Lande g-factor of Rb^{85} and Rb^{87} from Optical Pumping

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(Dated: November 1, 2011)

Optical pumping is a useful tool for determining the structure of atoms where other methods such as ESR are not possible. It also allows us to measure small magnetic fields precisely. Electrons in Rb^87 and Rb^85 vapor are pumped to nonthermal distributions using circulaly polarized light in the presence of the geomagnetic field. Sharp increases in the opacity of the vapor can be detected both from zero magnetic field and RF induced Zeeman transitions. Optical pumping can be used to determine the Lande g-factor for Rb^{85}, $g = 0.531 \pm .007$, for Rb^{87}, $g = 0.34 \pm .003$, and the Earth's magnetic field, $B = 106mG \pm 12mG$.

I. INTRODUCTION

Optical pumping gives us key incites to Zeeman splitting and can help quantify electron spin interactions. When atoms are subject to an external magnetic field, the hyperfine energy states (F) of the valence electrons are split into sublevels: a process called Zeeman splitting. Each sublevel has a value for M, the magnetic quantum number, ranging from $+F$ to $-F$. Photons are absorbed by the electrons causing them to jump to the next energy level ($^2S_{\frac{1}{2}}$ to $^2P_{\frac{1}{2}}$). The photons also carry one unit of angular momentum ($\Delta M = +1$) . This presents a problem for the electrons situated in the highest sublevel of the lower hyperfine level. For Rb^{87}, this is the $F = 2$ and $M = 2$ energy state.[2] In order to absorb a photon and jump to the higher energy state, they must gain momentum. But the higher energy state does not have a larger magnetic quantum number. The electrons cannot absorb any energy and are now stuck in that state. Excitation and emmision occur randomly between the energy states. After a period of time all of the electrons will likely be "pumped" to the highest sublevel of the lowest hyperfine state. Atoms in the pumped state have an increased opacity.

Electrons can be depumped given the correct energy input in the form of a photon. The energy allows the electrons to transition between the Zeeman levels and return to thermal distribution. The energy needed to depump an electron is given by:

$$\Delta M = h\nu = g\mu_B B \tag{1}$$

Where ν is input light frequency, g is the Lande g-factor, μ_B is the Bohr magneton, and B is the magnetic field.

Optical pumping is detected experimentally by the increase in opacity when no magnetic field is present. Without a field the Zeeman states collapse and no pumping occurs. The atoms are already in a field produced by the Earth. This field must be cancelled with Helmholtz coils. Further dips can be produced with the input of RF energy. The RF energy causes depumping as described by Equation 1.

II. DEVICE AND METHODOLOGY

Rubidium is selected because of its single valence electron and its low melting point. Rubidium also has two naturally occurring isotopes with distinct total spin and magnetic moments, which provide even more data during the experiment. Light from a temperature controlled rubidium lamp is first collimated. The rubidium lamp contains neon as a buffering gas to reduce the number of depolarizing collisions. The entire spectrum of rubidium and neon is produced and must be filtered. An interference filter that passes only 1.56 eV photons is used. The light is then circularly polarized with a 1/4 wave plate to increase and control absorption in the cell. The photons enter the rubidium vapor cell where the pumping will occur. The final stage focuses the light into a photodiode for detection. The photodiode converts the light intensity to current. A preamp then converts the current to voltage with three gain settings to control saturation. Figure 2 is a diagram of the optical rail. The photodiode output is also fed into a control box that can adjust gain up to 1000. A high gain is needed to observe the small signal change (about 1%). The optical rail is surrounded by two Helmholtz coils: a vertical and horizontal pair. Also included are a horizontal sweep coil and a radio frequency input coil. The vertical coil is kept at constant current to cancel out the vertical component of the Earth's magnetic field. The horizontal magentic field can be swept to eliminate the geomagnetic field at a point but also show optical pumping. RF input is provided by a sine wave function generator. The voltage for each coil is measured

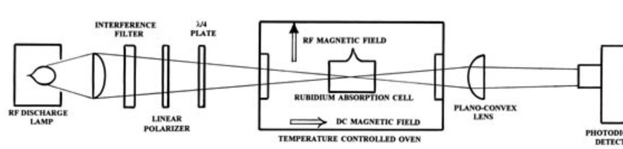

FIG. 1. Diagram of the rail used for optical pumping of Rubidium. From left: Rb discharge lamp, collimating lens, linear polarizer, 1/4 wave plate, Rb cell, decollimating lens, photodiode detector. [1]

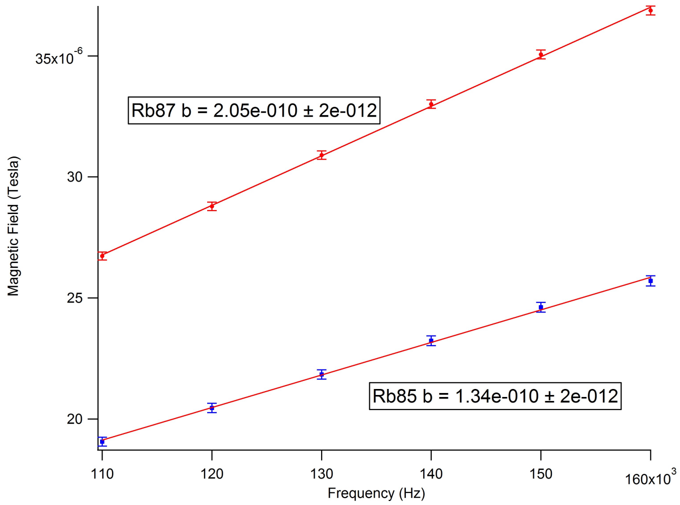

FIG. 2. Straight line fits from both isotopes of Rubidium. Slope is used to calculate Lande g-factor from Equation 1.

and converted to amperage using Ohm's law. The magnetic field in the coils can be approximated using the equation for magnetic field in a Helmholtz coil:

$$B = \frac{8\mu_0 NI}{5\sqrt{5}R} \tag{2}$$

I is the current in the coil, N is the number of turns, and $\mu_0 = 4\pi \times 10^{-7}$ Tm/A. The horizontal, vertical, and sweep coils provides 8.8 gauss/amp, 1.5 gauss/amp, and 0.60 gauss/amp respectively. In this experiment the RF input is set a specific frequency. The voltage is measured at each dip associated with a specific isotope. The slope of the straight line fit can be used to calculate Lande g-factor for each. The magnitude of the Earth's magnetic field is determined by the zero field transition point.

III. RESULTS AND DISCUSSION

The principle results of this experiment are:
$g_{Rb85} = 0.531 \pm .007$
$g_{Rb87} = 0.34 \pm .003$
$B_E = 106mG \pm 12mG$
The expected value for g_{Rb85} is ½. The expected value for g_{Rb87} is ⅓. The uncertainty from measurement of voltage is dominating. Other sources include stray and inhomogeneous magnetic fields and noise from the photodiode, filter, and amps. These, however, are insignificant. The data is not within tolerance. When the voltage in the coils is converted to current, a resistance value of 1Ω is assumed. The resistor has a tolerance of 1% which can result in an incorrect conversion and thus skew the data. An error in the resistance is more pronounced for data with a smaller change in voltage. This explains why the discrepancy in the Rb^{85} data is larger than the Rb^{87} data. Unfortunately the resistance can't be measured directly as it is locked inside the apparatus. Figure 2 illustrates the straight line fit used to determine the Lande g-factor for each.

IV. CONCLUSIONS

Optical pumping is very useful in determining small magnetic fields such as the Earth's. It is also closely related to the physics behind lasers. Alfred Kastler developed the technique of optical pumping in 1950 and was awarded the Nobel prize in 1966. Who knew his work would be used by every undergraduate physics science lab in the world? It might be useful in the future to not have the experiment located beside a moving elevator.

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[1] *Optical Pumping of Rubidium OP1-B* (TeachSpin Inc., Buffalo, 2002).
[2] Wolff-Reichert, Barbara *Conceptual Tour of Optical Pumping* (2009).