Electron Spin Resonance

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We used an Electron Probe and Oscillator in conjunction with a Spin Resonance Console and Universal counter to determine the Lande splitting factor of dephenyl-picri-hydrazyl (DPPH). This was measured by applying an electromagnetic wave through the DPPH sample at three different frequencies, 46.149 mHz, 60.051 MHz and 76.599 MHz. Using Landes formula $k = \frac{h}{g\mu_B}$, we calculated that DPPHs Lande splitting factor was 2.0 ± 0.4 , which agreed with previously published experiments for DPPH of 2.004.

I. INTRODUCTION

The atom is known to consist of a nucleus orbited by electrons. Electrons can occupy certain energy states that are characterized by four quantum numbers: n, m, l, s. The four quantum numbers describe the energy of an electron, their momenta, and orientation in space. The quantum number n describes their total energy; the numbers l and s describe their orbital and spin momenta, respectively; and m gives their orientation in space. All numbers are quantized, so the state of an electron is discrete.

The energy levels of an electron were investigated using photon absorption/emission phenomena and their configurations using magnetic phenomena to deflect atoms under non-uniform magnetic fields. Frank Hertz experiment from 235L showed us that discrete energies were absorbed by electrons, promoting them to different orbits. The orbits of an electron were initially thought of to be circular by Bohr but then extended to elliptical orbits by Wilson and Sommerfeld. The next paragraph summarizes the development of electron theory before spin was taken into consideration.

Orbiting electrons act as a current loop, are associated with angular momenta (described by a number l), and are therefor associated with a magnetic dipole moment μ_l. In the presence of an external magnetic field, the dipole moment precesses. To investigate the angular momenta of electrons, Stern-Gerlach accelerated Silver atoms through a nonuniform magnetic field. Non-uniform magnetic fields exert force on the electrons, resulting in translation in addition to precession. Atoms get deflected along the direction of increasing magnetic field density, call it $\hat{z}$; therefore leading to deflection. The deflection is theoretically proportional to the electrons angular momenta, l along the $\hat{z}$ direction. What they found was that the deflection was quantized and therefore the angle between the angular momenta and $\hat{z}$ was quantized. The projection of an electrons angular momenta along the $\hat{z}$ direction is described by a number m_l. The corresponding component of magnetic moment along the $\hat{z}$ is μ_{l_z}.

Up to this point in history, three numbers were theorized to describe the energy state of electrons. But it was found incomplete by an experiment by Peiter Zeeman. His experiment probed emission sprectra lines of Sodium D using high resolution techniques to discover what was thought to be one line was actually several lines. It turns out that theory needed to be extended to account for the electrons spin angular momenum, described by s. Let $j = l + s$ be the total angular momenta, then the l in m_l gets dropped because m is now due to the total angular momenta, not just the orbital. The phenomena discovered by Zeeman is called splitting.

A. Theory

Splitting occurs because in the presence of a magnetic field, the orientation of an electrons dipole moment with respect to the external field is associated with some energy. The electrons magnetic moment along $\hat{z}$ is given by:

$$\mu_j = -gj\mu_B$$

μ_B is the Bohr Magnetron, the fundamental unit of magnetic momenta. The factor g is called the Lande splitting factor. It is theoretically derived and depends on j and l. Equation (11.10) of the lab manual tell us that the energy difference between two orientations is:

$$\Delta E_j = mu_j B \frac{m_j}{j}$$

Plugging in the first equation gives us the following relation:

$$\Delta E_j = m_j g B \mu_B$$

Therefore the energy levels are quantized by $gB\mu_B$. We will apply an EM wave through the sample of DPPH at three frequencies: $45.167MHz$, $57.754MHz$, and $73.99MHz$, while varying the magnetic field. As the magnetic field varies, the energy associated with the EM wave will match the energy difference needed to excite its spin state and we will detect a pulse in the oscilloscope. The applied EM wave is polarized normal to the B field. Our detector detects E fields in the $\hat{B}$

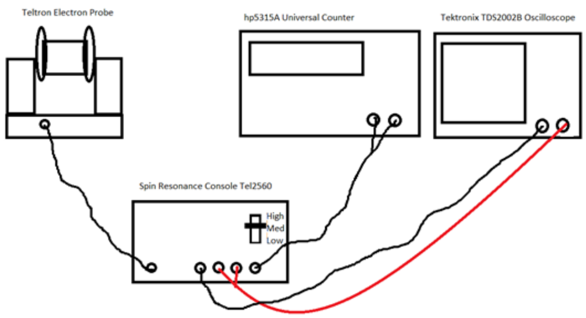

FIG. 1. Wiring Diagram

direction. When the EM wave excites the spin state, the change in state induces an E field along the $\hat{B}$ direction. Therefore leading to a detected pulse.

II. MATERIALS AND METHODS

We connected a Tel 2561 Electron Probe, Tel 2560 Spin Resonance console, HP 5315A Universal Counter, and TDS2002B Tektronix Oscilloscope in the wire configuration as seen in Image-1. After which we turn on the multiple devices and secure the DPPH sample in the coil chamber. The trigger level must stationery. The oscillator settings were: DC coupled, slope-falling negative, and both channels set to 200mV/division. Adjust the horizontal and vertical position of the visual observation on the oscillators screen. Using the trigger level knob, adjustments were made before each reading to have a stable graph image on the oscillator. The graphs were then adjusted to have a full-width-half-maximum where the sawtooth graph of the oscillators constant pulse was directly crossing such point. This graph was printed and used for calculations along with the frequency approximation shown on the Universal Counter.

III. DATA AND CALCULATIONS

The magnetic field applied to the DPPH sample is related to the applied voltage by:

$$B = V_r \cdot 3.67 \times 10^{-3} T \tag{1}$$

Figures 2, 3, and 4 are the oscilloscopes output for LO, MID, and HIGH frequencies, respectively. Note that the data saved from the oscilloscope was adjusted in Excel such that the leftmost point is at the origin. Below are the times for peak and FWHM:

1. LO 46.149MHz
   (a) Peak : 0.0252s
   (b) FWHM : 0.0239s, 0.0262s
2. MID 60.051MHz
   (a) Peak : 0.02714s
   (b) FWHM : 0.02568s, 0.02836s
3. HI 76.599MHz
   (a) Peak : 0.03284s
   (b) FWHM : 0.03140s, 0.03406s

Taking the above data, we tabulate the corresponding voltage applied to the magnet given by Channel 1 of the oscilloscope.

1. LO 46.149MHz
   (a) Peak : 0.456V
   (b) FWHM : 0.428V, 0.480V
2. MID 60.051MHz
   (a) Peak : 0.584V
   (b) FWHM : 0.552V, 0.616V
3. HI 76.599MHz
   (a) Peak : 0.736V
   (b) FWHM : 0.704V, 0.768V

Using equation 1, we tabulate the corresponding magnetic field.

1. LO 46.149MHz
   (a) Peak : $1.67 \times 10^{-3} T$
   (b) FWHM : $1.57 \times 10^{-3} T$, $1.76 \times 10^{-3} T$
2. MID 60.051MHz
   (a) Peak : $2.14 \times 10^{-3} T$
   (b) FWHM : $2.03 \times 10^{-3} T$, $2.26 \times 10^{-3} T$
3. HI 76.599MHz
   (a) Peak : $2.70 \times 10^{-3} T$
   (b) FWHM : $2.58 \times 10^{-3} T$, $2.82 \times 10^{-3} T$

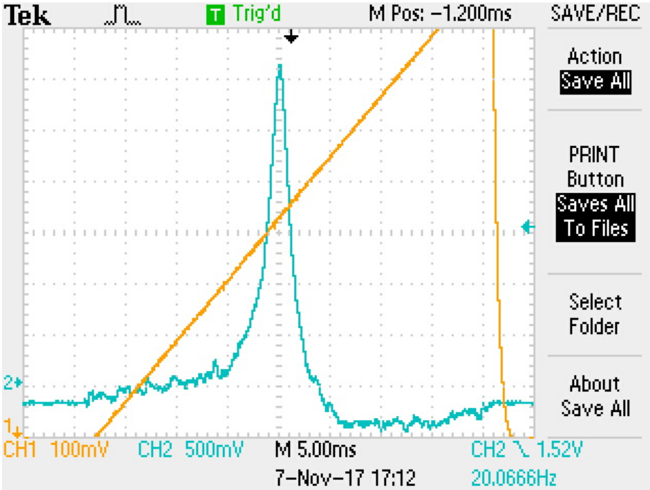

FIG. 2. 46.149MHz

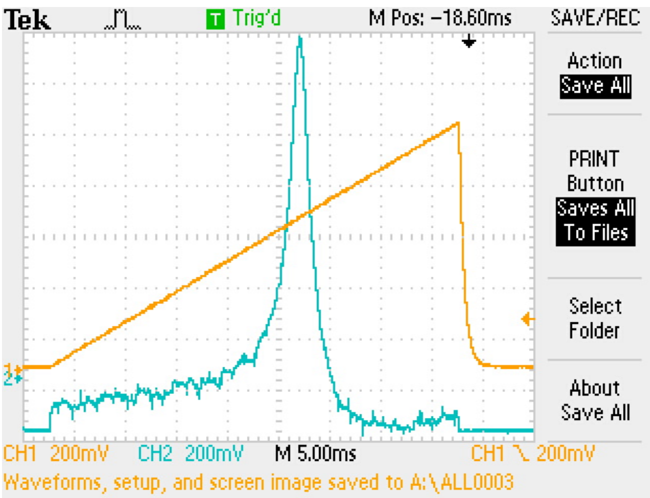

FIG. 3. 60.051MHz

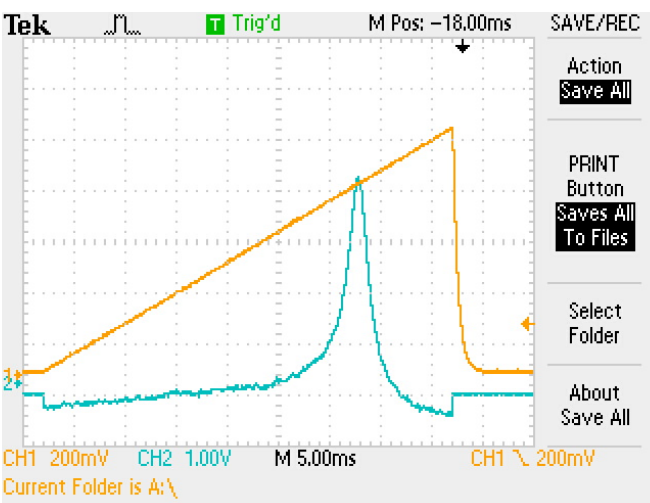

FIG. 4. 76.599MHz

IV. CALCULATION CONTINUED WITH ERROR ANALYSIS

We take the uncertainty of the magnetic field to be

$$\Delta B = max(|B_{best} - B_{FWHM1}|, |B_{best} - B_{FWHM2}|)$$

TABLE I. Magnetic Field with Uncertainty

Frequency	B ($\times 10^{-3} T$)	δB ($\times 10^{-3} T$)
LO	1.67	.10
MID	2.14	.12
HI	2.58	.12

We show a plot with error bars on B in figure IV. From Excel's best fit line, $k = 0.0338 \times 10^{-9}$. We will also tabulate k and δk from calculation below (Table II) using the relationship $B = k\nu$.

TABLE II. Error Calculations I

MHz	B	k	δk	
46.149	1.67	0.036187	0.003619	10%
60.051	2.14	0.035636	0.004276	12%
76.599	2.70	0.035249	0.00423	12%

Then Table III rounds off the values to account for significant digits.

TABLE III. Error Calculations II

MHz	B	k	δk	
46.149	1.67	0.036	0.004	11%
60.051	2.14	0.036	0.005	14%
76.599	2.70	0.035	0.005	14%

We take $k_{avg} = 0.036 \times 10^{-9}$ and

$$\delta k = \sqrt{\delta k_1^2 + \delta k_2^2 + \delta k_3^2}$$
$$= 0.008 \times 10^{-9}$$

Therefore,

$$k \equiv k_{avg} \approx (0.036 \pm 0.008) \times 10^{-9}$$
$$= (3.6 \pm 0.8) \times 10^{-11}$$

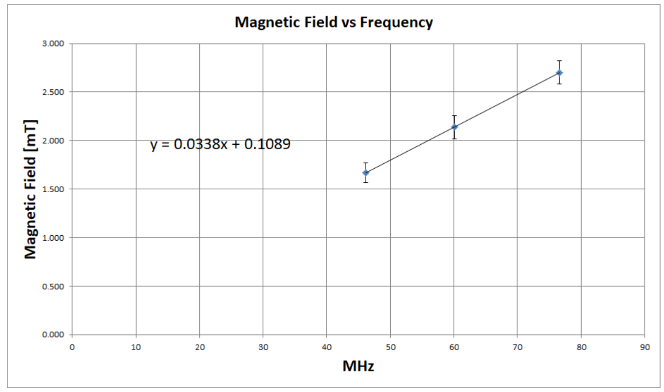

FIG. 5. B vs ν

$$g = \frac{6.626 \times 10^{-34}}{(3.6 \times 10^{-11}) \cdot (9.28 \times 10^{-24})}$$
$$= 2.0 \pm .4$$