Magentostriction with Michelson Interferometer

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ABSTRACT

Magnetostriction is a property exhibited by magnetic materials that causes them to change their shape or dimensions during the process of magnetization. This report investigates the phenomena of magnetostriction in the rods of Nickel, Iron and Copper by using a Michelson interferometer setup. The results showed that the magnetostriction effect was present in both Ni and Fe rods but absent in the Copper rod. Further, the effect of altering the arm lengths of the interferometer was examined. The effectiveness of this setup to study magnetostrictive effects was also discussed. Instruments interfaced with a LabVIEW program were used to record and export the data.

Contents

Chapter 1

Introduction

In the early 1800s, the study of electricity and magnetism was a burgeoning field, full of exciting discoveries and new insights. Hailing from Lancashire, English physicist James Joule, namesake for the SI unit of energy and heat, was studying the ways in which magnetic fields interacted with matter. He had already made a name for himself in the scientific community for his work on the relationship between heat and energy, but he was eager to explore the ways in which magnets could affect the behavior of materials.

In 1842, Joule made a groundbreaking discovery that would change the course of his research and contribute to the development of a new field of study: magnetostriction. While experimenting with a sample of iron that had been placed in a magnetic field, Joule noticed something peculiar. As he varied the strength of the field, he observed that the iron sample actually changed in size. When the field was turned off, the sample returned to its original dimensions.

Joule was fascinated by this behavior and began to explore it in more detail. He found that other materials, including nickel and cobalt, exhibited similar properties under the influence of a magnetic field. He called this phenomenon "magnetostriction," from the Greek words for "magnet" and "to twist."

Joule's discovery opened up a whole new area of research, as scientists sought to understand the underlying mechanisms behind magnetostriction and explore its potential applications. Over time, they discovered that magnetostriction was closely related to other magnetic effects, such as the magneto-optic effect and the giant magnetoresistance effect. Today, magnetostriction continues to be an active area of research, with applications in fields ranging from materials science to electrical engineering as it allows storing electrical energy in form of mechanical energy at scale.

In this term report, we used a Michelson interferometer setup paired with a He-Ne laser to study this phenomena.

1.1 Objectives

The following objectives were formulated and achieved for this experiment:

1. To study the phenomena of magnetostriction in Nickel, Iron and Copper rods.

2. To measure longitudinal strain with the applied varying magnetic field.

Chapter 2

Theory

In this chapter, the theoretical background will be detailed before we discuss the particulars of the experiment.

2.1 Magnetostriction

The internal structure of ferromagnetic materials is composed of domains, each of which is a region of uniform magnetization. The domain boundaries move and the domains rotate when a magnetic field is applied; both of these effects change the material's dimensions. Because it requires more energy to magnetize a crystalline material in one direction than in another, magnetocrystalline anisotropy[1] is the reason that altering a material's magnetic domains causes a change in the material's dimensions. The material will tend to rearrange its structure so that an easy axis is aligned with the field to minimize the free energy of the system if a magnetic field is applied to it at an angle to an easy axis of magnetization[2]. This differential induction of direction leads to strain in the material.

In fact, the reciprocal effect is also observed in the form of Villari effect, which is defined as the change in the magnetic susceptibility (which quantifies the response to an applied field) of a magnetic material under some form of mechanical stress. The Matteucci and Wiedemann effects are also two related phenomena where mechanical transformation of ferromagnetic materials leads to changes in their magentic

[1] A ferromagnetic material is said to have magnetocrystalline anisotropy if it takes more energy to magnetize it in certain directions than in others.

[2] Easy axis refers to the energetically favorable direction of the spontaneous magnetization in a ferromagnetic material.

properties.

The changes in dimensions of the material are always in the direction of magnetization, and it they can be positive or negative depending on if the material is contracting or elongating. The distortions are usually of the order 10^{-8} to 10^{-4}m.

2.2 LASER

2.3 Michelson Interferometer

2.4 Photo-diode Detector

Chapter 3

Experimental Set-up

Chapter 4

Experiments and Analysis

4.1 With Iron

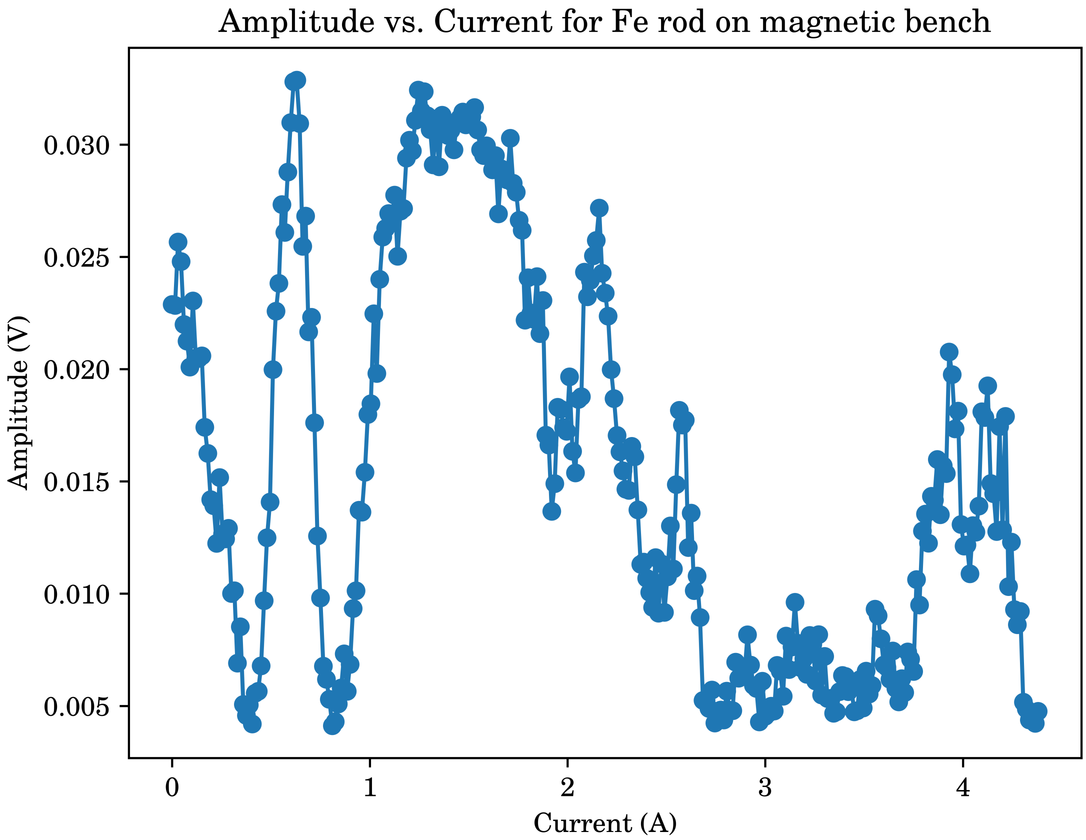

Figure 4.1: The amplitude versus current data obtained for Fe rod on the magnetic bench.

4.2 With Nickel

4.3 With Copper

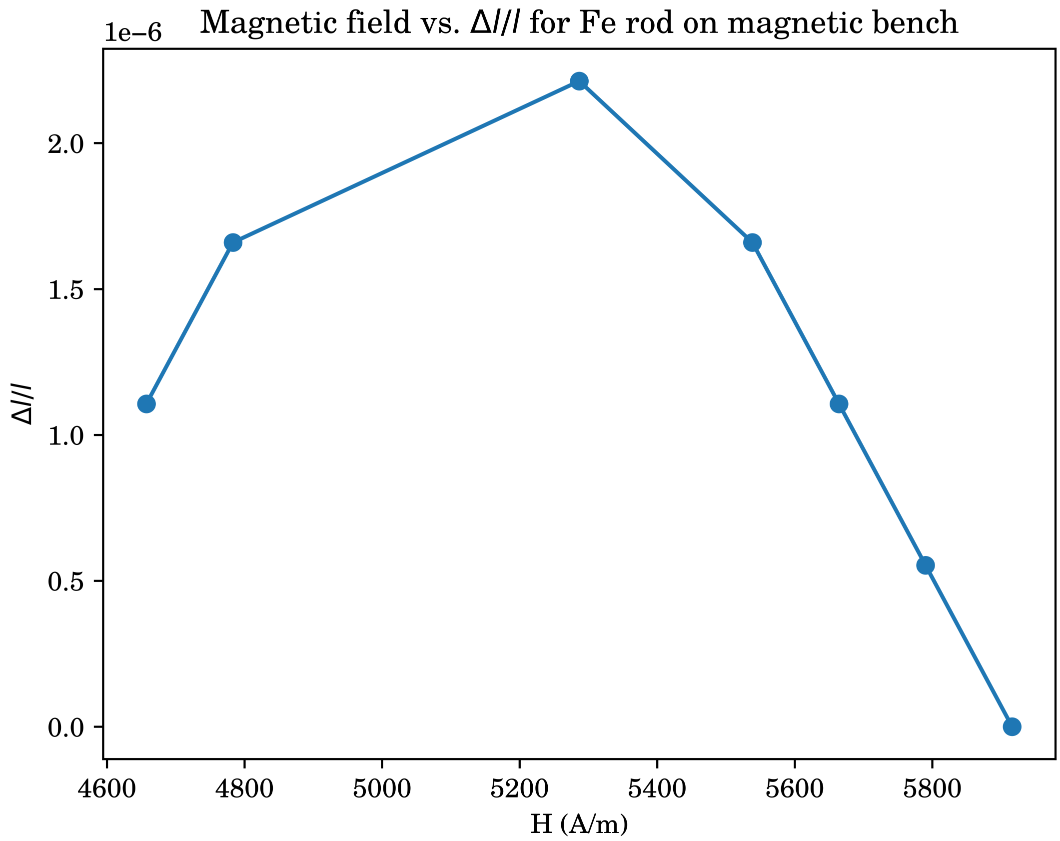

Figure 4.2: The variation in strain with applied magnetic field for Fe on the magnetic bench.

Current (A)	**Ring changes** (n)	Δl ($\times 10^{-9}$m)	**Magnetization,** H ($\mathrm{A\,m^{-1}}$)	$\Delta l/l$ ($\times 10^{-9}$m)
0.555	1	1.58E-07	4.66E+03	1.11E-06
0.57	1.5	2.37E-07	4.78E+03	1.66E-06
0.63	2	3.16E-07	5.29E+03	2.21E-06
0.66	1.5	2.37E-07	5.54E+03	1.66E-06
0.675	1	1.58E-07	5.66E+03	1.11E-06
0.69	0.5	7.91E-08	5.79E+03	5.53E-07
0.705	0	0.00E+00	5.92E+03	0.00E+00

Table 4.1: The variation in strain with applied magnetic field for Fe on the magnetic bench.

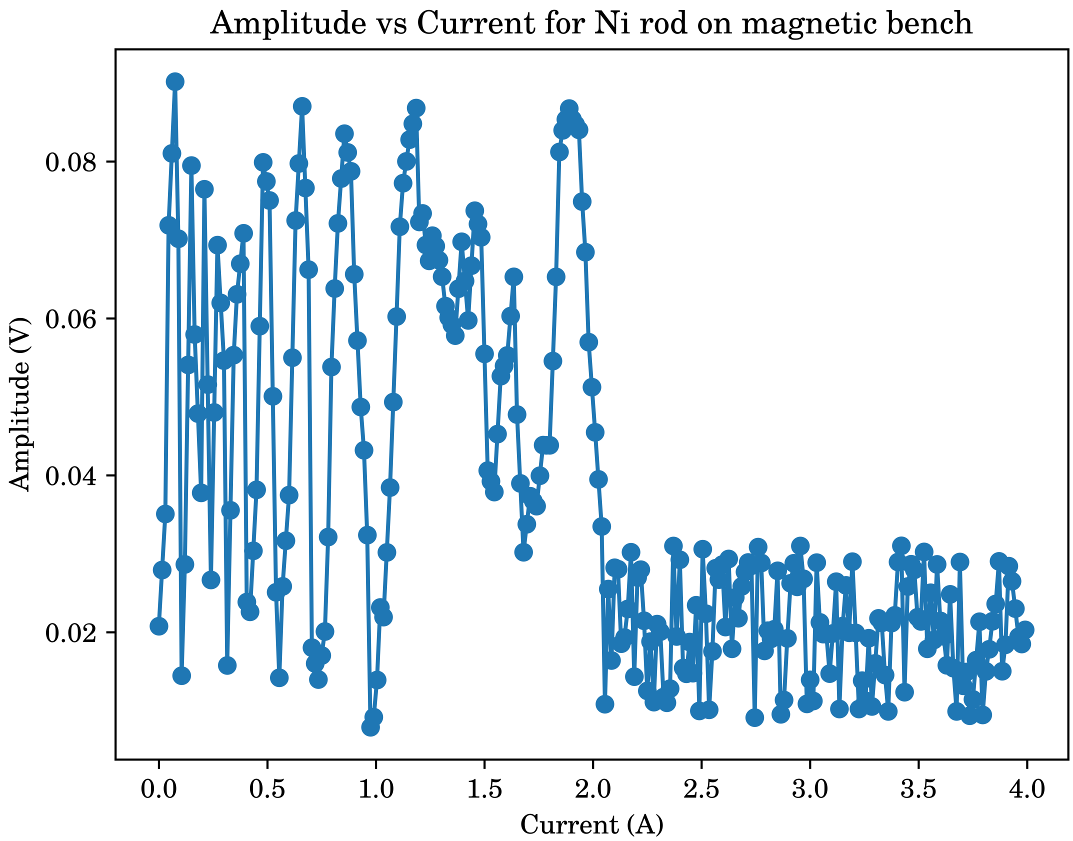

Figure 4.3: The amplitude versus current data obtained for Ni rod on the magnetic bench.

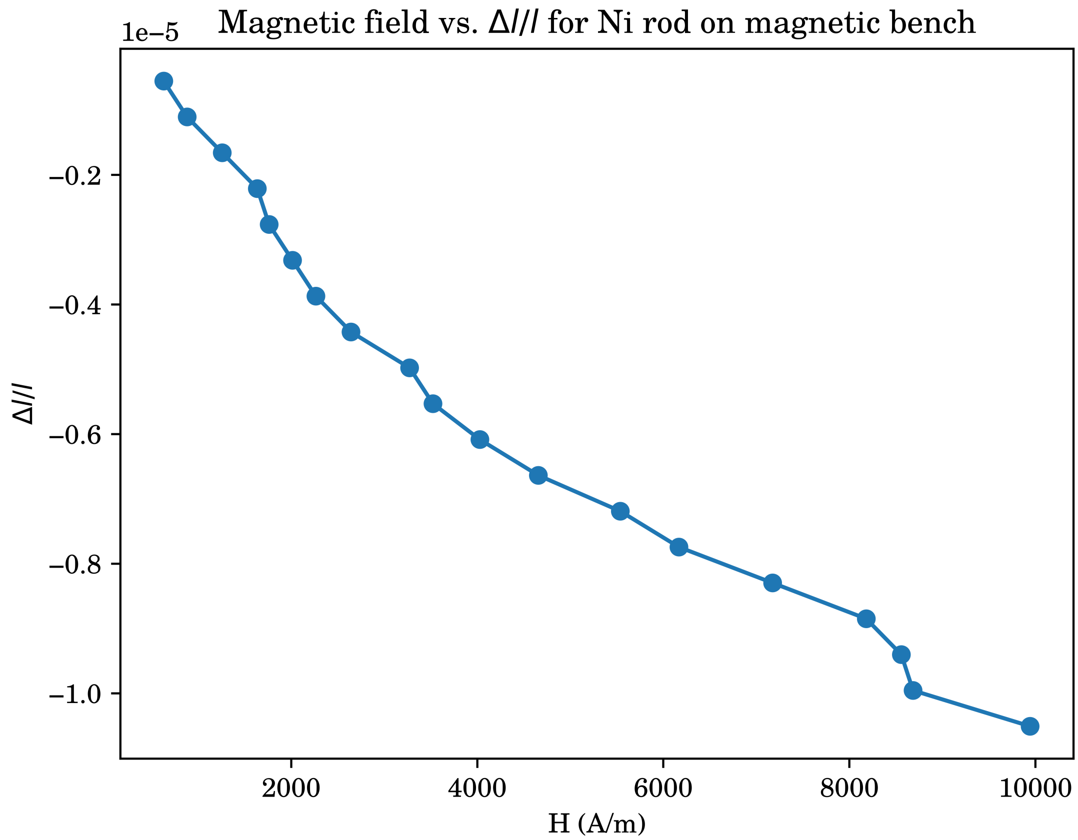

Figure 4.4: The variation in strain with applied magnetic field for Ni on the magnetic bench.

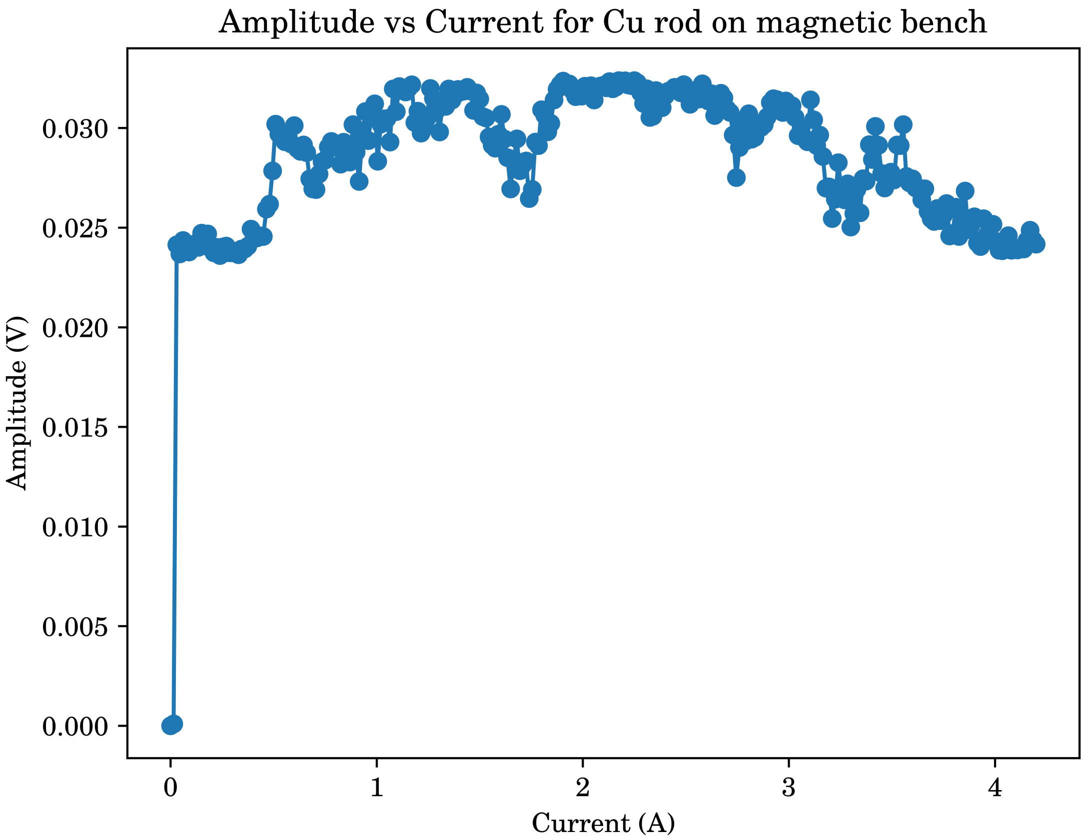

Figure 4.5: The amplitude versus current data obtained for Cu rod on the magnetic bench.

Current (A)	**Ring changes** (n)	Δl ($\times 10^{-9}$m)	**Magnetization,** H ($\mathrm{A\,m^{-1}}$)	$\Delta l/l$ ($\times 10^{-9}$m)
0.075	0.5	-7.91E-08	6.29E+02	-5.53E-07
0.105	1	-1.58E-07	8.81E+02	-1.11E-06
0.15	1.5	-2.37E-07	1.26E+03	-1.66E-06
0.195	2	-3.16E-07	1.64E+03	-2.21E-06
0.21	2.5	-3.96E-07	1.76E+03	-2.77E-06
0.24	3	-4.75E-07	2.01E+03	-3.32E-06
0.27	3.5	-5.54E-07	2.27E+03	-3.87E-06
0.315	4	-6.33E-07	2.64E+03	-4.43E-06
0.39	4.5	-7.12E-07	3.27E+03	-4.98E-06
0.42	5	-7.91E-07	3.52E+03	-5.53E-06
0.48	5.5	-8.70E-07	4.03E+03	-6.08E-06
0.555	6	-9.49E-07	4.66E+03	-6.64E-06
0.66	6.5	-1.03E-06	5.54E+03	-7.19E-06
0.735	7	-1.11E-06	6.17E+03	-7.74E-06
0.855	7.5	-1.19E-06	7.17E+03	-8.30E-06
0.975	8	-1.27E-06	8.18E+03	-8.85E-06
1.02	8.5	-1.34E-06	8.56E+03	-9.40E-06
1.035	9	-1.42E-06	8.69E+03	-9.96E-06
1.185	9.5	-1.50E-06	9.94E+03	-1.05E-05

Table 4.2: The variation in strain with applied magnetic field for Ni on the magnetic bench.

Chapter 5

Extensions and Innovation

5.1 With Iron

5.2 With Nickel

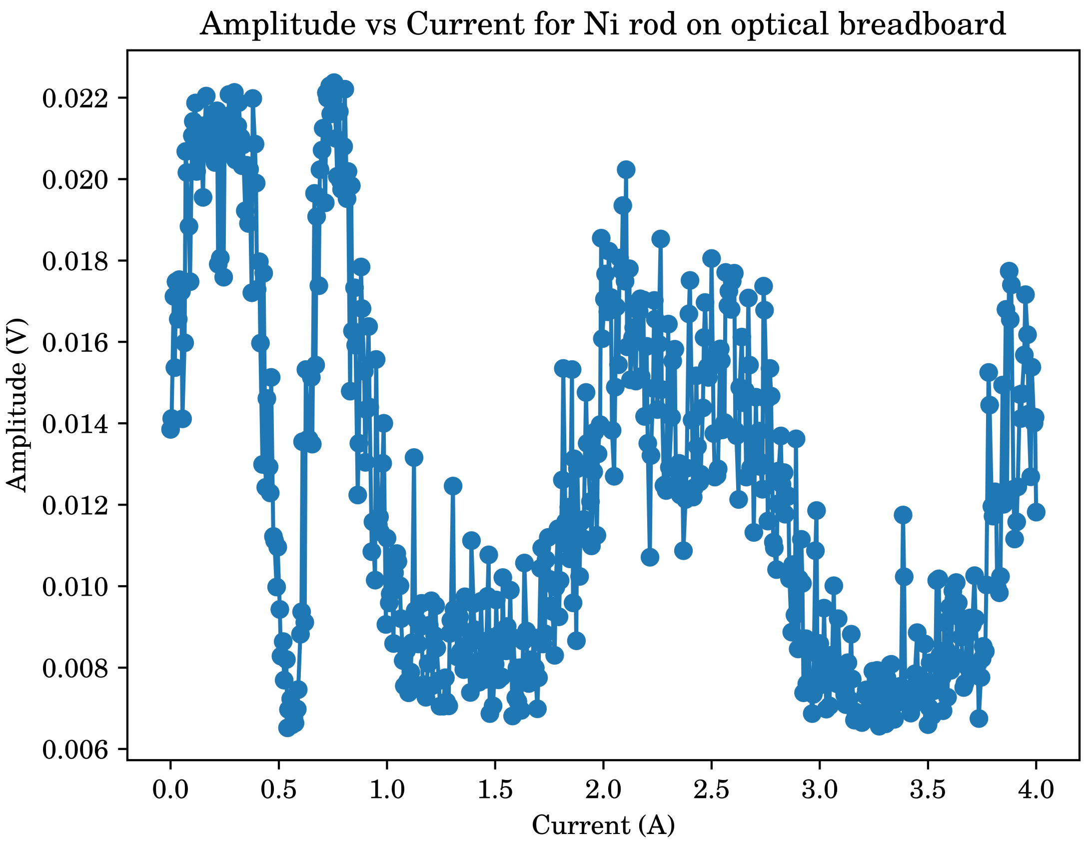

Figure 5.1: The amplitude versus current data obtained for Fe rod on the optical breadboard with altered arm lengths of the interferometer.

Current (A)	**Ring changes** (n)	Δl ($\times 10^{-9}$m)	**Magnetization,** H ($\mathrm{A\,m^{-1}}$)	$\Delta l / l$ ($\times 10^{-9}$m)
0.46	2	3.16E-07	3.86E+03	2.21E-06
0.465	2.5	3.96E-07	3.90E+03	2.77E-06
0.49	3	4.75E-07	4.11E+03	3.32E-06
0.495	2.5	3.96E-07	4.15E+03	2.77E-06
0.51	2	3.16E-07	4.28E+03	2.21E-06
0.52	1.5	2.37E-07	4.36E+03	1.66E-06
0.525	1	1.58E-07	4.41E+03	1.11E-06
0.535	0.5	7.91E-08	4.49E+03	5.53E-07
0.54	0	0.00E+00	4.53E+03	0.00E+00

Table 5.1: The variation in strain with applied magnetic field for Fe on the optical breadboard.

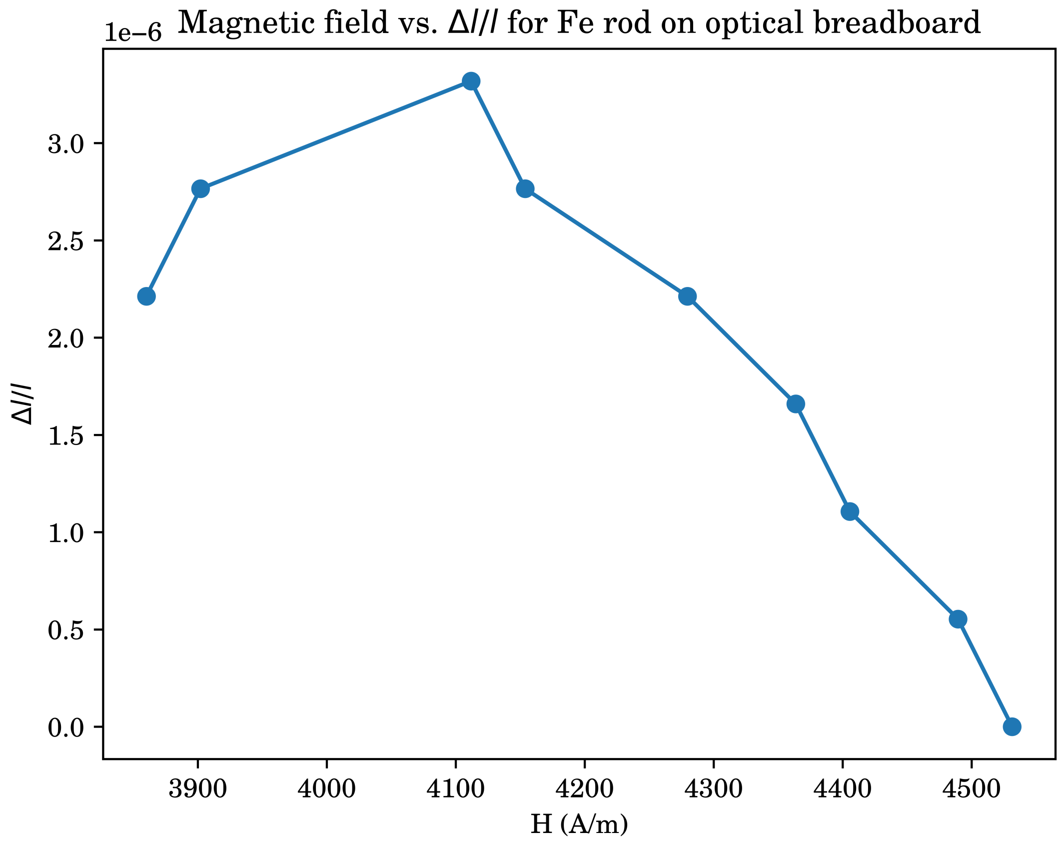

Figure 5.2: The variation in strain with applied magnetic field for Fe on the optical breadboard.

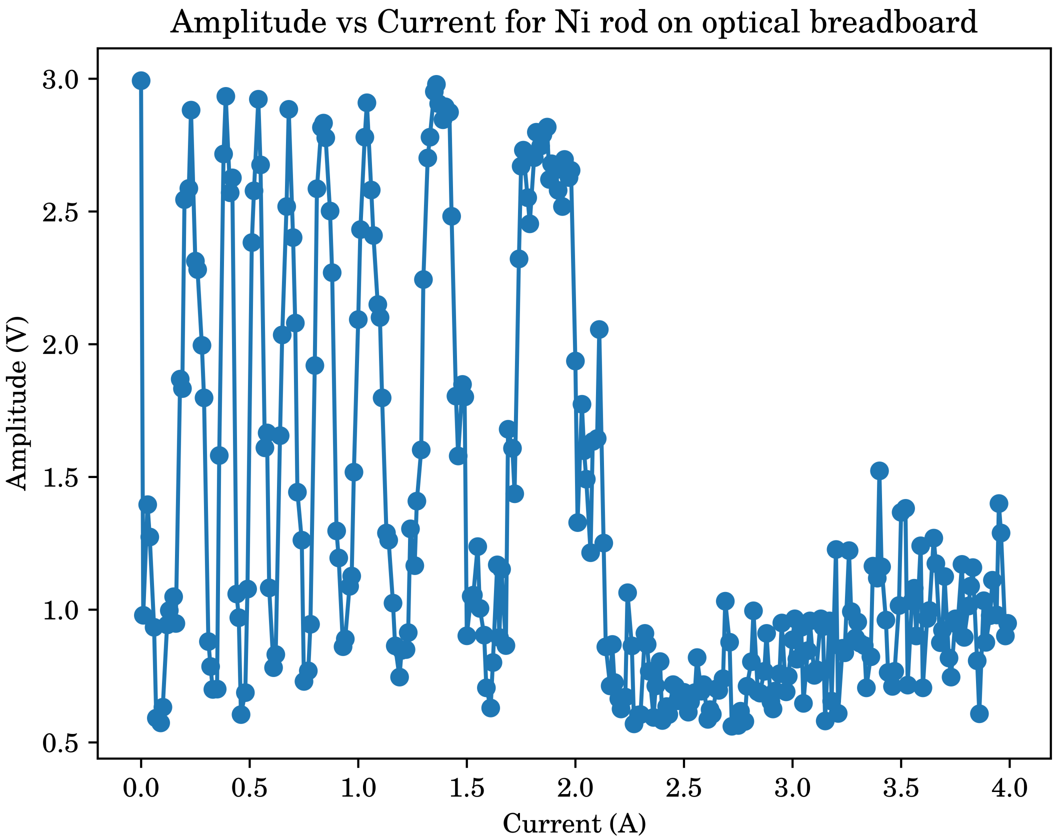

Figure 5.3: The amplitude versus current data obtained for Ni rod on the optical breadboard with altered arm lengths of the interferometer.

Current (A)	**Ring changes** (n)	Δl ($\times 10^{-9}$m)	**Magnetization,** H ($\mathrm{A\,m^{-1}}$)	$\Delta l/l$ ($\times 10^{-9}$m)
0.01	0.5	-7.91E-08	8.39E+01	-5.53E-07
0.03	1	-1.58E-07	2.52E+02	-1.11E-06
0.09	1.5	-2.37E-07	7.55E+02	-1.66E-06
0.15	2	-3.16E-07	1.26E+03	-2.21E-06
0.16	2.5	-3.96E-07	1.34E+03	-2.77E-06
0.18	3	-4.75E-07	1.51E+03	-3.32E-06
0.19	3.5	-5.54E-07	1.59E+03	-3.87E-06
0.23	4	-6.33E-07	1.93E+03	-4.43E-06
0.33	4.5	-7.12E-07	2.77E+03	-4.98E-06
0.39	5	-7.91E-07	3.27E+03	-5.53E-06
0.41	5.5	-8.70E-07	3.44E+03	-6.08E-06
0.42	6	-9.49E-07	3.52E+03	-6.64E-06
0.46	6.5	-1.03E-06	3.86E+03	-7.19E-06
0.54	7	-1.11E-06	4.53E+03	-7.74E-06
0.57	7.5	-1.19E-06	4.78E+03	-8.30E-06
0.58	8	-1.27E-06	4.87E+03	-8.85E-06
0.61	8.5	-1.34E-06	5.12E+03	-9.40E-06
0.68	9	-1.42E-06	5.71E+03	-9.96E-06
0.75	9.5	-1.50E-06	6.29E+03	-1.05E-05
0.84	10	-1.58E-06	7.05E+03	-1.11E-05
0.93	10.5	-1.66E-06	7.80E+03	-1.16E-05
1.04	11	-1.74E-06	8.73E+03	-1.22E-05
1.19	11.5	-1.82E-06	9.99E+03	-1.27E-05
1.24	12	-1.90E-06	1.04E+04	-1.33E-05
1.26	12.5	-1.98E-06	1.06E+04	-1.38E-05
1.36	13	-2.06E-06	1.14E+04	-1.44E-05
1.39	13.5	-2.14E-06	1.17E+04	-1.49E-05
1.4	14	-2.21E-06	1.17E+04	-1.55E-05
1.46	14.5	-2.29E-06	1.23E+04	-1.60E-05
1.48	15	-2.37E-06	1.24E+04	-1.66E-05

Table 5.2: The variation in strain with applied magnetic field for Ni on the optical breadboard.

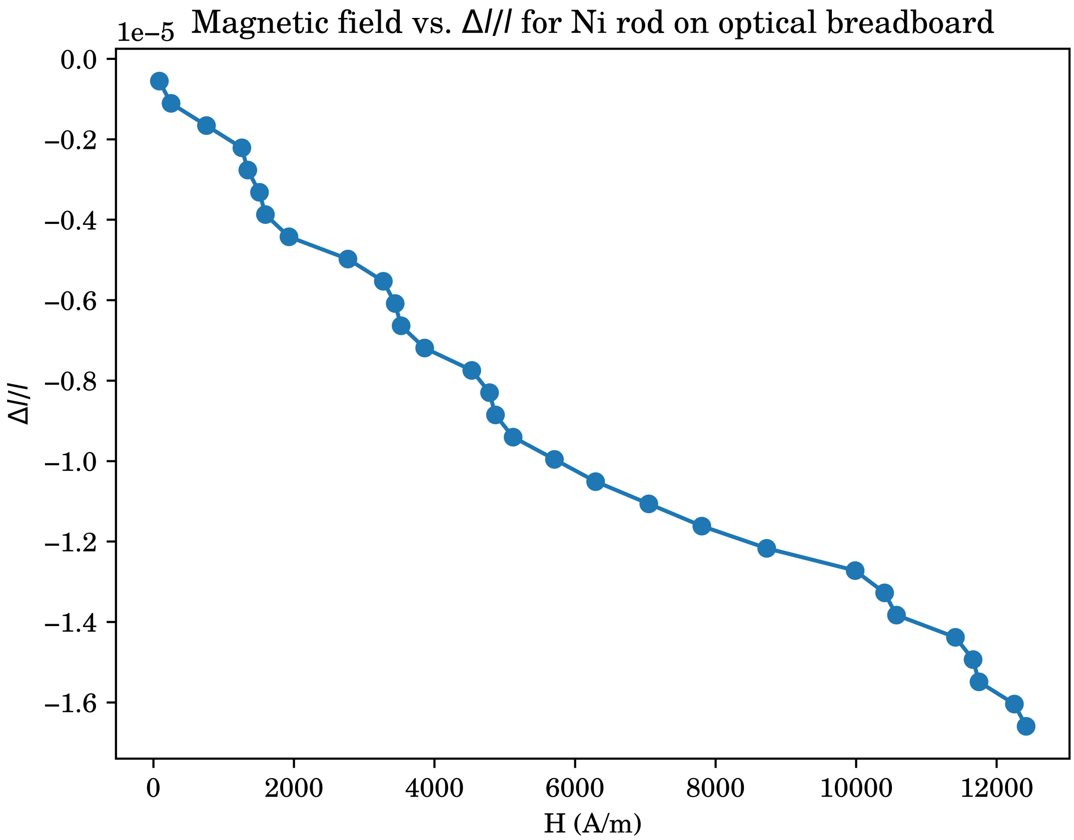

Figure 5.4: The variation in strain with applied magnetic field for Ni on the optical breadboard.

Chapter 6

Results and Discussion

Chapter 7

Summary and Conclusions

1.