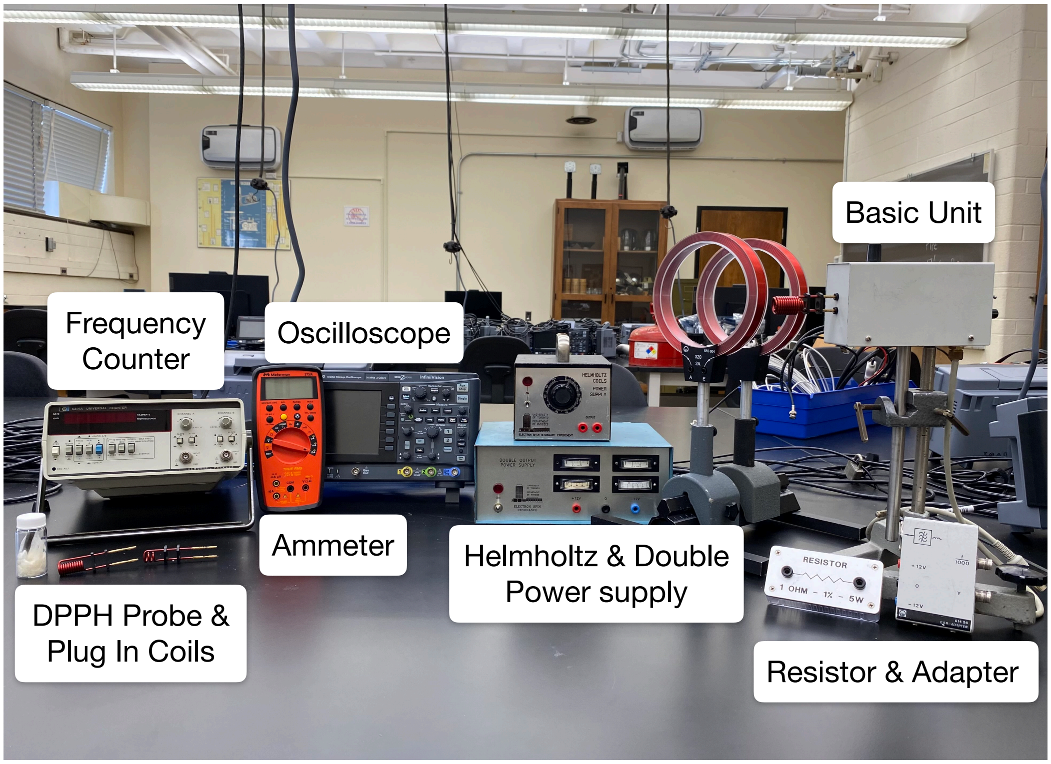
Physics
UNIVERSITY OF TORONTO

Electron Spin Resonance



Revisions

2023	T. Vahabi,
2022	H. Zhan, E. Horsley, A. Harlick, B. Wilson

current revision: d7bb05c
date: October 23, 2025

Introduction

Since electrons have charge e and are 'spinning' on their axis, they have a magnetic dipole moment $\vec{\mu}$. In the presence of an external magnetic field $\vec{B}$, a free electron will therefore acquire potential energy given by:

$$E = -\vec{\mu} \cdot \vec{B} \,. \tag{1}$$

The relationship between magnetic moment $\vec{\mu}$ and the spin angular momentum $\vec{S}$ can be written as:

$$\vec{\mu} = \gamma \vec{S} \,, \tag{2}$$

where γ is the gyromagnetic ratio.
You may show that if an electron is a uniform sphere with homogeneous charge distribution, one expects γ to be $e/2m$. Real electrons have a larger magnetic moment than this simple model predicts, and the discrepancy is often written in terms of the Landé g *factor* :

$$g = \frac{\gamma}{e/2m} > 1 \,. \tag{3}$$

If we consider the magnetic field $\vec{B}$ to be pointing in the z direction, the potential energy is:

$$E = \mu_z B_z = \gamma S_z B_z \,. \tag{4}$$

We know from quantum mechanics that S_z can only have two values: $S_z = \pm\frac{\hbar}{2}$, therefore the potential energy will have only two values:

$$E = \pm \frac{1}{2} \gamma \hbar B_z \,. \tag{5}$$

The difference in the two energies is then:

$$\Delta E = \gamma \hbar B_z \,. \tag{6}$$

If a photon incident on an electron has an energy corresponding to this energy difference and the electron is in the lower energy state, the photon may be absorbed, inducing the electron to 'flip' its orientation: this phenomenon is *electron spin resonance*. Since the photon energy is just $h\nu$, we can re-write Eq. (6) in terms of the frequency of the incident radiation:

$$\nu = \frac{1}{2\pi} \gamma B_z \,. \tag{7}$$

So far we have only discussed free electrons. However, in chemical free radicals there is one unpaired electron per molecule and these substances are paramagnetic. These unpaired electrons are almost entirely uninfluenced by their orbital motion. Thus it is possible to obtain a good value for the free electron gyromagnetic ratio from measurements on a free radical. This in turn will allow you to calculate the Landé g factor.

EXPERIMENT

The goal of this experiment is to determine the Landé g-factor using Electron Spin Resonance. This will be achieved by looking for the "spin-flip" transition of a free (unpaired) electron exposed to a magnetic field.
The free radical you will use in this experiment is diphenylpicryl hydroxyl ($DPPH$); it is contained in the small test tube. Note that it fits neatly inside each of the three small copper coils. (see Fig. 1)

Figure 1: Picture of the probe and three copper coils.

The Probe Unit

The heart of the apparatus consists of two boxes from Leybold (see Fig. 2). One called the *ESR Basic Unit*, contains a socket for mounting one of the small copper coils containing the $DPPH$ sample, a DIN cable, and two small knobs for controlling the strength and frequency of the high-frequency photons. The unit will generate a RF field inside the copper coil. The three different copper coils give you three different ranges of frequencies. Can you predict which of the copper coils will give the maximum frequency?

The other of the Leybold boxes, called an *ESR Adapter* (see Fig. 3), has:

1. DIN socket for connecting the *ESR Basic Unit*.
2. Inputs for +12 V AC, −12 V AC, and 0 V. You will connect these to an appropriate power supply.
3. BNC output, labeled Y, for looking at the absorption of the high-frequency photons. Connect to the other channel of the oscilloscope.
4. BNC output, labeled $f/1000$. When connected to a frequency counter it will allow you to determine the frequency of the photons.

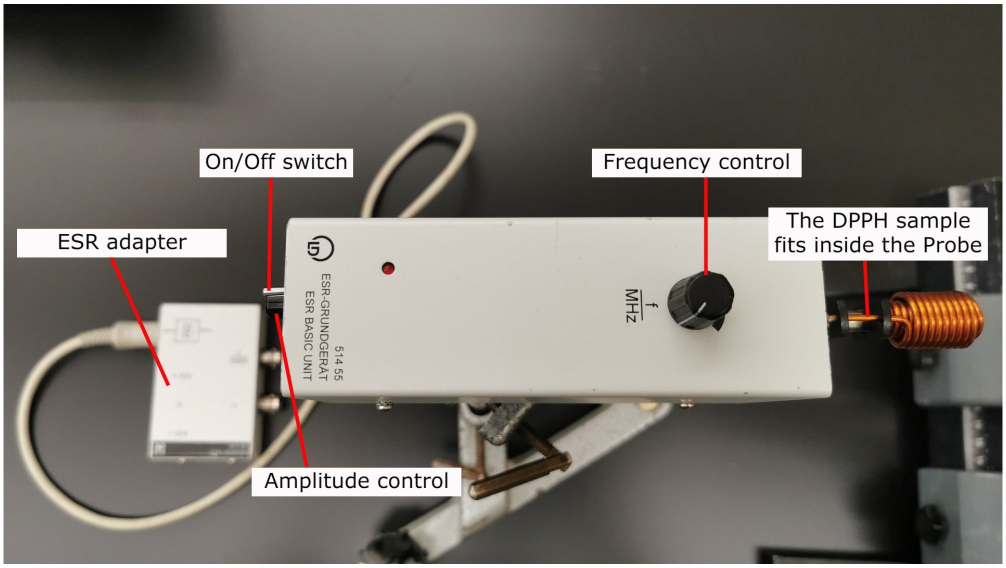


Figure 2: Picture of ESR probe unit.

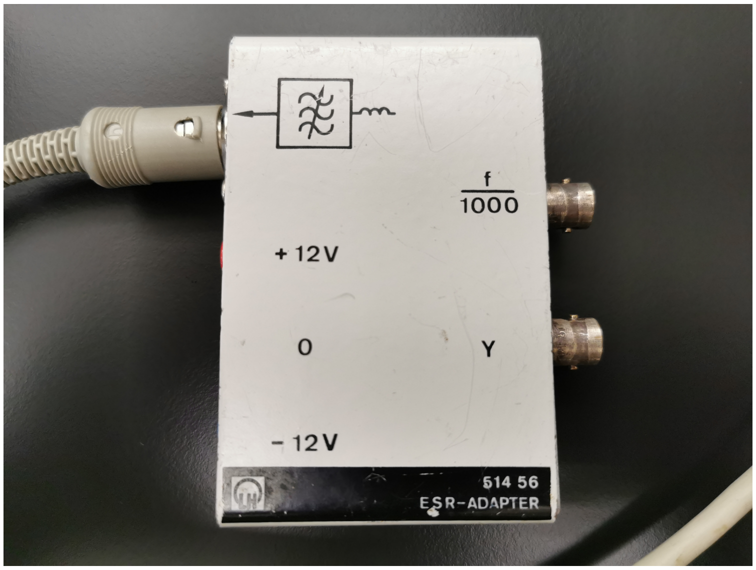


Figure 3: Picture of ESR Adapter.

Helmholtz Coils

The Helmholtz coils provide a highly uniform magnetic field B_z in which to place the sample material for the ESR measurement. Rather than a fixed B_z, you will use an AC current. As the field sweeps through the resonance point you will then see the absorption of the high-frequency photons. **(Important: Never exceed 1 A current through the coils!)** Recall that the field is most uniform when the distance between the coils is equal to (or smaller than) their radius. Also, the central field generated by a pair of coils is given by:

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

where:

1. $\mu_o = 4\pi \times 10^{-7}$ (N/A^2)
2. $R =$ the radius of the coils
3. $n =$ the number of turns
4. $I =$ the current through the coils

Note that if the coils are too far apart to their radius, this equation will no longer hold.

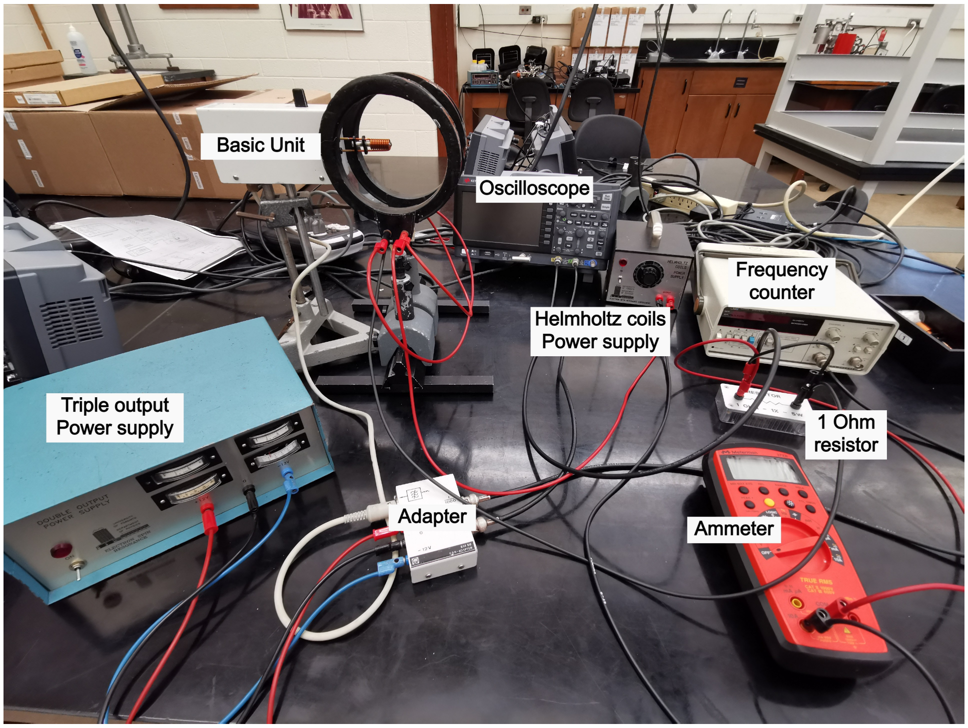


Figure 4: Equipment set up

Procedure

1. Connect the Helmholtz coils in parallel and position them appropriately. Connect the power supplies, ammeter, oscilloscope, and circuit components to the Helmholtz coils as shown in Fig. 5. Make sure the axis of the copper coil is perpendicular to the external field B_z.
2. Turn on the two power supplies, Basic Unit, and ammeter. Make sure to use AC mode to measure the current and never let it exceed 1 A current through the Helmholtz coils.

3. Setup the oscilloscope on the internal trigger. Monitor the current going into the coils both with an ammeter and by looking at the voltage drop across the supplied $1\,\Omega$ resistor with an oscilloscope.

4. Find a combination of frequency and current so that the two peaks have just merged into one, then the corresponding current at resonance is just the peak current going through the coils (see Fig.6). Measure the RF frequency and the AC current with uncertainty. Continue varying the current and finding new resonance frequencies (or vice versa) in order to collect data points. If possible, try to take five different data points for each of the three RF probes, covering as large a frequency range as possible. In order of decreasing number of turns the three RF probes cover approximate frequency ranges of 20-30 MHz, 30-40 MHz, and 40-60 MHz, respectively.

   (Note: Since the Helmholtz coils are connected parallel, the current through the coils is half of the current you measure from the ammeter.)

2.2 514 56 ESR adapter

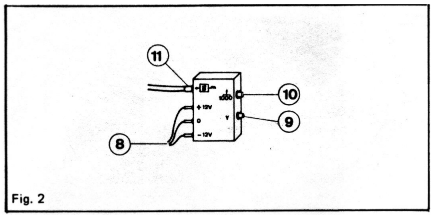


Fig. 2

Control elements:

- ⑧ Supply voltage connection
- ⑨ Signal output Y
- ⑩ Frequency output
- ⑪ Connection for the ESR basic unit (probe holder)

Technical Data:

Signal output Y:	BNC socket
Frequency output $\frac{f}{1000}$:	BNC socket
Supply voltage input +12 V, 0, −12 V:	4-mm sockets
Socket for ESR basic unit:	for 5-pin connector

3 Experiment Assemblies, Operation

3.1 Assembly for demonstrating the operating principle of the ESR basic unit (514 55)

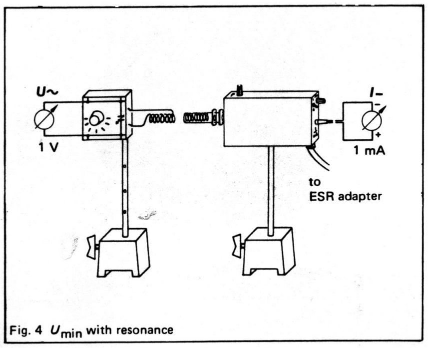


Fig. 4 U_{min} with resonance

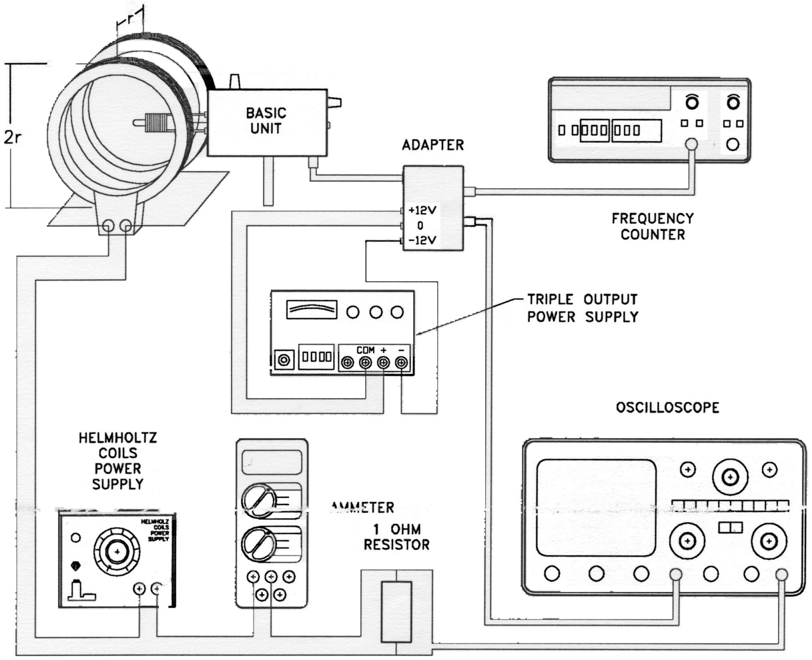


Figure 5: Diagram of ESR setup

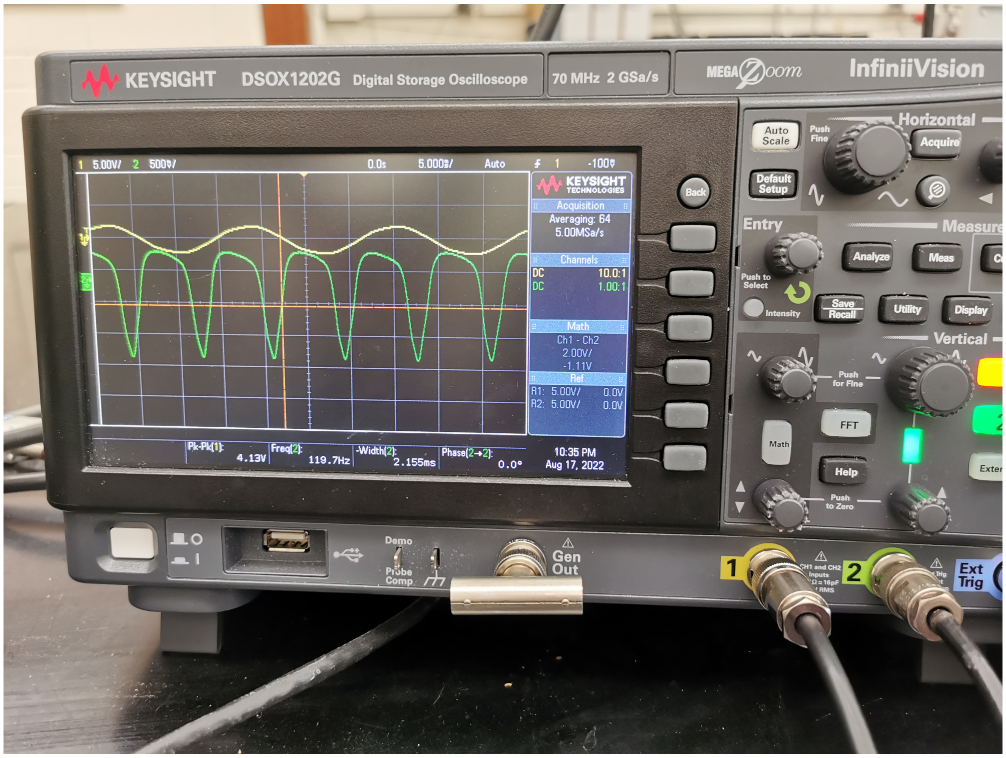


Figure 6: Scope displays

Questions

Incorporate answers to these questions into your report:

1. Is there uncertainty in your determination of when the two dips are merged? Think about the assumptions about resonance you make when taking your measurements.
2. Is the relation from Eq. (7) true over a wide range of frequencies, i.e., is the effect truly linear?
3. What is the physical interpretation of the width of the peak?