Magnetic Coil Design and Construction

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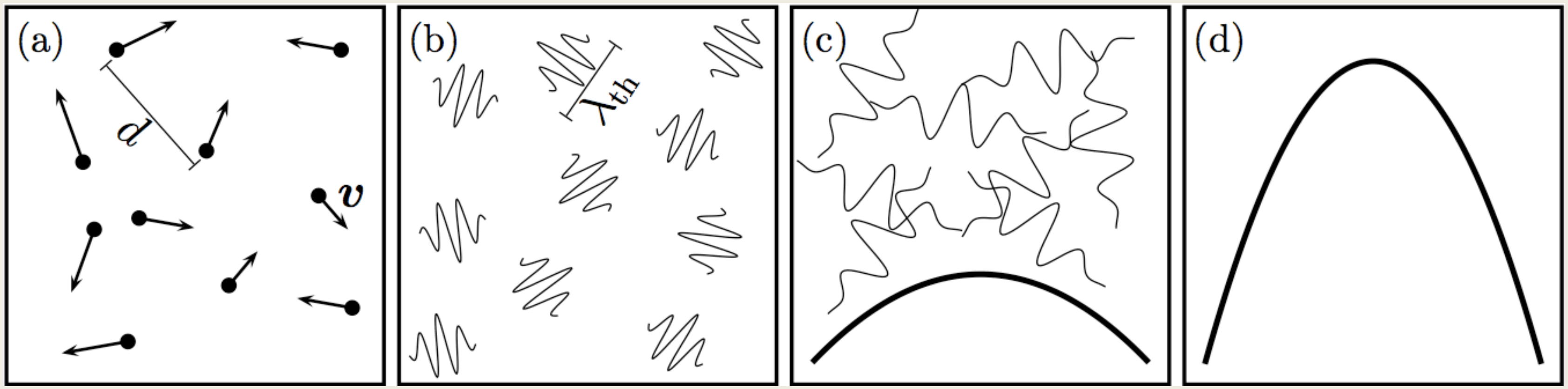
Quantum Degenerate Gases

- Ultracold Atom Research
  - Bose Einstein Condensates
    - Collapse identical wavefunction
    - Physical properties can be studied and controlled
  - Degenerate Fermi Gases
    - Pauli exclusion principle
    - Molecule formation and BCS-like pairing
    - Interactions can be tuned through Feshbach resonances

Bose-Einstein Condensate

- $n^{-1/3} \approx \lambda_{dB}$



[1]

Particle-like

Single wavefunction

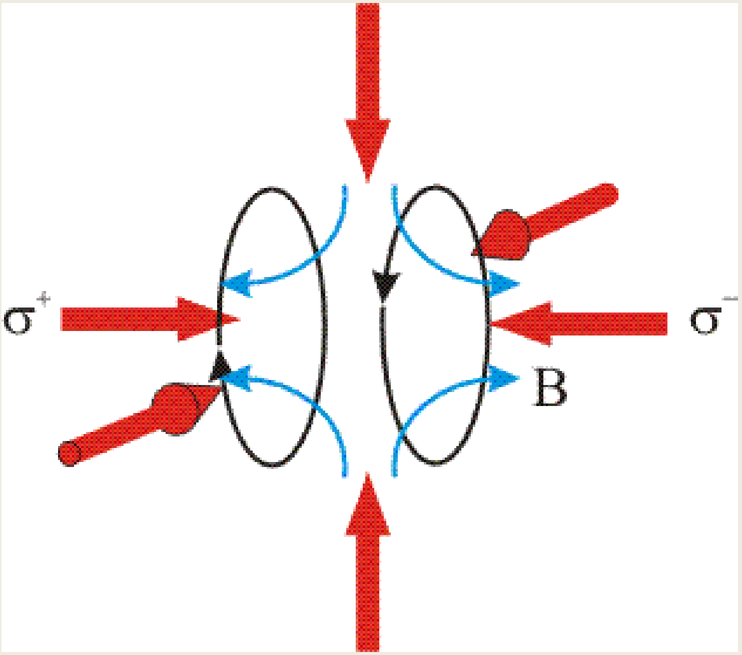
The Experiment

- Atom Source
- Zeeman Slowers
  - Counter-Propagating Resonant Laser
  - Tapered Solenoid Keeps Atoms in Resonance
- Magneto-Optical Trap (MOT)
  - Traps and Cools the Atoms
  - Lower Limit (Due to Photon Momentum)
- Evaporative Cooling
  - Lower trap depth (Optical Trap)
  - RF-induced spin flips (Magnetic Trap)
- Demonstration

[2]

Anti-Helmholtz Coils

- Arrangement
  - Opposite current direction for each coil
  - Spacing is not critical
- Field is zero at the center
- High gradient at the center



[3]

MOT

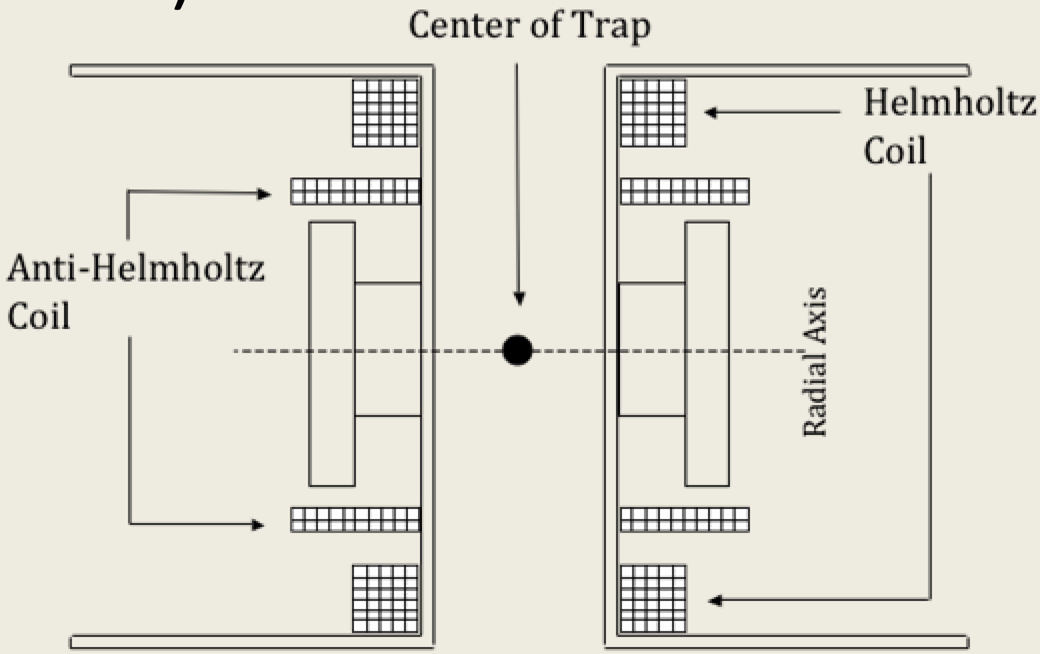
- Anti-Helmholtz coils provide magnetic field
- 3 pairs of counter-propagating lasers (red detuned)
- Atoms that move away from the center come into resonance with a laser that pushes it back toward the center of the trap (Zeeman Effect)

Helmholtz Coils

- Provide a strong homogenous field
  - Low gradient
  - Low curvature
- Arrangement
  - Current in same direction
  - Spacing equals radius
- High field to current ratio lowers heating ($P=I^2R$)
- Are used to tune interactions of the atoms through Feshbach resonances

Physical Constraints

- 2 sets of coils to avoid switching currents
- Recessed vacuum viewport (5.76")
- Flange at Center (2.73")



Modeling

- Law of Biot-Savart: $d\vec{B} = \frac{\mu_0}{4\pi}\frac{I \cdot d\vec{l} \times \hat{r}}{r^2}$

Off-Axis

$$B_Z = B_0 \frac{1}{\pi\sqrt{Q}}\left[E(k)\frac{1-\alpha^2-\beta^2}{Q-4\alpha} + K(k)\right] \qquad \beta = \frac{z}{a} \qquad \alpha = \frac{r}{a}$$

$$B_r = B_0 \frac{\gamma}{\pi\sqrt{Q}}\left[E(k)\frac{1+\alpha^2+\beta^2}{Q-4\alpha} - K(k)\right] \qquad \gamma = \frac{z}{r} \qquad Q = \left[(1+\alpha)^2 + \beta^2\right]$$

On-Axis

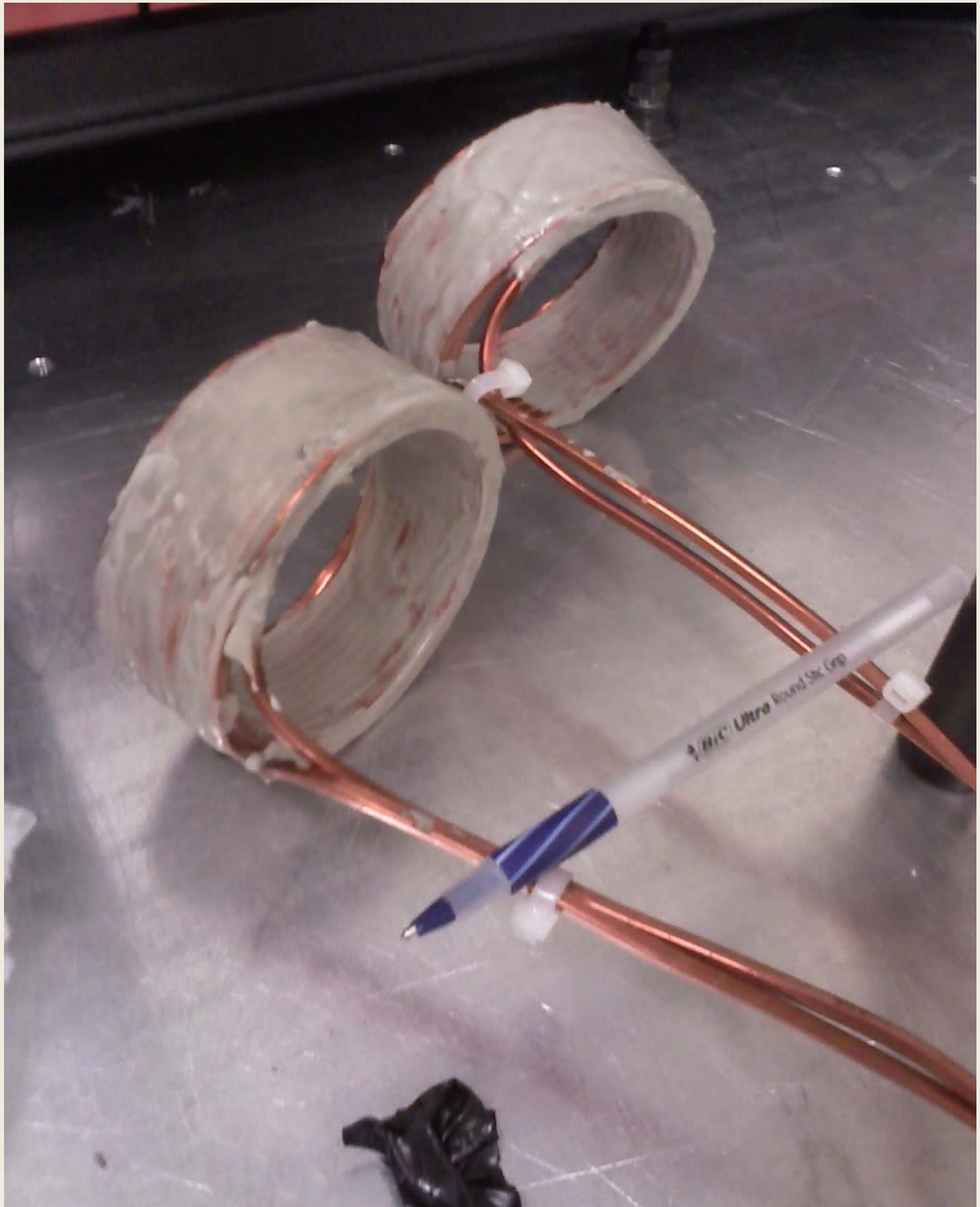
- Mathematica $B = \frac{\mu_0 i r^2}{2(r^2+z^2)^{3/2}}$ [4]
  - Coil approximated as many current loops
  - Field at any point is the vector sum of the field due to each current loop

Construction

- Winding
  - Wire guide
  - Mandrel
- Wire
  - Square (1/8”)
  - Copper
  - Kapton coated
  - Hole for coolant (1/16”)

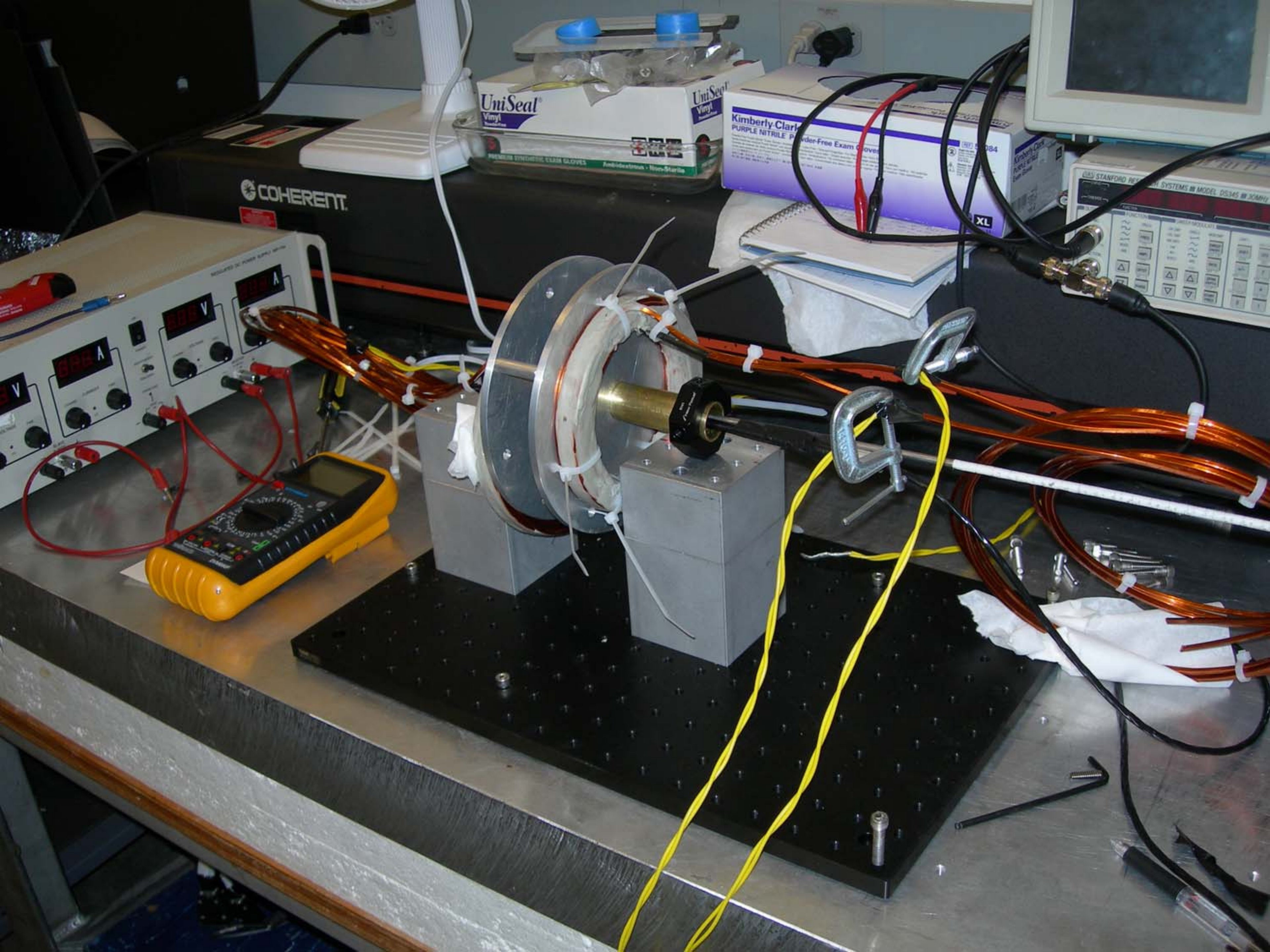
Mandrel

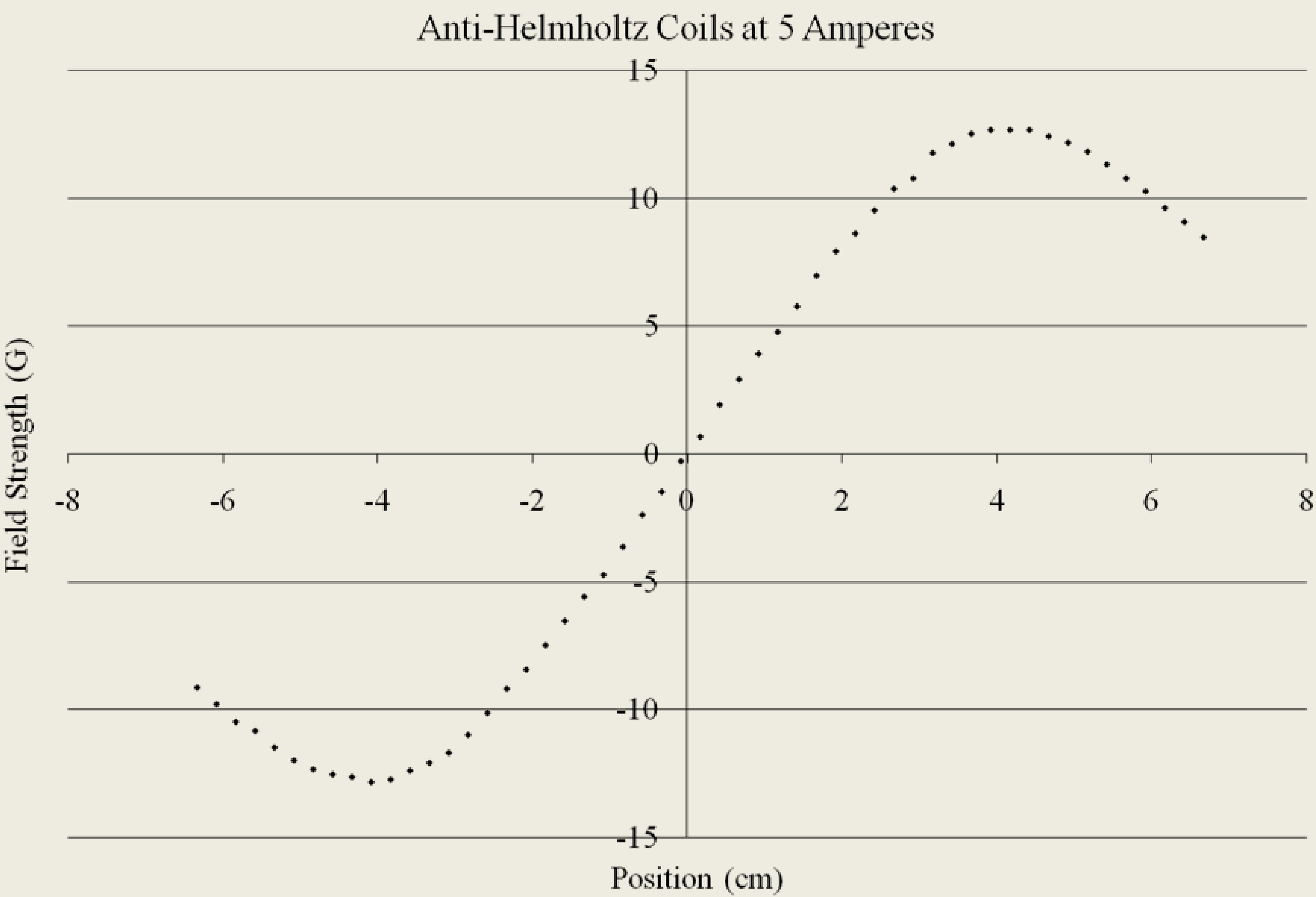

KEEP
FIRE
recyclable
R-583

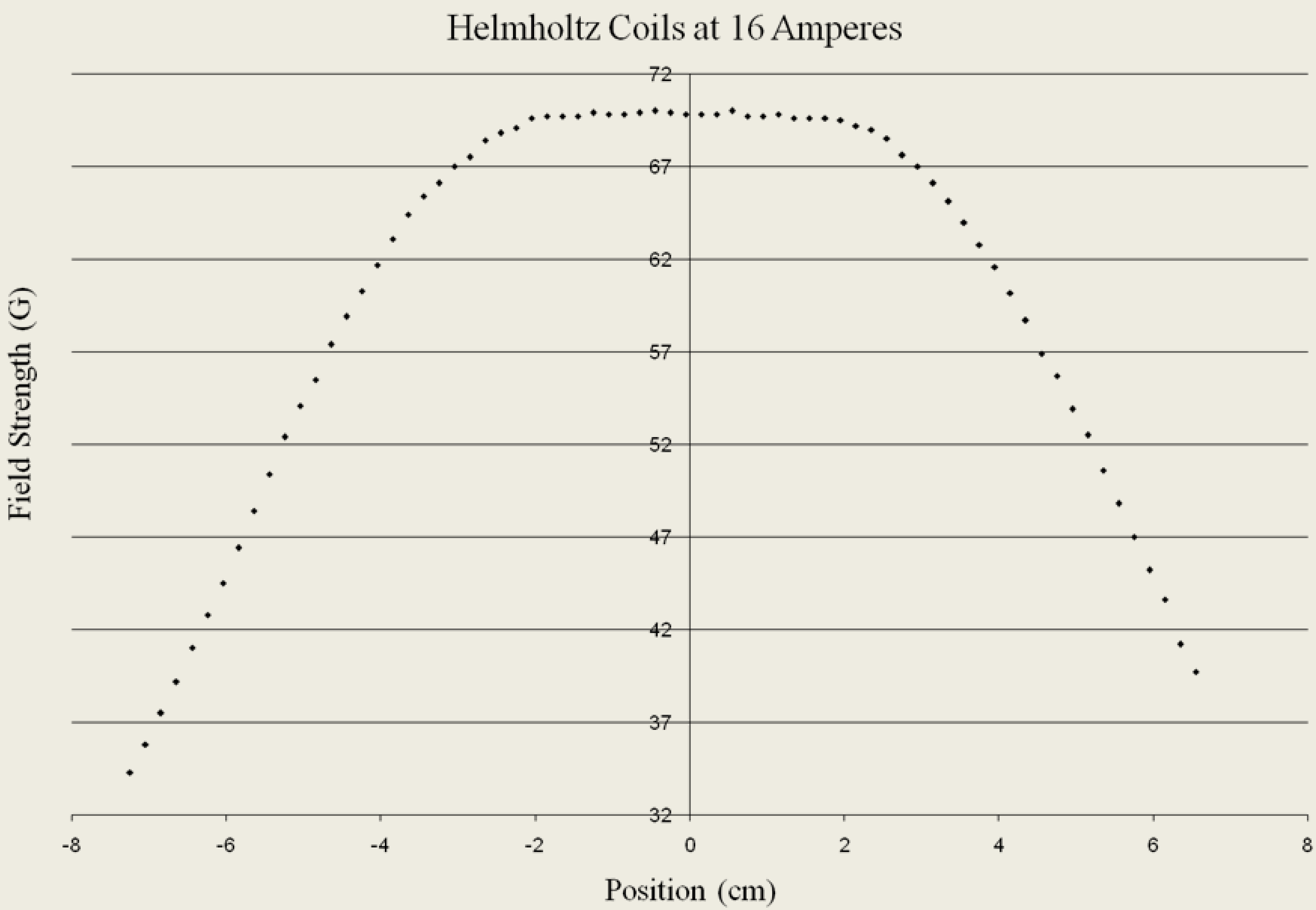

Ultra Round

Testing

- Mount for coils
  - Separation
  - No magnetic parts
- Gaussmeter and probe
  - Dowel attached to probe
  - Probe slides through brass tube


UniSeal
Vinyl
COHERENT
Kimberly-Clark
PURPLE NITRILE
XL


Anti-Helmholtz Coils at 5 Amperes
15
10
5
0
-5
-10
-15
-8
-6
-4
-2
0
2
4
6
8
Field Strength (G)
Position (cm)


Helmholtz Coils at 16 Amperes
72
67
62
57
52
47
42
37
32
Field Strength (G)
-8
-6
-4
-2
0
2
4
6
8
Position (cm)

Conclusion

- Helmholtz
  - Field Strength = 4.37 G/A (Mdl: 4.42)
  - Gradient < .013 G/cm/A (Mdl: 0)
  - Curvature < .025 $G/cm^2/A$ (Mdl: .009)
- Anti-Helmholtz
  - Curvature = .84 G/cm/A (Mdl: .86)
- Coils adequate

Thanks

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- NSF
- Deep Gupta and Research Group
- Janine, Linda, Wick, and Warren

References

[1] B. Froehlich. Ph.D. Thesis, University of Stuttgart, 2007.

[2] http://www.colorado.edu/physics/2000/bec/evap_cool.html

[3] http://www.npl.co.uk/server.php?show=conMediaFile.1335

[4]http://www.netdenizen.com/emagnet/