EKA Advanced Physics Laboratory

Nuclear Magnetic Resonance Experiment

Getting Started Guide

In this experiment you will be studying the principles of nuclear magnetic resonance (NMR). The purpose of this document is not to explain the experimental procedure or the physics involved (and assumes you are already somewhat familiar with the theory), but to provide a step-by-step guide to get started with the equipment, which is described on the following pages.

The workhorses of the experiment are the *main H-frame electromagnet* and its *main power supply*, pictured in Figures 1 and 2. This magnet is capable of generating a static field between its poles of up to 0.8 Tesla when a current of ~20 A is supplied.

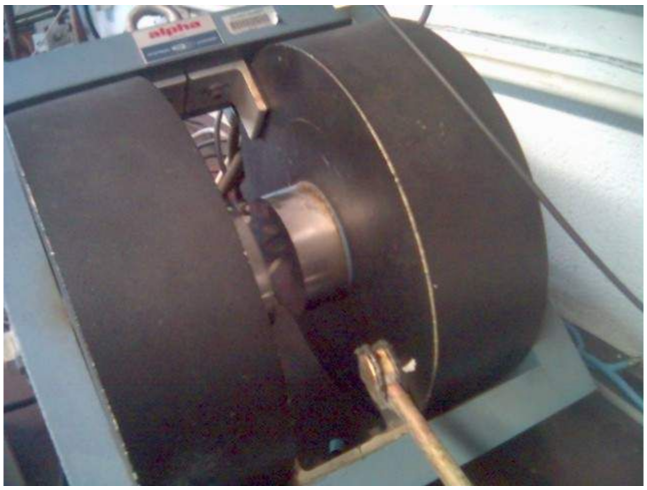


Figure 1: Main H-Frame electromagnet.

Figure 2: Main magnet power supply. The main power switch is at right; the current knobs and meter are at left.

Note that the main power supply provides *constant current* rather than *constant voltage*. This gives rise to some unfamiliar behavior. In particular, we know from Lenz's Law that a change in magnetic flux (as produced by a changing current through a coil, for example) results in an induced EMF which is proportional to (and opposes) the change in flux. For this reason, sudden changes in current can be dangerous; the power supply is in fact permanently wired to the magnet. Thus you should ALWAYS ramp the current gradually, and be sure that you set the current back to zero before turning it off.

Figure 3: Hall Effect Gaussmeter and field probe. There is also a manual available.

Figure 4: Cylinder of magnetically soft material, used to accurately calibrate the meter to zero field.

To measure the magnetic field, a *Hall effect gaussmeter* is provided (pictured in Figure 3). To ensure that the gaussmeter is properly calibrated, tbe gaussmeter tip can be inserted into a cylinder of magnetically soft "mu-metal" (pictured in Figure 4).

Setting up the main magnet and measuring the field

1. Turn on the cooling water supply, using the knob at the left side of the sink. This will flow water through the magnet, preventing it from heating up at high current settings. Water will flow into the sink from the flow unit.

   NOTE: Do not ever run the main magnet when the water is not running! (It should not power up anyway due to an interlock which prevents the application of current without adequate cooling supply, but it pays to be doubly sure.)

2. Turn on the main magnet power supply (Figure 2), and ramp the current to about 20A using the coarse knob at left.

NOTE: Do not let the current exceed 25A. To be safe, you should restrict your maximum current to about 20A, corresponding to a maximum field of about 0.8T.

3. You should accurately zero the Hall effect gaussmeter (Fig. 3) using the mu-metal cylinder (Fig. 4) and in a location away from any large magnets. Take special care not to bend or stress the gaussmeter probe tip, as it is fragile!

4. Now, by changing the current you should be able to measure the field between the magnet's poles. Note that the gaussmeter is only sensitive to **B** perpendicular to its flat axis, so you may need to rotate the probe slightly to get the maximum field.

Figure 5: Digital Ammeter
This meter provides an accurate reading of the main power supply current.
Use this meter instead of the analog ammeter located on the power supply.

Your first task will be to produce a plot relating the applied current (as measured by the ammeter) to the produced field (as measured by the gaussmeter). You will note the proportionality of field to applied current and the effect of hysteresis (magnetic charging history).

Finding the Proton Resonance

The actual NMR effect is observed by measuring the response of a sample to an applied RF signal as a function of the signal's frequency. There are several pieces of equipment used for this, pictured on the following pages.

The primary pieces of equipment used are the *RF coil* (Figure 7), which in addition to holding the sample also holds a set of coils which create a rapidly oscillating field as set by the knobs on the *RF Unit* (Figure 6) to which it is attached. There is a *frequency counter* (Figure 9) which gives an accurate reading of the RF frequency being applied.

There are several different RF coils depending on the frequency range of interest; they may be found hanging on a rack on the opposite side of the room.

The resonance signal is detected as a change in the RF signal in the coil; this signal is amplified by the *amplifier* and passed along to the oscilloscopes where it can be detected.

Figure 6: RF Unit.

Figure 7: End of RF coil.

RF Unit (Figure 6)

This unit connects to the RF coil and sample holder (at left), and provides the RF current. The frequency is adjusted by the large knob at center, and the main power is located at lower right. At lower left is the current (intensity) control, and at upper left is a switch we'll set to B.

Switch the RF Unit on using the switch at lower right.

RF Probe and Coil (Figure 7)

The coils are located in the round piece at the end of the probe. The sample (in a small test tube) is dropped into the hole visible at the top of the coil unit. For the first part of our experiment we will use the mineral oil sample.

Note that there are several RF probe units, each with a preset range of frequencies. For the first part of our experiment (proton resonance) we will use the 13-37 MHz coil. The deuteron resonance will be found at a lower frequency (around 5 MHz), so you will want to use a probe in that frequency range for that part of the experiment.

Let's attach the 13-37 MHz probe (if it isn't attached already) and insert the mineral oil sample. By moving the RF unit around, center the RF coil and sample between the main magnet's poles.

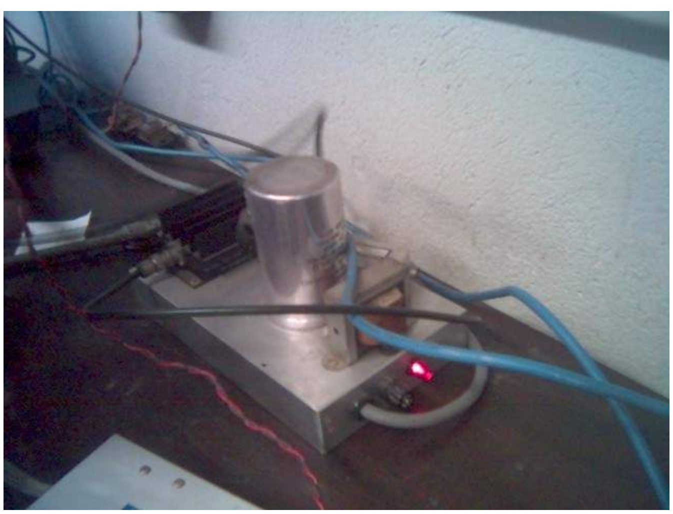


Figure 8: Amplifier (located behind RF Unit).

Figure 9: Frequency counter.

Amplifier (Figure 8)

This unit amplifies the resonance signal and passes it along to the oscilloscope so that it can be viewed (See Figs. 12 and 13). There is a small power switch at right, next to the power indicator light.

Let's switch on the amplifier.

Frequency counter (Figure 9)

This digital meter gives an accurate readout of the RF frequency being applied by the RF unit.

Let's switch on the frequency counter. Note how adjusting the frequency knob on the RF unit changes the frequency value displayed on the meter.

In order for the signal to be detectable, we must vary RF frequency across the resonant peak, in order to see the "on-off" effect of fine tuning the applied signal. To do this we use a *marginal oscillator* (Figure 11), which applies a 60 Hz signal to rapidly tune the signal on and off of resonance.

Figure 10: Voltage supply for 60 Hz marginal oscillator.

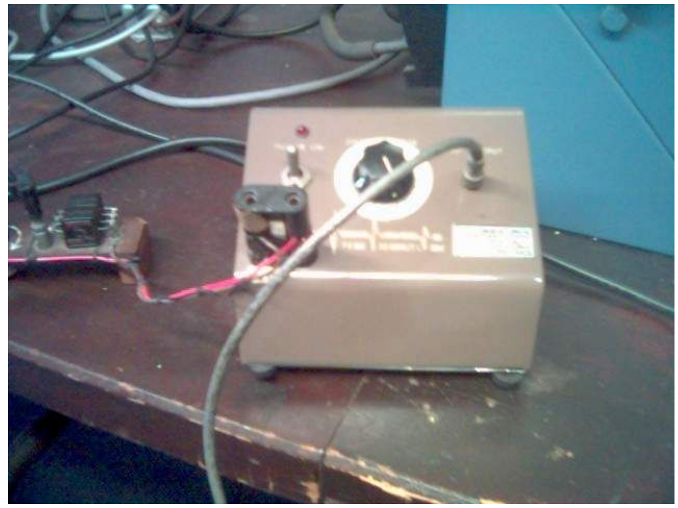


Figure 11: 60 Hz marginal oscillator.

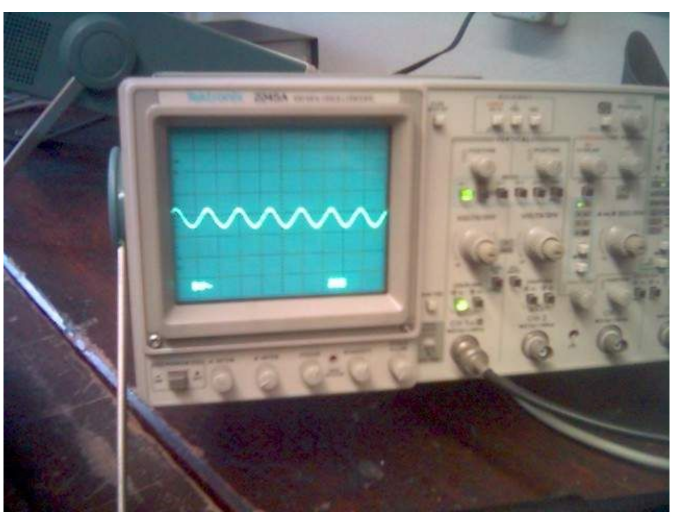
Voltage supply (figure 10)

Supplies voltage to the marginal oscillator. We won't do much with this except to switch it on and set it to 20 V. Set this voltage to 20 V and leave it there for the duration of the experiment.

60 Hz marginal oscillator unit (figure 11)

This device supplies a 60 Hz signal to the RF coil to enable detection of the resonance signal by causing the applied signal to oscillate back and forth across the resonance. It is powered on using the switch at left, and may be adjusted using the knob at center, as well as the potentiometer on the unit at the left of the picture.

Finally, to view the output signal we have two oscilloscopes, pictured in Figures 12 and 13.



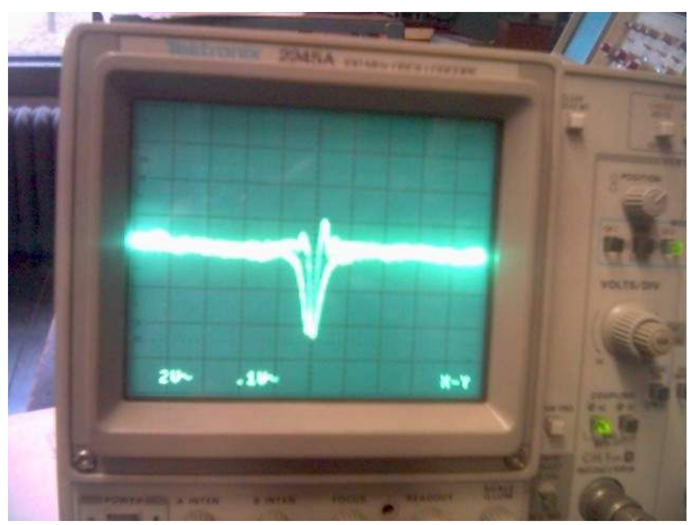


Figure 12 and 13: Oscilloscopes 1 (left) and 2 (right). Power switches are at lower left.

Oscilloscope 1

This oscilloscope reads the signal being supplied by the RF Unit.

Set the RF unit current (using the knob at its left) to the maximum value it can have without substantial distortion of the signal on Oscilloscope 1.

The larger the RF signal being applied, the larger the NMR effect will be. But if the signal becomes so large that significant distortion occurs, then there will be problems. So we set the RF unit current to the maximum value it can have without significant distortion.

Oscilloscope 2

Reads the output of the RF coil (plus marginal oscillator), as amplified by the amplifier in Figure 8. Visible at the center of the screen is the proton resonance.

Since the gyromagnetic ratio of the proton is 42.57 MHz/T, using the present value of the magnetic field (say, 0.8T), we can calculate the resonant frequency of the proton: f = (42.58 MHz/T) * (0.8T) = 34.06 MHz.

Set the current to about this value (or whatever value you calculate from your measured field), and sweep the RF unit frequency until you find the proton resonance, as depicted in Figure 13.

The Actual Experiment

First, you will find the resonance of the proton for the mineral oil sample.

Then, using samples with varying copper sulfate (Cu_2SO_4) concentration, observe the effect of relaxation generated by the presence of magnetic (Cu) ions.

Finally, locate the resonance peak of the deuteron using a sample containing heavy water. The most effective way to do this is to first find the proton resonance at low frequency ~5 MHz (by ramping down the field to ~0.1 - 0.15T), then replace the sample and adjust the current upwards by an appropriate factor such that the deuteron resonance appears at approximately the same frequency.