Measuring the Magnetic Field Profile of a Cylindrical Magnet

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This document is a supplement to the student manual for the experiment, *Steering Paramagnetic Leidenfrost Drops in an Inhomogeneous Magnetic Field*. The experiment can be found at `https://bit.ly/2JE0msT`

1 Method of Measurement

In order to calculate the magnetic energy density of the azimuthal-symmetric magnetic field produced by the cylindrical magnet, we must measure the field on surface on which the oxygen drops move. A reasonably accurate method would be to measure the radial component $B_r(r)$ and the axial component $B_z(r)$ at $r = 1$ mm intervals, moving away along the radius r. The following figures illustrate this measurement process.

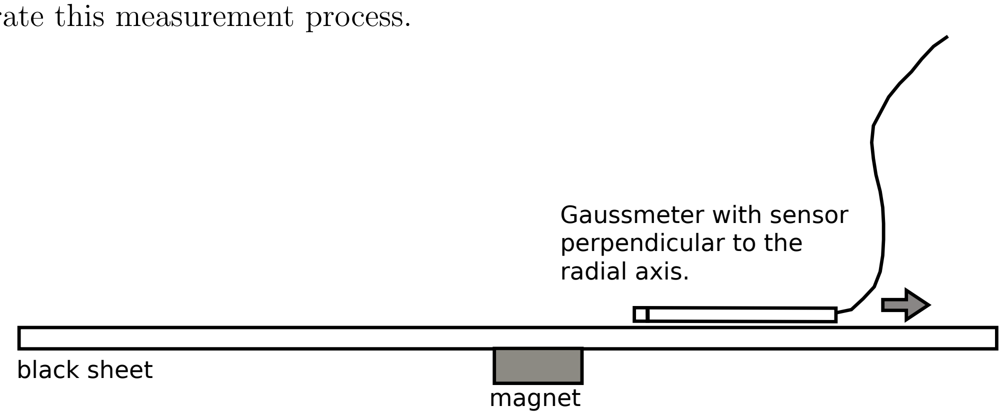

Figure 1: Setup for measuring B_r.

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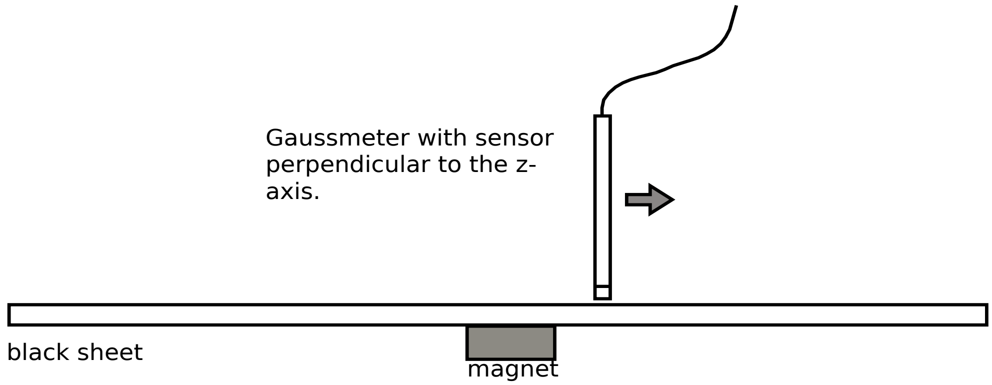

Figure 2: Setup for measuring B_z.

magnetic field is represented by,

$$\mathbf{B} = B_r\hat{\mathbf{r}} + B_z\hat{\mathbf{z}} \tag{1}$$

Once the measurements are complete, we use the following relationship to calculate B at each point,

$$B = \sqrt{B_r^2 + B_z^2} \tag{2}$$

and then plug these values into the following equation to get E_{mag} at each point.

$$E_{\text{mag}} = -\frac{\chi}{2\mu_0}B^2 \tag{3}$$

2 Data

The following is a set of data measured in the laboratory.

Table 1: Data for the field of three cylindrical magnets stacked onto each other.

r (mm)	B_r (mT)	B_z (mT)	E_{mag} (J/m^3)
0	0.300	414	-239
1	23.5	408	-233
2	61.4	398	-226
3	99.0	380	-215
4	124.8	350	-192
5	152.5	310	-166
6	173.2	264	-139
7	188.0	217	-115
8	193.5	155	-85.6
9	184.5	112	-64.9
10	169.3	65	-45.8
11	149.5	42	-33.6

Continued on next page

Table 1– concluded from previous page

r (mm)	B_r (mT)	B_z (mT)	E_{mag} (J/m^3)
12	134.5	23	-25.9
13	114.8	11	-18.5
14	102.0	3.3	-14.5
15	87.8	1.7	-10.7
16	76.2	5.3	-8.13
17	65.7	8.1	-6.10
18	57.6	9.4	-4.74
19	49.8	10.3	-3.60
20	43.6	10.8	-2.81
21	39.1	11.1	-2.30
22	34.3	11.0	-1.81
23	30.0	10.8	-1.44
24	26.7	10.5	-1.15
25	24.3	10.2	-0.967
26	22.0	9.8	-0.808
27	19.8	9.4	-0.669
28	17.6	8.9	-0.542
29	16.0	8.4	-0.455
30	14.3	8.0	-0.374
31	13.2	7.7	-0.325
32	12.0	7.2	-0.273
33	10.8	6.8	-0.227
34	10.0	6.5	-0.198
35	9.20	6.1	-0.170
36	8.40	5.8	-0.145
37	7.70	5.4	-0.123
38	7.10	4.2	-0.108
39	6.60	4.9	-0.0941
40	6.10	4.6	-0.0813

The data of Table 1 is shown in Figures 3, 4 and 5.

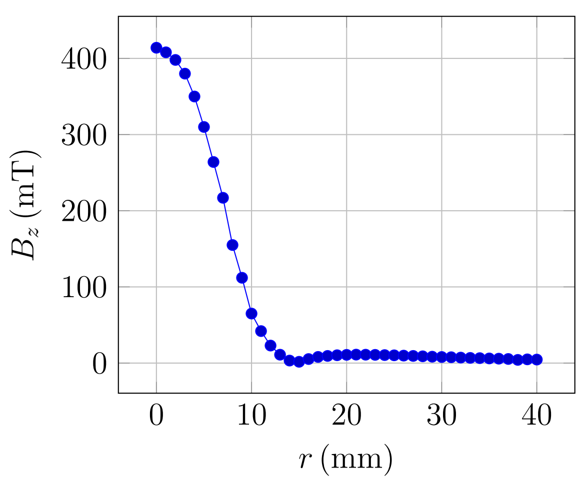

Figure 3: B_z as a function of r.

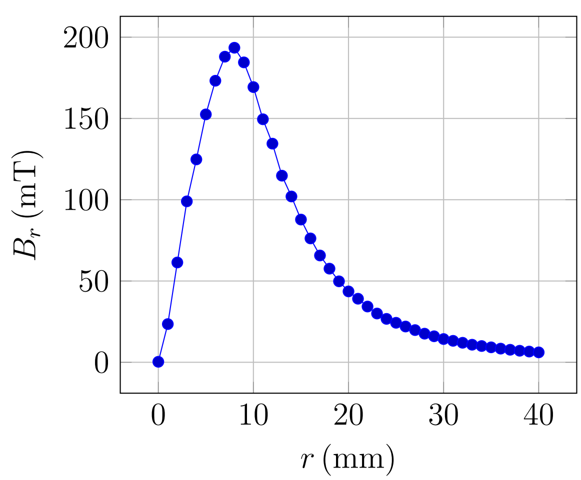

Figure 4: B_r as a function of r.

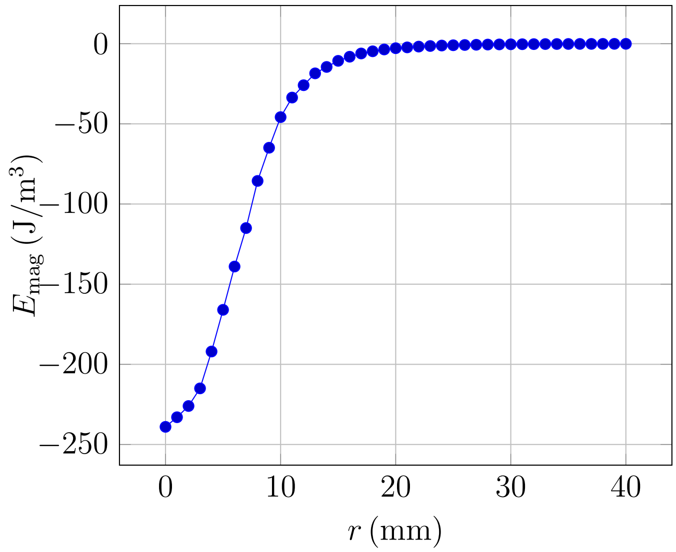

Figure 5: E_{mag} as a function of r.

3 Fitting the Data

The magnetic energy density is proportional to $1/r^6$. It can be written as,

$$E_{\mathrm{mag}} = -\frac{E_o}{q + (r/r_o)^6} \tag{4}$$

where E_0, q, and r_0 are parameters that can be found by fitting the experimental data to this model [**1**]. One particular way to do this is to enter the data into arrays in MATLAB. Then use the `cftool` to find the parameters. Our experimental data yielded the values $E_o = 66.9$ J/m^3, $q = 0.3122$ and $r_o = 0.008886$.

References

[1] K. Piroird, C. Clanet and D. Quere, *Phys. Rev* E **85**, 056311, (2012).