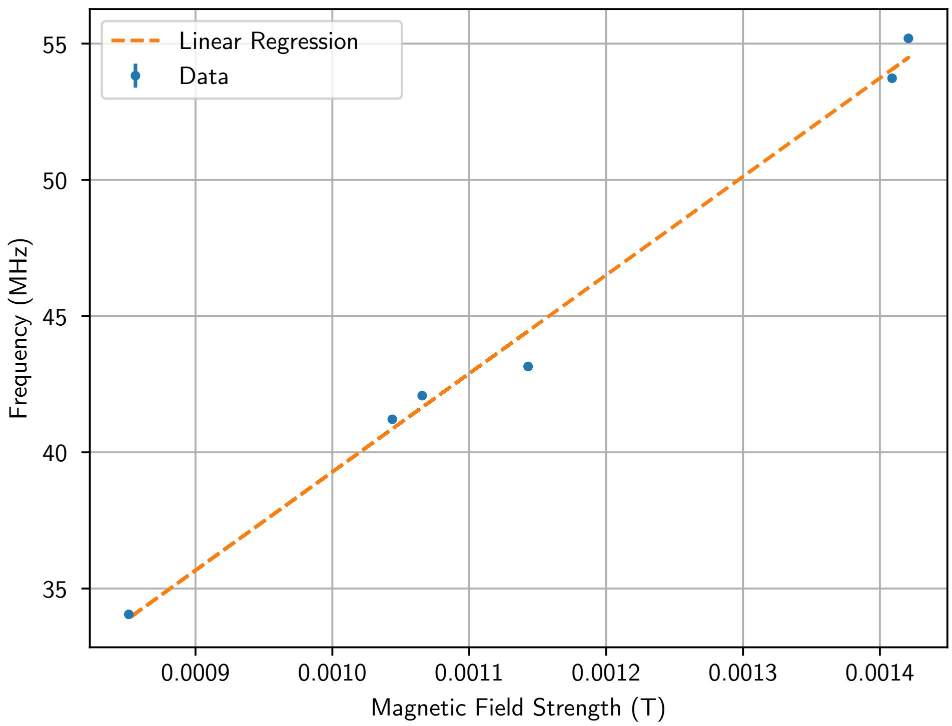

Figure 2: Frequency of Photons as a function of Magnetic Field Strength using the medium coil. *Current error bars are present, however they are* ≈ 100 *times smaller*.

From `scipy.optimize` the line of best fit is,

$$y_{\text{Medium}} = 36135B + 3.15$$

where the slope has uncertainty $m = 36135 \pm 20$ Mz/T, and the y-intercept $b = 3.15 \pm 0.02$ Hz.

Using Equation (7) we can calculate γ and substitute that into Equation (1) to find,

$$g = 2.18 \pm 0.02$$

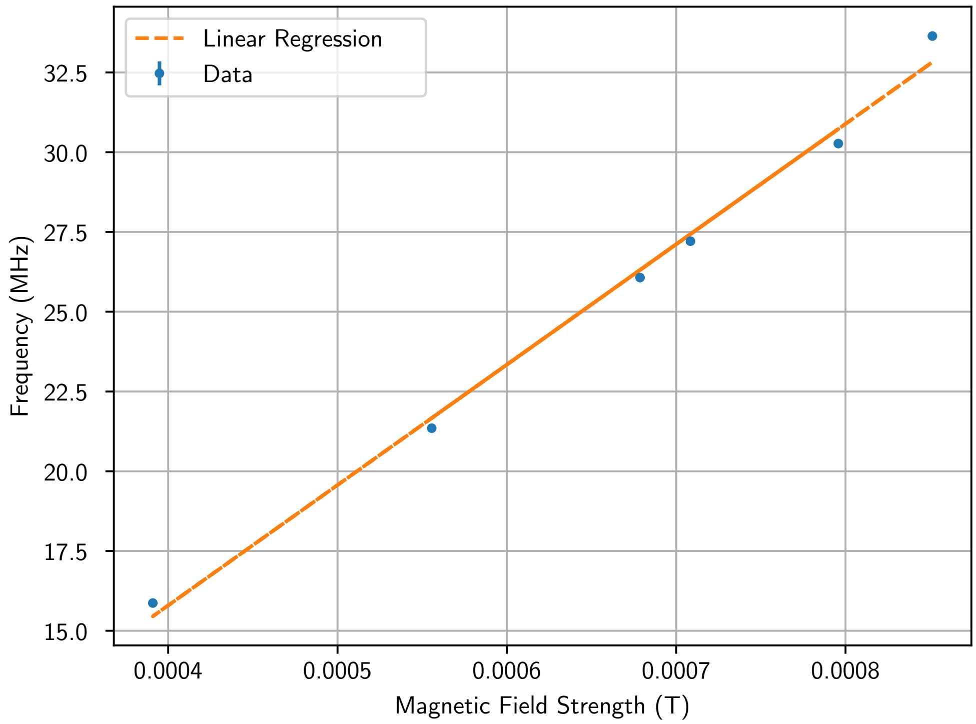

Figure 3: Frequency of Photons as a function of Magnetic Field Strength using the largest coil. *Current error bars are present, however they are* ≈ 100 *times smaller*.

From `scipy.optimize` the line of best fit is,

$$y_{\text{Small}} = 37730B + 0.70$$

where the slope has uncertainty $m = 37730 \pm 30$ Mz/T, and the y-intercept $b = 0.70 \pm 0.02$ Hz.

Using Equation (7) we can calculate γ and substitute that into Equation (1) to find,

$$g = 2.27 \pm 0.02$$

The average g-factor for all three copper coils is $g = 2.27 \pm 0.05$, where the uncertainty is $\sigma/\sqrt{3}$ (σ is the standard deviation).

3 Conclusion

In this investigation we varied the current in the coils to vary the magnetic field in the region around the free radical. We also varied the frequency of the photon incident on the free radical, to excite it giving us the resonance frequency. This was repeated with three different copper coils to get a diverse range of resonant frequencies.

Q4 - By absorbing the photon, the free radical gets excited to a higher energy level. This frequency is then sent to the oscilloscope (via the Y output) to be plotted. The frequency knob on the top of the Basic Unit is connected to a potentiometer within the circuit. This effects the frequency of the photon that is incident on the free radical to excite it.

By plotting the magnetic field (which we assume is constant in the region where the Basic Unit is located in) and the resonant frequency, we get a linear relation from which we calculate the γ factor. Which is used in equation (1) to find the g factor. From the three different copper coils, we found that the average g factor was 2.27 ± 0.05. The theoretical g factor of an electron is known to a very high precision to be 2.0023.

Notice that the theoretical value falls outside the uncertainty range of the calculated value, which illustrates that a large systematic or random error exists. In this investigation, we used a compound with a free radical to calculate the g factor, however since the free radical is not isolated, there may be effects from the rest of the compound which results in largely different g factor. Another source of potential error can come from the non-uniform magnetic field created by the coils.

Q1 - Measurement with the coils have certain errors inherent with the non-uniform nature of the magnetic fields generated by the Helmholtz coils, which may lead to imbalanced peaks (since different regions of the compound lie within different magnetic fields). These variations can be reflected in both the width of the peak and the asymmetric look of the peak.

4 Appendix

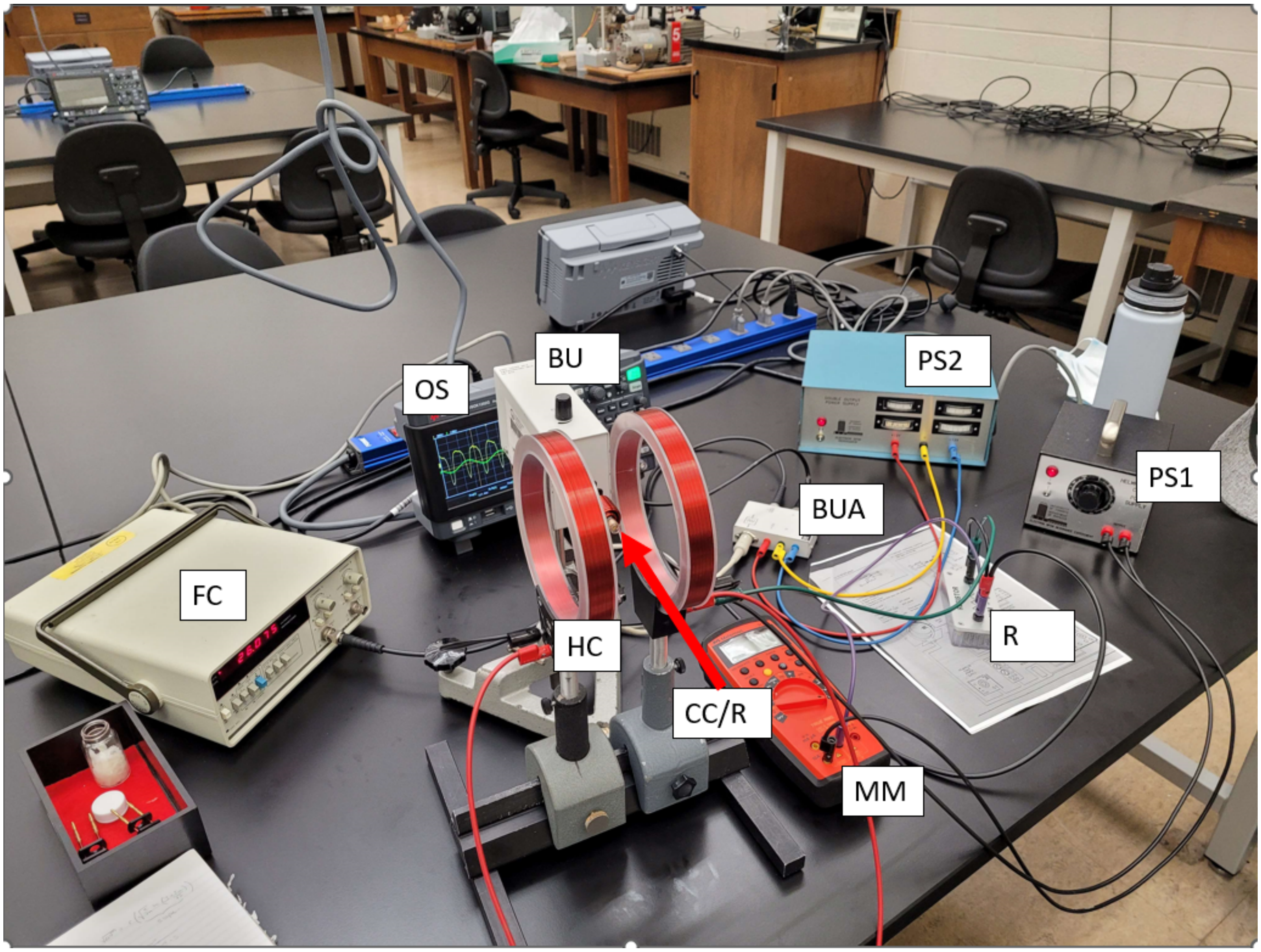

Figure 4: Apparatus Setup where: FC - Frequency Counter. OS - Oscilloscope. BU/BUA - Basic Unit/Basic Unit Adapter. HC - Helmholtz Coils. CC/R - Copper Coil with Free Radical Chemical Compound. MM - Ammeter. R - 1Ω Resistor. PS1 - Coil Power Supply. PS2 - Basic Unit Power Supply