MAGNETIC FORCES

1. Goal.

In this lab session, you will measure the force that a current carrying conductor suffers because of the effect of a magnetic field, i.e. Lorentz force.

2. Overview.

When a current carrying conductor is inside a space region where there is a magnetic field, it suffers a net force which is the sum of the magnetic forces exerted on all the charged particles whose motion produces the current.

In the case of a straight current section in the presence of a uniform magnetic field, the magnetic force is given by:

$$\vec{F}_m = I\vec{\ell} \times \vec{B} \qquad \textbf{[1]}$$

were, I, is current in the section, $\vec{l}$, is a vector whose direction is parallel to the current flow, its magnitude is equal to the length of the conductor and $\vec{B}$ is the magnetic field.

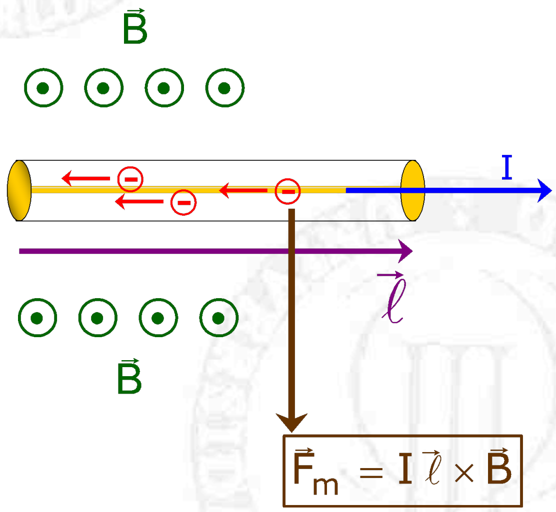

Figure 1: Magnetic force on cable charge carriers.

If $\vec{B}$ and $\vec{l}$ are perpendicular to each other, the magnitude of the magnetic force magnitude experienced by the current reduces to a very simple expression:

$$F_m = I\ell B \qquad \textbf{[2]}$$

3. Learn more...

- **SERWAY, RA & JEWETT, JW. "FISICA" Volume 2. 3th edition Ed. Thomson 2003 - Ch. 22 "Magnetic Forces"**

- **TIPLER, PA & MOSCA, G. "FISICA" Volume 2. 5th edition Ed. Reverté 2005 Ch. 26 "Magnetic Field"**

In the internet:

http://www.sciencejoywagon.com/physicszone/lesson/otherpub/wfendt/lorentzforce.htm
http://www.walter-fendt.de/ph11e/electricmotor.htm
http://www.sc.ehu.es/sbweb/fisica/elecmagnet/campo_magnetico/varilla/varilla.htm (In spanish)

4. Equipment.

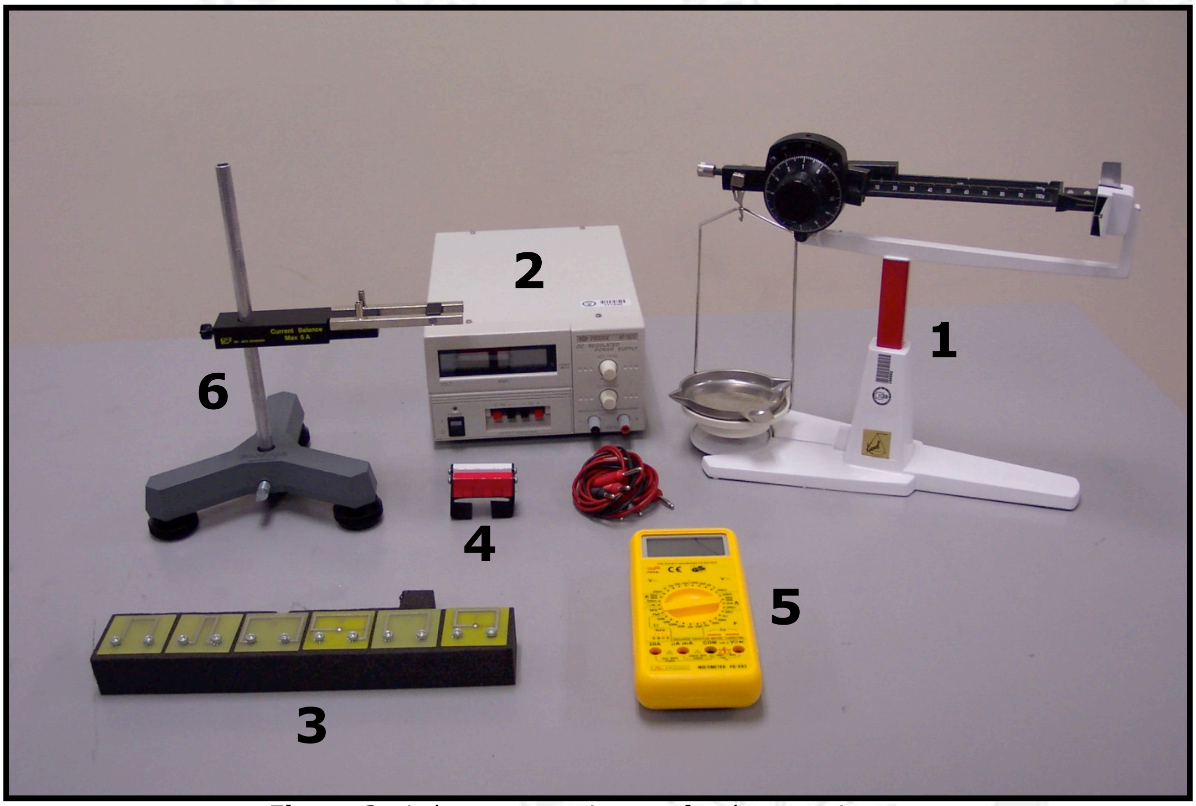

Figure 2: Laboratory equipment for the experiments.

1. Precision scale with a 0.01 g precision.
2. Variable DC Power supply 0-5 A.
3. Printed Circuit Boards (PCB) SF circuits and connectors
4. Permanent magnet
5. Digital multimeter
6. Support structure.

If you have any doubt about the use any equipment, please consult the "Electrical Measurements" guide.

5. Experimental procedure.

5.1 Precision Weight Balance Scale: Measurements

We should put the scale on a horizontal surface, free of vibrations. Then put the magnet on the scale plate. Before starting with the calibration process, move the two sliding weights (100 g and 10 g) to the left until they are both placed at position "0". Next, turn the dial to position "0". After that, free the scale arm.

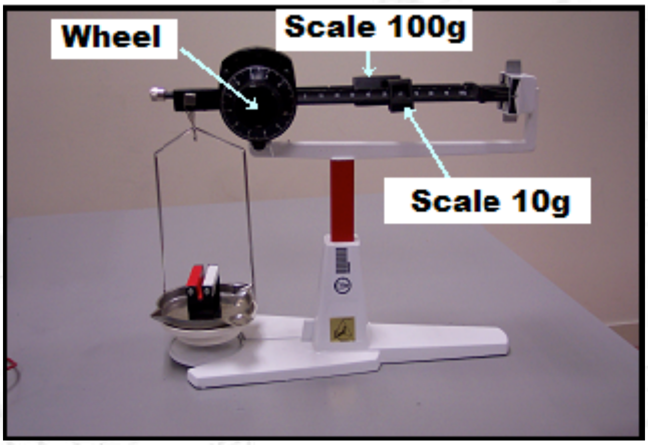

Figure 3: Precision scale

To balance the scale, move first the 100g weight, step by step, to the right. At some point the arm of the scale will start turning down. Leave the weight at the position just before that happens. Next, star moving the 10g weight to the right, again the arm of the scale will move down. Leave it at the location before this happens.

Finally, balance the scale using the graduated wheel. We should move the gauge until the notch at the right edge of the balance arm levels with the position marked with a "0" as shown in Figure 4.

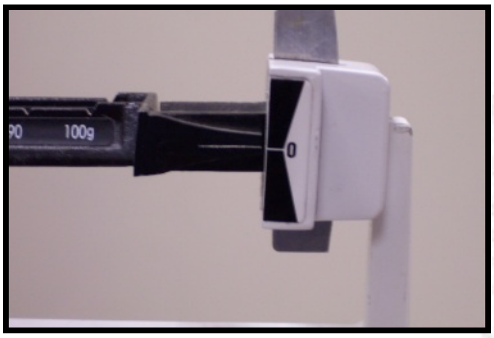

Figure 4: balance level.

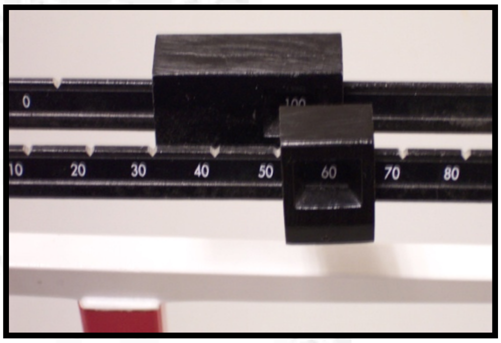

Figure 5: 10 and 100 grams weights

Once the arm of the scale is perfectly balanced, we will start estimating the mass by adding the values of the positions of the sliding weights of 100g and 10g. This first, rough estimation, m_1 will be the sum of both measurements:

$$m_1 = m_{10g} + m_{100g} \qquad [3]$$

In this example, the m_1 value is 160 g. The maximum precision of the measurement is obtained using the graduated dial. The measurement has two contributions. In the first one, every number in the inner scale corresponds to 1g and has 10 divisions (thus, giving a minimum measurement of 0.1g). Using the outer reference mark, locate the position of the inner scale. If it is between two marks, as in figure 6, where it is between 0.6 and 0.7, take the smallest one. In this example, the second contribution to the weight will be m_2 = 0.6 g.

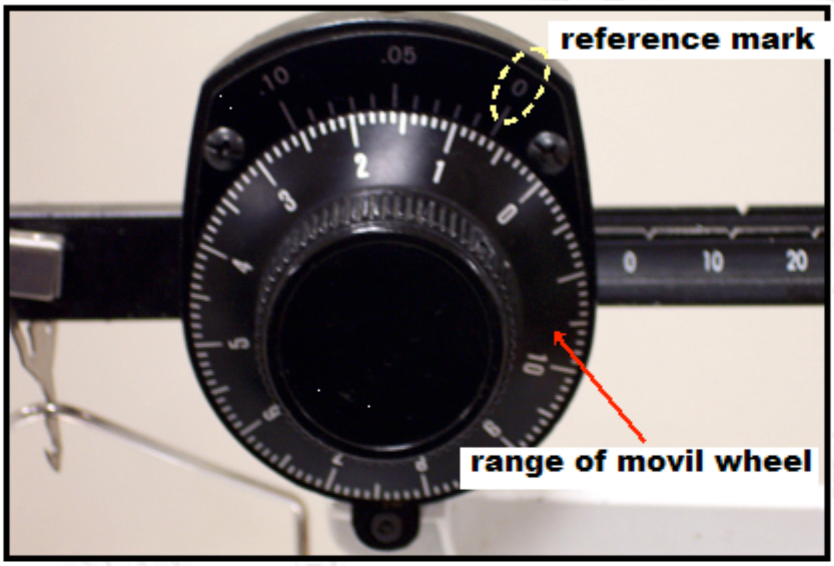

Figure 6: Weight balance scale dial.

Finally, we will use the scale of rigid part of the wheel, going counterclockwise from 0 to 1.0, whose unit corresponds to 0.01 g. The measurement on this scale, that will be called m_3, is taken in the same way as with a gauge: finding the rigid scale mark that coincides with the mark of the sliding scale.

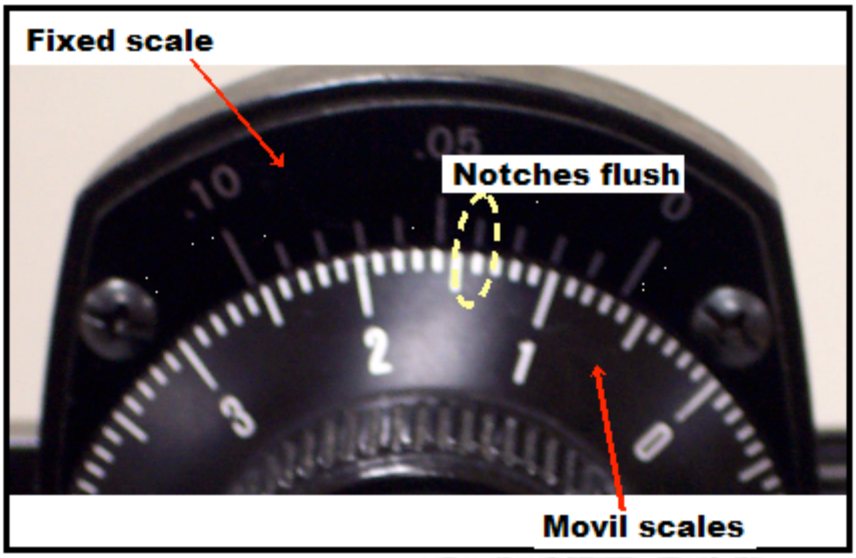

Figure 7: Weight balance scale fixed dial scale.

In the example of Figure 7, the mark of the fixed scale that coincides with a mark of the sliding wheel scale is 0.4. Therefore, m_3 = 0.04 g. The final value of the mass is given by the sum of the different scales.

$$m = m_1 + m_2 + m_3 \quad [4]$$

The uncertainty (error) of the measurement is given by the lowest precision of all scales used. In our case that accuracy is 0.01 g. For the example described above the mass would be:

$$m = 160.64 \pm 0.01\text{g}$$

5.2 Dependence of the magnetic force with the current.

This experiment will be made using the reference board SF38 that has a conductor on the lower part of the circuit that measures 4 cm, see Figure 9.

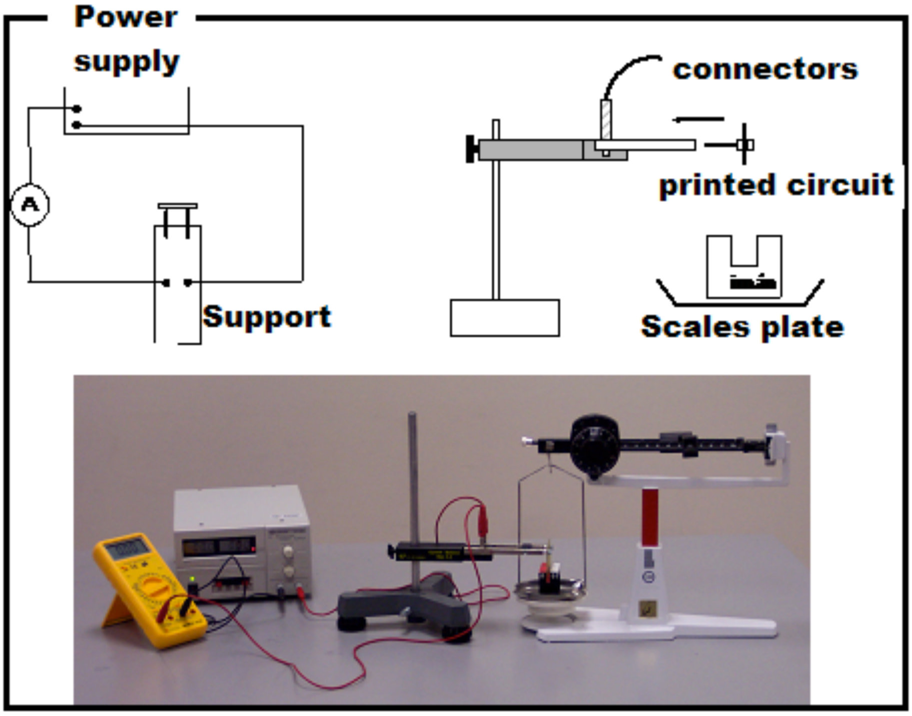

Figure 8: Schematic of experimental setup.

First, fix the circuit board SF38 to the support structure. Make sure that the power supply is disconnected.

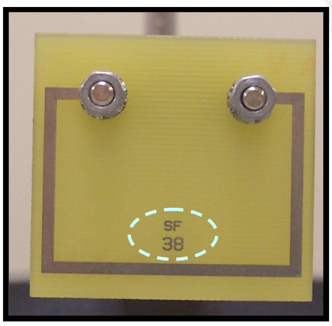

Figure 9: Detail of SF 38 circuit.

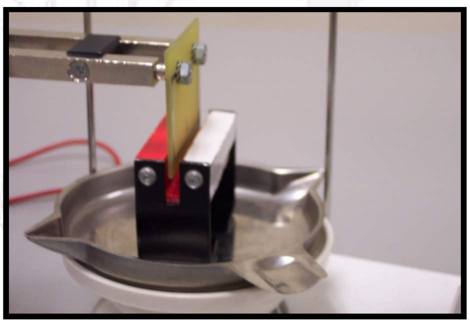

Figure 10: Magnet and circuit setup.

Then, connect the board circuit to the power supply and the ammeter as shown in Figure 8. Remember to use the 20 A connection position of the ammeter (not mA connection). Next, adjust the support height so that the bottom part of circuit lies within the magnet. It is VERY IMPORTANT that the printed circuit board NEVER TOUCHES the magnet. With everything set, balance the scale following the procedure outlined in Section 5.1. The measured value, in the absence of current in the circuit will be m_0. Next, turn on the power supply and adjust it until the current measured in the ammeter is 1A.

The section of the circuit inside the magnet will experience a force given by the expression [2]. As can be seen in Figure 1, the direction of this force is contained in the vertical plane. The direction of the magnetic force depends on the direction of the magnetic field (remember that magnetic field lines always go from North to South poles) and the current direction, that depends on the circuit connections (remember that current always flows from higher to lower potentials). By means of the principle of action and reaction, the magnet will experience a force equal and opposite to that exerted on the circuit.

The force is added or subtracted to the weight, which causes an imbalance of the scale. To measure the value of that force, re-balance the scale and take a new measurement, denoted by m_I. The magnitude of the magnetic force will be then given by:

$$F_m = |m_I - m_0|g \qquad \textbf{[5]}$$

where g is the value of the acceleration of gravity. Finally, all the steps should be repeated for different values of the current in the circuit. In summary, the experimental procedure to follow is:

1. Measure the value of m_0 (when no current flows through the circuit)

2. Measure the weight m_I for currents of I = 1, 2, 3, 4 and 5 A.

WARNING: Never exceed the value of 5 A

3. To improve the accuracy of the experiment, repeat all weight measurement at least twice for every current. Use these values to calculate averages for m_0 and m_I and its corresponding uncertainties.

4. Calculate and plot the magnetic force F_m, using eq. [5], as a function of the current, I.

5. Fit the data using the least squares technique and explain the meaning of the fitted coefficients. What is the magnetic field, B, created by the magnet?

Don't forget to include error estimations of all quantities.

5.3 Dependence of the magnetic force with the length of the conductor.

To perform this study, we will keep constant the current and use circuits with different lengths to see the effect on the magnetic force. To this end we will use a current of I = 3 A and circuits with lengths of: 1 (SF40), 2 (SF37), 3 (SF39), 4 (SF38), 6 (SF41) and 8 cm (SF42). The experimental procedure is the same as above:

1. Measure the value of m_0 (when no current flows through the circuit)

2. For each circuit, measure m_I (remember to keep the current I = 3A)

3. To improve the accuracy of the experiment, repeat all weight measurement at least twice for every current. Use these values to calculate averages for m_0 and m_I and its corresponding uncertainties.

4. Calculate and plot the magnetic force F_m, using eq. [5], as a function of the circuit length.

5. Fit the data using the least squares technique and explain the meaning of the fitted coefficients. What is the magnetic field, B, created by the magnet?

Again, don't forget to include error estimations of all quantities.

5.4 Compare the values of B obtained in parts 5.2 and 5.3.

1. Are the results consistent with each other?

2. Justify your answer.