Exploring Magnetic Fields and Quantum States in Atomic Clouds

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Introduction

- Our lab works with ultracold atoms.
- Our Focus: rubidium 87's unique **energy structures**.
- The lab uses diode and fiber lasers along with magnetic traps for atomic cooling.

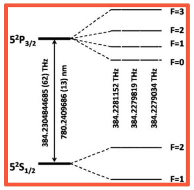


Fig. 1 These are the hyperfine structures of Rubidium 87. [4]

- My research aims to explore what occurs in the center of the atomic cloud and how the magnetic field changes the **hyperfine structures** of the atom.
  - Dutch physicist Pieter Zeeman established the theory that an atoms **spectral lines** will split when placed in an external magnetic field. [2]
- Our lab's goal is to create a stable environment to aid longer analysis periods of atoms.
- We are using home-built magnetometers to measure the magnetic field in the center of the atomic cloud.

Fig. 2 Home-built Magnetometer.

Purpose

- Measure magnetic field in atomic cloud center.
- Create a stable magnetic field to measure the electron's hyperfine structures accurately.
- Aid in the research for the eventual creation of qubits for quantum computers.
  - Quantum computers use **qubits** which are basic units of quantum information and can exist in **1** and **0**, but also have a **superposition** state which allows it to be in **both states at once**. [3]

Fig. 3 The setup in our lab.

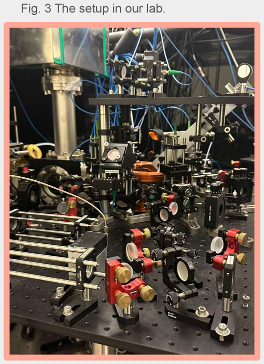
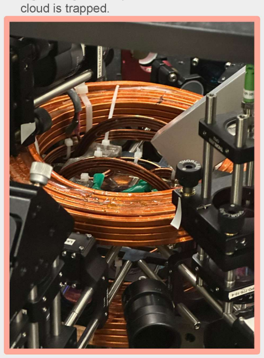


Fig. 4 Magnetic trap where the atomic cloud is trapped.



Calibration

- We started by calibrating the home-built magnetometers using bipolar operational power supply and taking data on how they measure the surrounding magnetic field within the **Helmholtz coils**.
  - We took measurements of the **X,Y,Z** current output vs. magnetometers detection of magnetic field in **X,Y,Z** directions.
  - Next, we made **linear regression graphs** to show the correspondence with the power source current and what the magnetometer was reading.

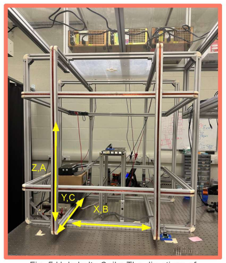


Fig. 5 Helmholtz Coils: The directions of X,Y,Z are equivalent to the magnetometers B,C,A directions.

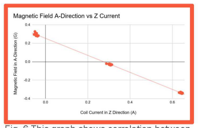


Fig. 6 This graph shows correlation between the A direction of magnetometer and Z direction of current.

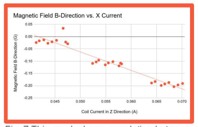


Fig. 7 This graph shows correlation between the B direction of magnetometer and X direction of current.

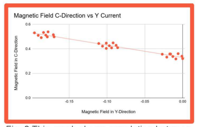


Fig. 8 This graph shows correlation between the C direction of magnetometer and Y direction of current.

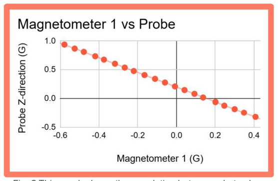


Fig. 9 This graph shows the correlation between what value Magnetometer 1 is measuring in the Z direction vs. the Probe.

- We then put the **home-built magnetometer** in the center of our Helmholtz coils with a **factory made magnetometer probe** to see if our home built magnetometer is reading measurements accurately.

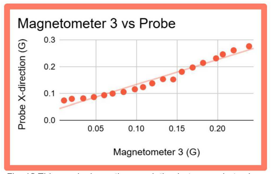


Fig. 10 This graph shows the correlation between what value Magnetometer 3 is measuring in the X direction vs. the Probe.

- Afterwards, we realized our **Z direction** was more accurate and had a better slope than all other directions, so we kept calibrating to get the best results possible.

- Then, we wanted to test how the home-built magnetometers measured the **distribution of magnetic field** between two permanent magnets.

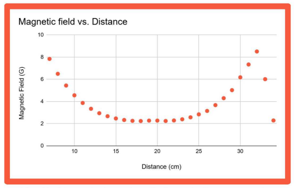


Fig. 11 This graph shows how the home-built magnetometer measures the magnetic field at different distances.

- As the magnetometer gets closer to the permanent magnets, the magnetic field should get stronger and as you move it away it gets weaker as shown in the chart. This accurately represent our theory and we begin reconstructing the magnetic field.

Reconstruction

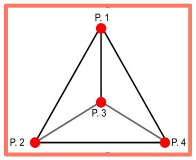
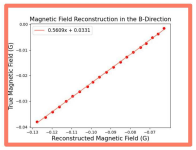


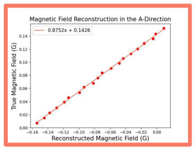
Fig. 12 This is the tetrahedral shape we used when reconstructing the magnetic field.

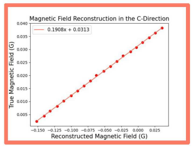
- When reconstructing the magnetic field we needed to choose a shape with **four points** to measure the center magnetic field.
- We decided to use a tetrahedral shape for our design because it's the best shape to have the magnetometers **evenly spaced** out.
- We then started to calibrate the magnetometers individually in the **tetrahedral shape** and collect **arbitrary values** of what the **center** magnetic field is.
- Using this formula, we created a coded matrix to help in reconstructing the magnetic field.

$$\hat{B}_m^i = B_m + \sum_{k\in\{x,y,z\}} \partial_k B_m r_k^i \quad \forall i \in \{1,2,3,4\}, m \in \{x,y,z\}.$$

Fig. 13 Formula used to reconstruct the magnetic field. [1]







- When looking at the plotted data we noticed that each home-built magnetometer had **unique values from one another**.
  - The home-built magnetometers gave us arbitrary values and we had to convert them into values we can use and understand in the lab.
  - We noticed that some of the magnetometers conversion rates are x7 or x1 their value when converting into gauss.

Conclusion

- The reconstruction of the magnetic was **fairly accurate**, but some changes need to happen in order to improve the readings off the magnetometers.
- There are also some flaws in the home built magnetometers in terms of **accuracy** and how the magnetometers interpret the magnetic field.
- Once the home-built magnetometers are ready to be installed in the system, we will use them to measure the magnetic field in the **center** where the atom is trapped.

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