Investigating the effect of passing current on the oscillation period of an electric circuit placed in magnetic field

TED Ankara College Foundation High School

International Baccalaureate

Physics Extended Essay

May 2015

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Word Count: 3541

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ABSTRACT

This essay, intending to demonstrate the real life application of right hand rule, is formed by combining magnetic field and electric circuit. The experiment was designed to answer the major question of "How does changing the current passing through an electric circuit, which is placed between two square magnets, affect the period of oscillation of the resistant steel wire?". After the required set-up was constituted by setting up an electric circuit and magnetic field, the investigation was carried out in two parts. In part 1, the current was set in a specific direction to create an upwards magnetic force acting on the resistant steel wire. The current was altered until the upwards magnetic force cancelled out the downward gravitational force. When the two opposite forces were equal, the current was measured and recorded. Necessary calculations were made to find the value of magnetic field $\vec{B}$. In part 2, the direction of current was reversed and a downward magnetic force was obtained, strengthening the downward gravitational force. For nine different values of passing current, the resistant steel wire was disturbed from its equilibrium position and made to oscillate as a simple pendulum. The time the steel wire took to complete three laps was measured for each of the nine values of passing current and periods of oscillation were determined. Later, several formulas and equations were used to calculate theoretical periods of oscillation. Finally, the measured and theoretical values were analysed and compared. The relation between the current passing through an electric circuit and the period of oscillation of the resistant steel wire was determined. Both measured and theoretical periods of oscillation turned out to be resembling a similar general pattern. In conclusion, it was found that the period of oscillation of steel wire decreases with increased current passing through the circuit.

Word Count: 300

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1. INTRODUCTION

Aim of the Study:

Magnets are commonly used in daily life, even though they remain unnoticed. That is to say, magnetism holds a vast part of everyday life as it appears in television screens, speakers, electrical motors and even in refrigerator doors. Similarly, the topic of magnetism is really important in high school physics curriculum. The relation between electrical charges and magnetism is taught in detail sooner or later during high school. However, as magnetism is an abstract subject, understanding the real-life usage of magnets is really though. Therefore, in this project, the behavior of an electric circuit, which is placed between two magnets, will be investigated. Although the initial aim of this investigation is to perceive the real life applications of magnetism, the main objective of this essay evolved into finding out and representing the consequences of changing the current passing through an electric circuit inside a magnetic field. The results will be analysed and further evaluations will be made in order to express the reliability of the outcomes.

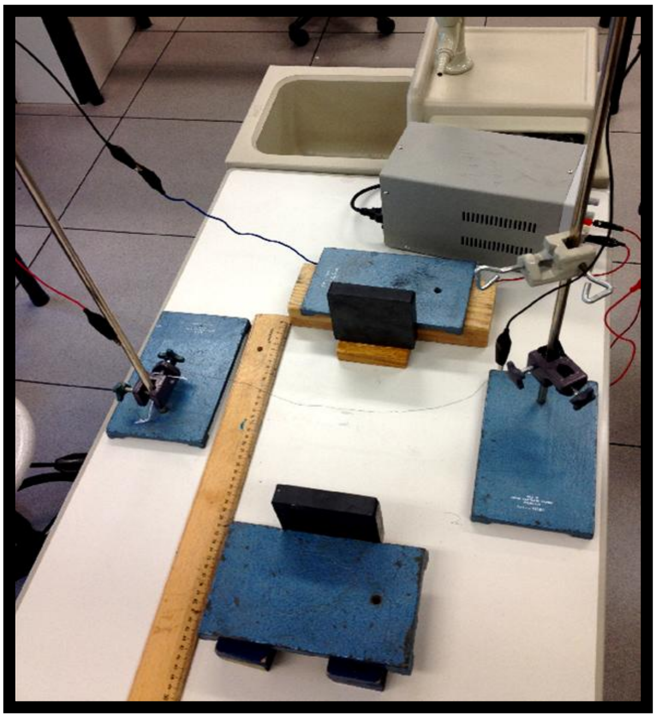


Figure 1: The setup of the experiment.

Background Information:

Magnetic field, a vectoral quantity, is the magnetic influence produced by magnetic materials and electric currents. It is symbolized with the letter "B" and its unit in SI is tesla (T). Magnetic field is usually defined according to the Lorentz force law [1]. However, magnetic field can also be determined by force equilibrium. In order to use force equilibrium to determine the magnetic field, the direction of magnetic force must be known. The direction of magnetic force on any current-carrying wire is determined by using the "right hand rule". Right hand rule is a common method to identify directions of vectors in three dimensional operations. The vectors showing the directions of the current passing through a wire, the magnetic field and the magnetic force is found by right hand rule.

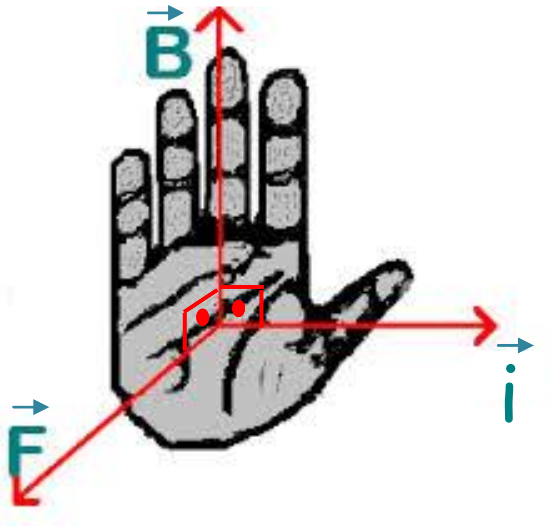


Figure 2: Figure representing the right hand rule and the directions of vectors that the rule identifies, where $\vec{B}$ is magnetic field, $\vec{F}$ is magnetic force and $\vec{\imath}$ is current. [2]

Oscillation means a continuous variation from the equilibrium position. The disturbance of any object from equilibrium will result in oscillation. Unless the friction force of surroundings is abolished, oscillation will eventually be damped and the oscillating object will return to equilibrium position. However, a frictionless medium does not exist naturally and, thus, calculations are usually made according to the assumption that no damping occurs during an oscillation. Period of oscillation is the term used to define the time taken by the oscillating object to complete one full lap of oscillation.

Research Question: How does changing the current passing through an electric circuit, which is placed between two square magnets, affect the period of oscillation of the resistant steel wire?

Hypothesis: The period of oscillation of resistant steel wire will decrease with increased current passing through the electric circuit.

The hypothesis above is formed by taking several scientific formulas into consideration. Initially the formula of $\overrightarrow{F_m} = \vec{B}il$ [3] can be used to indicate that when the current *i* is increased, the magnetic force $\overrightarrow{F_m}$ (which is added up with gravitational force, producing downwards net force acting on the resistant steel wire) is increased. Net force and acceleration are directly proportional to each other so increased net force causes increased acceleration ($\vec{a}$) which can be inferred from the formula of $\overrightarrow{F_{net}} = m\vec{a}$. Therefore, acceleration of the wire will be greater and the period of oscillation (T) shorter in turn, as period and acceleration are inversely proportional:

$$T = 2\pi\sqrt{\frac{l}{\vec{a}}} \text{ [4]}$$

As a result, increasing the current *i* will lead to decreased period of oscillation.

Variables:

- Independent Variable

The current passing through the electric circuit, which is placed inside the magnetic field. (A/±0.01)

- Dependent Variable

The period of oscillation of the resistant wire as a simple pendulum. (s/±0.01)

- Controlled Variables

For collecting accurate data, some variables are kept constant. The type of resistant wire, steel (FeCrAl), is kept constant throughout the study because a different type of resistance would have different resistivity, therefore, it would change the current. The same length of the steel wire is used in all trials since changing the length would cause the current to differ by altering the resistance. Similarly, the number of crocodile wires, eight, and the length of crocodile wires, 47.7cm, remained the same to ensure that total resistance of electric circuit is not affected from them. Besides, the distance between the magnet and the steel wire in both sides is equal to16cm, allowing the magnetic field to apply equally from both sides. Again, in order to stabilize the location of steel wire between magnets, the distance between laboratory stands is kept constant. Thus, a regular magnetic field is maintained. The angle of disturbance is also a controlled variable, since variation of the angle would change the period of the oscillation as stronger or weaker magnetic field would apply on the wire at different distances. Also, same power supply and chronometer are used during all measurements to eliminate the chance of deviation caused by the change in equipments. Lastly, an air-conditioner is used to stabilize the room temperature at 25°C and control the air circulation in the room, in order to make sure that air friction force would damp the oscillation equally.

Experimental Set-Up and Materials:

The following materials listed below are used in this investigation to prepare the needed experimental set-up.

- (2x) Square magnets (10x10cm^2)
- (2x) Laboratory stands
- Electric resistance steel wire (FeCrAl) (60cm)
- (4x) Wooden stabilizers
- (2x) Iron stabilizers
- TT T-ECHNI-C DC Power supply

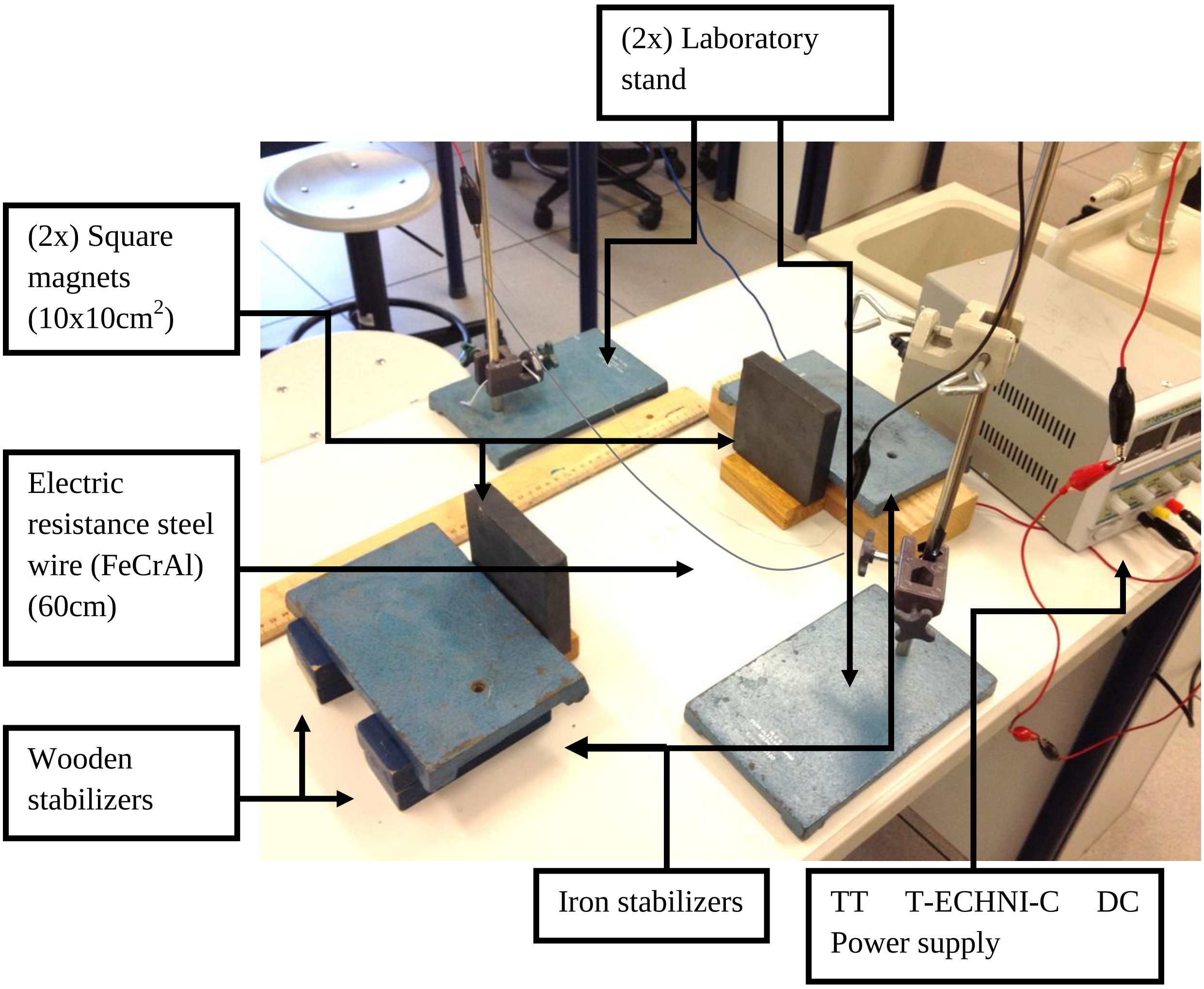


Diagram 1: Diagram representing the real experimental set-up along with the indication of used materials and equipments.

Additional materials and equipments not shown in the *Diagram 1* are as following:

- (8x) Crocodile wire (10.64g/47.7cm)
- Chronometer (±0.01s)
- Ruler (100cm/±0.01cm)

In order to confirm that the power supply functions properly and measures accurately, before the actual experiment, an ampermeter and a voltmeter are borrowed to check whether the values of current and voltage shown on the power supply are mathcing with the values shown on the ampermeter and the voltmeter.

Method:

The experimental set-up is formed by following several steps. First, an electric circuit is constructed. A connection between the power supply and one of the edges of the resistant steel wire is maintained with four crocodile wires tied end-to-end. The other edge of the steel wire is also connected to the power supply with the other four crocodile wires. The resistant steel wire is hanged down, by hanging the crocodile wires from the two parallel laboratory stands. Two identical magnets are placed 16cm apart both at the left and right sides of the steel wire.

The experiment is carried out in two parts.

In the first part, the current flow is set-up in order to maintain a magnetic force acting upwards on the steel wire. Then, by slowly increasing the current passing from the circuit, the *exact* moment when the magnetic force cancels out the gravitational force and the net force acting on the steel wire is zero is determined. In this way, $\vec{B}$ between magnets is found from the force equilibrium.

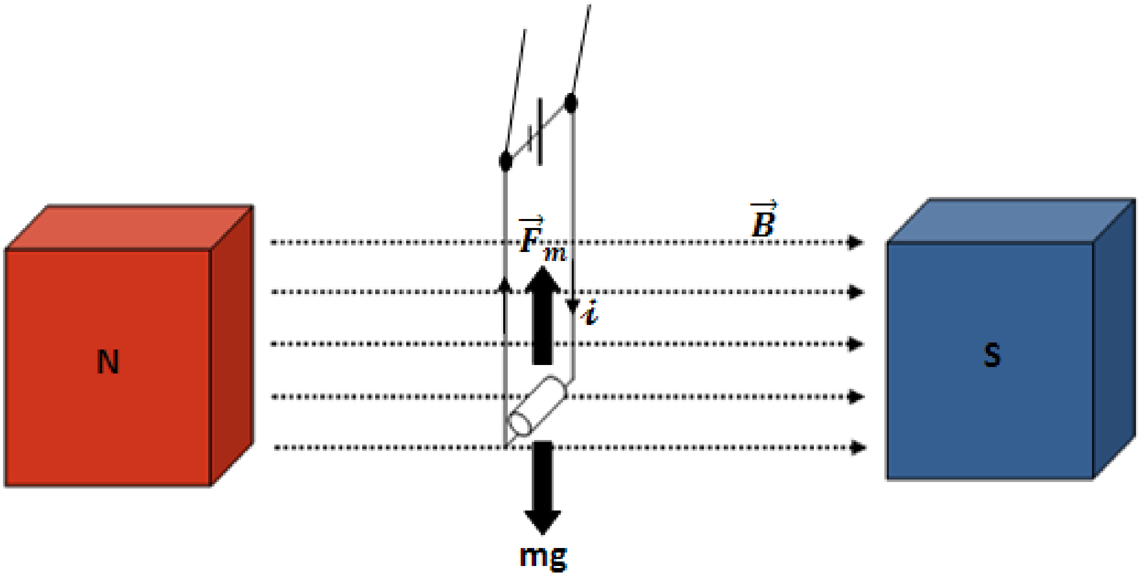


Diagram 2: Diagram representing the illustration of the experimental set-up and the first part of the experiment.

In the second part of the experiment, the ends of the crocodile wires connected to the power supply is switched, creating an reversed current in the circuit. The steel wire is disturbed from equilibrium position with a certain angle and is made to do a periodic oscillation. Then, with nine different values of passing current, the time taken for three complete laps by the wire is measured.

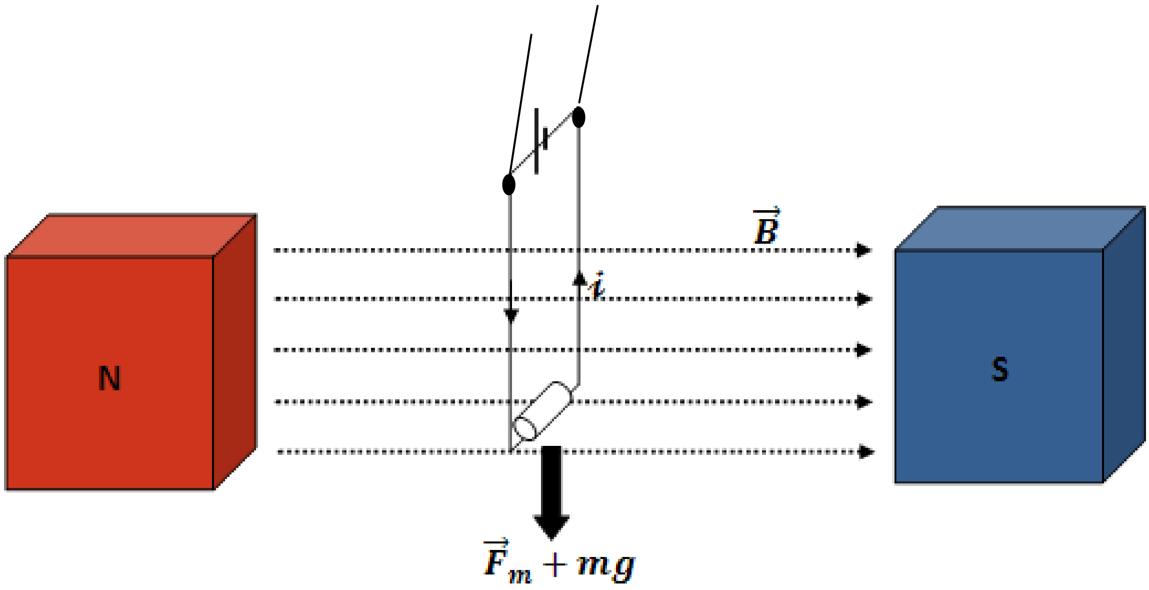


Diagram 3: Diagram representing the illustration of the experimental set-up and the second part of the experiment.

2. DATA ANALYSIS

The following data were collected while performing the experiment. Resistant steel wire in the circuit has a mass of 0.481±0.001 grams and a length of 57.2±0.1 cm. The circuit setup includes 8 crocodile wires in total, each weighing 10.644±0.001 grams and are 47.7±0.1 cm long.

Part 1

First, the direction of current is set in order to make the magnetic force act upwards on the steel wire. While the magnetic force is acting upwards, gravitational force acts downwards. At the moment when these forces cancel each other, the current is 1.88±0.01 A and the voltage is 10.7±0.1 V.

Based on the force equilibrium, the following calculations are made. Fort he calculation of the gravitational force, the weight of 6 crocodile wires is included along with the weight of the steel wire because they are hanging down freely from the laboratory stands.

Gravitational acceleration (g) = 9.81 ms^{-1} [5]

Total mass hanging: $(6\ x\ 10.644) + (0.481) =\ 64.345$ g

1000 g = 1 kg

100 cm = 1 m

64.345 g = 64.345 x 10^{-3}kg

57.2 cm = 57.2 x 10^{-2} m

$$\overrightarrow{F_{net}} = 0$$

$$mg = \vec{B}il$$

$$(64.345\ x\ 10^{-3})(9.81) = \vec{B}(1.88)(57.2\ x\ 10^{-2})$$

$$\vec{B} = 5.870 \text{ x } 10^{-1}\ T$$

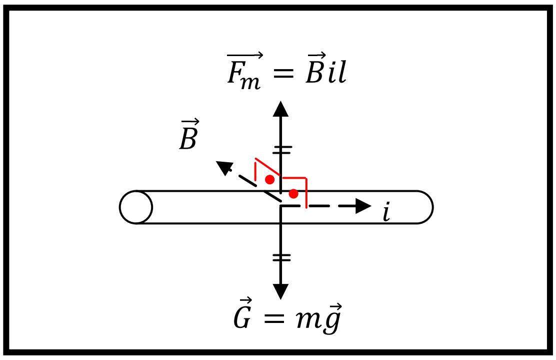


Diagram 4: Diagram representing the free-body diagram of part 1.

Uncertainty Calculations for $\overrightarrow{B}$:

In order to find the uncertainty of $\overrightarrow{B}$, uncertainties of all variables which are included in the calculations are determined.

$\Delta m=(6x0.001)+(0.001)=0.007$ kg

$\Delta i=0.01$ A

$\Delta l=0.1$ m

Absolute uncertainties are converted into percentage uncertainties for calculating $\Delta\overrightarrow{B}$.

$\Delta m\% = \frac{0.007\ x\ 100}{64.345\ x\ 10^{-3}} = 10.879\%$ kg

$\Delta i\% = \frac{0.01\ x\ 100}{1.88} = 0.532\%$ A

$\Delta l\% = \frac{0.1\ x\ 100}{57.2\ x\ 10^{-2}} = 17.482\%$ m

$\overrightarrow{B} = \frac{m.g}{i.l} \longrightarrow \Delta\overrightarrow{B} = \Delta m\% + \Delta i\% + \Delta l\%$

$\Delta\overrightarrow{B} = 10.879 + 0.532 + 17.482$

$\Delta\overrightarrow{B} = 28.893\%$ T

$\overrightarrow{B} = (5.870 \text{ x } 10^{-1}) \pm (28.893\%)\ T$

Part 2

In this part of the experiment, the direction of current is reversed. Therefore, both the magnetic force and the gravitational force on the steel wire are acting downwards. The time taken by the steel wire to complete three laps is detected as the current passing from the electric circuit is changed.

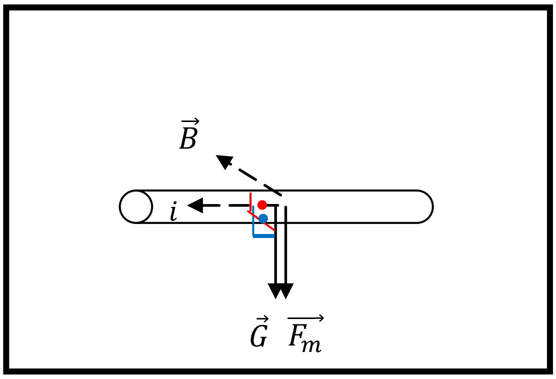


Diagram 5: Diagram representing the free-body diagram of part 2.

Passing Current (*i*) (A/±0.01)	**Voltage (V) (V/±0.1)**	**Time (t) (s/±0.01)**				
		t_1	t_2	t_3	t_4	t_5
0.50	2.7	5.53	4.97	5.22	5.34	5.47
0.75	4.2	5.10	5.17	4.88	5.03	4.96
1.00	5.7	4.75	4.94	4.63	4.86	4.81
1.25	7.1	4.63	4.57	4.53	4.72	4.69
1.50	8.5	4.35	4.68	4.16	4.55	4.41
1.75	10.1	4.13	4.09	4.07	4.14	4.20
2.00	11.6	3.97	3.94	4.00	3.99	4.04
2.25	12.2	3.91	3.86	3.94	3.96	3.88
2.50	14.7	3.59	3.72	3.87	3.64	3.67

Table 1: The table shows collected data of passing current, voltage and the time taken by the electric circuit to complete three laps of the steel wire, which is observed 5 times for each different value of current. Uncertainties of passing current and voltage come from the smallest unit of power supply, while uncertainty of time comes from the smallest unit of digital chronometer.

- For 2.50 A current:

$t_{average}$=$\frac{3.59\ +\ 3.72\ +\ 3.87+3.64+3.67}{5}$= 3.70 s

$\Delta t_{average}$= $\frac{t_{max}-t_{min}}{2}$ = $\frac{3.87-3.59}{2}$ = 0.14 s

Because the calculated value of $t_{average}$ is for three laps, $t_{average}$ should be divided by three to find the period of oscillation.

T= $\frac{3.70}{3}$= 1.23±0.14 s $\longrightarrow$ ΔT= $\frac{0.14}{1.23}x100$= 11.38% s

Passing Current (*i*) (A/±0.01)	**Voltage (V) (V/±0.1)**	**Period of Oscillation (T) (s)**	**Percentage Uncertainty of Period (Δ(s)**
0.50	2.7	1.77	15.82%
0.75	4.2	1.68	8.63%
1.00	5.7	1.60	9.69%
1.25	7.1	1.54	6.17%
1.50	8.5	1.48	17.57%
1.75	10.1	1.38	4.71%
2.00	11.6	1.33	3.76%
2.25	12.2	1.30	3.85%
2.50	14.7	1.23	11.38%

Table 2: The calculated values of period of oscillation of the circuit and percentage uncertainties of period values.

Since the forces acting on the steel wire are both downwards, the net force is not zero. Thus, the acceleration of the wire has changed. In order to determine the new acceleration, force equilibrium is used.

$\overrightarrow{F_{net}} = m\vec{a}$

$mg + \vec{B}il = m\vec{a}$

$(64.345\ x\ 10^{-3})(9.81) + (5.870\ x\ 10^{-1})(0.50)(57.2\ x\ 10^{-2}) = (64.345\ x\ 10^{-3})\vec{a}$

$\vec{a} = 12.419\ m/s^2$

Uncertainty Calculations for $\vec{a}$:

$\Delta\vec{\imath}\% = \frac{0.01\ x\ 100}{0.50}$ = 2.000 A

$\Delta\overrightarrow{F_m}\% = \Delta\vec{B}\%+\Delta\vec{\imath}\%+\Delta\vec{l}\%$ = 28.893+2.000+17.482 = 48.375% N

$\Delta\overrightarrow{F_m} = \frac{0.168\ x\ 48.375}{100}$ = 0.079 N

Δm=0.007 kg

$\Delta(mg + \overrightarrow{F_m})$ = 0.086 N

$\Delta(mg + \overrightarrow{F_m})\% = \frac{0.086\ x\ 100}{0.232}$ = 37.069% N

$\vec{a} = \frac{mg+\overrightarrow{F_m}}{m} \longrightarrow \Delta\vec{a} = \Delta(mg + \overrightarrow{F_m})\% + \Delta m\%$

$\Delta\vec{a}$ = 37.069 + 0.007

$\Delta\vec{a}$ = 37.076% m/s^2

$\vec{a}$ = 12.419 ± 37.076% m/s^2

Calculation of the Theoretical Values of Period of Oscillation:

$T = 2\pi\sqrt{\frac{L}{\vec{a}}}$ is the general formula for determining period of pendulum T (s) where L (m) is the length of rope and a is acceleration (m/s^2). According to the acceleration calculated above, the period of the pendulum is determined.

$$T = 2(3.14)\sqrt{\frac{(57.2\ x\ 10^{-2})}{12.419}}$$

$$T = 1.3478\ s$$

Uncertainty Calculations for T:

$\Delta\left(\frac{L}{\vec{a}}\right)\% = \Delta l\% + \Delta\vec{a}\% = 17.482 + 37.076 = 54.558\%\ s^2$

$\Delta\sqrt{\frac{L}{\vec{a}}}\ \% = \frac{1}{2}\ x\ 54.558 = 27.279\%\ s$

$\Delta T\% = 27.279\%\ s$

$$T = 1.3478\ \pm 27.279\%\ s$$

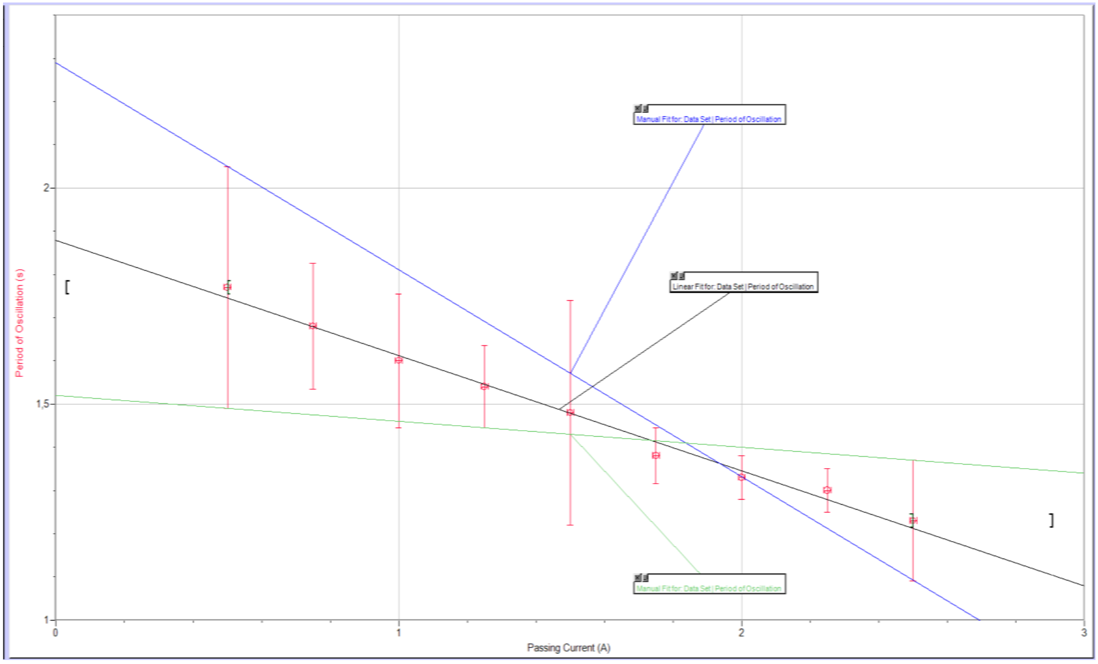
Uncertainty calculations of theoretical period of oscillation are made for each value of passing current.

Passing Current (*i*) (A/±0.01)	**Theoretical Period of Oscillation (T) (s)**	**Percentage Uncertainty of Theoretical Period of Oscillation (ΔT%) (s)**
0.50	1.348	27.279%
0.75	1.282	15.936%
1.00	1.225	17.326%
1.25	1.175	18.419%
1.50	1.131	19.492%
1.75	1.091	20.350%
2.00	1.056	21.098%
2.25	1.023	21.730%
2.50	0.993	22.314%

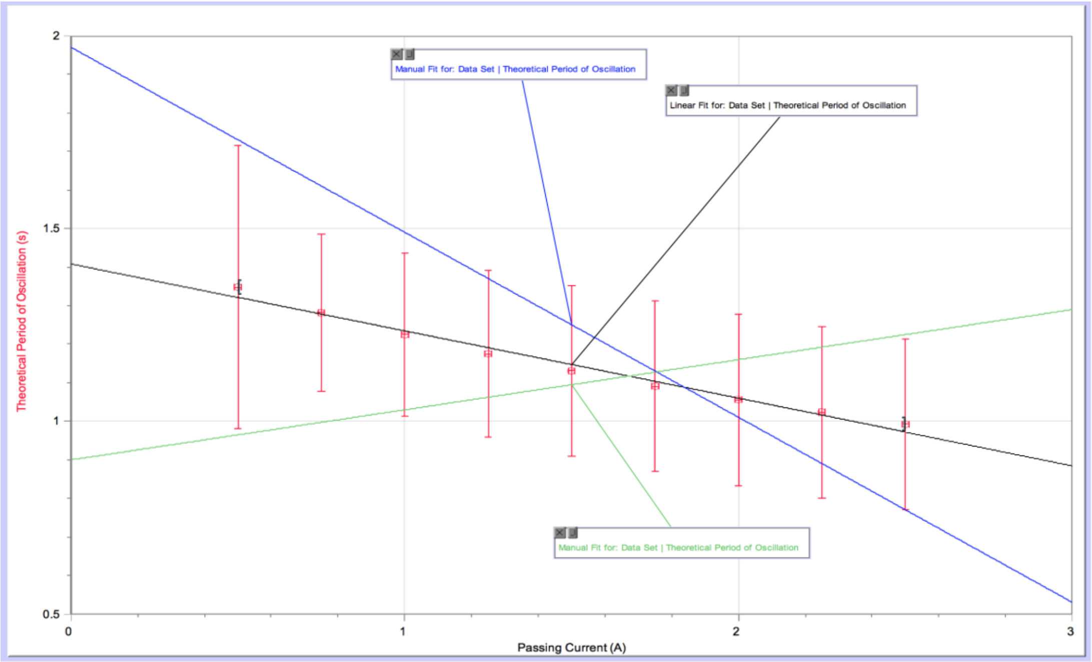
Table 3: Table representing theoratically calculated values of period of the oscillation for each different value of passing current.

Graphs and Graphed Data Interpretation:

Both the measured period of oscillation versus passing current graph and theoretical period of oscillation versus passing current graph are sketched by using the values from *Table 2* and *Table 3*, respectively. Therefore, the common pattern can be observed and supportable comparisons can be made.



Graph 1: Period of oscillation(s) versus passing current(A) graph, including worst lines.



Graph 2: Theoretical period of oscillation(s) versus passing current(A) graph, including worst lines.

As it can clearly be observed from the graphs, period of oscillation and passing current are indirectly proportional. Although their general patterns are nearly the same, there are slight differences between the graphs. Firstly, the values of period of oscillation in *Graph 1* are approximately 0.5A higher than the values of theoretical period of oscillation values in *Graph 2.* Besides, the uncertainties of *Graph 1* are smaller when compared to the uncertainties of *Graph 2;* thus, the measured period of oscillation values are more accurate than theoretical period of oscillation values. Although the uncertainties of *Graph 1* are smaller, their precision is low. The uncertainties values of *Graph 2* are numerically very close to each other, indicating higher precision.

The equation of best line given in *Graph 1* is as following:

$$T = [(-0.27)\ x\ I] + 1.88$$

The equation of best line given in *Graph 2* is as following:

$$T = [(-0.17)\ x\ I] + 1.41$$

where,

T: period of oscillation (s)

I: passing current (A)

These equations are further proof of the judgements given above. The slopes of lines are very similar to each other, showing that the general pattern is also very similar.

3. CONCLUSION AND EVALUATION

Conclusion:

The aim of this experiment was to find out the relation between the passing current in an electric circuit, which was placed between two square magnets, and the period of oscillation of the resistant steel wire acting as a simple pendulum. As the theoretical values of period of the oscillation illustrates, it is observed that as the passing current in an electric circuit increases, the period of oscillation of the steel wire decreases. This indirect proportion of current and period can be proven by data provided at *Graph 1* and *Graph 2,* since it is obvious that as passing current values increase, period of oscillation values decrease. Therefore, the previously made hypothesis is clearly verified. In addition, the relation between measured and theoretical values of period of oscillation was analysed and the percentage error for each different value of passing current was calculated. Percentage error calculations and standard deviation calculations are shown in appendix 1 on page 24.

Although there is an overall percentage error of 28.75%, which can be referred as a numerically moderate value, the data are precise because the standart deviation of errors is small when compared to overall percentage error. Small standart deviation indicates that results are highly precise. However, there are still some experimental errors that caused the encountered percentage error.

Evaluation:

Uncertainties of collected data are not significantly large numbers which affirm that there are not too many errors depending on experiment contents throughout this investigation. Since collected data have small uncertainties, processed and calculated values also have small uncertainties. Thus, the precision of the experiment increases.

The uncertainties of measured period of the oscillation and calculated theoretical period of oscillation were caused by random errors. These could be related to the observer or the environment. The observer might be distracted during measuring the time taken by the steel wire to complete three laps, leading to slight variance from the actual time and, therefore, to random errors. The room was crowded which increases the possibility of distraction. In addition, the observer’s reflex time, which might easily shift from one measurement to another, may cause random errors due to longer or shorter measurements than normal.

The graphs show that, systematic errors are plentiful in number as many points are found to be far from the best line. Then, it is clear that the main weaknesses of the experiment were caused by systematic errors leading to encountered percentage error and the difference between measured periods of oscillation and theoretical periods of oscillation.

First of all, the resistant steel wire, acting as a simple pendulum, was released by a person who might have given the wire some initial velocity. In such case, as the motion did not start from rest, the time taken by the wire to complete its motion would be shorter than it should have been.

The friction force of the air acting on the steel wire was another weakness. Although the air pressure of the room throughout the experiment was almost constant, it was impossible to keep air pressure constant in every instant of swing. Since the steel wire was performing simple harmonic motion in this experiment, damping was one of the limitations. An oscillating system will eventually stop and lose energy under the effect of frictional and other resistance forces. Thus, instant changes in air friction, which might result from ongoing movements in the room, decelerated the motion of the pendulum and the time taken by the steel wire to complete three laps elongated.

A similar weakness was heating of the steel wire during the trials due to the fact that the passing current faced an opposed resistivity from the steel wire. This heating process, also known as *Joule heating*, increases with increased current. Therefore, a chain of reactions was triggered. Although the temperature of the room was stabilized by an air-conditioner, heating of the resistance caused the air to gain kinetic energy and expand. Subsequently, air density would drop and undermine the air friction force acting on the steel wire. With a smaller air friction, less damping occured and the time of swing gets longer. Scientific foundation of the change in air friction force is shown in appendix 2 on page 25.

Another weakness of this experiment was lack of first-hand measurements. The force equilibrium was used to derive and determine the magnetic field $\vec{B}$, instead of measuring it directly in the experiment. The uncertainties of data included in the calculations to derive the magnetic field $\vec{B}$ added up more uncertainties to the final results.

The sizes of square magnets also limit the accuracy of the experiment because this causes magnetic field lines to bend. Bended lines represent that the direction of the magnetic field has changed in accordance with the altitude of the steel wire. As the direction of magnetic field changes, from the right hand rule, the direction of magnetic force changes. All calculations were made considering the assumption that there was an uniform magnetic field between the magnets and vertical magnetic force acting on the steel wire. Thus, the calculations lacked the variance of magnetic field and magnetic force directions.

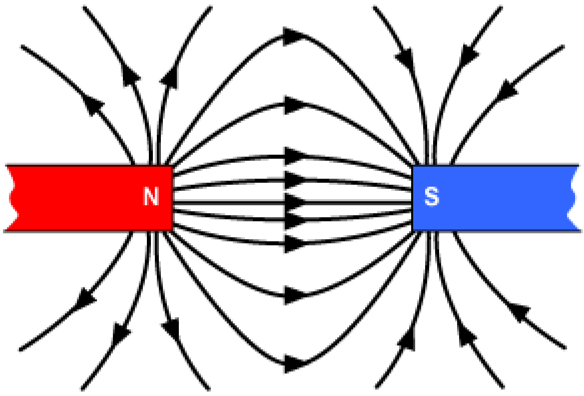


Diagram 6: Diagram representing the magnetic field between two magnets and the bending of lines on the outer regions of magnets.[6]

Lastly, a problem occurred with the position of steel wire since the wire should be standing parallel to the upper surface of the table. Level differences between the ends of the steel wire would lead to unequal distribution of magnetic force.

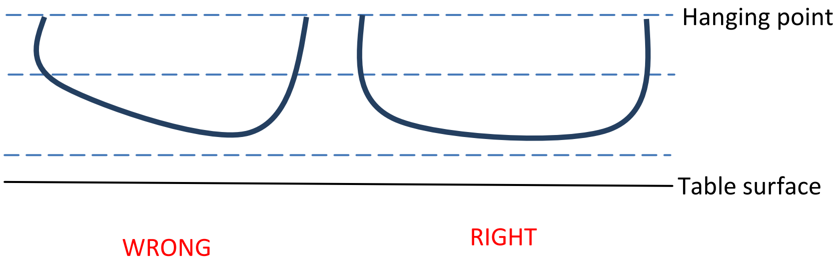


Diagram 7: Diagram representing the wrong and right positioning of steel wire.

On the other hand, the steel wire was released from same initial angle which minimized the percentage error. This is the most important strength of this experiment. The angle was kept constant by placing a ruler vertically to a particular drawn line on the table in every trial. Thus, the same releasing point for every trial was provided.

Again, using crocodile wires to hold the steel wire and to complete the circuit was really useful because crocodile wires were covered with plastic, enabling themselves not to be affected from magnetic field. Hence, the deviation from expected value was diminished.

Improving the investigation:

In the experiment, three trials for each current value of the pendulum was made but as in all experiments, it would have been better to make more trials. Making reputations over and over again reduces the random errors and contributes to experiment to be more accurate.

Also, a silent and empty room would be more suitable for the experiment as there would be no external factor distracting the observer. Therefore, the time measurements would be more accurate. Even a video recorder can be used to record the experiment. Then, from the video the exact time can be determined.

Keeping the room empty would also be helpful to minimize the changes in air friction because there would be less movement which would be beneficial to conserve the air pressure. Conserved air pressure would generate constant air friction, therefore damping of the pendulum would be reduced.

To improve the investigation, it would be wise to tie a thread to the back of pendulum. The other end of the thread could be stabilized by taping it to a wall. Then in each trial the motion could be started by cutting the thread which would guarantee that the initial velocity of the pendulum is zero. It would also be useful for keeping the pendulum on track because the possibility of shifting during the release would be eliminated.

Moreover, covering the steel wire completely with a “high temperature epoxy fiberglass sheet” [7] would be really functional to prevent heat emission. Those fiberglass sheets are suitable as they both reduce temperature rising and have excellent magnetic permeability.

Using a magnetic field sensor to measure the magnetic field would be logical because no calculations or equilibriums would be needed to find out the magnetic field. Thus, uncertainties emerging from the calculations of part 1 would be eliminated and accuracy of the experiment would get better.

To obtain uniform magnetic field, magnets which are a lot larger than the length of wire should have been used. Therefore, parallel lines of magnetic field can be acquired in the middle part of the magnets with minimum amount of bending, preventing changes in the directions of magnetic field and magnetic force.

Additionally, the steel wire should be positioned according to the “right” illustration on *diagram 7*. Thereby, equal magnetic field would apply entirely on the steel wire.

Further investigation:

Conclusions and evaluations show that there is a certain correlation between the current passing through the electric circuit and the period of oscillation of resistant steel wire. Further investigation ideas which emerge after this experiment are:

- ✓ Exploring the oscillation periods in vacuum
- ✓ Exploring the oscillation periods in an anti-gravity setup
  (For example in an elevator decelerating oppositely to the gravitational acceleration, creating zero acceleration acting on the experimental setup)
- ✓ Using different types of resistant wires

Appendix 1:

Percentage error is as following;

$$\text{Percentage error}=\frac{|Theoretical\ value-Measured\ value|}{Theoretical\ value}x\ 100$$

For passing current 0.5 A;

$$\text{Percentage error} \quad =\frac{|1.35-1.77|}{1.35}x\ 100= 31.11\ \%$$

Similar calculations are made for each different value of passing current.

Passing Current (*i*) (A/±0.01)	**Percentage Error**
0.50	31.11%
0.75	31.25%
1.00	31.15%
1.25	30.51%
1.50	30.97%
1.75	26.60%
2.00	25.47%
2.25	27.45%
2.50	24.24%

Table 4: Percentage error values of each different value of passing current.

Overall average percentage error is as following:

$$\text{Percentage error} = \frac{31.11 + 31.25 + 31.15 + 30.51 + 30.97 + 26.60 + 25.47 + 27.45 + 24.24}{9} = 28.75\%$$

The standard deviation of percentage error is as following:

$$\sigma = \sqrt{\frac{\sum(x-\bar{x})}{N}}$$

Where, σ=the standard deviation $\quad$ x=each value in the sample

$\bar{x}$=the mean of the values $\quad$ N=the number of values

$$\sigma = 2.65$$

Appendix 2:

Joule’s first law expresses that the heat (Q) produced from the resistor of an electric circuit is directly proportional to the current squared. [8]

$$Q \propto I^2$$

Therefore, by using the ideal gas law, it can be expressed that the density of the air (ρ) decreses, when temperature (T) of the air increases with the heat released from the resistor. [9]

$$\rho = \frac{P}{R_{specific}\, x\, T}$$

P: Absolute pressure

$R_{specific}$: Specific gas constant for dry air

Then, decreased air density leads to decreased air drag f_{drag} (air friction). [10]

$$f_{drag} = -\frac{1}{2}\, C\rho A V^2$$

C: Numerical drag coefficient

A: Cross-sectional area

V: Velocity

With a decreased air drag, less damping occurs and oscillation period elongates.

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*Graphs on page 16 are drawn with the graphing program: “*Logger Pro*”