<u>THE STRENGTH OF AN ELECTROMAGNET.</u>

Christopher Hampton

Physics GCSE coursework

Class 11L

Introduction.

The object of this project is to plan and carry out a simple, fair, controlled and safe experiment to determine the factors that control the strength of an electromagnet. I know from previous years work that the strength of an electromagnet is determined by the number of coils of wire used, by the amount of current fed through the wires and that by putting a piece of iron or steel in the middle of the coil that the strength is increased.

In this project I will investigate the pattern by which changing the amount of current flowing through the coil will change the strength of the electromagnet. I will need to make the experiment fair, simple, reproducible and safe. I will use the ability of an electromagnet to pick up a metal object as the measure of its strength. A panel pin is a small nail that is made of metal and so will be attracted to a magnet. The number of panel pins the electromagnet could lift is therefore a measure of magnetic strength and as panel pins are small it would be better to weigh the amount lifted, although it would also be possible to count the number lifted. Having determined my strength measurement I need to keep all other factors the same, except the one I wish to investigate in the experiments.

Scientific background.

When a current flows along a wire, it induced a magnetic field around the wire. The magnetic field occurs at a right angle to the direction in which the current flows. The magnetic field can be made visible by using iron-filings on a piece of paper, with the wire going through he paper. When a current flows along the wire, circles of magnetic field can be seen on the paper, made out of iron-filings. If you wind more than 1 turn of wire, then the effect is increased. Two turns give twice the magnetic field of 1 turn and so on. Fifty turns gives quite a strong magnetic field, but only as long as a current is flowing in the wire.

As wire is made into a coil then the strength of the magnetic field is increased. This is the principal that is used to make an electromagnet. The effect can be further amplified by putting a piece of metal that can be magnetized (iron, nickel, cobalt or steel) in the middle of the coil.

Magnets can be formed from certain metals (listed above). These metals have a crystal or domain structure. Magnets are made up of hundreds of thousands of domains. A domain is about1/1000th mm long and would consist of about 10 thousand million atoms. A domain is similar to a little crystal of iron. In a non-magnetized piece of iron the domains point in random directions, and there is overall no magnetic field.

A non-magnetized piece of iron would look like this:

You can see that all the domains point in different directions. Using the current in the coils, you would be able to re-align some or even most of the domains depending on how rigid is the internal structure of the metal or alloy. If an external current, and hence magnetic field, is applied to a metal core the result will be that more of the domains would be lined up and pointing in the same direction. The iron core would then be a magnet.

An iron core acting as a magnet looks like this:

When you switch off the current, the domains would no longer be under the influence of an external magnetic field and the n the domains would begin to return to their original random alignment, which would result in the loss of the magnetic effect. Once the domain structure had returned to a completely random formation there would be no magnetic effect left.

Preliminary Experiment.

For my preliminary experiment I decided to find out which material is the more appropriate to use as the core in the electromagnet for my subsequent experiments. I tested an iron and a steel coil. I know that without a metallic Core the electromagnet would be too weak to use in an experiment. The metal core acts as an amplifier of the magnet and increases its strength.

Apparatus:
Wire
Iron core
Steel core
5V power supply
Panel pins

Method:
First of all I found an iron and steel core of the same length, diameter and size. Then I took the same length and diameter wire for both cores and wrapped it around the cores a different number of times; 20 times, 30 times, 40 times and 50 times. For each number of coils I placed the end of the core in a pile of panel pins and turned on the power. I then lifted the electromagnet out and turned off the power. Most of the pins fell off, but some stayed on the core. First I counted how many pins stayed on the core when the power was off and then I counted how many pins had fallen off. By adding the two figures I could find out the total number of pins lifted by the electromagnet.

Results
The results are as follows.

	Iron core		Steel core	
Number of coils	Number of pins, Current on	Number of pins, Current off	Number of pins, Current on	Number of pins, Current off
20	85	9	49	25
30	101	10	63	31
40	188	14	142	47
50	247	17	201	52

From these results you can clearly see that when iron is used as the core material a stronger electromagnet results when there is a current flowing in the circuit. A steel core results in a less strong electromagnet. The iron core does stay magnetized after the current is switched off but to a much lesser degree that a steel core. Thus a steel core results in a weaker electromagnet that stays magnetized to a much greater extent after the current has been switched off. The reason for this is that the domains in iron are more freely mobile than in the steel alloy. In iron when the current flows all the domains line up and increase the power of the magnet a lot, but then they are free to return to an almost random pattern when the current stops flowing. In the steel core it is more difficult for the domains to line up with the current, so the amplification of the magnetic power is less, but when the current is switched off it is more difficult for the domains to move and many of them remain lined up, leaving an residual magnetic effect that retains more of the panel pins. This suggests iron is better for the core of an electromagnet, while steel would be a better material for making a permanent bar magnet. Looking at my results I have decided to use an iron core in my further investigation of electromagnets.

Factors that affect an electromagnet.

The following factors affect the strength of an electromagnet:
Current in the circuit
Number of coils
Size and type of core
Type and diameter of wire in the circuit
Temperature of the apparatus

Therefore to carry out a fair experiment only one factor can be varied at one time. In my experiment I will vary the current, while keeping the wire, the number of coils, the core and the temperature the same.

My prediction.

I predict that the relationship between the current and the power of the electromagnet will be linear. I think that if all other variables are kept the same then if the current is doubled then the strength of the magnet will double. I believe this will happened because I think there is a direct linear relationship between the strength of an electromagnet and the currant. So if the currant increases the strength will increase by the same amount.

Methods.

Apparatus used in the experiment:
5 volt power pack
Variable resistor to vary the current in the circuit
Ammeter to measure current
Coil of wire to make electromagnet
Piece of iron and similar sized piece of steel to use as core
200g of panel pins on a paper towel for the magnet to pick up
Balance calibrated in grams to weigh the panel pins

The power pack, variable resistor, ammeter and the coil of the electromagnet were connected in series to make an electrical circuit. We used the iron core in the electromagnet, as we had determined in the preliminary experiment that this was better than the steel core, and we used a many turns of wire as possible on the core. The most turns of the wire we could fit on the iron core were 162 turns. The temperature, type and thickness of the wire and the number of turns were kept the same for all the experiments. The only factor that was varied was the amount of current flowing through the circuit. This was measured using the ammeter and controlled using the variable resistor. The amount of nails lifted was the outcome measure we recorded using the panel pins and the balance. The current was varied to 0.1, 0.3, 0.5, 0.7, 0.9, 1.1, and 1.3 amps and the weight of panel pins lifted at each current was recorded. The experiment was carried out three times so that three data points were recorded for each current point and these recordings could then be compared and averaged to give the experiment greater precision and accuracy. It also allowed us to see how reproducible the experiment was. If preformed properly, the results of all three sets of experiments should be the same.

Circuit Diagram.

Results.

Table of results:

Current In Amps	Mass of panel pins lifted (grams) Experiment 1	Mass of panel pins lifted (grams) Experiment 2	Mass of panel pins lifted (grams) Experiment 3
0.1	1.23	1.14	1.31
0.3	1.89	1.83	1.96
0.5	2.31	2.12	2.46
0.7	3.01	2.99	3.12
0.9	3.84	3.69	4.00
1.1	4.22	4.12	4.42
1.3	4.97	3.21	5.21

From the above table and the graphs it can be seen that as the current flowing through the wire coil that makes the electromagnet increases so the strength of the magnet as measured by the number of panel pins lifted increases. The relationship over this range of currents is linear, that is the graph gives a straight line. I interpret this a showing that the relationship between strength and current is directly proportional.

It can also be seen that the reproducibility of the experiment is strong. There is little variation between the individual recordings for each of the experiments at each current strength. Thus I think that the three readings can be averaged.

There is one exception to this. For experiment 2 current 1.3 amps the reading is anomalous. Not only is this reading much less than the reading for 1.1 amps, and I would expect it to be higher, but it is also out of line with the readings for this current strength in experiments 1 and 3. I have therefore excluded it from the table of average results.

Current in Amps	Average mass of panel pins lifted (grams)
0.1	1.23
0.3	1.89
0.5	2.29
0.7	3.04
0.9	3.84
1.1	4.25
1.3	5.09

Analysis.

The results of this experiment show that for the voltage and current range that I tested in the experiment, there was a direct linear relationship between current and magnetic strength. This is shown by the straight-line relationship between weight of panel pins lifted and current in the coil.

The slope of the line is not however at 45 degrees, so my prediction that doubling the current would double the strength of the electromagnet is not correct. If you double the current the strength increases by only ???

There is one anomalous result, at current 1.3 amps in experiment 2. The result is less than I would expect. This could be for any of the following reasons: the variable resistor could have jumped and been delivering the wrong current, there could have been a loose connection in the circuit, or the mass of panel pins weighted could have been wrong, some having fallen off prior to weighing. This droppage problem prior to weighing is a weakness of the experimental model.

Evaluation.

Overall this experiment went well. The experiment fitted the design brief by being safe, simple, controlled and reproducible. There was little difference between the three times I repeated the experiment. The hypothesis that as the current increases so the strength of the electromagnet also predicted, as the increase in the power of the magnet was not exactly increases is true, and the relationship is linear, but not exactly what I proportional to the increase in current in the wire.

The experiment could be improved by taking more readings at each point. This would increase the accuracy of the average readings. Also you could use a new set of panel pins for each experiment so that they do not get magnetized and so give a slight over-reading. It would also be possible to completely demagnetize the iron core between each experiment, because although the residual magnetism is less with iron than steel, there is still some residual effect that will carry over from one reading to the next. The temperature control was not prefect. The magnet and coil tended to warm up when the power was on and then cool down when it was turned off. It would have been better if the temperature was constant throughout. Finally you could use a different type of weight such as iron filings, to prevent dropping of the pins before weighing them. Iron filings weigh less per individual piece so may give a more accurate result, although they are difficult to use because they are so light and may be worse. Another preliminary experiment would answer this question.

Varying the number of coils, while keeping the current the same, could extend the experiment. Also the relationship could be tested at greater currents to see if the relationship hold true as the power is increased. Finally you could keep the current and number of coils the same and vary the size of the iron core.