Goals
Observe and understand the phenomena of nuclear magnetic resonance.

Introduction
When a nucleus of non-zero angular momentum is placed in a magnetic field, the differently magnetic sublevels are "split" in energy due to the interaction of the nuclear angular momentum and the magnetic field. The application of a rf magnetic field of the appropriate frequency can be used to induce transitions between the sublevels. This phenomena is called nuclear magnetic resonance. The transitions may be observed in a sample by detecting the rf power absorbed when the rf is at "resonance". Much information may be obtained about the sample from the details of the resonance. This technique has many applications in physics, chemistry, and medicine.

The magnetic resonance occurs in the sample when the rf field frequency, $\nu_0$, set to:

$$\nu_0 = \frac{1}{2\pi} g \mu_N B_0$$  \hspace{1cm} (1)

where $B_0$ is the static field applied to the sample, $\mu_N$ is the nuclear magneton, and $g$ is the "g-factor" for the nucleus under study (see [1], table M.1).

Equipment
- 12-inch magnet with power supply.
- Hall-probe gaussmeter (Bell 610 or Walker MG-3A): This device uses the Hall effect[1] to measure the magnetic field.
- NMR apparatus: sample holder and readout circuit, rf generator, amplifier, oscilloscope, multimeter, counter, function generator, several material samples.

Preparation
- Using Equation 1 above, calculate the numerical relationship between $\nu_0$ and $B_0$ for the proton (hydrogen) so you can quickly calculate frequency given a magnetic field and vice versa.
- Read over the manuals for the magnet and control electronics and for the gaussmeter.

Experiment
In this experiment, you will calibrate the magnetic using a gaussmeter, then you will find the resonant frequency $\nu_0$ to measure a value for $g$. You will then turn the method around and use the known value for $g$ and the measured $\nu_0$ to determine the magnetic field.
1. Calibrate and position the Hall-probe gaussmeter.
- Following the instructions in the manual, zero and check the calibration of the gaussmeter. Keep the probe from the area of the magnet while calibrating. Don't spend too much time calibrating with zero field as it is difficult to get the calibration precise at both low and high fields and you will be measuring high fields (several kG).
- Then, use the calibrated magnetic field box to calibrate the device. Think about errors at this step.
- Position the Hall-probe in the center of the air gap between the magnet pole tips. Remember that the Hall-probe is sensitive to a single component of the magnetic field vector, B.

2. Start up the magnet in non-regulated mode.
- Turn on magnet cooling water.
- Make sure the current control switch (at bottom of control panel) is off and "mode select" switch is set to "field set"
- Turn control power on.
- Turn course current control knob (at bottom of control panel) all the way CCW and turn current control switch to "on".
- Press black "on" push button (lower right of control panel).
- Slowly turn course current control up and watch the magnet current. Be patient, the control circuits take a while to respond to any changes on control panel.
- Monitor the current to the magnet with a DVM on the current monitor point (above the current meter).
Once warmed up, the current (and, thus, the mag. field) should be quite stable.

3. Measure the magnetic field
- With the Hall probe in the center of the magnet, measure the magnetic field as a function of current in ~5A steps from 0A to a maximum current of ~50A. Repeat this working down from maximum current. Is the measured field zero at zero current? Does the measured field vary linearly with current?
- At a mid-range current setting (~35A), measure the magnetic field transversely across the gap of the magnet. Is the field uniform across the gap?

4. Set up the NMR apparatus
- Remove the faceplate on the sample holder and examine the rf coil. Replace the faceplate and position the sample holder in the center of the magnet so that the axis of the rf coil is transverse to the field direction of the magnet.
- Insert one of the NMR samples (water with a small amount of ferric chloride is the best one to use at the start).
- Connect the electronics as shown in Fig. 1 (don't turn anything on yet). Be sure to understand the function of each unit.
- Set the magnetic field to ~7kG.
- Turn on the rf generator, following the instructions on the unit.
- Turn on the freq. meter, voltmeter, instrumentation amplifier, oscilloscope, and signal generator. Set the signal generator to 100Hz, triangle wave, amplitude=-1.5V. The output from this unit should be split - One leg goes to the NMR probe sweep field coils and one to the oscilloscope. Trigger on this signal and adjust the oscilloscope so that you can see 1-2 periods of the signal.
- Using the relationship between $\nu_0$ and $B_0$ that you calculated above (from Eq. 1), calculate the NMR frequency and set it.
- Attach the output from the instrumentation amp to the oscilloscope and set the scope to view this signal (AC coupled).
- Adjust the capacitor on the NMR readout circuit to maximize the DC voltage displayed on the voltmeter, set the gain of the instrumentation amp to ~15.
- Look for a peak in the NMR signal at the same amplitude of the triangle wave, adjust the frequency around the calculated value while searching for the peak. For a given $\nu_0$ the NMR peak will stay in phase with the sweep field signal, while noise does not. This is the signature of the NMR signal. If you think you found it, use the average feature of the oscilloscope to enhance the signal-to-noise ratio.

Finding the NMR signal, takes patience and practice - your instructor will help. Some subtleties to consider and/or adjust are:
- The best place for the sample seems to be slightly (3 cm) below the center of the magnet.
- The rf supply has some "dead" spots in the dials. Watch out for these. In general the amplitude from this unit should be set to the maximum (~500mV).
- The instrumentation amp saturates above a gain setting of ~15.

The NMR readout circuit used in this lab is similar to that explained in Ref [1] p273ff. The addition of a diode allows the circuit to be "tuned" to have a resonant frequency near that of the NMR $\nu_0$. This is what you are doing when adjusting the variable capacitor to maximize the DC voltage on the voltmeter. The sweep field allows for the NMR signal to be seen in a small window around the central frequency as well as shows the transition between out of and into resonance.

Once you have found the signal, turn the sweep field frequency down to 1-2 Hz. This allows for a more simple interpretation of the signal. Then get a good measure (and picture) of the signal by letting the scope average over 100-200 samples. Go back to a higher sweep field frequency when searching for the signal with a new configuration.

4. Measure g for the proton
- Find the NMR signal and adjust $\nu_0$ so that the peak is where the sweep field signal (triangle wave) crosses zero. At this point the sweep field is zero and the DC magnetic field is solely due to the 12-inch magnet.
- Do this for several value of magnetic fields around 7kg. Work in small steps up and down from 7kg as the signal may not be visible far from this value.
- Using the data from the gaussmeter that you took in step 3 above, calculate $g$ for the proton for each mag field setting. Use proper error analysis!
- Fit this data to obtain a measurement of $g$. Compare to the theoretical value.

5. (Re)measure the magnetic field
- With the data from step 4, use the known value for $g$ to calculate the magnetic field of the 12-inch magnet as a function of current. Use proper error analysis!
- Plot this data and compare to the measurement of the field with the gaussmeter. Compare the errors of the two methods.

7. Calibrate the sweep field.
- Set the rf so that the NMR signal occurs at different phases of the sweep field (triangle wave).
- Use this data to calibrate the sweep field.

Ideas for additional measurements
- Investigate the NMR signal for other material samples.
- Determine $T_2$ from the width of the NMR signal.
- Why does the NMR signal occur at different values of the sweep field, $B_s$, for positive vs negative $\frac{dB_s}{dt}$?
References