A Measurement of the Magnetic Moment of Flourine

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Abstract

We measure the gyromagnetic ratio of Flourine ($\gamma_F$). To calibrate the strength of the magnetic field, we use a proton sample of glycerin. To measure the relative moments between hydrogen and flourine, we use an NMR apparatus to find the resonant RF frequency and use a signal generator with an antenna to measure beating against the RF frequency. To verify that we are indeed seeing the relaxation of the target nucleus, we show the decay envelope of the NMR signal encloses a $\cos(kt^2)$ oscillation. We report our measurement of $\gamma_F$ to be 40.055 $\pm$ 0.1 $\pm$ 0.001 MHz/Tesla$^2$ where the errors are systematic and statistical respectively. This is in good agreement with the the accepted value of 40.054 MHz/Tesla$^2$ $\pm$ 4.1 ppm [1].
INTRODUCTION

During the birth of quantum mechanics, it was noticed that particles contained another property besides those well known properties of mass, charge, position and momentum. This property has been shown to be mathematically, and physically equivalent to an intrinsic angular momentum of the particle($L$). Each atomic nucleus has a minimum value of intrinsic angular momentum equal to an integer multiple of one half of Planck’s constant($\hbar$). Since each nucleus has a charge, and a minimum spin, it is natural to suggest that each nucleus will have a magnetic dipole moment($S$) associated with it, just as a loop of wire with a current will produce. This dipole moment is proportional to the angular momentum of the particle($\mu$), and this proportionality constant is called the gyromagnetic ratio($\gamma$).

\[ \mu = \gamma (\hbar S) \] (1)

When a sample is put into a magnetic field ($B$), there will be a torque($\tau$) on nuclei with magnetic moments in the sample.

\[ \tau = \mu B \] (2)

This torque will cause the nuclei to precess around the magnetic field with a precessional angular frequency ($\omega_o$).

\[ \omega_o = \tau / L \] (3)

A radio-frequency (RF) field with a frequency($\omega_{rf}$) near the resonance frequency of the nucleus of an atom can be absorbed by the nucleus causing the RF field to decrease in intensity. This technique is called nuclear magnetic resonance (NMR) [2].

Resonance with sub-atomic particles is a very sensitive technique and is used in a variety of applications today. NMR is used for medical imaging and chemical analysis. Complex radio frequency sequences on a background field gradient can provide three dimensional information on the density and type of material in the sample being studied. Electron spin resonance (ESR) and nuclear quadrupole resonance (NQR) are examples of other modern spin resonance techniques that can be used to study quantum mechanical properties such as the crystal structures of bulk samples and the bond geometries and energies of molecules.

This experiment was done as Experiment 4 of the Graduate Laboratory class at the University of Utah. The purpose of this experiment was to measure the magnetic moment of the Flourine nucleus.

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EXPERIMENT

Figure 1 shows the NMR apparatus at the University of Utah Graduate Laboratory that was used in this experiment. The apparatus consists of a magnet UU inventory #40036580 and the RF generator which held the sample UU inventory #40036589. In order to find the strongest field, we moved a proton sample, glycerin $C_3H_5(OH)_3$, in the central region of the magnet while resonating with the RF generator. The strongest field was found when the signal reached the maximum amplitude.

We found the largest error in the experiment was a systematic error observed in the strength of the magnetic field. In the data it is clear that the field strength was systematically decreasing while the measurements were being taken. The measurements for this experiment were all done on one day which made it possible to correct for the drift of the magnetic field in time as it heated up. This correction led to the large variance in the dataset due to the uncertainty of the field drift between proton and fluorine measurements.

In this experiment we used a Krohn-Hite 4100A oscillator to measure the frequency of the RF field using a beating technique. We were able to measure the frequency of the RF
field by connecting an antenna to the oscillator and watching the RF signal on the LeCroy oscilloscope. When the oscillator and the RF signal were close, a beating interference could be observed on the RF signal. The frequency at which this disappeared, with slow beating on either side, gave us the frequency of the RF signal. We estimate the error in this method to be approximately ten hertz or ten parts per million.

The Stanford Research Systems DS345 function generator was used to modulate the RF signal. By introducing a slow, 20 Hz ($\omega_m$), modulation to the RF signal, it was possible to sweep a range of RF frequencies making it easier to identify the nuclear resonance. When the NMR signal was observed at each of the zeroes of this generator, the RF signal was exactly resonating with the nuclei in the samples. When the field passes through resonance
at a fixed frequency, the signal should oscillate at the beating frequency (\(\omega_b\)). \(\omega_b = \frac{\gamma F}{2} \frac{dB}{dt}\) where \(\frac{dB}{dt}\) is equal to \(\omega_m\) multiplied by the amplitude of the modulation [3]. The amplitude of the modulation was measured to be about \(+/- 20\) gauss [4]. The NMR signal came as a damped sinusoidal that oscillated as \(t^2\). This was checked for the Flourine signal and is shown in figure 2. Using our measurement for \(\gamma_F\), the oscillation according to equation 4 should equal 8.9e-9 and the data are in good agreement.

CONCLUSION

We have measured the gyromagnetic ratio of Flourine with NMR using glycerin as a proton source to calibrate the field strength. We also verify that the NMR signal is consistent with a \(\cos(k t^2)\) oscillation where the constant \(k\) is related to the beating frequency of our modulation. The proton calibration led to a systematic drift as a finite amount of time passed between measuring the proton and flourine resonances. Correcting for this, we report our measurement of \(\gamma_F\) to be 40.055 \(+/- 0.1\) \(+/- 0.001\) MHz/Tesla\(^2\) where the errors are systematic and statistical respectively. This is in good agreement with the accepted value of 40.054 MHz/Tesla\(^2\) \(+/- 4.1\ ppm\).

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