Ferromagnetic Properties of Nickel & Co

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(Dated: September 15, 2020)

Abstract

We demonstrate the use of H-fields as a means to measure both the number of effective Bohr magnetons for Nickel (Ni)(p_f), and the coercivity of Cobalt (Co). Samples of Nickel and Cobalt were placed in a H-field of varying strength, and their ferromagnetic responses were measured to determine these values. p_f was found to be 0.4476 ± 0.1782, which agrees with accepted values. This confirms that this method is an accurate way to measure $M_{SAT,T=R}$. The coercivity of Cobalt was found to be $C_{Co} = 0.1396 \pm 0.0197$ kOe, which is significantly lower than the accepted value. This technique should be reproduced for Cobalt to verify whether this is discrepancy was inherent to the technique used, or an error within the experimental design.

I. INTRODUCTION

The magnetic properties of different elements/compounds is of great interest to many areas of technology, computer engineering, etc. And thus, Ferromagnetism is relevant to the study and production of many electro-mechanical devices such as electromagnets, computational components, generators, transformers and many more. It is used in these devices for is study of magnetic materials as well as the rate at which these materials can retain a magnetic field after being exposed to an external magnetic field.

In this lab, p_f for Nickel, and the coercivity of Cobalt will be measured. Both of these values have been measured before, and this experiment's purpose is to verify the accepted values. We are measuring these values by placing sample materials into a H-field which will vary in strength to determine the saturation magnetization at room temperature$M_{SAT,T=R}$, which we can then use in combination with specific known properties of the ferromagnetic solid to determine the Bohr magneton per atom (p_f) for Nickel. Using a similar measurement for Cobalt, we can determine its coercivity by finding the point at which its ferromagnetic response cancels the field around it. In this report, we describe the theory behind ferromagnetic materials, the properties of these materials, the experimental setup in which the H-field is created around our samples, and, lastly, describe our results and their validity.

II. THEORY

In order to study the magnetic properties in solids, both spin and orientation need to be taken into consideration. The magnetic properties depend on the orientation of the atoms and the individual magnetic field altered by the spin and angular momentum of the electron within each atom. Depending on the structure of the atom, these small microscopic fields emitted by the atoms can align and produce a non-zero macroscopic field in a vector-like fashion that is detectable with the right equipment.[1] The alignment of these microscopic domains occur in ferromagnetic materials when exposed to an external magnetic field. The magnetic properties of solids can be measure by submitting them to an external magnetic field and then measuring the resulting magnetization.[2]

The macroscopic field can be represented as vectors that align depending on the solid structure as well as the ambient temperature of the sample. Depending on the ferromagnet, such as Nickel, the solid will either behave with para-magnetic order or ferromagnetic order. The difference between these two is that para-magnetic order is slightly weaker and less uniform whereas in ferromagnetic order, the material will self-producing external field assuming perfect conditions. Unfortunately this only occurs and holds when the material held at extremely low temperatures. However, the switch of para-magnetic order and ferromagnetic order of a single material can be found using the Curie Temperature.

$$t = \frac{RoomTemperature}{C_{t,Ni}} \tag{1}$$

Using this equation, and substituting in the Curie Temperature of Nickel (in this case 627K) below to find a value of t. This equation is necessary to find the saturation magnetization for the solid at O Kelvin without actually reducing the temperature that low. Without the low temperature, the recently alligned magnetic fields from the electrons within the atom will return to a demagnetized state. Coercivity also comes into play when when talking about demagnetization. The coercivity of a material simply is a representation of how able or unable to resist the rate of demagnetization after being exposed to an external magnetic field. The higher the number, the less coercive the material and the faster the material will return to a demagnetized state. Low coercivity is often seen in ferromagnetic materials such as Nickel. Once all of the atoms have an aligned the microscopic domains creating a magnetization in the solid, saturation occurs. Saturation is when the magnetization of a solid, due to an external field reaches the maximum magnetization. On a graph this is shown by comparing Electromagnetic Units, and kilo-Oersteds. As the graph reaches the extremes, the curve will plato signaling saturation. Saturation can only occur in materials with low coercivity and when placed in a strong enough external field, like Nickel. To find an accurate account of saturation, the sample must be saddled or aligned properly with the external field. Otherwise the data will be skewed.[3] In order to find the Saturation point, this equation is used.

$$\frac{M_{SAT,T=R}}{M_{SAT,T=0}} = m \tag{2}$$

in conjunction with

$$m = \tanh \frac{m}{t} \tag{3}$$

This allows both the room temperature Saturation and the saturation of the material when at lower temperatures to be found synchronously. Small t as recognized in the second equation above relates to the constant found equation (1). The final step in understanding ferromagnetic properties is the Bohr magneton. The Bohr magneton is a constant that represents the magnetic moment of an individual electron within a solid.[4] This can be found using the equation

$$\mu_b = \frac{e\hbar}{2m_e} \tag{4}$$

This constant is necessary to solve for the final number of Bohr magentons per atom. Combining the O Kelvin temperature saturation with this constant

$$M_{SAT,T=0} = Np_f\mu_b \tag{5}$$

as well as the chemical make-up of the solid

$$N = \frac{num.of atoms}{kg} \tag{6}$$

solves for the Bohr magneton per atom, which will vary depending on the ferromagnetic material.

III. EXPERIMENTAL SETUP

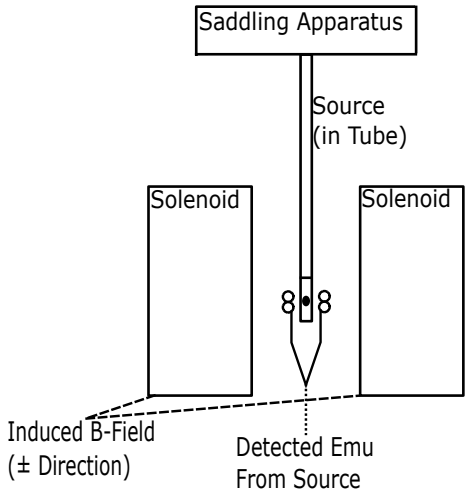

FIG. 1: Schematic of Experimental Setup. Shown (from a side-view) are the solenoids, sample source, saddling apparatus, and detector.

The samples of Nickel/ Cobalt were to be put into a magnetic field and then measured as its strength varied. This was done by aligning two solenoids with a Hall probe between them. The sample is held directly between the solenoids/ detectors by a saddling apparatus. The saddling apparatus is then used to accurately center the sample between the solenoids/ detectors. A schematic of the setup is shown in FIG. 1.

A current is then run through the solenoids to induce a magnetic field, which allows the ferromagnetic effects of the sample able to be measured with the detectors. The same is then done with the current running the opposite direction, as to make data for a magnetic field in the opposite direction.

For the measurement of Co, data taken must be taken once while strictly increasing the magnetic field strength through a range, and then once more while deceasing. This ensures that the sample would be have correct magnetic alignment throughout the data acquisition, which is crucial to the method of measuring coercivity being used.

IV. DATA AND ANALYSIS

The first set of data taken used a 0.2017 ±0.00005 g Nickel sample. The magnetic field strength was swept between ± 4 kOe with .25 kOe steps (additional measurements were taken between ± 0.75 kOe for accuracy). Measurements at these values are shown in FIG. 2.

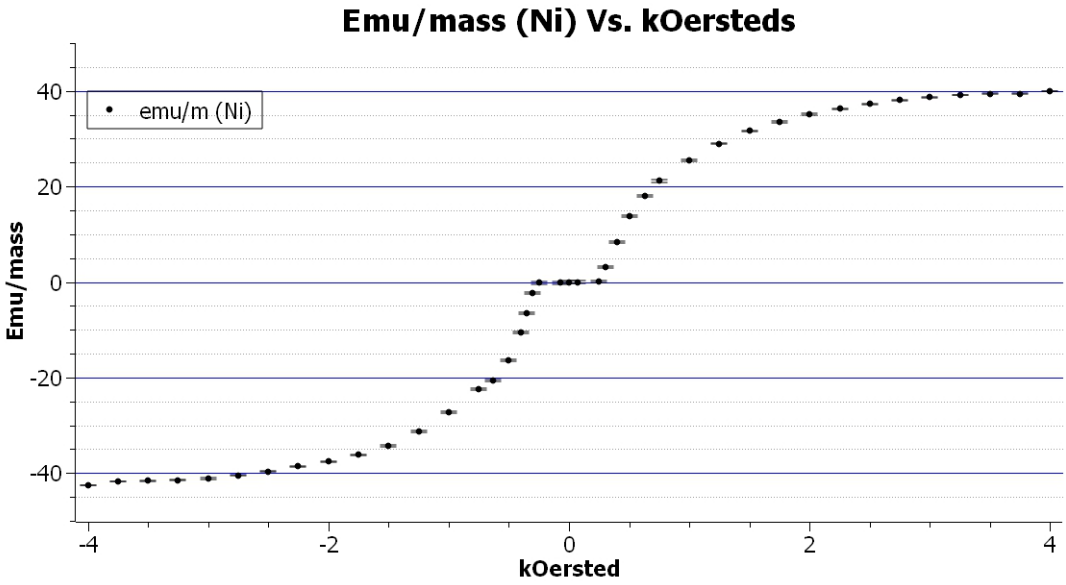

FIG. 2: Experimental data for Nickel.: Magnetic response per unit mass vs. magnetic field strength.

The data shows a strong trend, as well as distinguishable asymptotes. The graphical interpretation of $M_{SAT,T=R}$ would be the y-value of the horizontal asymptotes on the plot. To find this, the absolute value of emu/m was averaged between the left-most and right-most points to find that $M_{SAT,T=R}$= 41.25 ± 1.592 emu/g.

Using a room temperature of 293.15 K, and the Curie point of Nickel (627 K), eq. (1) is used to find t=0.4676. With this value used in eq. (3), m is then 0.9689. Eq. 2 and eq. 5 can also be combined as:

$$\frac{M_{SAT,T=R}}{mN\mu_b} = p_f \tag{7}$$

Using this, p_f can be measured as 0.4476 ± 0.1782. The accepted value for the number of Bohr magnetons per Nickel atom is 0.5, which this result agrees with.

The second set of data taken used a 0.1497 $\pm$0.00005 g Cobalt sample. The magnetic field strength was swept between $\pm$ 1 kOe with 0.1 kOe steps. First, the measurements started at -1 kOe, and swept positively, then the experiment was repeated going from 1 kOe down negatively. Measurements at these values (for both runs) are shown in FIG. 3.

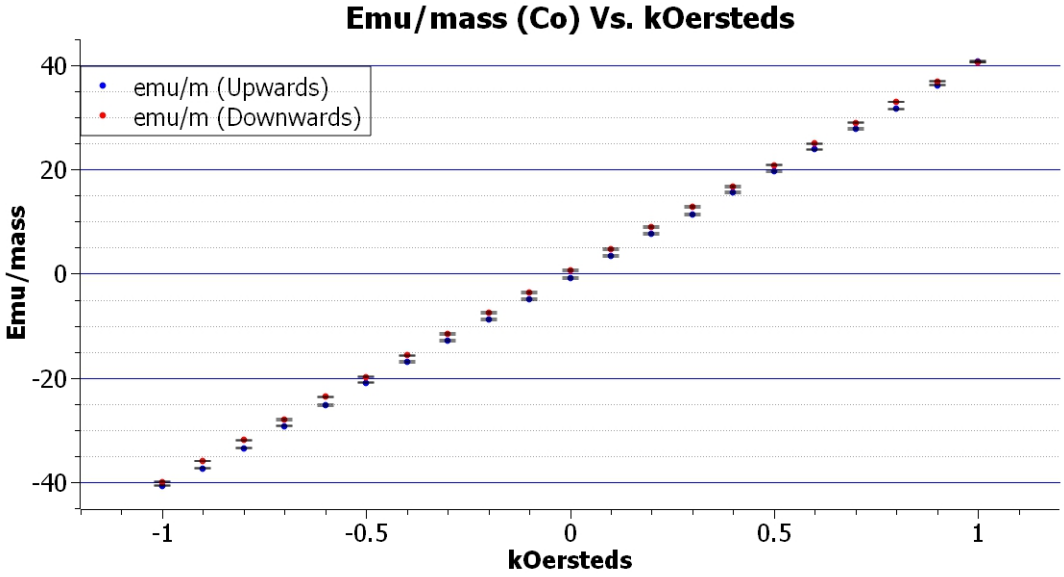

FIG. 3: Experimental data for Cobalt: Magnetic response per unit mass vs. magnetic field strength. Increasing magnetic field strength (blue with error bars,) compared to decreasing magnetic field strength (red with error bars), both plotted against magnetic field strength.

The data shows a distinct difference between the first and second run. The measurement of coercivity for Cobalt depends on the intersection of both data sets with the x axis (the point where there is no magnetic field generated from the sample). To find this, a polynomial regression was fit to each data set, and the x-intercept was found for each, along with their propagated error. These values were: $C_{up} = -0.1535 \pm 0.0149$, and $C_{down} = 0.1256 \pm 0.0092$ kOe. Averaging these values gives the value for the coercivity of Cobalt at room temperature as $C_{Co} = 0.1396 \pm 0.0197$ kOe. The accepted range of values for this measurement is .8-72 kOe, and so our value was unsatisfactory.

For both the measurement taken for Nickel and for Cobalt, there was minimal error. The error on the measurement was between 0.015 and 0.045 emu, which averaged as about a 1% error for each point. For the measurement of mass, there was a scale error of 0.00005, which is also minuscule. This resulted in a propagated uncertainty that was very narrow for the final values of p_f (Ni) and coercivity (Co).

One anomaly with the data taken was for Ni's emu vs kOe measurement. The region of the graph close to y=o flattens out abruptly, while it should follow the trend. The source of this error is unknown, but is ultimately inconsequential, as the measurement's purpose was to find $\lim_{x\to\pm\infty} f(H)$, so that range of values has little to no effect on the findings. The group is confident about the measurement of p_f for nickel.

The experiment done to find the coercivity of Cobalt had obvious faults, however. While it is inconclusive what exactly lead the measurement astray, there are two possibilities which seem likely. The first could be that the Cobalt was not properly saddled in the setup. When switching from Nickel to Cobalt, the sample had to be re-saddled in order to show correct results. The sample was re-saddled, but it is very possible that the source was off in 1 or more directions. This would have lead the sample's ferromagnetic response to be measured less effectively, which could explain the discrepancy in the found value and the expected. Another possibility is that the sample was not started close enough to saturation. The magnetization saturation for Cobalt is quite high, so the experiment did not attempt to start the runs at saturation. Instead, the experiment started at an arbitrary field level. In this experiment, ± 1 kOe was used. It is very possible that this is not high enough, which would have not saturated the sample enough for the graph to accurately display coercivity. Even though there was very minimal error in propagation and measurement, the data showed a coercivity that was to small to be acceptable, and the group is not confident in this result.

V. CONCLUSION

In conclusion, we have demonstrated the use of H-fields to measure the number of effective Bohr magnetons for Nickel(p_f), and the coercivity of Cobalt. We found p_f to be 0.4476 ± 0.1782. This is within error of the accepted value, and thus verifies it. There was minimal

error in the measurement and analysis of this value, and so we have a high confidence level. We found $C_{Co} = 0.1396 \pm 0.0197$ kOe, which was not within error of the acceptable range of 0.8-72 kOe. There was minimal error in the measurement and analysis of this value, so we believe that there was a problem with the experiment's execution or design. We were not able to definitively pinpoint this discrepancy on one factor, so another experiment should be done. To further the study of ferromagnetism, especially for Cobalt, an additional run of the initial experiment is required. Using a different maximum/minimum H-field for the runs of Cobalt, the experiment would be re-run to test the hypothesis behind the Cobalt coercivity error. This will allow both the reasoning behind the initial error to come to light as well as an accurate measurement of Cobalt coercivity to be recorded. Our findings successfully verified the value for the p_f, but deviated from the accepted value of Cobalt's coercivity.

VI. BIBLIOGRAPHY

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