On the Properties of Solenoid Originated Magnetic Fields

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1 Introduction

1.1 Aim

This small project aims to investigate some of the properties of solenoid originated magnetic fields.
This will be accomplished with a combination of theoretical calculations along with experimental evidence.

1.2 Methods

1.2.1 Neutralising Magnetic Fields

1. Zero hall monitor agaist earths magnetic fields.
2. Position two solenoids 20cm apart.
3. Reverse current connections on one of the solenoids in order to reverse the direction of the magnetic fields.
4. Set power supply to 1.5A.
5. In a systematic manner, vary the hall probe along the common axis of the the solenoids and record the magnetic field in Gauss and the distance from a solenoid of ones choice.
6. Plot Gauss against distance z (cm).

1.2.2 Alternate Axis Measurements from a Single Solenoid

1. Zero hall monitor agaist earths magnetic fields.
2. Set up a single solenoid at 1.5A.
3. Vary the hall probe's distance along the x axis 90°from $+z_0$ as seen in **Figure 1**.

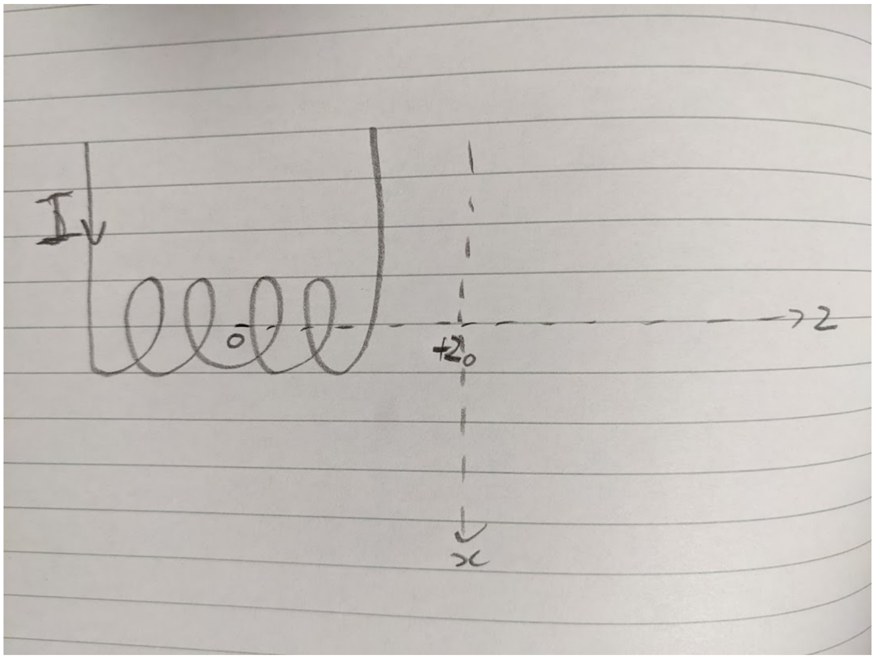


Figure 1: Alternate Axis Setup

4. Record hall effect in Gauss and distance x in cm.
5. Plot Gauss against distance x (cm).

2 Results

2.1 Neutralising Magnetic Fields

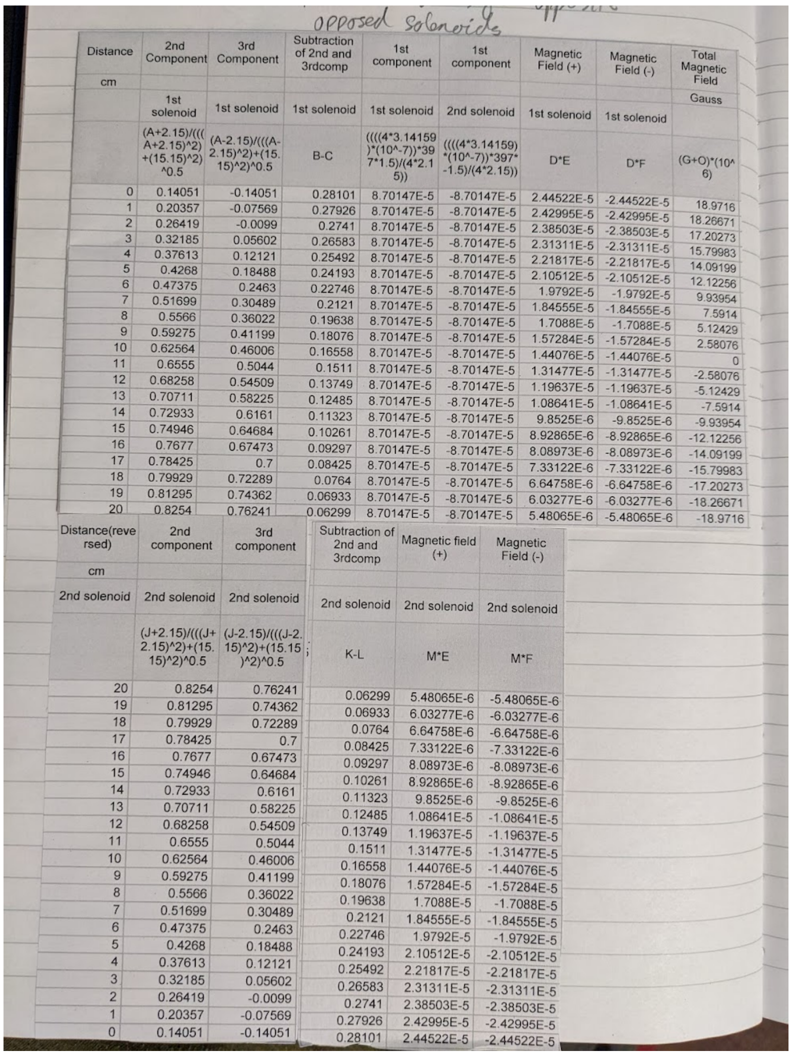
The magnetic fields generated by the opposed solenoids can be seen in **Figure 3** creating system of magnetic fields between the 2 solenoids that oppose each other. The theoretical values can be calculated with the **Biot-Savat Law**;

$$d\mathbf{B} = \frac{\mu_0}{4\pi} \frac{I d\ell \times \hat{\mathbf{r}}}{r^2} \tag{1}$$

B in (1) is measured in Tesla, so in order to compare it to our experimental values, we converted it to Gauss by multiplying by 10^4.
The method of calculation using the Origin graphing software can be seen in **Figure 2**

2.2 Expected Results

The results expected from this experiment are as follows



opposed solenoids

Distance	2nd Component	3rd Component	Subtraction of 2nd and 3rdcomp	1st component	1st component	Magnetic Field (+)	Magnetic Field (-)	Total Magnetic Field
cm								
	1st solenoid	1st solenoid	1st solenoid	1st solenoid	2nd solenoid	1st solenoid	1st solenoid	Gauss
	(A+2.15)/(((A+2.15)^2)+(15.15)^2)^0.5	(A-2.15)/(((A-2.15)^2)+(15.15)^2)^0.5	B-C	((((4*3.14159)*(10^-7))*397*1.5)/(4*2.15))	((((4*3.14159)*(10^-7))*397*-1.5)/(4*2.15))	D*E	D*F	(G+O)*(10^6)
0	0.14051	-0.14051	0.28101	8.70147E-5	-8.70147E-5	2.44522E-5	-2.44522E-5	18.9716
1	0.20357	-0.07569	0.27926	8.70147E-5	-8.70147E-5	2.42995E-5	-2.42995E-5	18.26671
2	0.26419	-0.0099	0.2741	8.70147E-5	-8.70147E-5	2.38503E-5	-2.38503E-5	17.20273
3	0.32185	0.05602	0.26583	8.70147E-5	-8.70147E-5	2.31311E-5	-2.31311E-5	15.79983
4	0.37613	0.12121	0.25492	8.70147E-5	-8.70147E-5	2.21817E-5	-2.21817E-5	14.09199
5	0.4268	0.18488	0.24193	8.70147E-5	-8.70147E-5	2.10512E-5	-2.10512E-5	12.12256
6	0.47375	0.2463	0.22746	8.70147E-5	-8.70147E-5	1.9792E-5	-1.9792E-5	9.93954
7	0.51699	0.30489	0.2121	8.70147E-5	-8.70147E-5	1.84555E-5	-1.84555E-5	7.5914
8	0.5566	0.36022	0.19638	8.70147E-5	-8.70147E-5	1.7088E-5	-1.7088E-5	5.12429
9	0.59275	0.41199	0.18076	8.70147E-5	-8.70147E-5	1.57284E-5	-1.57284E-5	2.58076
10	0.62564	0.46006	0.16558	8.70147E-5	-8.70147E-5	1.44076E-5	-1.44076E-5	0
11	0.6555	0.5044	0.1511	8.70147E-5	-8.70147E-5	1.31477E-5	-1.31477E-5	-2.58076
12	0.68258	0.54509	0.13749	8.70147E-5	-8.70147E-5	1.19637E-5	-1.19637E-5	-5.12429
13	0.70711	0.58225	0.12485	8.70147E-5	-8.70147E-5	1.08641E-5	-1.08641E-5	-7.5914
14	0.72933	0.6161	0.11323	8.70147E-5	-8.70147E-5	9.8525E-6	-9.8525E-6	-9.93954
15	0.74946	0.64684	0.10261	8.70147E-5	-8.70147E-5	8.92865E-6	-8.92865E-6	-12.12256
16	0.7677	0.67473	0.09297	8.70147E-5	-8.70147E-5	8.08973E-6	-8.08973E-6	-14.09199
17	0.78425	0.7	0.08425	8.70147E-5	-8.70147E-5	7.33122E-6	-7.33122E-6	-15.79983
18	0.79929	0.72289	0.0764	8.70147E-5	-8.70147E-5	6.64758E-6	-6.64758E-6	-17.20273
19	0.81295	0.74362	0.06933	8.70147E-5	-8.70147E-5	6.03277E-6	-6.03277E-6	-18.26671
20	0.8254	0.76241	0.06299	8.70147E-5	-8.70147E-5	5.48065E-6	-5.48065E-6	-18.9716

Distance(reversed)	2nd component	3rd component	Subtraction of 2nd and 3rdcomp	Magnetic field (+)	Magnetic Field (-)
cm					
2nd solenoid	2nd solenoid	2nd solenoid	2nd solenoid	2nd solenoid	2nd solenoid
	(J+2.15)/(((J+2.15)^2)+(15.15)^2)^0.5	(J-2.15)/(((J-2.15)^2)+(15.15)^2)^0.5	K-L	M*E	M*F
20	0.8254	0.76241	0.06299	5.48065E-6	-5.48065E-6
19	0.81295	0.74362	0.06933	6.03277E-6	-6.03277E-6
18	0.79929	0.72289	0.0764	6.64758E-6	-6.64758E-6
17	0.78425	0.7	0.08425	7.33122E-6	-7.33122E-6
16	0.7677	0.67473	0.09297	8.08973E-6	-8.08973E-6
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12	0.68258	0.54509	0.13749	1.19637E-5	-1.19637E-5
11	0.6555	0.5044	0.1511	1.31477E-5	-1.31477E-5
10	0.62564	0.46006	0.16558	1.44076E-5	-1.44076E-5
9	0.59275	0.41199	0.18076	1.57284E-5	-1.57284E-5
8	0.5566	0.36022	0.19638	1.7088E-5	-1.7088E-5
7	0.51699	0.30489	0.2121	1.84555E-5	-1.84555E-5
6	0.47375	0.2463	0.22746	1.9792E-5	-1.9792E-5
5	0.4268	0.18488	0.24193	2.10512E-5	-2.10512E-5
4	0.37613	0.12121	0.25492	2.21817E-5	-2.21817E-5
3	0.32185	0.05602	0.26583	2.31311E-5	-2.31311E-5
2	0.26419	-0.0099	0.2741	2.38503E-5	-2.38503E-5
1	0.20357	-0.07569	0.27926	2.42995E-5	-2.42995E-5
0	0.14051	-0.14051	0.28101	2.44522E-5	-2.44522E-5

Figure 2: Theoretical Values for Neutralising Magnetic Fields

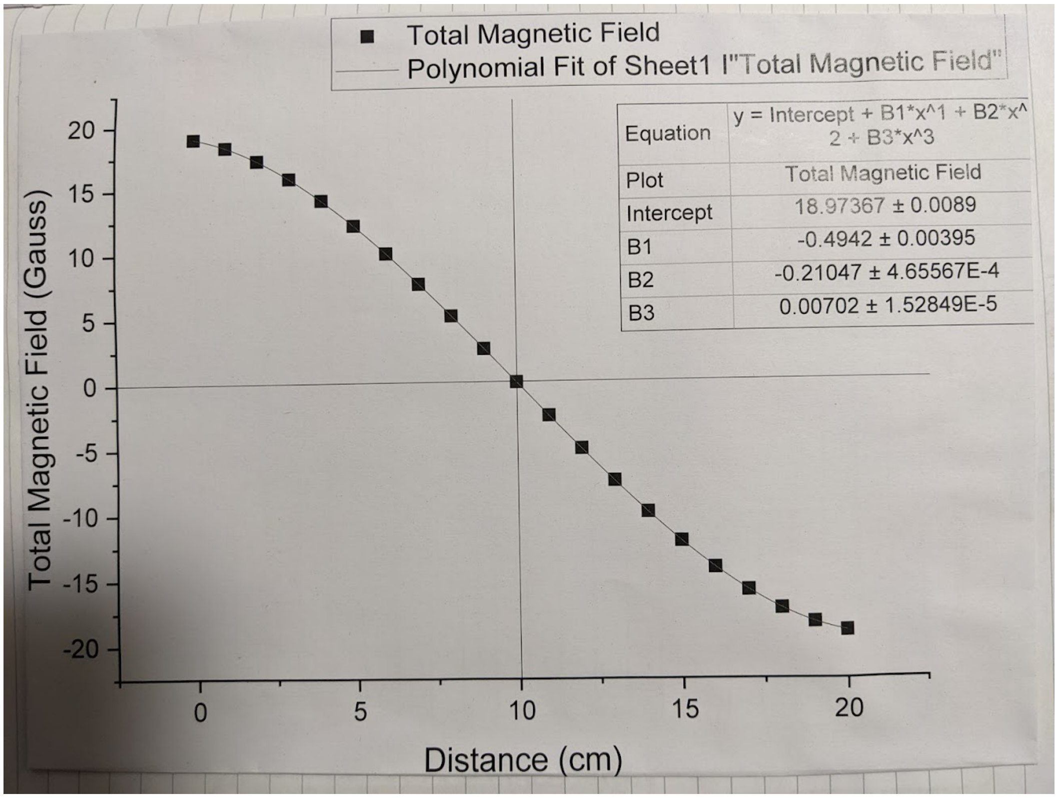

Figure 3: Graphing Theoretical Magnetic Field in Gauss against z distance in cm

Distance	Magnetic Field Strength	Hall effect	Magnetic Field Strength	Hall Effect	Magnetic Field Strength		
cm	T	Gauss	T	Gauss	Gauss		
		1st try		2nd try			
	C*10^4		E*10^4		((B+D)/2)/10^4	0.05	0.1
0	199000	19.9	199000	19.9	19.9	0.05	0.1
2	180000	18	179000	17.9	17.95	0.05	0.1
4	146000	14.6	145000	14.5	14.55	0.05	0.1
6	101000	10.1	101000	10.1	10.1	0.05	0.1
8	50000	5	49000	4.9	4.95	0.05	0.1
9	22000	2.2	22000	2.2	2.2	0.05	0.1
9.5	9000	0.9	8000	0.8	0.85	0.05	0.1
9.8	0	0	0	0	0	0.05	0.1
10	-5000	-0.5	-5000	-0.5	-0.5	0.05	0.1
11	-32000	-3.2	-33000	-3.3	-3.25	0.05	0.1
12	-60000	-6	-60000	-6	-6	0.05	0.1
14	-110000	-11	-110000	-11	-11	0.05	0.1
16	-153000	-15.3	-153000	-15.3	-15.3	0.05	0.1
18	-184000	-18.4	-184000	-18.4	-18.4	0.05	0.1
20	-201000	-20.1	-201000	-20.1	-20.1	0.05	0.1

Figure 4: Experimental Values for Neutralising Magnetic Fields

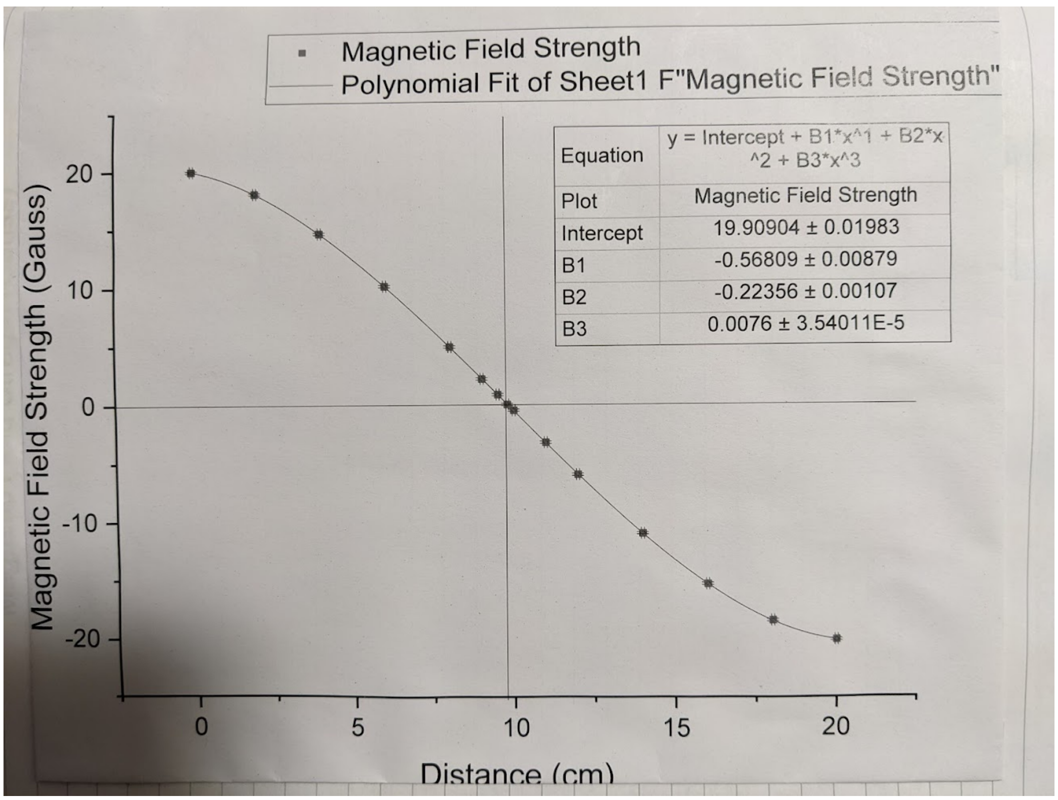

Figure 5: Graphing Experimental Magnetic Field in Gauss against z distance in cm

- The same magnitude of magnetic field at distances 0cm and 20cm.
- Manetic field 0 Gauss at 10cm.
- Opposing quadratic relationships "added" together to create a cubic relationship since the magnetic field strength varies like $\frac{1}{r^2}$.

These critical features can clearly be seen in theoretical values calculated seen graphed in **Figure 3**.

2.3 Observed Results

From experimental values shown in **Figure 5**, these features can clearly be identified in realation to the expected model, however, accounting for standard unccentainty represented in the curve fit some aspects are still far from theoretical values. These aspects and possible explanations include;

- Different values at 0cm and 20cm $\rightarrow$ This arises from the two solenoids generating different magnetic fields from the same current supply, as seen from **Figure 4**, a differance of 0.2 Gauss in magnitude can be observed, with the solenoid generating a more powerful magnetic field being the one located at 20cm. This may be for a variety of reasons such as different number of loops, higher density of loops or lower resistance.
- The experimental difference referanced above also affects a non 0 Gauss measurment at 10cm $\rightarrow$ Due to the difference in generated magnetic fields and the solenoid located at 20cm being stronger at the same current of 1.5A, instead of the magnitudes of magnetic field being equal at equal radius, they are instead different by 0.5 Gauss bias toward the solenoid located at 20cm. This means that the actual location of equilibrium of the magnetic fields is at 9.8cm instead of 10cm.
- Another inconsistency is in the absolute values when compared to theoretical values, most easily seen at 0cm and 20cm, where comparing theoretical against experimental yields differences from the expected 18.97 Gauss where the solenoids at 0cm generate a magnitude of 19.9 Gauss and at 20cm generate a magnitude of 20.1 Gauss. $\rightarrow$ If you consider an average of the two experimental values at 20 Gauss, this is roughly 1 Gauss higher than the expected theoretical value. While we are unsure as to what definitively caused this difference since 1 Gauss difference is much larger than the uncertainty maximum of ± 0.11 Gauss one can speculate that this difference is perhaps due to other factors such as greater unmeasurable inaccurancies in the hall probe or miscalculations in the hall voltage to gauss automated calculations not under our control.

Focusing now on the similarities;

- Experimental results yielded values and relationships extremely similar to theoretical values (**Figure 3, Figure 5**), both boast a negative cubic relationship formed from the difference of two $\frac{1}{r^2}$ relationships.