11/36 2/170083

International Baccalaureate

Extended essay cover

Candidates must complete this page and then give this cover and their final version of the extended essay to their supervisor.			
Candidate session number	0 0 0 2 5 0		
Candidate name			
School number	0 0 0 2 5 0		
School name	St. Petersburg High School		
Examination session (May or November)	May	Year	2013

Diploma Programme subject in which this extended essay is registered: Physics

(For an extended essay in the area of languages, state the language and whether it is group 1 or group 2.)

Title of the extended essay: When Looking at Electromagnetic Fields, How Does the Change in the Conductor's Temperature Affect the Strength of the Magnetic Field Generated, and its Magnetic Flux

✓

Candidate's declaration

This declaration must be signed by the candidate; otherwise a grade may not be issued.

The extended essay I am submitting is my own work (apart from guidance allowed by the International Baccalaureate).

I have acknowledged each use of the words, graphics or ideas of another person, whether written, oral or visual.

I am aware that the word limit for all extended essays is 4000 words and that examiners are not required to read beyond this limit.

This is the final version of my extended essay.

✓ ✓

Candidate's signature: ____________ Date: 2/26/2013

Assessment form (for examiner use only)

Candidate session number	0	0	0	2	5	0	

Achievement level

Criteria	Examiner 1	maximum	Examiner 2	maximum	Mr. Smith ~~Examiner 3~~
A research question	1	2		2	2
B introduction	1	2		2	2
C investigation	1	4		4	2
D knowledge and understanding	1	4		4	2
E reasoned argument	1	4		4	3
F analysis and evaluation	1	4		4	3
G use of subject language	2	4		4	2
H conclusion	1	2		2	1
I formal presentation	1	4		4	2
J abstract	1	2		2	2
K holistic judgment	0	4		4	1
Total out of 36	11				22

Name of examiner 1: FERDİ KAYA Examiner number: 088164
(CAPITAL letters)

Name of examiner 2: ______ Examiner number: ______
(CAPITAL letters)

Name of examiner 3: ______ Examiner number: ______
(CAPITAL letters)

IB Cardiff use only: **B:** 1/

IB Cardiff use only: **A:** 116539 **Date:** 10/4

Supervisor's report and declaration

The supervisor must complete this report, sign the declaration and then give the final version of the extended essay, with this cover attached, to the Diploma Programme coordinator.

Name of supervisor (CAPITAL letters) KYLE J. SMITH

Please comment, as appropriate, on the candidate's performance, the context in which the candidate undertook the research for the extended essay, any difficulties encountered and how these were overcome (see page 13 of the extended essay guide). The concluding interview (viva voce) may provide useful information. These comments can help the examiner award a level for criterion K (holistic judgment). Do not comment on any adverse personal circumstances that may have affected the candidate. If the amount of time spent with the candidate was zero, you must explain this, in particular how it was then possible to authenticate the essay as the candidate's own work. You may attach an additional sheet if there is insufficient space here.

Harsha came up with an innovative essay idea. I tried to encourage him to test the temperature of the electromagnet's core vs. change in magnetic field instead of the conductor, but he chose the latter. He conducted all of his trials at home.

✓

This declaration must be signed by the supervisor; otherwise a grade may not be issued.

I have read the final version of the extended essay that will be submitted to the examiner.

To the best of my knowledge, the extended essay is the authentic work of the candidate.

I spent 6.0 hours with the candidate discussing the progress of the extended essay.

Supervisor's signature: [signature] Date: 2/26/13

✓

A-B → R.Q is not explained clearly. Some terms in R.Q should have been defined.

C → There is no citation in the core(a). Limitations were not explained. He just takes the picture of the graphs and makes some general comments about them!

D → Some common comments about the trends without using any math relations don't show a good understanding. Relevant physics formulas were not enough to show a good knowledge.

E → Sources of unc. were not explained. Statements were not supported by math relations or physics formulas.

F → No error bars. No explanation about the graphs. A scientific paper can not just include decrease and increase comments all the time.

When Looking at Electromagnetic Fields, How Does a Change in the Conductor's Temperature Affect the Strength of the Magnetic Field Generated, and its Magnetic Flux?

0250-

Mr. Kyle Smith – Physics HL

February 25, 2013

Word Count: 3600

G: Graphs were not numbered. SI units were not used. ~~Abbreviations were not defined.~~

I: No citations. Bibliography is not alphabetic order. Presentation of equations were not good.

K: There is no creativity or originality. There is not a good understanding. There is nothing special with this EE.

Abstract

This essay studies the effects of temperature change of a conductor of an electromagnet on the strength of the resulting magnetic field generated by the electromagnet with a brief look at how changing a conductor's temperature affects the magnetic flux of an electromagnet. The research is conducted by performing an experiment in which a soft-iron nail is wrapped by copper wiring in order to create a simple electromagnet. Then, using a temperature, current, and magnetic field probe, the strength of the magnetic field generated by the electromagnet powered by a 6.15V battery will be measured in relation to changing temperatures as induced by heating and cooling the core with a small oven and dry ice. The data will then be compiled in order to establish a correlation between temperature, current, and the strength of a magnetic field when compared to the strength of an electromagnet at a temperature of 30°C.

phases should have been included there -

, what's that correlation?

The research showed a strong correlation between the strength of a magnetic field, temperature, and current. As the temperature of the conductor was increased in phase II of the experiment, the overall strength of the electromagnet decreased. Conversely, in phase III of the experiment, the overall strength of the electromagnet increased as the temperature of the conductor decreased. This phenomenon is explained by using Ohm's Law and the basic concept of resistivity in electrical circuits. Overall, this experiment shows that temperature plays a key role in determining the strength of an electromagnet.

Word Count: 242

Table of Contents

1. Introduction

The worthiness of the topic is not explained clearly.

1.1. Background

Electromagnets are incorporated into most facets of everyday life. Electromagnets are used in devices ranging from electric motors and generators which function because of the scientific principle of electromagnetic induction, to methods of transportation such as Maglev trains which utilize powerful electromagnets as a means of propulsion along a track. These electromagnets can be made to act just as natural magnets do; however, the intensity of attraction (in Newtons) can be altered depending on the number of rings on the coil, the intensity of the current flowing through the coil, and the core chosen to act as the electromagnet. However, do electromagnets work more efficiently in some locations than in others? Do changes in temperature conditions affect the strength of the electromagnets used in devices such as Maglev trains and telephones; if so, to what extent? It is interesting to see how and to what extent changes in temperature affect these commonplace components that are so heavily integrated into our lives.

1.2. Objective

R.Q ??

The objective of this study is to give an explanation to the extent a change in temperature (moving away from room temperature) of the conductor affects the overall strength of an electromagnet. Then, based on this change, determine if the magnitude of the magnetic flux between the conductor and the electromagnet is connected to this change in temperature. In essence, I will attempt to answer the question: "**When Looking at Electromagnetic Fields, How Does a Change in the Conductor's Temperature Affect the Strength of the Magnetic Field Generated, and its Magnetic Flux?**"

These terms should have been explained or defined clearly.

2/

2. Components of Electromagnets

2.1. Introduction to the Components

An electromagnet is a type of magnet that uses the flow of electric current in order to produce a magnetic field. When this electrical current is switched off, the magnetic field begins to disappear. To any electromagnet there are three main components: the core, the wire that is wrapped around the core, and a power supply which runs the current through the wire.

2.2. The Core

The primary component of an electromagnet is the core. The most effective electromagnets utilize ferromagnetic cores which are much more receptive to magnetization by the electrical current that flows through the coils wrapped around it. Although there are two other categories of magnetic material that exist (paramagnetic and diamagnetic materials), neither are viable substitutes for ferromagnetic materials when choosing a core for an electromagnet. This is primarily because ferromagnetic materials are largely susceptible to an external magnetic field; whereas diamagnetic materials have a weak and negative susceptibility to magnetic fields (meaning that these materials are repelled by magnetic fields) and paramagnetic materials, although susceptible to magnetic fields, are very weak. This high susceptibility for ferromagnetic materials is largely due to the presence of a large quantity of magnetic domains which essentially act as little magnets. Before the ferromagnetic material is magnetized, each magnetic domain is oriented in a different direction. This lack of uniformity among the magnetic domains is why the material is not magnetic in its current state.

2.3. The Coil and Power Supply

The secondary components which help with the magnetization of the core material are the coil and power supply. The current which flows from the power supply through the coil which is wrapped around the magnet magnetizes the core by aligning the magnetic domains that were previously randomly oriented. As long as this current flows through the coil which surrounds the core, the magnetic domains will retain their alignment; however, after the current is removed, in ferromagnetic materials the core will not immediately lose its magnetic properties. This is due to the concept of hysteresis. This phenomena states that when an external magnetic field is applied to ferromagnetic materials, the ferromagnetic material will absorb some of the external field generated. Even after the electric current in removed from the conductor, the ferromagnetic material will retain some of the magnetic field.

3. Equipment Description and Setup

3.1. General Description

This experiment was performed outside around midday. The equipment used to perform the experiment is shown in Figure 2 and the setup can be described as follows:

1.) Firstly, 75cm ± 1cm of copper wiring (AWG 16 stranded) is wrapped thirty-seven times helically around a 10cm ± 0.5cm centimeter long iron nail core (shown as object A in Figure 2).

2.) Second, the core wrapped by the bare copper wiring is positioned horizontally on a piece of cardboard and is then fastened to the cardboard using a plastic zip-tie. The nail is mounted on a cardboard box using plastic in order to prevent the flow of the current from being diverted.

3.) Third, after the core is successfully fastened to the cardboard, the negative (black) end of a Vernier Current Probe® (shown as object B in Figure 2) is attached to the end of the bare copper wiring protruding from the head of the core, while the positive (red) end is fastened to the positive wire of a four D-cell battery holder (shown as object C in Figure 2).

4.) Fourth, a Vernier Magnetic Field Sensor® (shown as object D in Figure 2) is placed one centimeter away from the negative end of the nail and will be fastened there, again, by using a plastic zip-tie.

5.) Fifth, a Vernier Temperature Probe® will be used to measure the temperature of the iron nail.

6.) Sixth, before completing the circuit, all three probes will be connected to a Vernier LabQuest Reader® (shown as object E in Figure 1) which takes the data that the probes receive and then displays the data. This device is plugged into a laptop which takes measurements of any given part of the experiment and outputs a graph that shows the relationship between temperature and magnetic field strength.

7.) Finally, to complete the circuit, the negative end of the battery holder will be connected to the negative end of the bare copper wire.

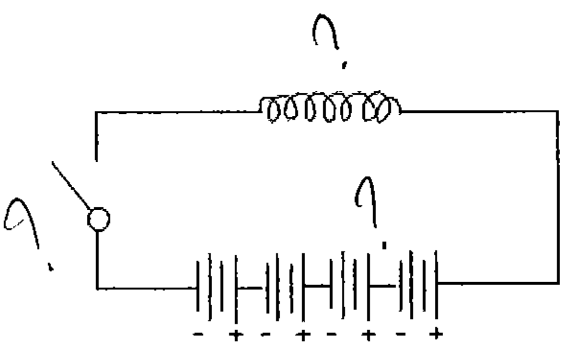


Figure 1 – Generic Setup (Electrical Schematic)

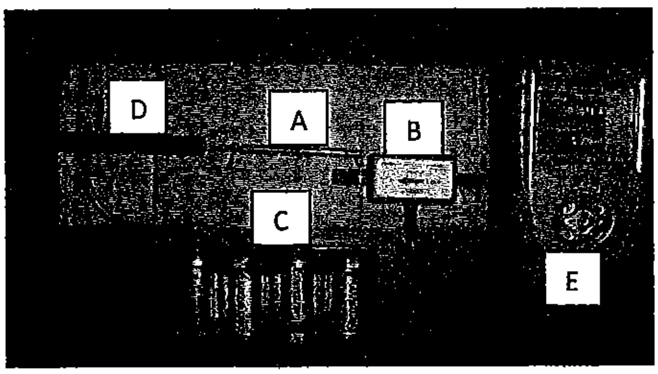


Figure 2 – Generic Setup

4. Procedure

4.1. Preparation

4.1.1. General

Before performing this experiment, there were several key measurements to be taken to ensure that the experiment remained controlled, and that the results remained as consistent as possible with few extraneous variables. The measurements that needed to be taken include the current flowing through the circuit and the voltage used to allow the current to flow, the temperature of the electromagnet, and the resistivity in relation to voltage, current, and temperature.

4.1.2. Current and Voltage

This investigation, in order to obtain consistent data, it was crucial that the voltage that pushed the current through the circuit remained constant. The first task that was done before each stage of this experiment was to measure the voltage of the battery (which refers to the combination of all four D-cell batteries) using a multimeter. The voltage needs to be measured in order to understand the rate at which electrons are flowing through the circuit, or current. In order to do this, the multimeter was attached to the positive and negative leads of the battery holder (shown in Figure 3). The output on the multimeter shows that the voltage for four D-cell batteries attached in series is 6.15V ± 0.01V (of direct current). This measurement served as the benchmark for the voltage that will be used throughout the experiment. Voltage is directly proportional with current as stated by Ohm's Law (V = IR) assuming that the resistivity of the conductor is kept constant. The magnitude of magnetic field produced by a current carrying wire at its center is directly proportional to the current passing through the circular wire. Since this experiment focuses solely on how changing temperatures affect the magnetic field strength of an electromagnet, it is important to keep voltage constant.

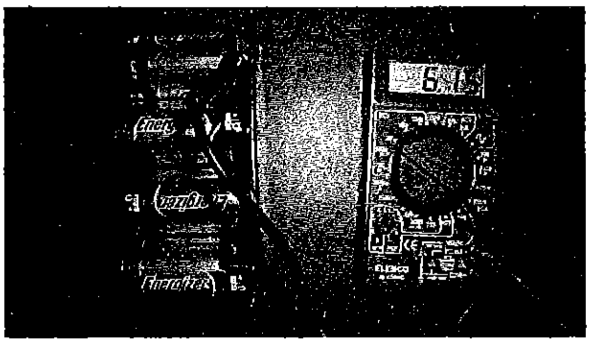


Figure 3 – A Digital Multimeter Taking the Battery Voltage

4.1.3. Temperature

Careful regulation of temperature is extremely important in this experiment; therefore, the ambient temperature must carefully be monitored at all times. This was done using a Vernier Temperature Probe® which constantly recorded the ambient temperature of the environment around the electromagnet. By subtracting the ambient temperature from the temperature of the heated or cooled nail, the change in temperature of the nail can be calculated: $\Delta T = T_F - T_0$. The change in temperature is key because the objective is to figure-out a correlation between changing temperatures and magnetic field strength.

4.1.4. Resistivity

Resistivity, or electrical resistivity, is a measure of how strongly a material opposes the flow of an electrical current. Resistivity is dependent on several factors including the type of wiring, the length of the wiring, and the temperature ranges the wiring is exposed to. Since resistivity regulates the amount of current that flows through the electromagnet, it therefore affects the strength of the magnetic field generated. The resistivity of the 16 AWG copper wire was calculated by using the equation: $R = \frac{\rho L}{A}$ where ρ is the coefficient for the resistivity of the material that the wire is composed of, L denotes the length of the wire, and A is the area of the cross section of the wire. For a 16 AWG wire that is 75cm ± 1cm long that is supporting a load of 0.625A ± 0.001A (as measured by the Vernier Current Probe® which acted as an ammeter shown in Figure 5), the resistivity is approximately 0.01 ohms at 25°C. This was then verified with the multimeter which gave an output of 0.02 ohms ± 0.01 ohms. These calculations set the base resistivity for a given current at a given temperature. The change in resistivity will give a clear indication of how a change in the temperature of the core will ultimately affect the magnetic field strength.

4.2. Execution

4.2.1. Phase I – Constant Temperature of the Core

For the first part of this experiment, the change in the magnetic field strength (measured in militesla) and the current flowing through the circuit (measured in Amperes) must be measured with no change in the ambient temperature in order to set a benchmark for data collection. The experiment will be setup as shown in Figure 2 (Section 3.1) with the Vernier Temperature Probe® resting beside the nail 2cm from the tip. For the first phase of the experiment, the ambient temperature will not be changed and data on the temperature, current, and magnetic field strength will all be logged in relation to time for a duration of 300 seconds with a sampling rate of two samples per second. Data collection for temperature, current, and magnetic field strength will be triggered after the Vernier Current Probe® picks-up a current that registers greater than 0.0100A flowing through the circuit. The resulting data will be processed and used for comparison with other trials where the ambient temperature is changed.

4.2.2. Phase II – Increasing the Temperature of the Core

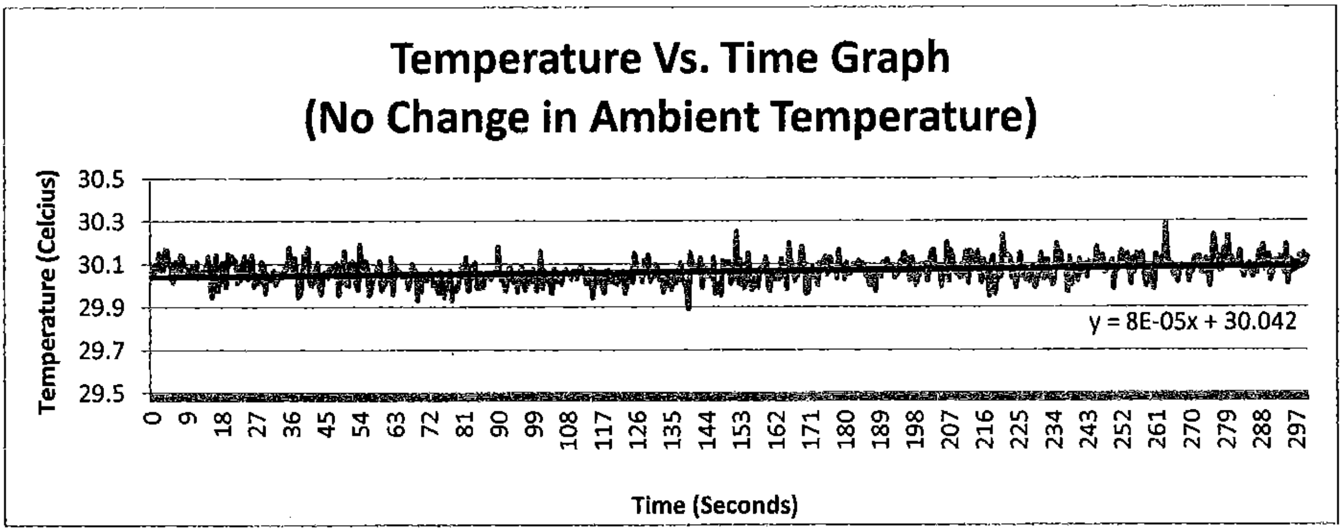
For the second part of the experiment, the change in the magnetic field strength and the current flowing through the circuit will be measured with a gradual increase in the temperature of the core. Before the core is attached to the circuit, the core and the copper wiring that is coiled around it will be placed into an oven in order to change the temperature of the conductor. For the first trial of Phase II, the core will be placed into the oven for five minutes with a temperature control of 200°C. After five minutes, the core will be removed using metal tongs and reattached to the circuit. Before completing the circuit by attaching the negative lead of the battery holder to the copper wiring wrapped the core, the temperature probe will be placed 2cm from the tip of the nail and the distance between the magnetic field sensor and the core (1cm) will be ensured. Once the circuit is complete, data will be collected for duration of 675 seconds with 2 samples being taken every second. After the data collection for Trial 1 is completed, the connection from the negative terminal of the battery holder to the negative end of the core will be removed. This process will be repeated three more times with the core being in the oven for 10 minutes (Trail 2), 15 minutes (Trial 3), and 20 minutes (Trial 4).

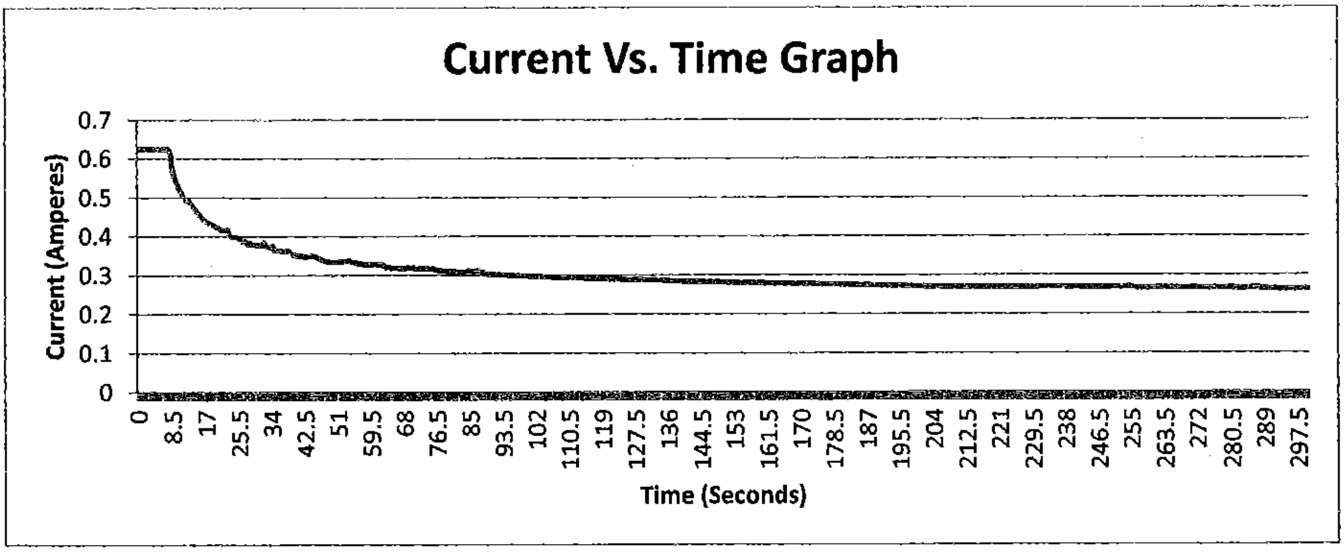
4.2.3. Phase III – Decreasing the Temperature of the Core

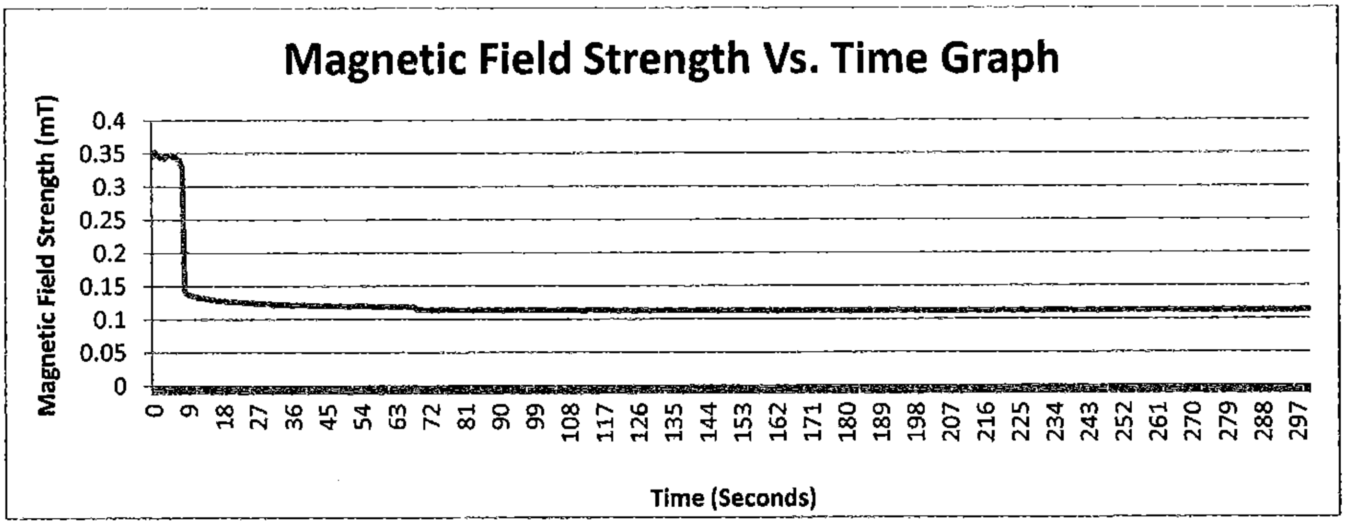
For the third part of the experiment, the change in the magnetic field strength and the current flowing through the circuit will be measured with a gradual decrease in the temperature of the core. A new core will be used for this phase of the experiment, the core will still be an iron nail wrapped by bare copper wiring (as outlined by the specifications found in section 3.1). The core will be attached to the circuit prior to the cooling process; however, the circuit will be in the off position. The temperature probe and magnetic field sensor will be moved into their corresponding positions before the cooling process is initiated. Once the magnetic field sensor and temperature probes are in place, using metal tongs a piece of dry ice is placed on the core, half-way from the head. As soon as the dry ice is in place, the circuit will be switched into the on position. Data will be logged for 675 seconds with 2 samples being taken every second. After the data collection for Trial 1 is completed, the connection from the negative terminal of the battery holder to the negative end of the core will be removed. Once the circuit is off, the core will be removed from the circuit and will sit until the temperature of the core is returned to room temperature (as determined by phase I). This process will be repeated three more times with the core being exposed to two pieces of dry ice (Trail 2), three pieces of dry ice (Trial 3), and four pieces of dry ice (Trial 4).

5. Data Collection and Processing

5.1. Phase I Data Collected and Analysis



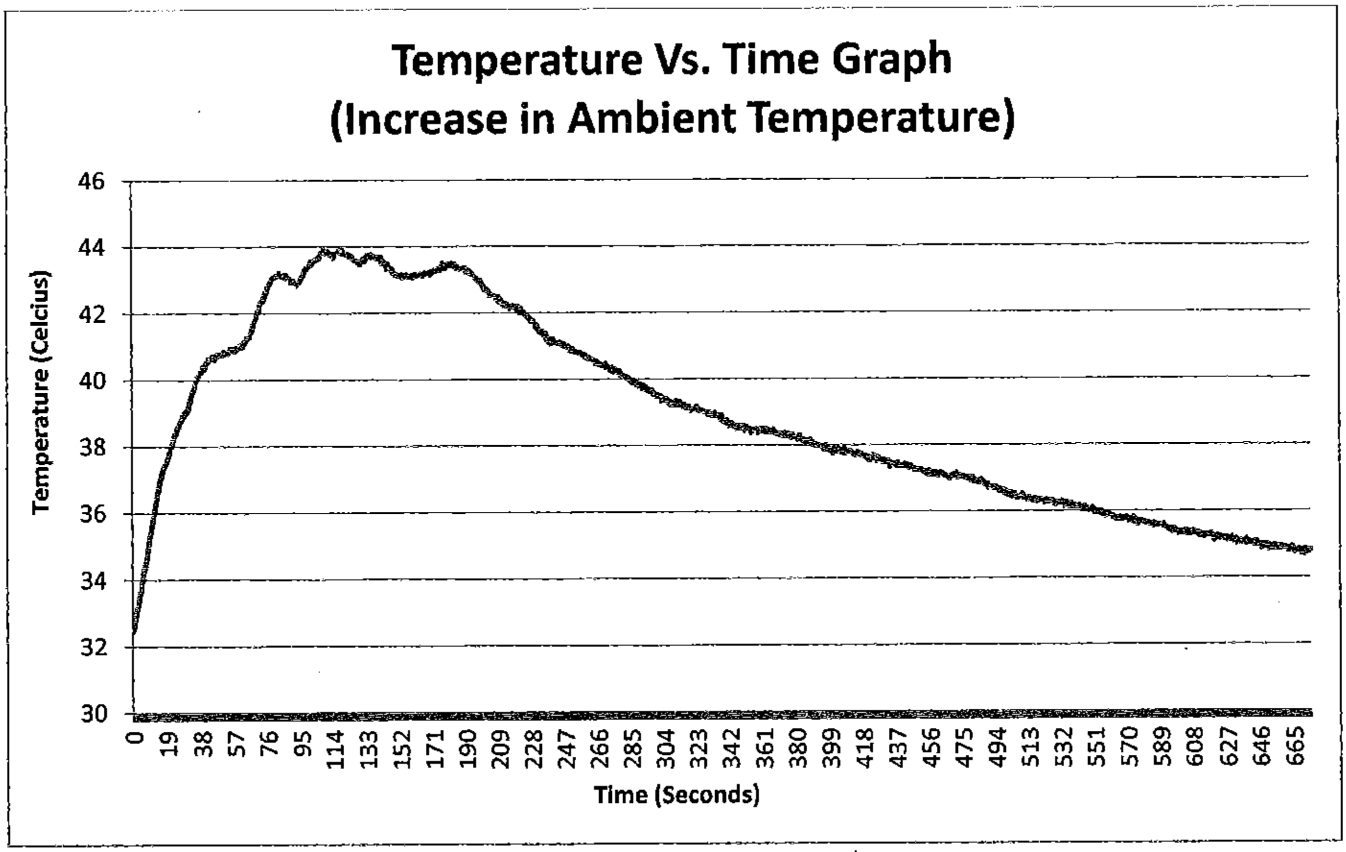


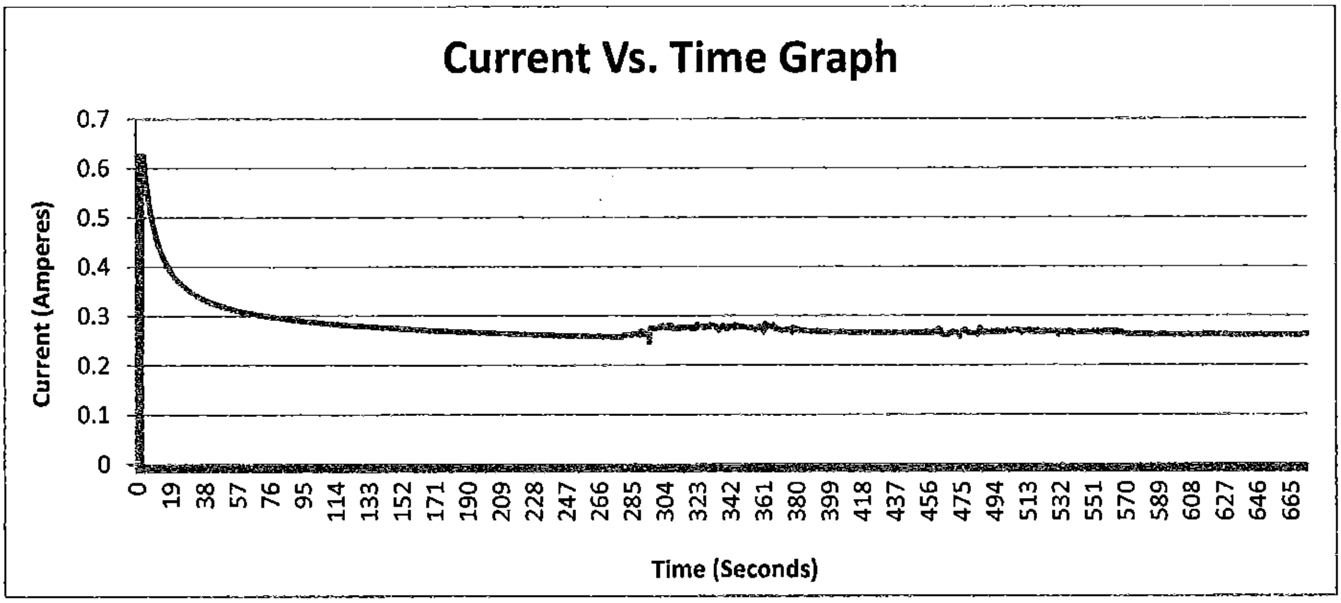


Firstly, the equation for the temperature vs. time graph indicates that the ambient temperature was kept at 30°C ± 0.5°C with very little change in the temperature over the course of the 300 seconds that data was being collected (as indicated by the slope of 8×10^{-5}). Secondly, the current vs. time graph shows that current is inversely proportional with time for this circuit and directly proportional with the strength of the magnetic field generated due to the current. At the moment that data was beginning to be logged, the current was 0.625A ± 0.001A which was the load that was measured for the 16 AWG copper wire before the core was inserted (as explained in section 4.1.4). However, as time passes, the current flowing through the circuit decreases to 0.2627A. This can be attributed to the generation of eddy currents and then to energy lost as heat.

5.2. Phase II Data Collected and Analysis

5.2.1. Trial 1




Current Vs. Time Graph
Current (Amperes)
0.7
0.6
0.5
0.4
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0.2
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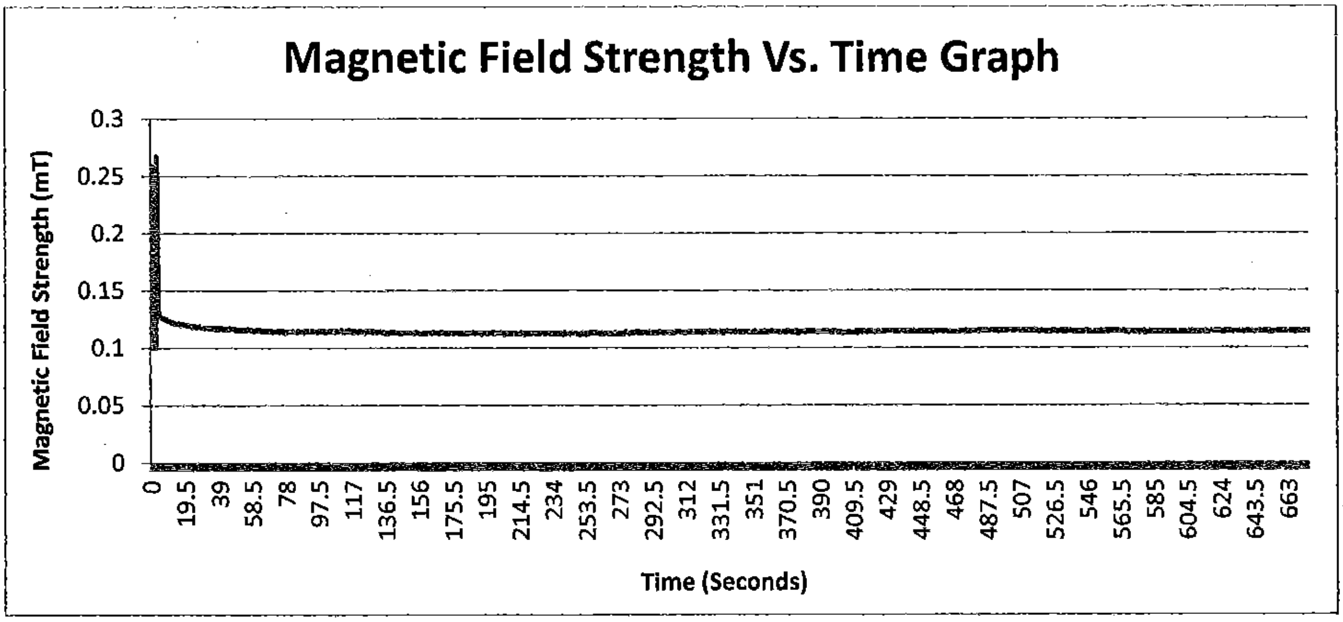
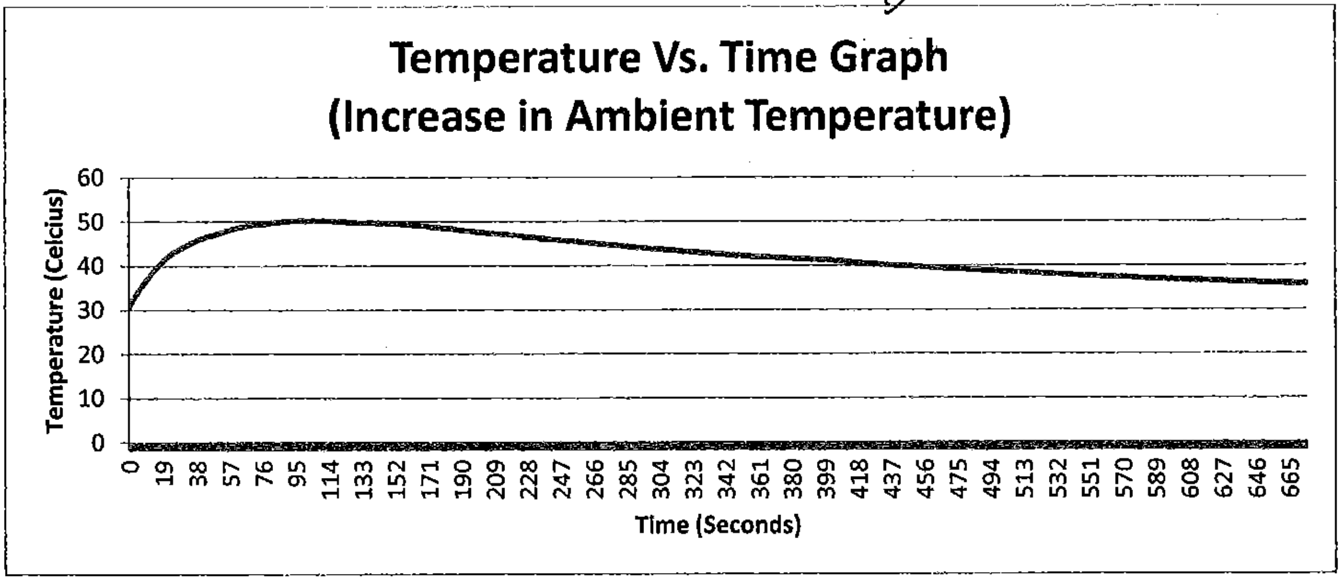
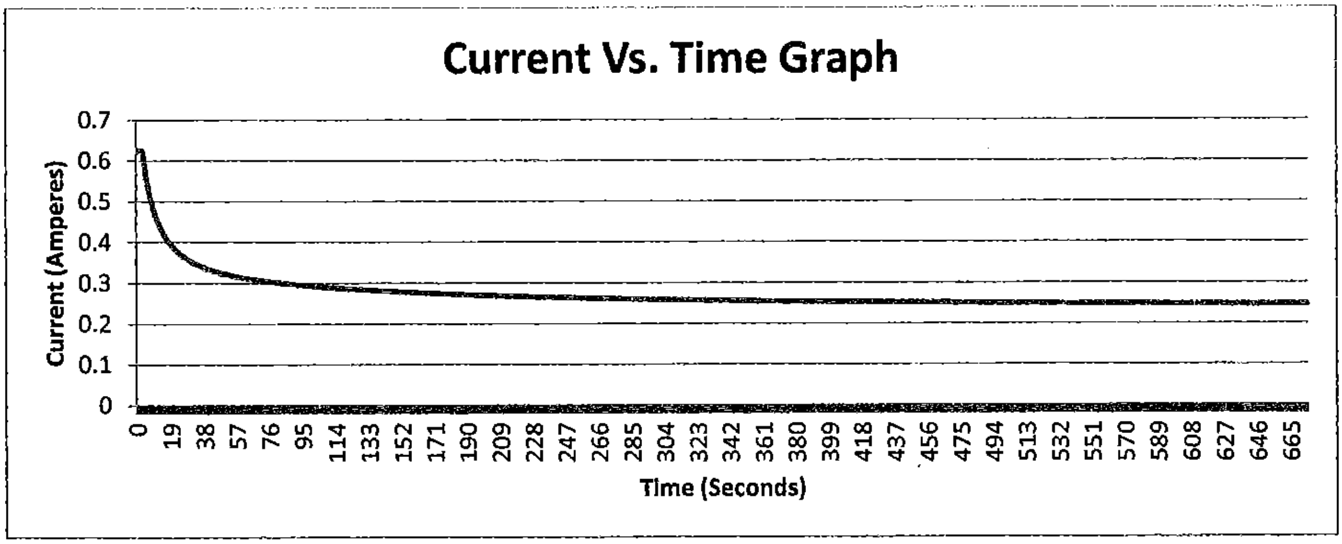
Time (Seconds)


Magnetic Field Strength Vs. Time Graph
Magnetic Field Strength (mT)
0.3
0.25
0.2
0.15
0.1
0.05
0
0 19.5 39 58.5 78 97.5 117 136.5 156 175.5 195 214.5 234 253.5 273 292.5 312 331.5 351 370.5 390 409.5 429 448.5 468 487.5 507 526.5 546 565.5 585 604.5 624 643.5 663
Time (Seconds)

5.2.2. Trial 2


Temperature Vs. Time Graph
(Increase in Ambient Temperature)
Temperature (Celcius)
60
50
40
30
20
10
0
0 19 38 57 76 95 114 133 152 171 190 209 228 247 266 285 304 323 342 361 380 399 418 437 456 475 494 513 532 551 570 589 608 627 646 665
Time (Seconds)


Current Vs. Time Graph
Current (Amperes)
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0.4
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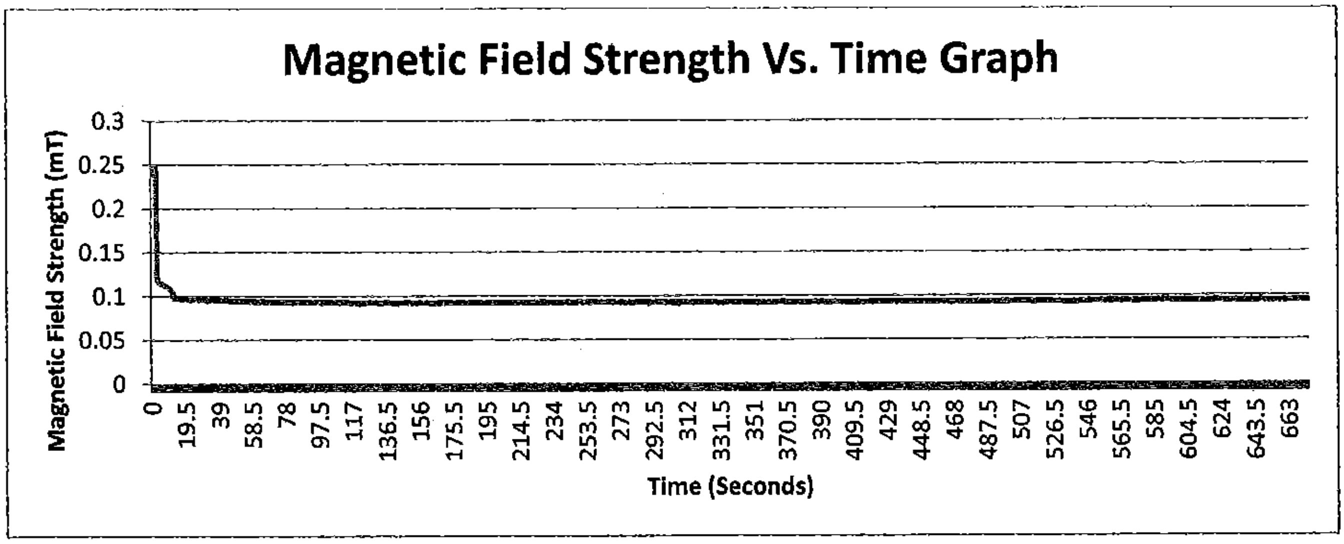
0 19 38 57 76 95 114 133 152 171 190 209 228 247 266 285 304 323 342 361 380 399 418 437 456 475 494 513 532 551 570 589 608 627 646 665
Time (Seconds)


Magnetic Field Strength Vs. Time Graph
Magnetic Field Strength (mT)
0.3
0.25
0.2
0.15
0.1
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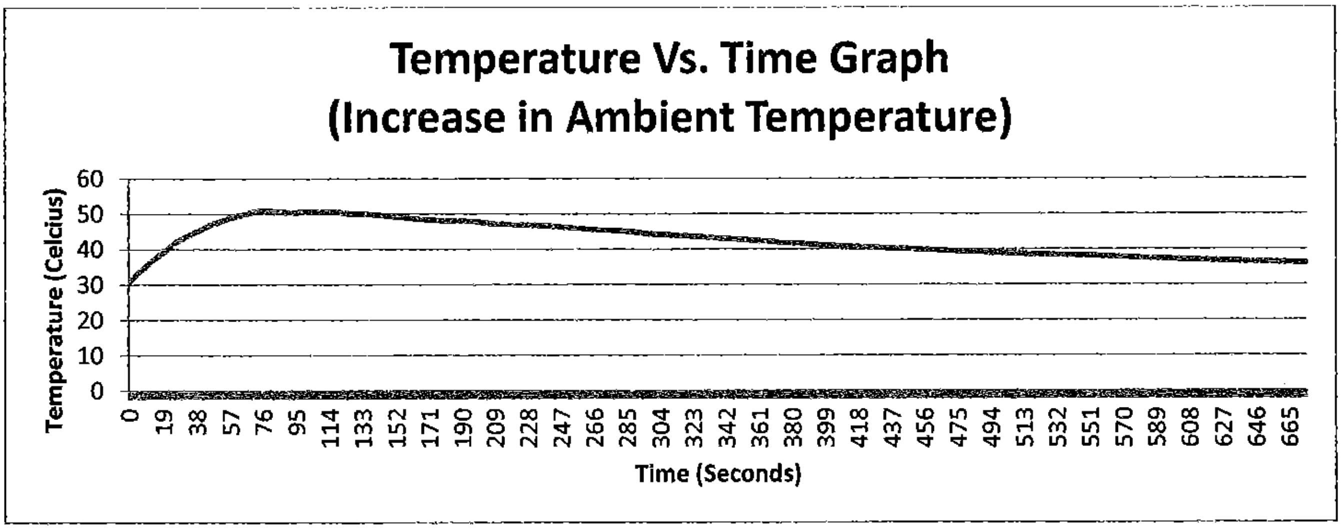
0 19.5 39 58.5 78 97.5 117 136.5 156 175.5 195 214.5 234 253.5 273 292.5 312 331.5 351 370.5 390 409.5 429 448.5 468 487.5 507 526.5 546 565.5 585 604.5 624 643.5 663
Time (Seconds)

5.2.3. Trial 3


Temperature Vs. Time Graph
(Increase in Ambient Temperature)
Temperature (Celcius)
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40
30
20
10
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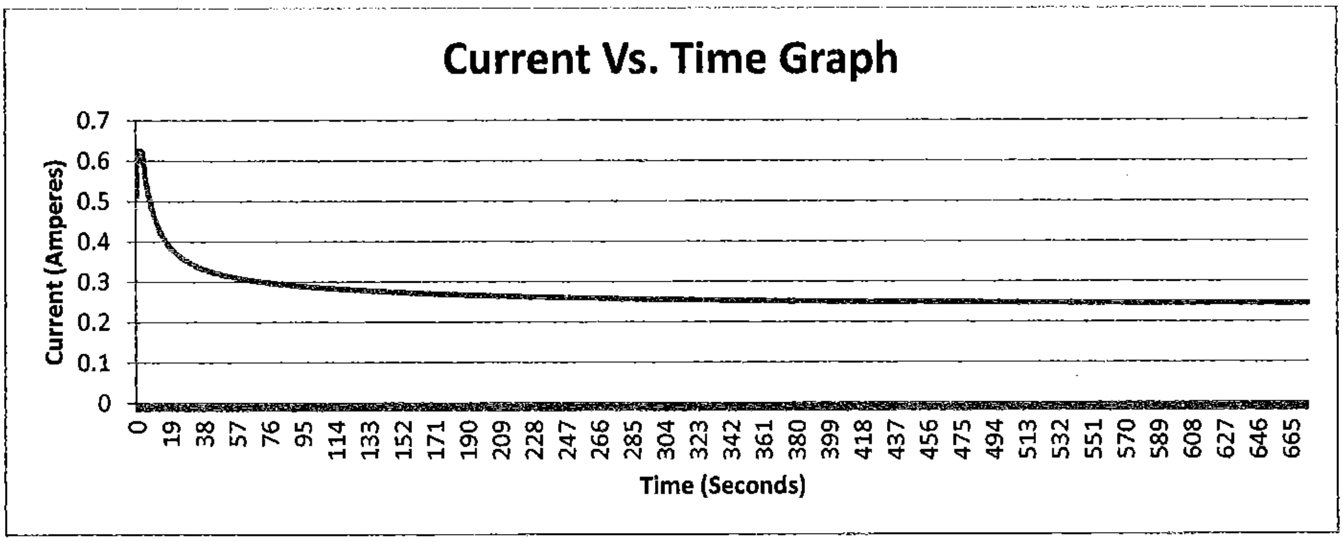
0 19 38 57 76 95 114 133 152 171 190 209 228 247 266 285 304 323 342 361 380 399 418 437 456 475 494 513 532 551 570 589 608 627 646 665
Time (Seconds)


Current Vs. Time Graph
Current (Amperes)
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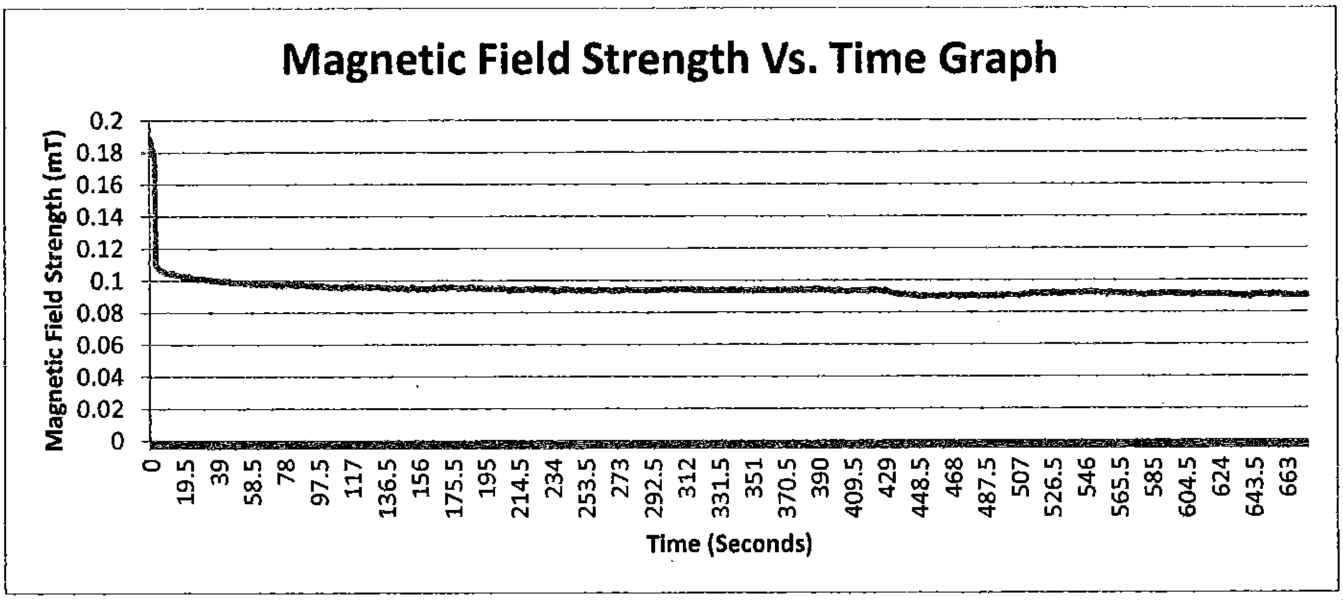
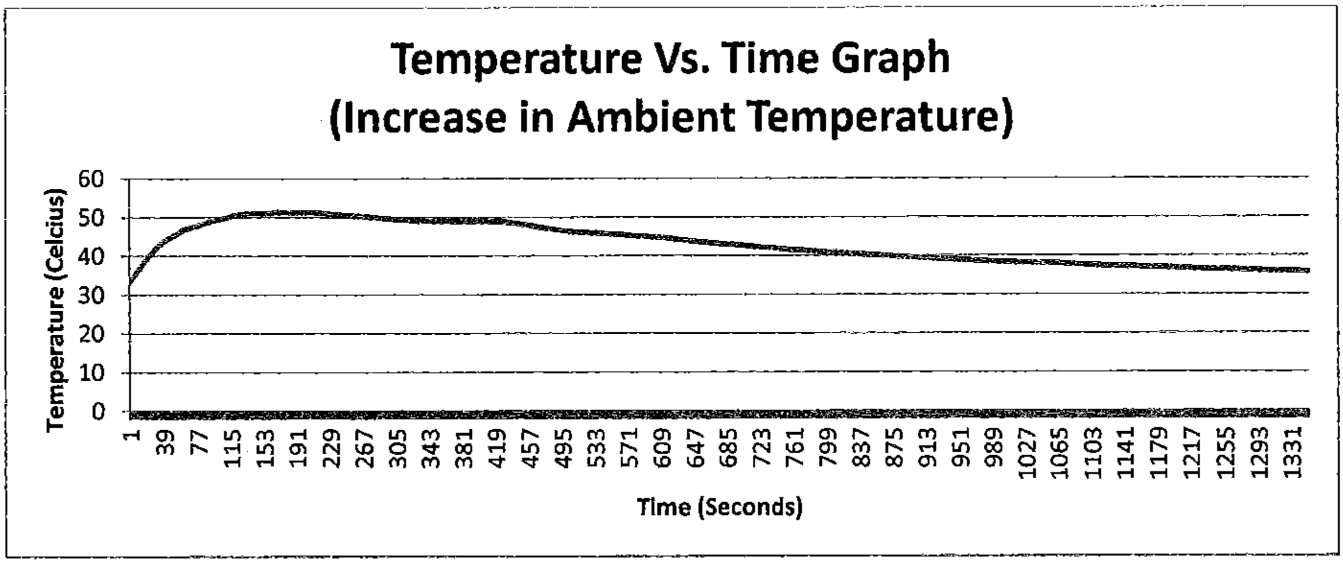
Time (Seconds)


Magnetic Field Strength Vs. Time Graph
Magnetic Field Strength (mT)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0 19.5 39 58.5 78 97.5 117 136.5 156 175.5 195 214.5 234 253.5 273 292.5 312 331.5 351 370.5 390 409.5 429 448.5 468 487.5 507 526.5 546 565.5 585 604.5 624 643.5 663
Time (Seconds)

5.2.4. Trial 4


Temperature Vs. Time Graph
(Increase in Ambient Temperature)
Temperature (Celcius)
60
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40
30
20
10
0
1
39
77
115
153
191
229
267
305
343
381
419
457
495
533
571
609
647
685
723
761
799
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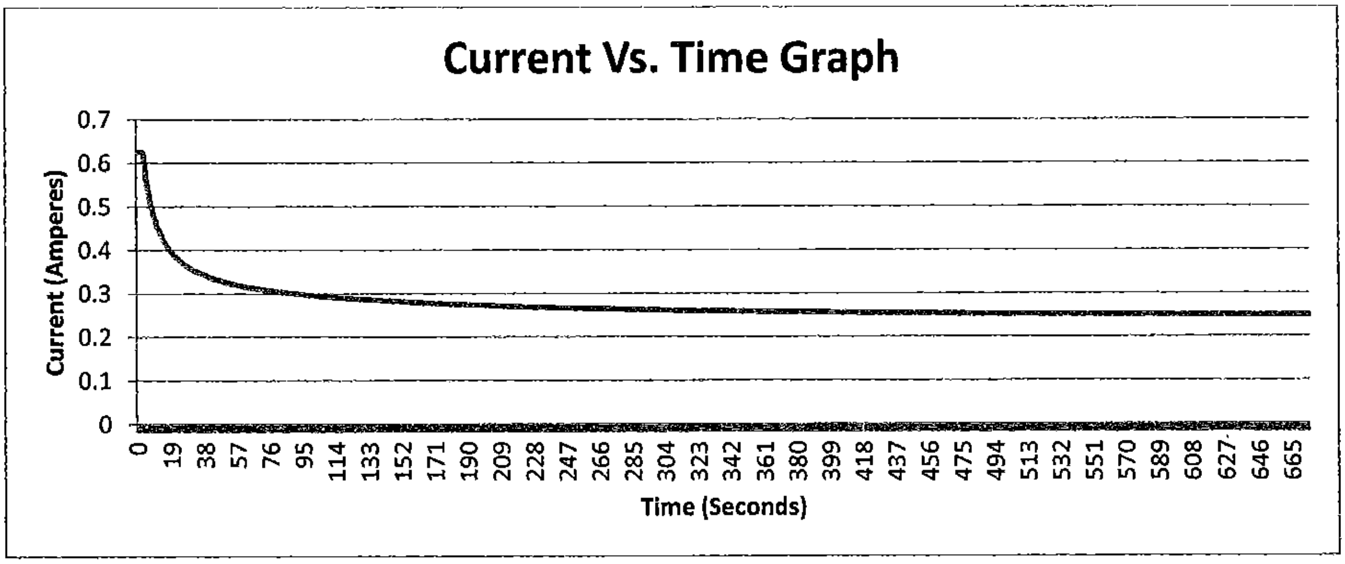
1293
1331
Time (Seconds)


Current Vs. Time Graph
Current (Amperes)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
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0
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38
57
76
95
114
133
152
171
190
209
228
247
266
285
304
323
342
361
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418
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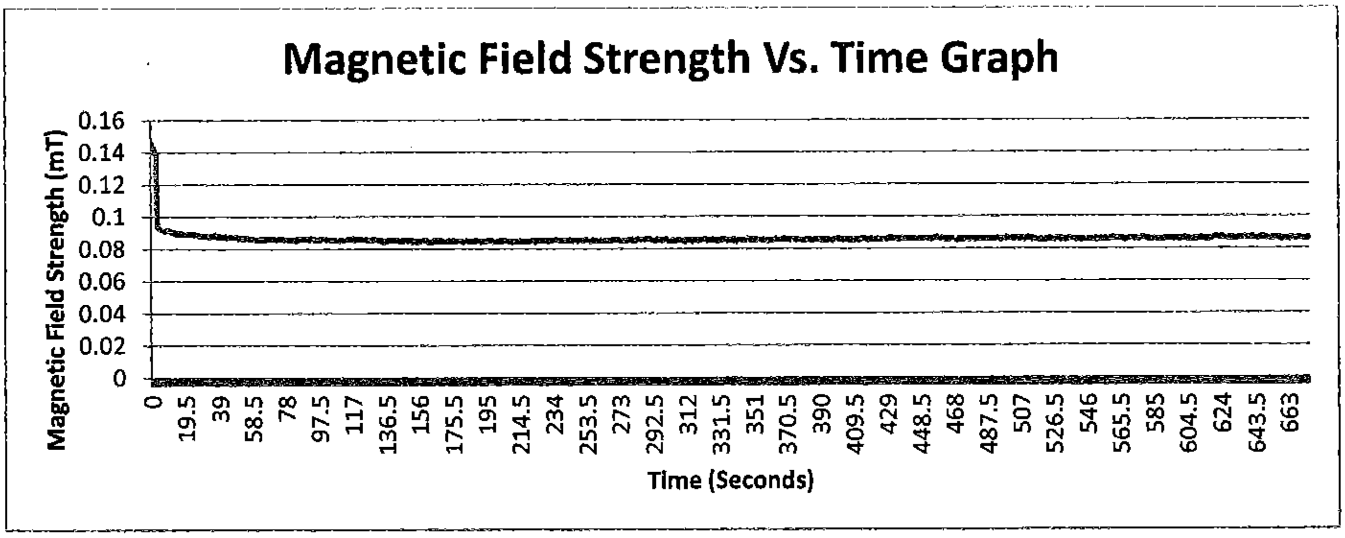
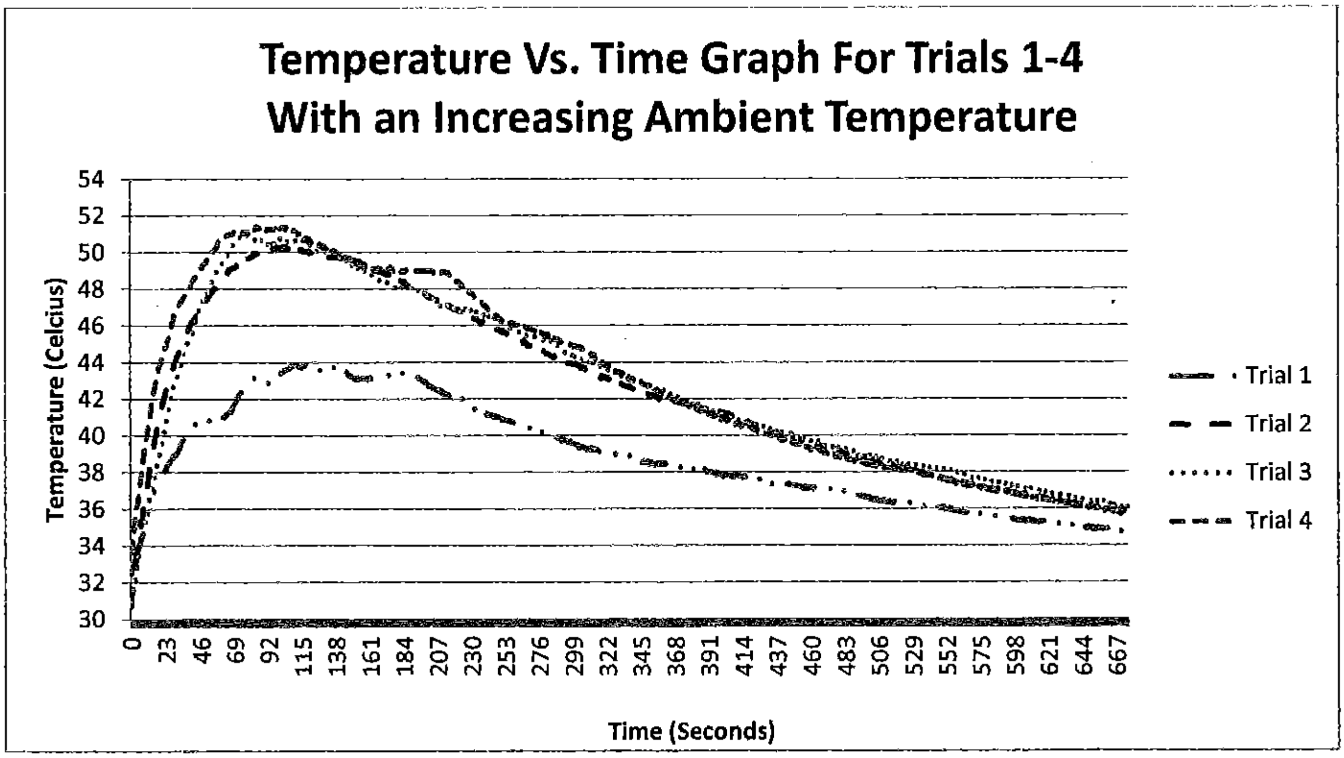
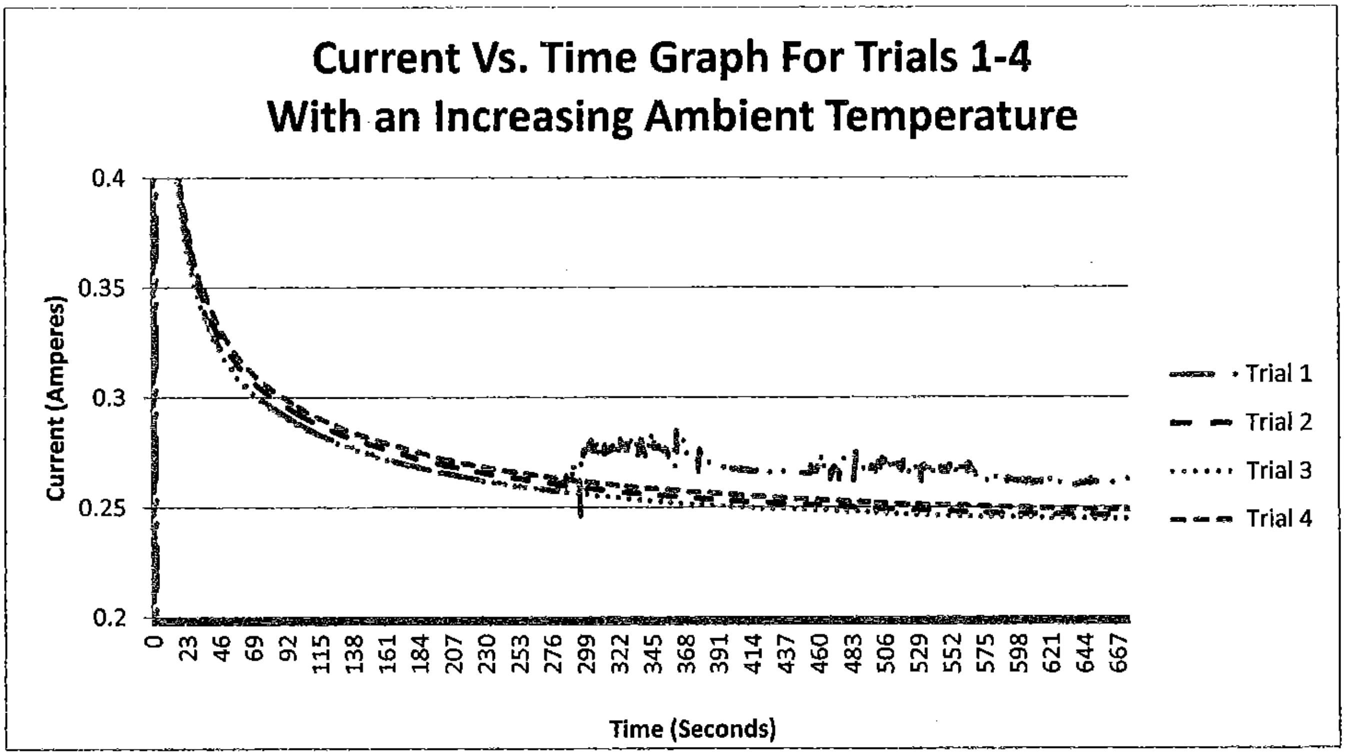
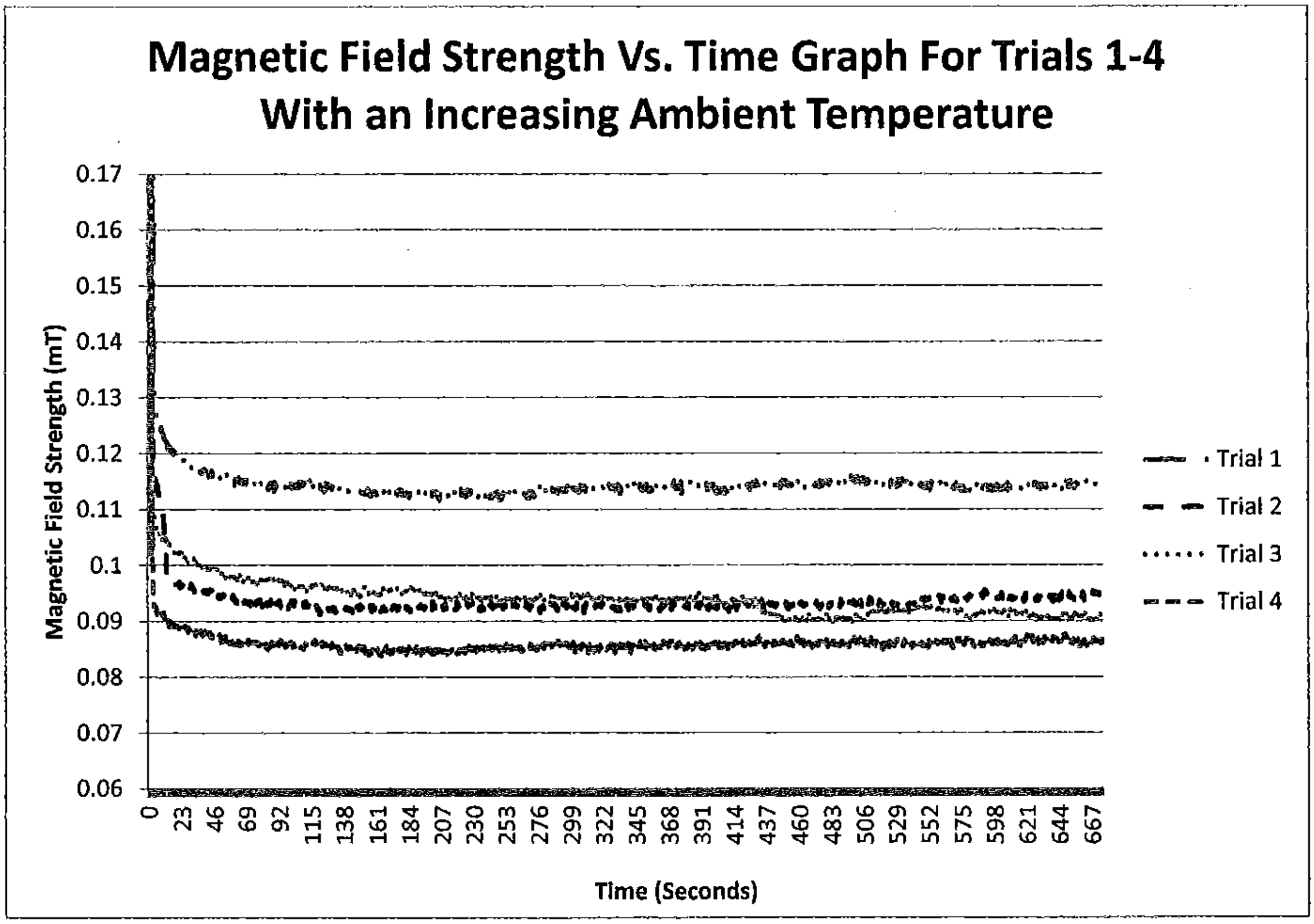
456
475
494
513
532
551
570
589
608
627
646
665
Time (Seconds)


Magnetic Field Strength Vs. Time Graph
Magnetic Field Strength (mT)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
19.5
39
58.5
78
97.5
117
136.5
156
175.5
195
214.5
234
253.5
273
292.5
312
331.5
351
370.5
390
409.5
429
448.5
468
487.5
507
526.5
546
565.5
585
604.5
624
643.5
663
Time (Seconds)

5.2.5. Analysis



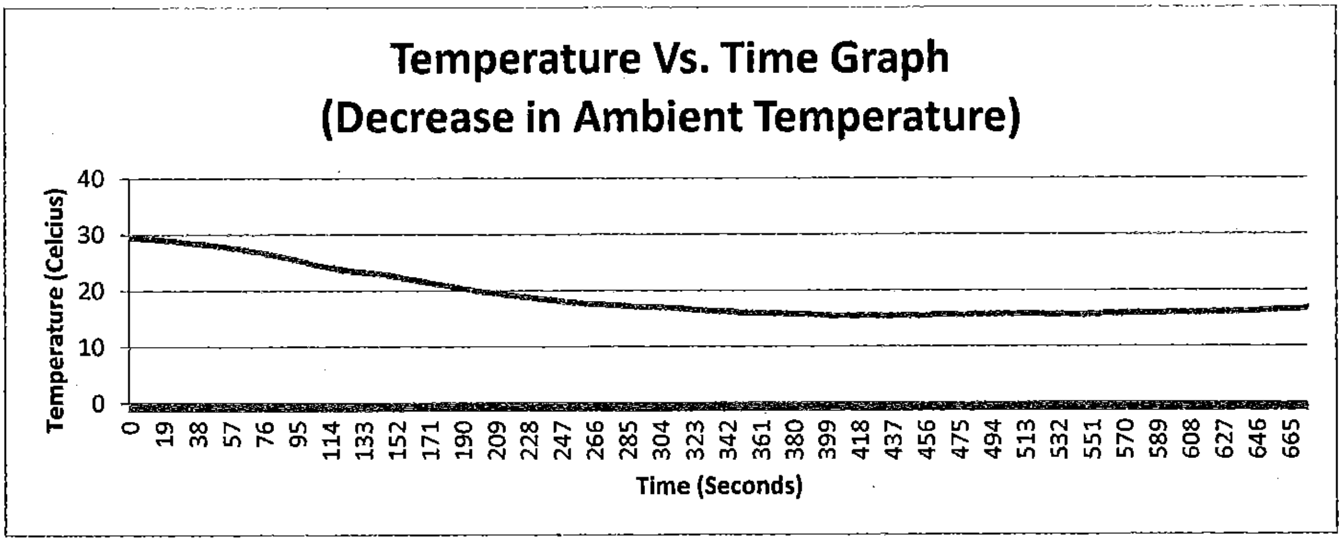


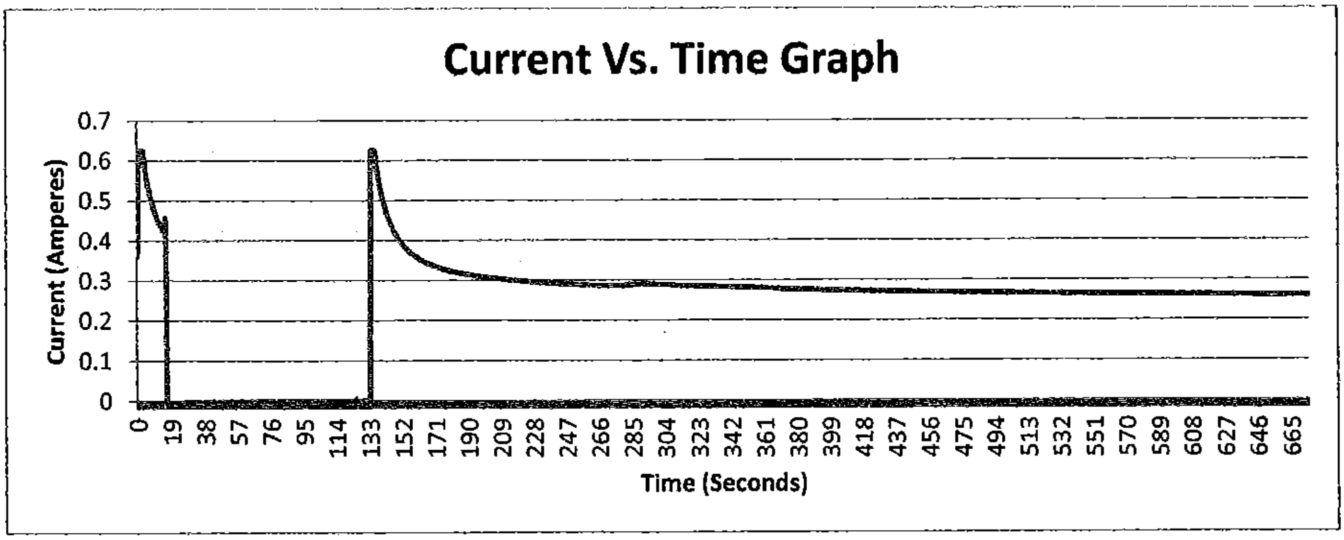


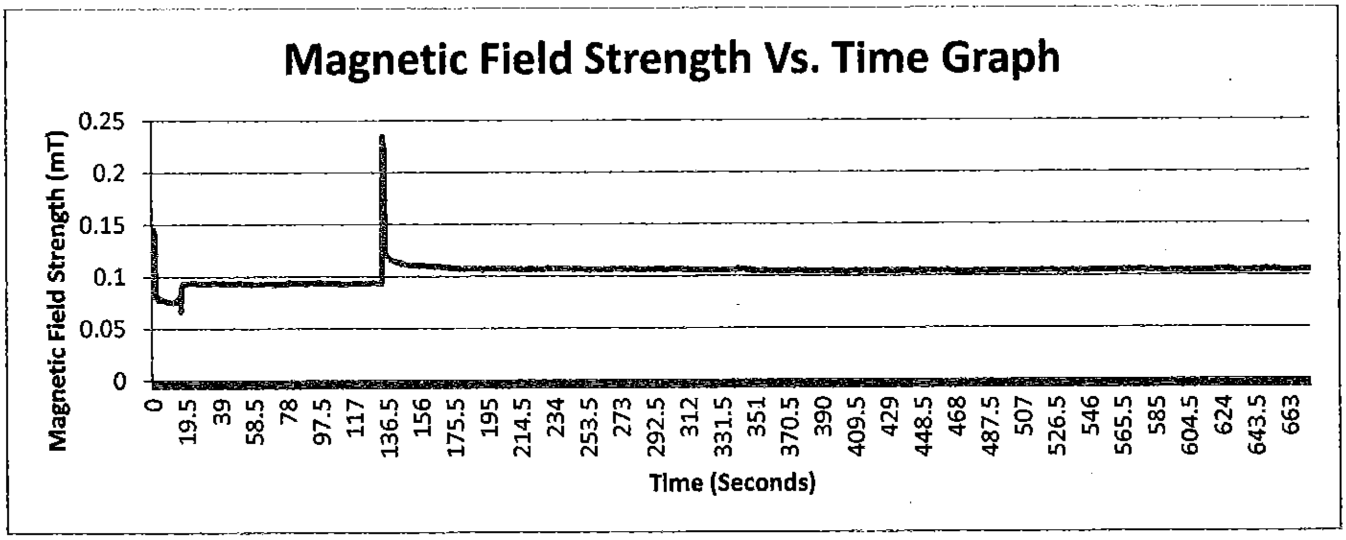
Looking at the graphs, there is a correlation between temperature, current, and magnetic field strength. Based off of the data, as temperature increases, the flow of current decreases; as the flow of current decreases, the strength of the magnetic field also decreases. For example, the highest temperature that the core in trial 1 reached was 49.3°C ± 0.5°C, the lowest amount current flowing through the circuit for trial 1 was 0.257A ± 0.001A, and the lowest magnetic field strength was 0.1005mT ± 0.0001mT. For trial 2, the highest temperature that the core reached was 50.3°C ± 0.5°C, the lowest amount of current flowing through the circuit was 0.245A ± 0.001A, and the lowest magnetic field strength was 0.0913mT ± 0.0001mT. This decreasing trend continues with the remaining two trials as shown by these graphs. Looking back at the research question, from this phase of the experiment it is possible to infer that an **increase** in the conductor's temperature slowly **decreases** the strength of the magnetic field due to **increasing** the resistivity of the conductor thereby **decreasing** the current that is able to travel through the circuit.

5.3. Phase III Data Collected and Analysis

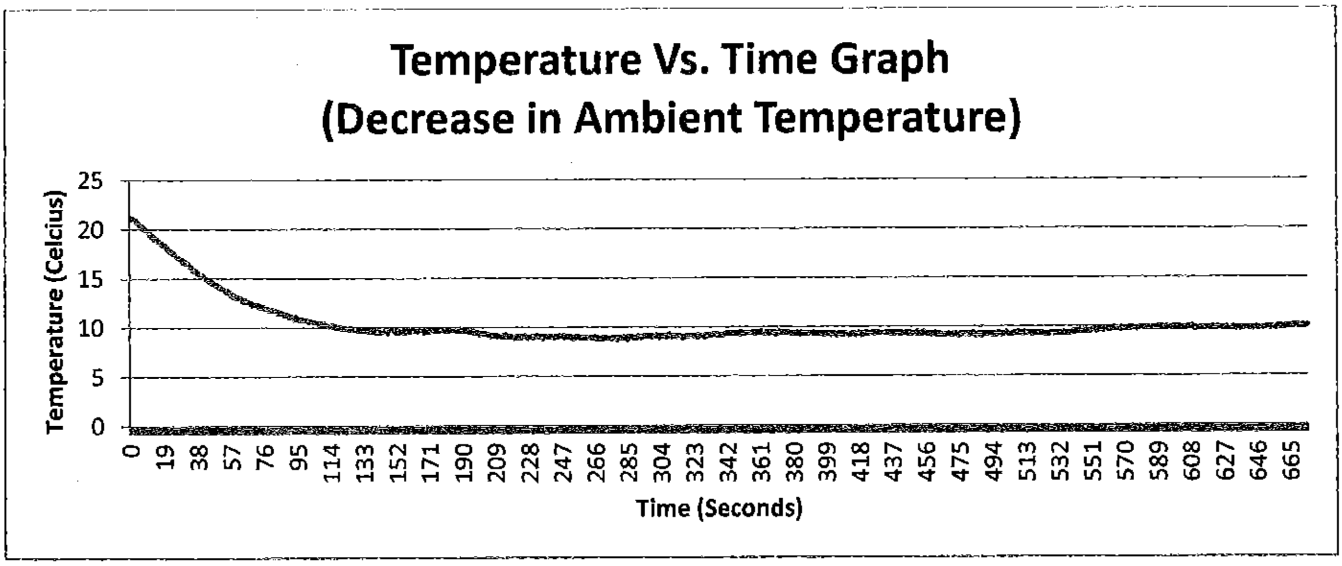
5.3.1. Trial 1

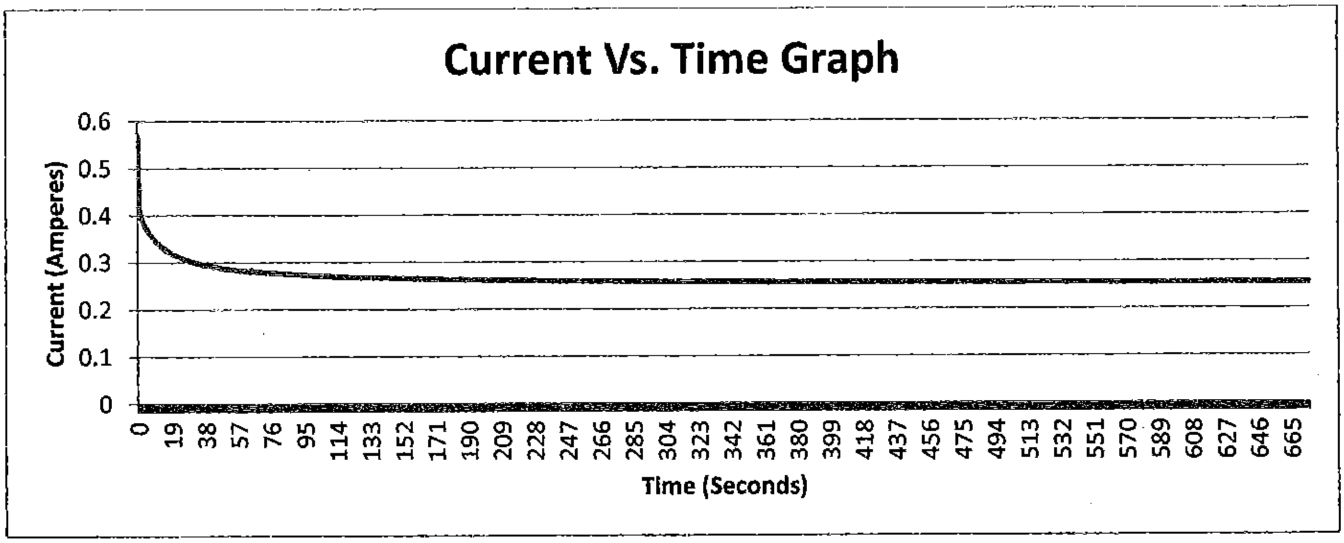


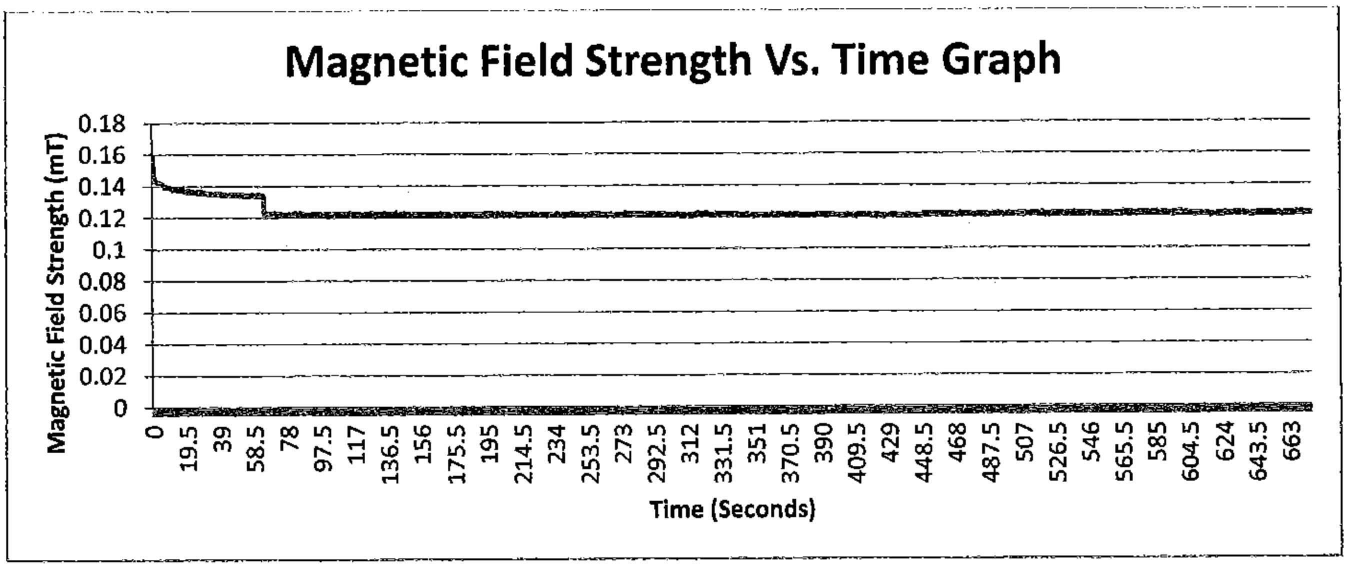




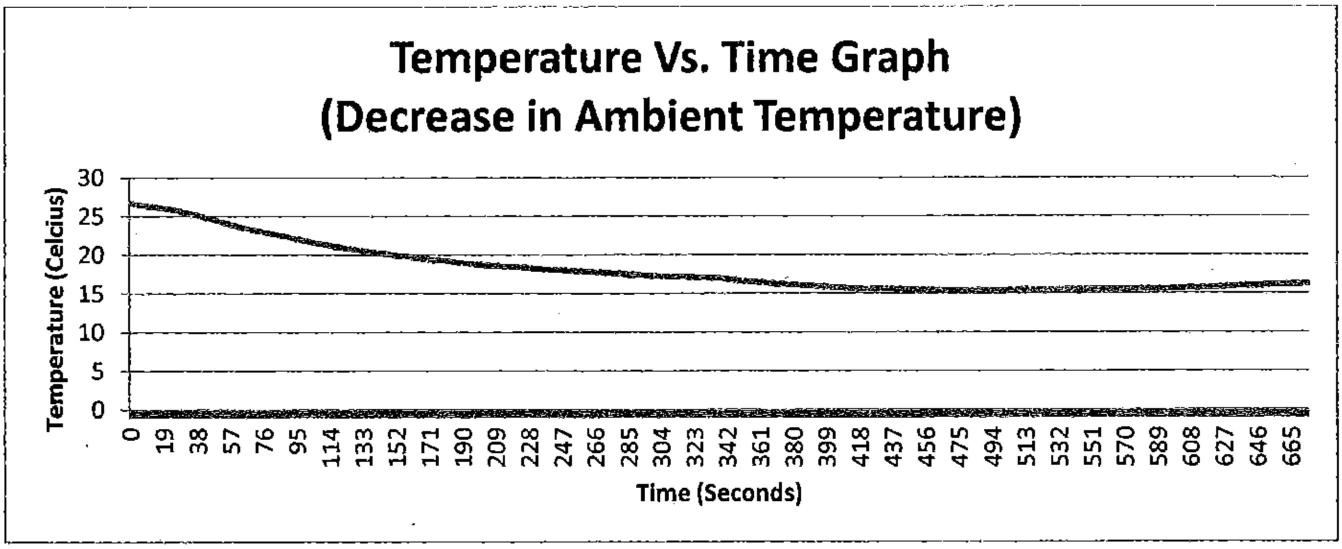
5.3.2. Trial 2

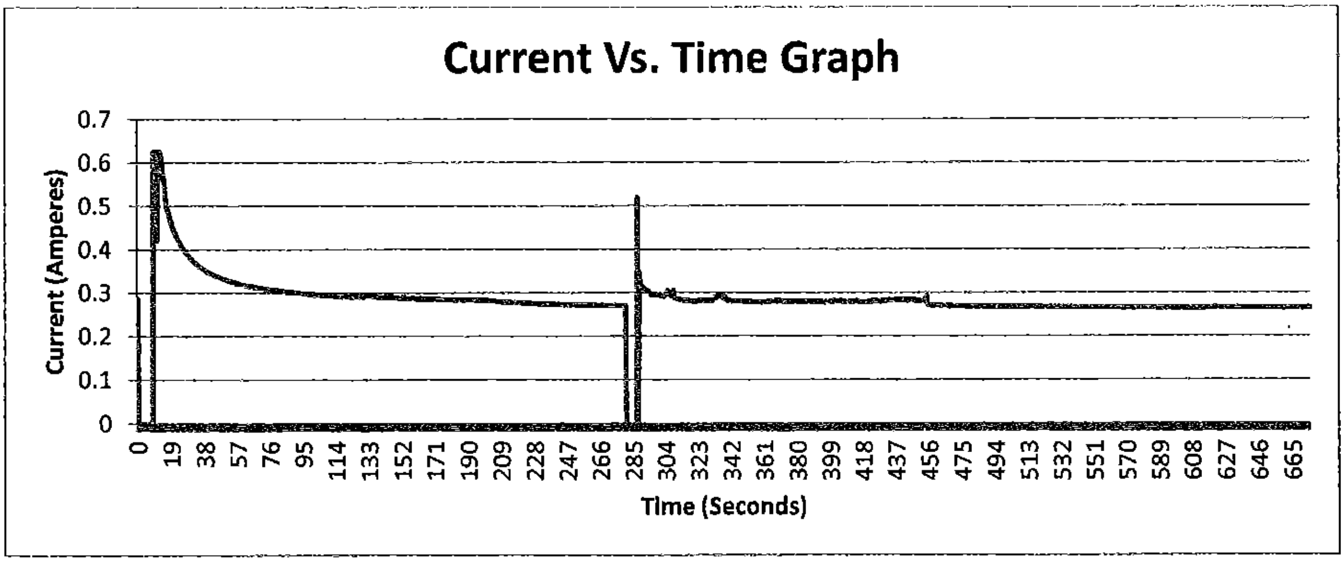

Temperature Vs. Time Graph
(Decrease in Ambient Temperature)
Temperature (Celcius)
0 5 10 15 20 25
Time (Seconds)
0 19 38 57 76 95 114 133 152 171 190 209 228 247 266 285 304 323 342 361 380 399 418 437 456 475 494 513 532 551 570 589 608 627 646 665

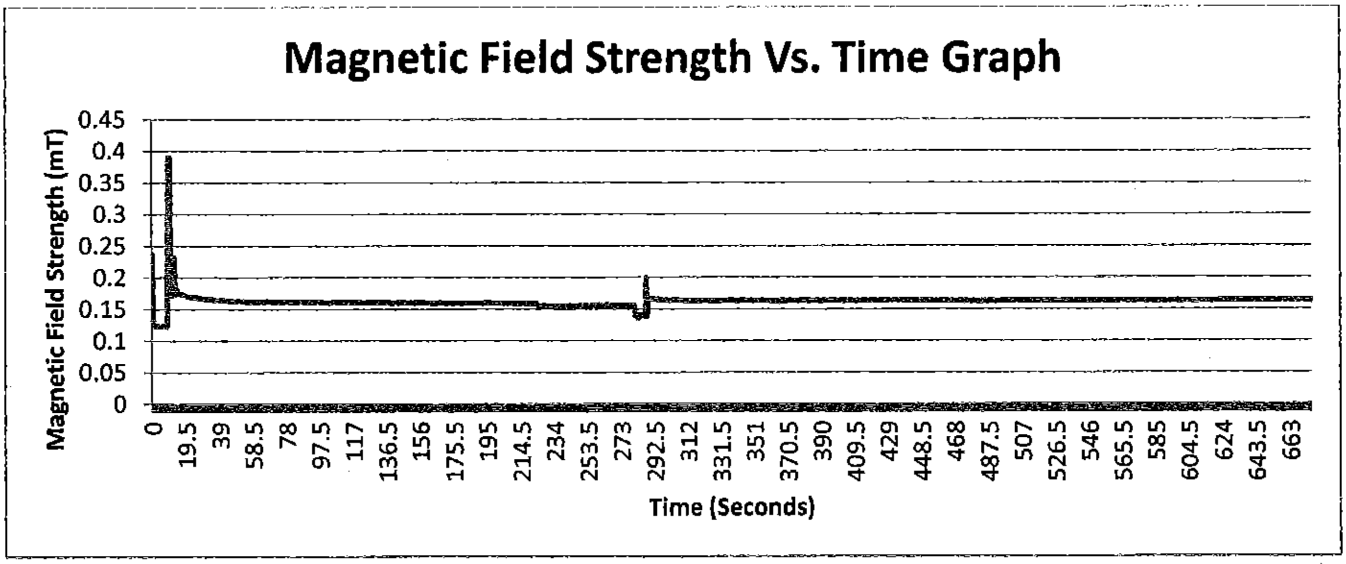

Current Vs. Time Graph
Current (Amperes)
0 0.1 0.2 0.3 0.4 0.5 0.6
Time (Seconds)
0 19 38 57 76 95 114 133 152 171 190 209 228 247 266 285 304 323 342 361 380 399 418 437 456 475 494 513 532 551 570 589 608 627 646 665


Magnetic Field Strength Vs. Time Graph
Magnetic Field Strength (mT)
0 0.02 0.04 0.06 0.08 0.1 0.12 0.14 0.16 0.18
Time (Seconds)
0 19.5 39 58.5 78 97.5 117 136.5 156 175.5 195 214.5 234 253.5 273 292.5 312 331.5 351 370.5 390 409.5 429 448.5 468 487.5 507 526.5 546 565.5 585 604.5 624 643.5 663

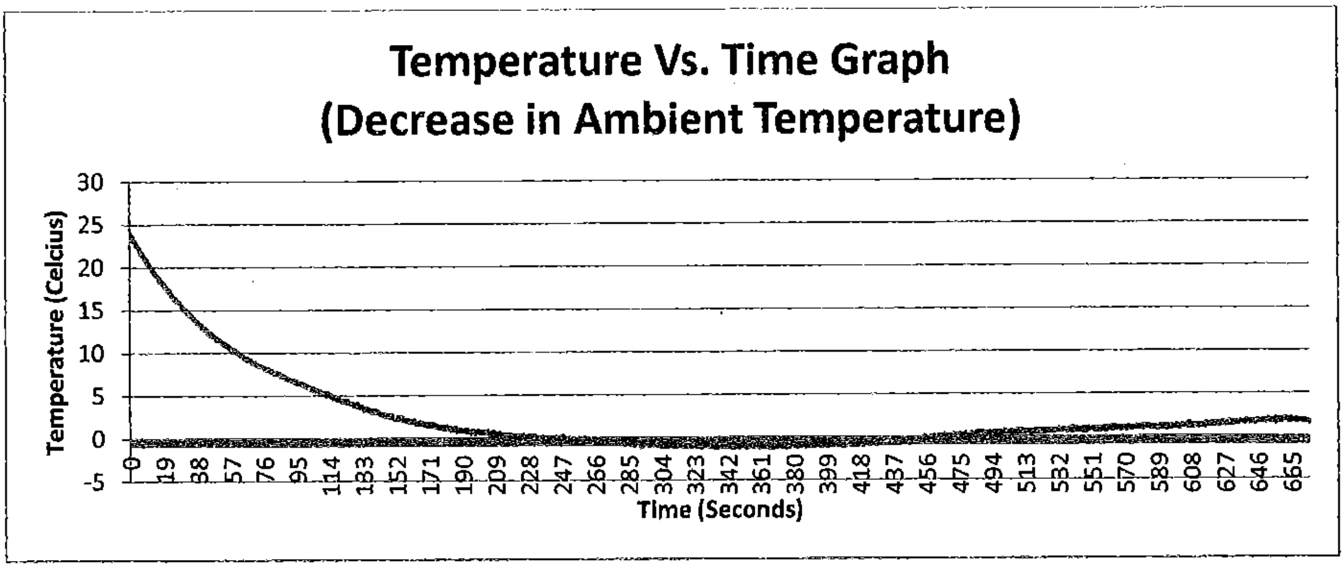
5.3.3. Trial 3

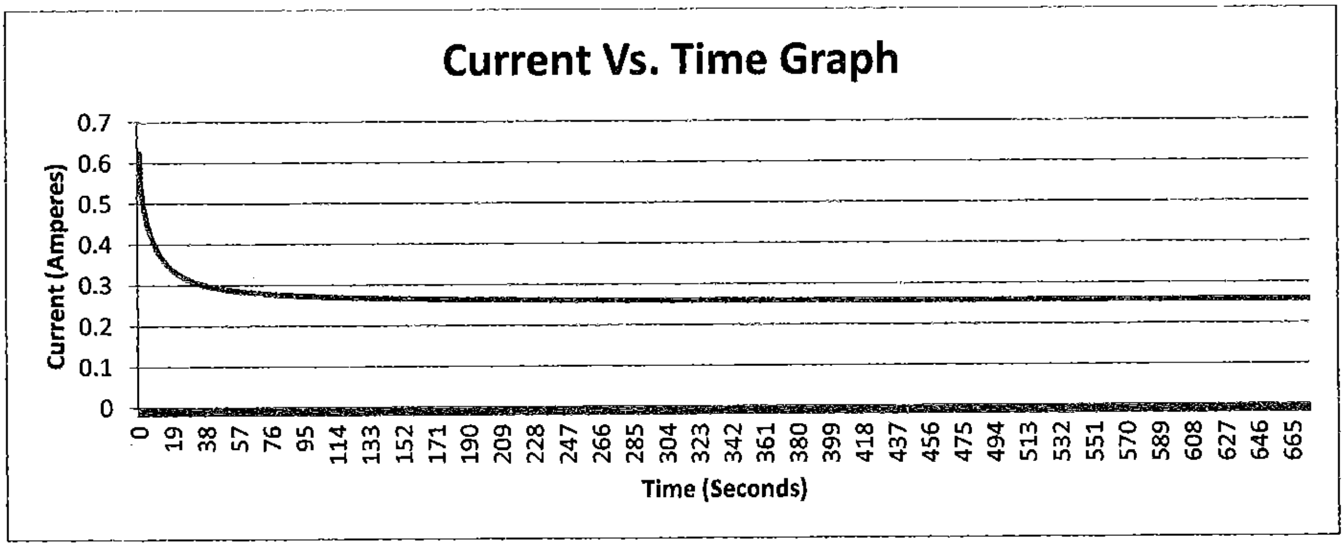

Temperature Vs. Time Graph
(Decrease in Ambient Temperature)
Temperature (Celcius)
30
25
20
15
10
5
0
0 19 38 57 76 95 114 133 152 171 190 209 228 247 266 285 304 323 342 361 380 399 418 437 456 475 494 513 532 551 570 589 608 627 646 665
Time (Seconds)

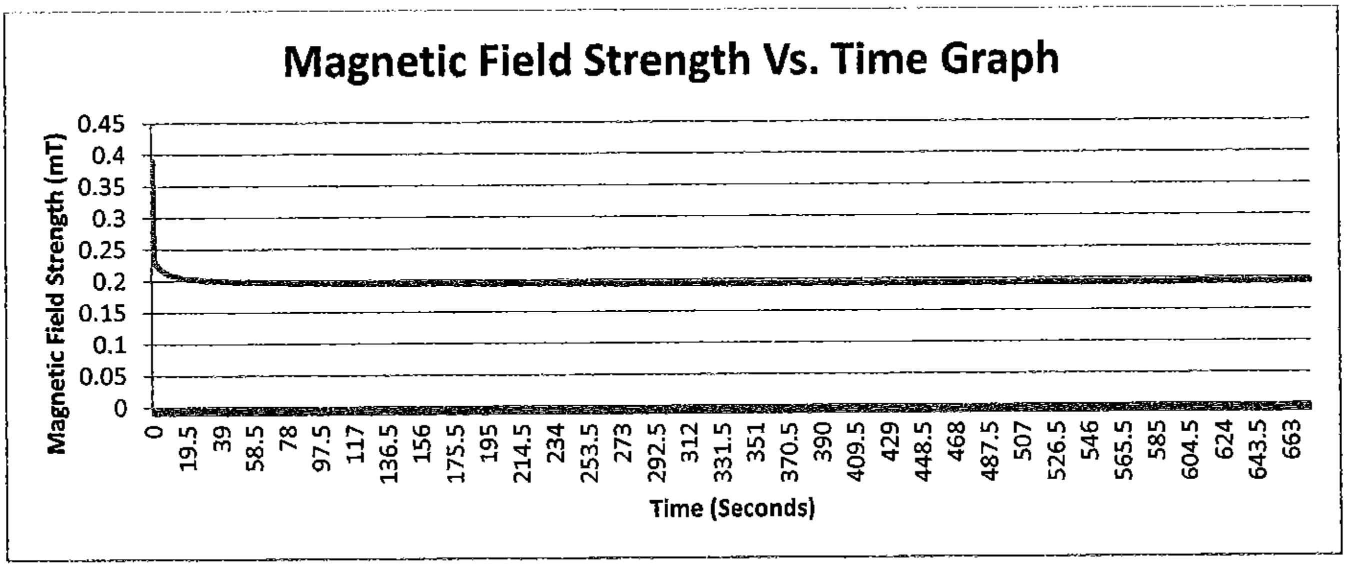

Current Vs. Time Graph
Current (Amperes)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 19 38 57 76 95 114 133 152 171 190 209 228 247 266 285 304 323 342 361 380 399 418 437 456 475 494 513 532 551 570 589 608 627 646 665
Time (Seconds)


Magnetic Field Strength Vs. Time Graph
Magnetic Field Strength (mT)
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0 19.5 39 58.5 78 97.5 117 136.5 156 175.5 195 214.5 234 253.5 273 292.5 312 331.5 351 370.5 390 409.5 429 448.5 468 487.5 507 526.5 546 565.5 585 604.5 624 643.5 663
Time (Seconds)

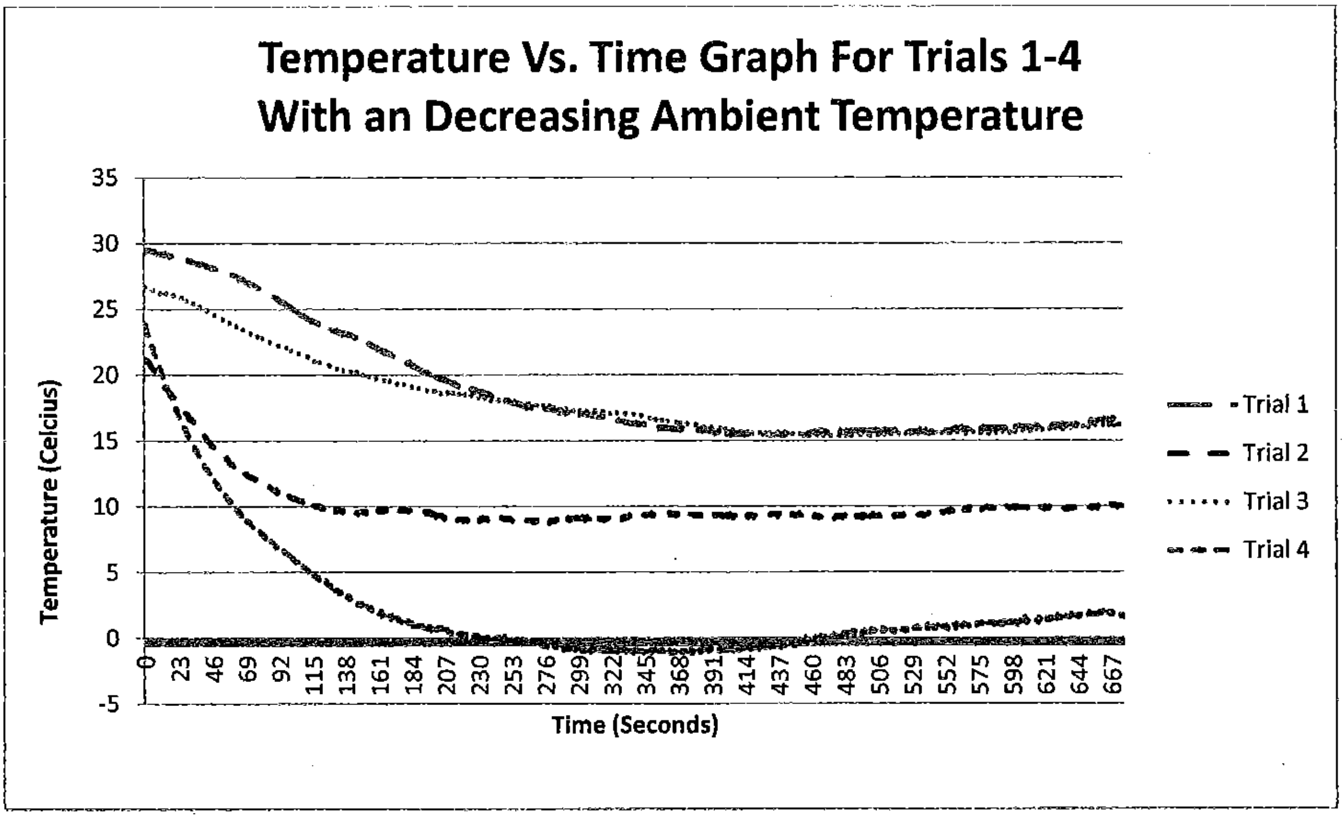
5.3.4. Trial 4

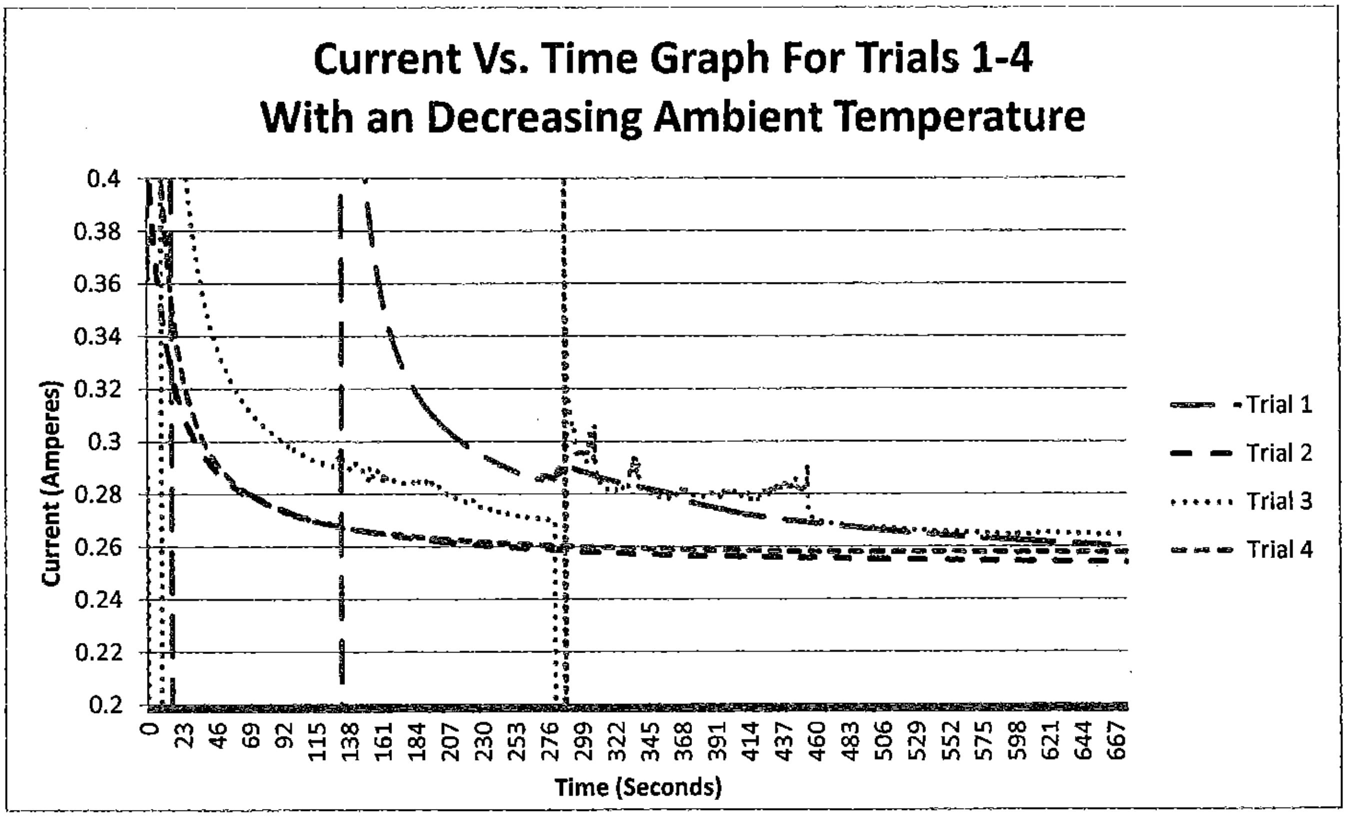

Temperature Vs. Time Graph
(Decrease in Ambient Temperature)
Temperature (Celcius)
30
25
20
15
10
5
0
-5
0 19 38 57 76 95 114 133 152 171 190 209 228 247 266 285 304 323 342 361 380 399 418 437 456 475 494 513 532 551 570 589 608 627 646 665
Time (Seconds)

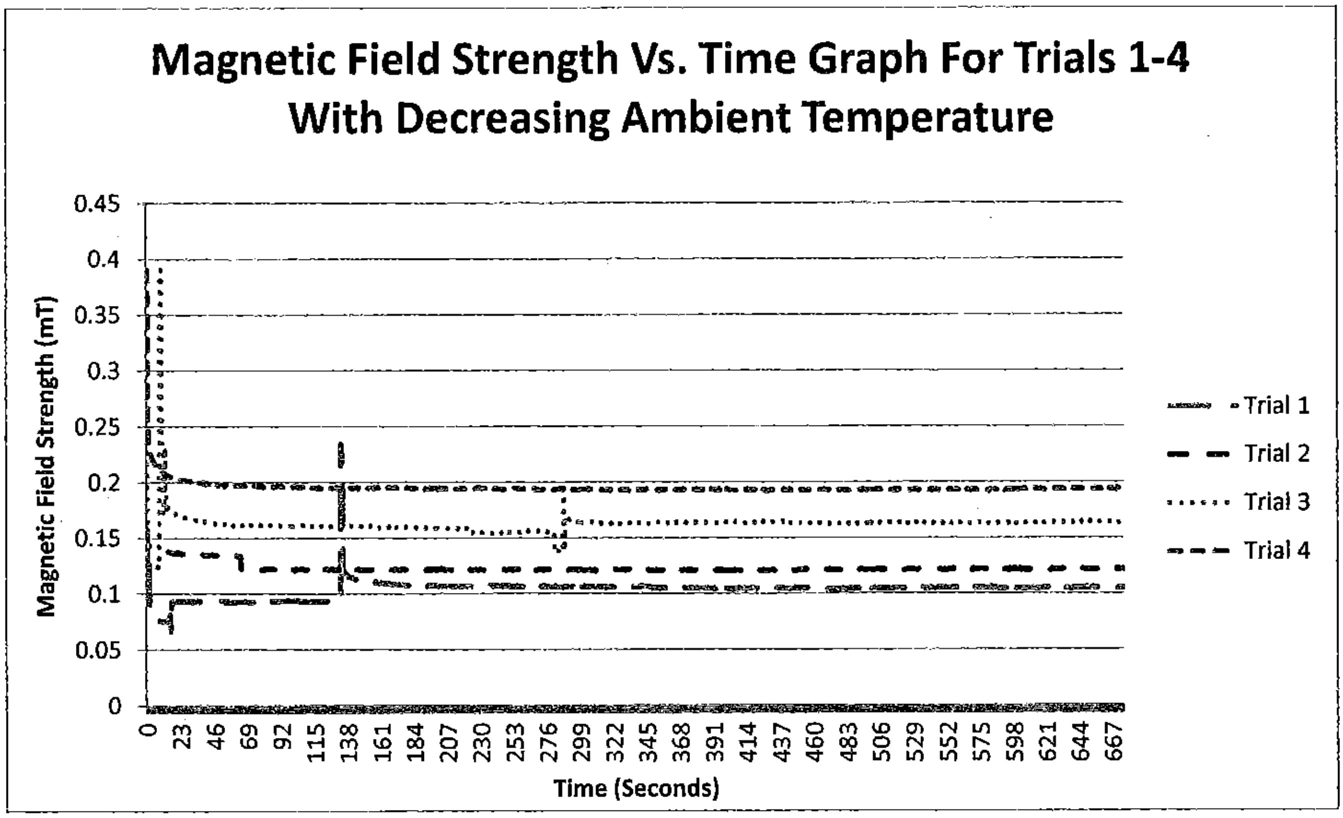

Current Vs. Time Graph
Current (Amperes)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 19 38 57 76 95 114 133 152 171 190 209 228 247 266 285 304 323 342 361 380 399 418 437 456 475 494 513 532 551 570 589 608 627 646 665
Time (Seconds)


Magnetic Field Strength Vs. Time Graph
Magnetic Field Strength (mT)
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0 19.5 39 58.5 78 97.5 117 136.5 156 175.5 195 214.5 234 253.5 273 292.5 312 331.5 351 370.5 390 409.5 429 448.5 468 487.5 507 526.5 546 565.5 585 604.5 624 643.5 663
Time (Seconds)

5.3.5. Analysis







Looking at the graphs, there is a clear correlation between temperature and magnetic field strength. Based off of the data, as temperature decreases, the flow of current (in this experiment) generally increases; as the flow of current increases, the strength of the magnetic field also increases. For example, looking at trial 1, the lowest temperature that trial 1 reaches is 15.4°C ± 0.5°C, the lowest amount current flowing through the circuit for trial 1 was 0.257A ± 0.001A, and the lowest magnetic field strength was 0.1034mT ± 0.0001mT. For trial 4, the lowest temperature that the core reached was -1.2°C ± 0.5°C, the lowest average current flowing through the circuit was 0.258A ± 0.001A, and the lowest magnetic field strength was 0.1918mT ± 0.0001mT. Although there doesn't appear to be a clear relationship between current and magnetic field strength in this phase of the experiment, there *are* clear relationships between temperature and magnetic field strength. Going back to the research question, from this segment of the experiment it can be inferred that and **decrease** in the conductor's temperature **increases** the strength of the magnetic field due to **decreasing** the resistivity of the conductor thereby **increasing** the current that is able to travel through the circuit. With decreasing temperatures, the core is moving closer to a state of superconductivity in which electrical resistance decreases to the point where there is zero electrical resistance. As seen with this phase of the experiment, as the temperature decreased, the current that was capable of moving through the copper wiring increased.

6. Conclusion and Evaluation

6.1. Conclusion

The goal of this investigation was to attempt to answer the question: "**When Looking at Electromagnetic Fields, How Does a Change in the Conductor's Temperature Affect the Strength of the Magnetic Field Generated, and its Magnetic Flux?**" and offer a valid explanation as to why the outcome is what it is. Based off of the experiment conducted, the results show a strong correlation between the temperature of the conductor and the overall strength of the electromagnet. From section 5.1, it was determined that even when the conductor's temperature is not changed, the current that passes through the circuit decreases as time increases and, similarly, the strength of the magnetic field decreases as well. From this benchmark data, it was inferred that current and the strength of a magnetic field are directly proportional. Then section 5.2.5 showed that as temperature of the conductor increases, the overall strength of the magnetic field decreases. When looking at a trial that reached a higher temperature than the others before it, the magnetic field that was generated was measured significantly less than those trials in which the core was not heated to such high temperatures. This phenomenon can be explained by using Ohm's Law which states: $sistance = \frac{Voltage}{Current}$, since voltage was kept constant throughout the experiment, the formula is changed to $R = \frac{1}{Current}$. From section 5.2.5, there is a correlation between temperature and current; since current decreases as temperature increases, resistance of the electromagnet will increase. The stronger the resistance, the weaker the magnetic field. In higher temperatures, electrons found in the conductor vibrate much faster than they do at lower temperatures. Due to this speed, the free electrons come in contact with phonons far more frequently which results in these free electrons being scattered more frequently. In section 5.3.5, there was a similar correlation between temperature, current, and magnetic field strength in decreasing temperatures. This data suggests that when the conductor's temperature is lowered, the current that flows through the circuit is increased, and that the strength of the magnetic field generated also increases; this can also be explained with Ohm's Law. Lower temperatures mean more current flowing through the circuit; as current approaches infinity, the resistance approaches zero (superconductivity). The lower the resistance, the stronger the magnetic field. **In conclusion, when looking at electromagnetic fields, an increase in the conductor's temperature decreases the strength of the magnetic field generated while a decrease in the conductor's temperature increases the strength of the magnetic field generated; the magnetic flux increases or decreases (looking only at temperature) depending on the strength of the magnetic field.**

6.2. Evaluation

Although the conclusion is logical, there are several sources of error for this experiment. This first of these problems include that this experiment was performed in an open environment where the outside temperature changed by a couple degrees while conducting the experiment. The result of this was the occasional misshapen temperature curve for a given trial because of an inconsistent ambient temperature, although it did not significantly alter the data or the conclusion. Another key source of error for this experiment was the current probe that was used. Although it provided consistent data when logging changing intensity of the current within the circuit when inducing higher temperatures on the conductor, when using the dry ice in phase III of the experiment, the current probe had some difficulty registering a current. The result of this was the irregular, inconsistent current vs. time graph in 5.3.5. Despite this error, a conclusion could still be inferred based on the remaining data.

Some ways to improve the overall success of this experiment would be to work in a closed environment where the temperature (apart from the temperatures manually induced on the conductor) remained constant. To increase the overall effectiveness of the electromagnet, a core of pure iron would have been more effective to use than semi-soft iron. A better system of heating and cooling the cores would have improved range and smooth continuity of the temperature vs. time graphs.

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none of them were citated in the core.