Experiments in Nuclear Magnetic Resonance

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Abstract

The constituents of matter and their fundamental properties are of great importance to our understanding and modeling of nature. From consumer technology applications, to weaponry, astrophysics, and to atmospheric physics, magnetic phenomena dominate many physical reactions and dictate the interactions of matter and energy we wish to predict. Here, I measured the intrinsic dipole moment of the proton with a glycerine probe and used the results to characterize an electromagnet, and attempted to find the magnetic dipole moment of an atomic nucleus. The measured value on the proton was 7.903×10^{-11} eV/G $\pm 1.0 \times 10^{-12}$ eV/G. The results of the magnet modeling were that the B field increases linearly with voltage (or current), and the data and results will be discussed in further detail in later sections. Given the magnetic field strength and resonant frequency, the unknown probe appears to be Fluorine.

Introduction

The energy of a dipole in a magnetic field is simply the inner product of the dipole moment and the magnetic field strength. A dipole 'flipping' from being antiparallel with the field to being parallel is then

$$\Delta E = 2\mu B \tag{1}$$

A photon or electromagnetic wave released by this would then have the energy

$$f = \frac{2\mu B}{h} \tag{2}$$

After the nuclear dipole moments align with the external field, this energy is no longer being released. Boltzmann statistics show this happens on time scales much shorter than a second, so a set of Helmholtz coils, being driving by a 120 Hz AC current serve to scramble the dipole alignment. The probe holding the sample includes a marginal oscillating antenna, which provided the electromagnetic radiation to perturb the dipoles. Finally, because the energy released is dependent on the magnetic field strength and direction, it is then important to ensure a uniform field over the volume of the sample. This was done by having the samples be on the end of a long probe that sits directly in the center of two flat magnet faces.

Procedure

The initial measurement was that of the proton magnetic moment in a fixed permanent magnet. I used a Hall Effect teslameter to find the magnetic field of the permanent magnet. Several measurements show 540 mT, and the characteristic resonant frequency for the glycerine sample for this magnetic field strength was 20.627 MHz. This was done by connecting the signal from the antenna to an oscillocope. The frequency of the marginal ocillator is controlled by a fine tuning knob on the probe. When the frequency was resonant with the proton, the signal on the oscilloscope shows peaks seperated in time, which can be tuned until they are equally spaced in time. Then, a Radio Shack radio was used to find this frequency.
Given the emperical number for the magnetic moment, I began to characterize the electromagnet. I set the radio to 16.0Mhz, tuned the marginal oscillating

antenna to this frequency, then found the matching current that would induce resonance. The radio and antenna would be tuned up 0.5 Mhz, and the process would continue.

Finally, finding the magnetic resonance of the unknown sample was done in kind using the electromagnet. I set the radio to 19.000 MHz, tuned the marginal oscillating antenna to roughly that frequency, then scanned over the possible currents from the electromagnet until finding resonance. Then, each parameter was tuned to find resonance.

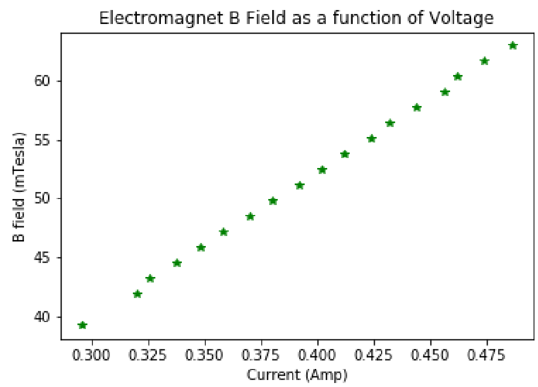

Figure 1: Graph of B field vs. current

Analysis

The proton magnetic moment was found using equation 2, and all reported uncertainties were calculated using strategies outlined in Chapter 3 of *An Introduction to Error Analysis* by John Taylor.

To find the relationship between magnetic field strength and current of the electromagnet, I used the polyfit package from the python library numpy. The slope of the fit is 124.5, with an intercept of 2.4, although naturally, with no current, the electromagnet has no magnetic field.

I found the magnetic moment of the unknown probe using the same method outlined for the glycerine sample, and converted it into units of 5.05505×10^{24} erg/gauss *CRC Handbook of Chemistry and Physics, 49th Edition.* This number most closely matched that of Fluorine.

Conclusion and Remarks

I feel my measurement of the proton magnetic moment accurately reflects numbers reported elsewhere, and found this to be an accurate way of making this measurement. The characterization of the electromagnet is very subjective to the intial dipole measurement, but it was used (presumeably) correctly to characterize the unknown probe. Various bits of uncertainty found their ways all the way through the problem, including relying on the Hall Effect sensor to reliably measure the B field of the permanent magnet. The reading of this meter was very dependent of position and angle relative to the magnet, making getting a truly 'accurate' reading of the magnet difficult. The results all depend on this reading, and so increasing the accuracy would improve the accuracy of the results.

However, given the linearity of the B field vs. Current graph, as long as strong enough B fields can be made, this method could be used to identify many substances. It raises other questions, including magnetic moments of other subatomic particles, and the implications of those values.

Appendix

References

Wolfram Alpha; http://www.wolframalpha.com
Python, numpy; http://www.python.org
CRC Handbook of Chemistry and Physics 49th Ed.
An Introduction to Error Analysis; Taylor, John R.

Data

Table 1: Data as recorded while characterizing electromagnet

Voltage (mV)	**Frequency (MHz)**
14.8	15.0000
16.0	16.002
16.3	16.501
16.9	17.005
17.4	17.502
17.9	18.001
18.5	18.500
19.0	19.000
19.6	19.500
20.1	19.998
20.6	20.500
21.2	21.000
21.6	21.501
22.2	22.000
22.8	22.501
23.1	23.000
23.7	23.500
24.3	24.000