Measuring dipole moment from with quadrupole magnetic fields

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In this experiment we set out to give the TeachSpin magnetic force apparatus its inaugural run. First we calibrated a hall effect probe and measured the on axis field of a Helmholtz coil pair in both Helmholtz and quadrupole configurations. We used these results to verify theory for the magnetic field gradient of one coil and for the constant gradient in the center of two coils in the quadrupole configuration. Next, with a calibrated spring we measure the force on a small neodymium magnet in the quadrupole field. Combining this measurement with the gradent model, we were able to find the dipole moment of the magnet.

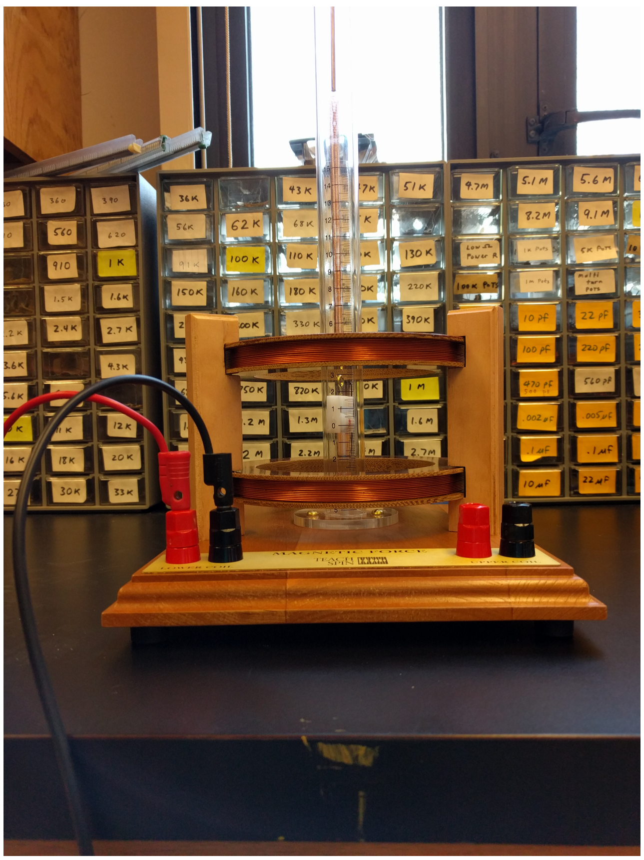

FIG. 1: Helmholtz coils are named in honor of the German scientist Herman von Helmholtz, who, among others researched electromagnetism. Helmholtz coils are made from two identical coils with radius R. The centers of both coils are placed on the same axis distance R away from one another. In this apparatus the coils are spaced slightly more than one radius apart to compensate for the physical size of the wire and maintain a uniform field in the center.

I. HALL PROBE CALIBRATION

To calibrate our probe we wound a 575 turn solenoid. Our calibration rides on the error in the current supplied to the solenoid, the length of the solenoid as well as the field model of the solenoid:

$$\vec{B} = \frac{\mu_0 N I}{L}$$

With the probe inserted roughly two fifths of the way into the solenoid, we took several measurements with a constant current supply. Plotting the theoretical field as a function of the sensor's output voltage gives us the gain of the sensor from a fit line. The output is linear in the range we intend to utilize in our next experiments with an rsq of 0.9999973. and we were able to measure the uncertainty in the calibration as: this combined with the uncertainty in our voltmeter will let us measure magnetic fields at: $\pm 0.5\mu T$.

II. MAPPING THE HELMHOLTZ FIELD

With our calibrated hall probe we measured the b field at different points along the symmetry axis of the TeachSpin Helmholtz coil pair. We modeled the theoretical field by deriving the on axis field of one current loop and then taking a sum of the field for each wire in the apparatus. Derived from the Biot-Savart law, the field for one loop of wire is:

$$\vec{B} = \frac{\mu_0}{2} \frac{I R_z^2}{\sqrt{R_y^2 + R_z^2}^3}$$

Where R_z the radius of the loop and R_y is the distance along the axis of symmetry away from the plane of the loop. [1]

We also used the Helmholtz coils in quadrupole configuration. The only difference in the field model is that we reverse the field influence of the second coil. The With the quadrupole configuration, we can get a very uniform gradient field in the center of the coil pair, which allows us to verify that the force on a magnetic dipole is proportional to the gradient in the field.

III. FORCE ON A MAGNETIC DIPOLE

With the coils in quadrupole mode, we set up the

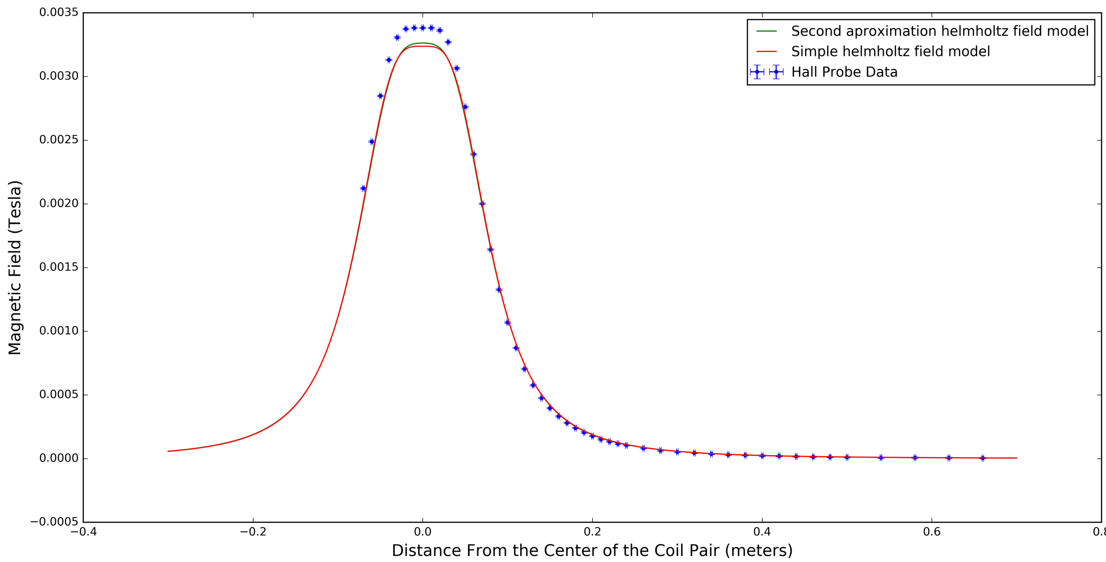

FIG. 2: Helmholtz configuration. The first field model used only two current loops (one for each coil). The second model splits the current over each loop of wire in the apparatus which respects the volume of each winding. The correction in the second model does little to encompass the error bars in our data.

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[1] Randall D. Knight *Physics for Scientists and Engineers 3rd Edition* Pearson 2013

[2] J. Higbie *Off-axis Helmholtz field* American Journal of Physics 46, 1075 (1978)

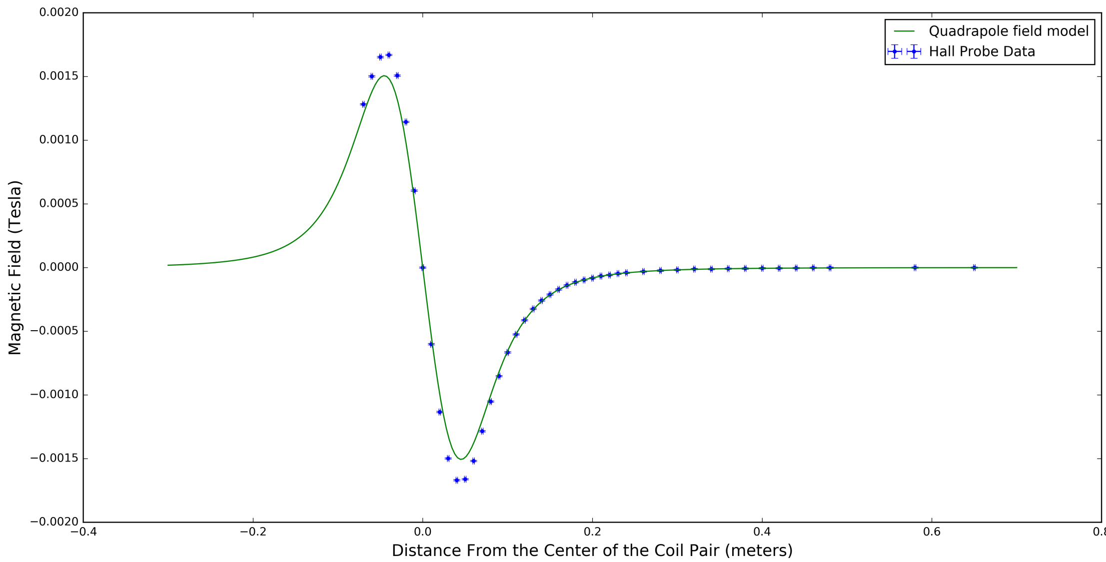

FIG. 3: Quadrupole configuration

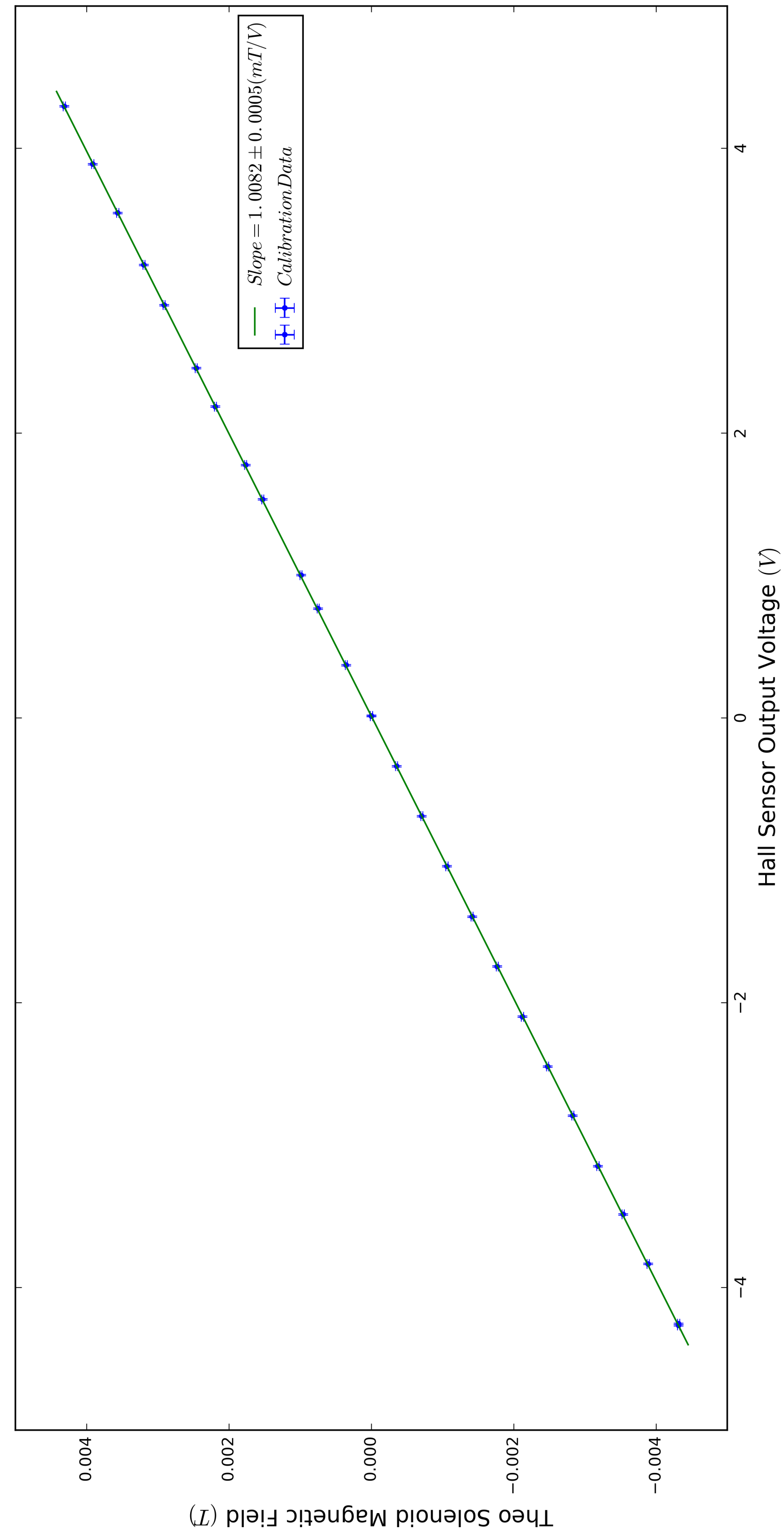

FIG. 4: Our Hall Probe calibration