MAGNETIC FORCES

1. Aim.

In this lab session you will measure the magnetic force (or Lorentz force) that a point charge feels due to magnetic field.

2. Overview.

When a current is immersed in a space region where a magnetic field exists, it feels a force which is the sum of the magnetic forces exterted on all the charged particles whose motion produces the current.

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

$$\vec{F}_m = I\vec{\ell} \times \vec{B}$$

[1]

I is current in the section, ℓ is a vector whose magnitude is the length of straight current section, its direction is that parallel to the straight section and its sense is that in which the current flows. $\vec{B}$ is the magnetic field.
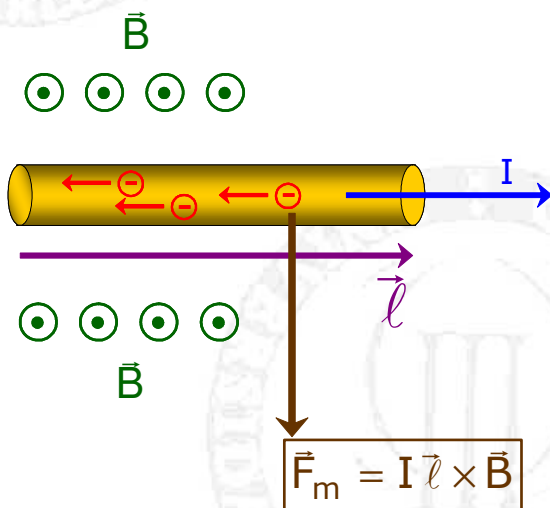

Figure 1

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

$$F_m = I\,\ell\,B$$

[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

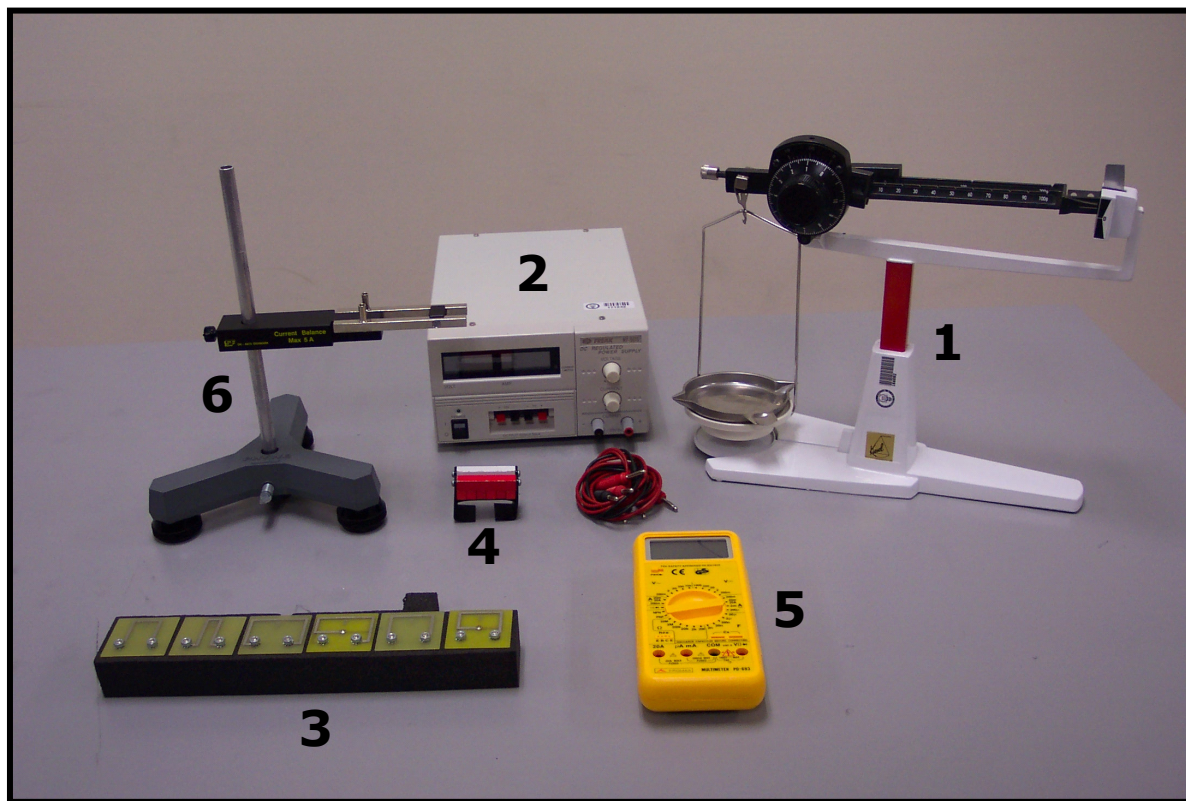**1.** Precision scale 0.01 g

2. Generator 0-5 A DC (direct current)

3. Connectors

4. Magnet

5. Ammeter

6. Support.

5. Experimental procedure.

5.1 Precision scale: Well-balanced and Measurement

We should put the scale on an horizontal surface free of vibration. Then put the magnet on the scale platee. Before starting with the calibration process, the two sliding weights (100 g and 10 g) must be moved to the left, until both of them are placed at position "0". Also the dial must be set to "0". In this situation, the scale arm should be turned up.
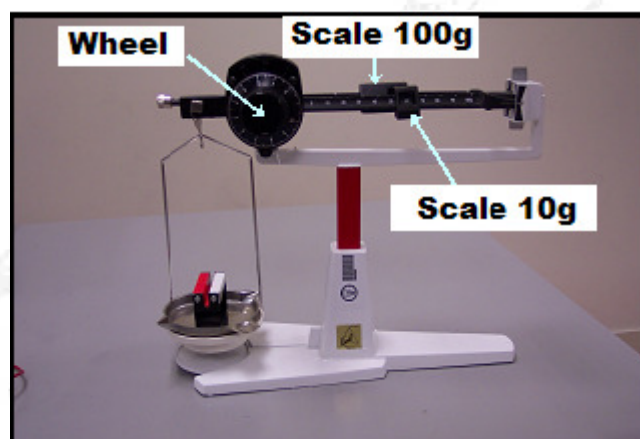

Figure 3

To balance the scale, we will move the 100g weight to the right. There will be a location in which the arm of the scale starts to turn down. We will leave the weight at the position just before that happens.

Then, the 10 g weight is moved to the right, again the arm of the scale begins to turn down. Leave it at the location before this happens.

The final balance of the scale is achieved 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 Fig. 4.
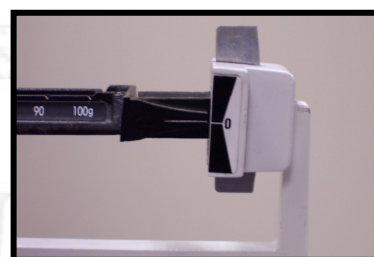

Figure 4

Once the arm of the scale is well-balanced, we can measure the mass. We will sum the values of the positions in which the sliding weights of 100 and 10 g are placed. We will call m_1 at sum of these two values.
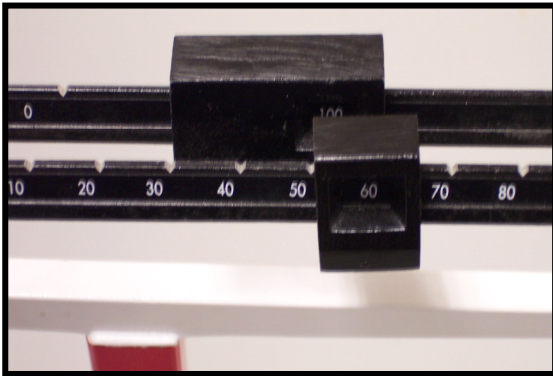
$$m_1 = m(100g) + m(10g) \qquad \textbf{[3]}$$

4

In this example, the m_1 value is 160 g

Figure 5

The maximum precision of the measurement is obtained by means of a graduated ruler. First we use the scale of the moving wheel. On this scale, the unit corresponds to 1 gram. The accuracy of this scale, corresponds to the minimum measurement possible, which is 0.1 g. Taking as a reference mark the "0" on the upper part of the scale (i.e., rigid part of the sample), a measurement can be taken using the moving wheel. The reference mark will be normally situated between two marks on the scale of the moving part. We will take as a lower value m_2. In the example shown in Figure 6, the reference mark is positioned between the 0.6 g and 0.7 g marks, so that measurement would yield a value of $m_2 = 0.6$ g.
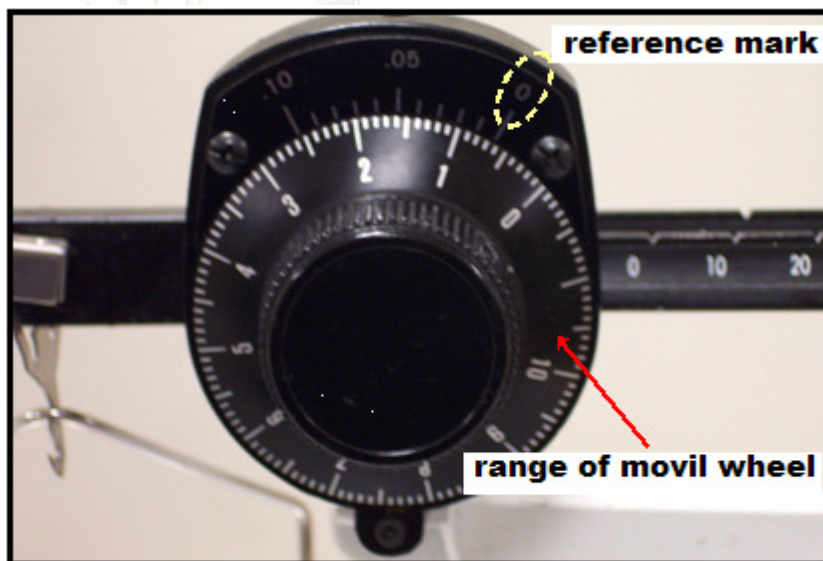

Figure 6

Finally, we use the scale of rigid part of the wheel. On this scale, the unit corresponds to 0.05 g. The precision of this scale, corresponds to the minimum measurement possible which is 0.01 g. The measurement on this scale will be called m_3, which is taken in the same way as with a gauge. We search for the rigid scale mark that coincides with the mark of the sliding scale. The value of m_3 is given by the value of that mark on the rigid scale.
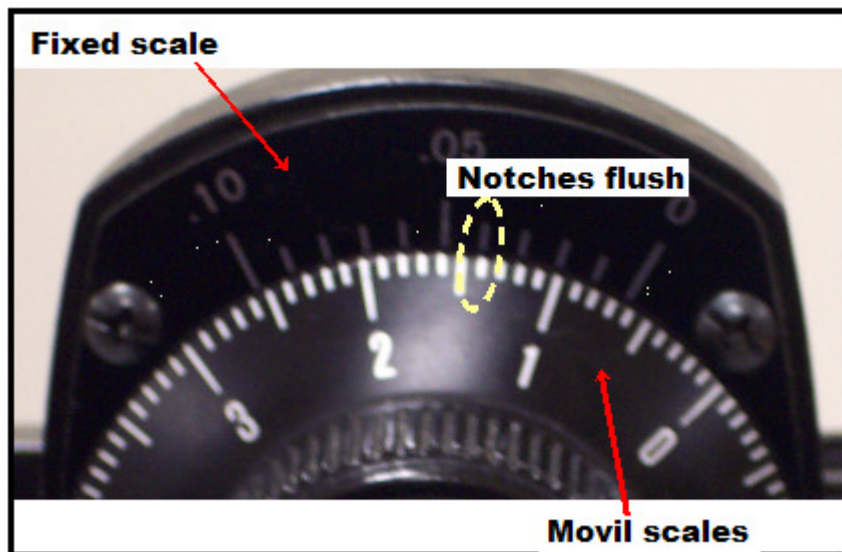
Figure 7

   In the example of Figure 7, the mark of the fixed scale that coincides with a mark of the sliding wheel scale is 0.04. Therefore, we must m_3 = 0.04 g

   The final value of the mass is given by the sum of the values measured on different scales.

$$m = m_1 + m_2 + m_3 \qquad \textbf{[4]}$$

The precision of the measurement is given by the lowest precision of all scales used. In our case that accuracy is 0.01 g. The value of the mass obtained from the measurements illustrated in the figures above would be:

   m = 160.64 ± 0.01 g

5.2 Dependence of the magnetic force with the current.

   This experiment will be made using the reference conductor SF38. The length of the lower part of the circuit is 4 cm.
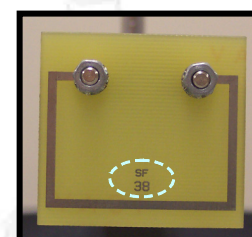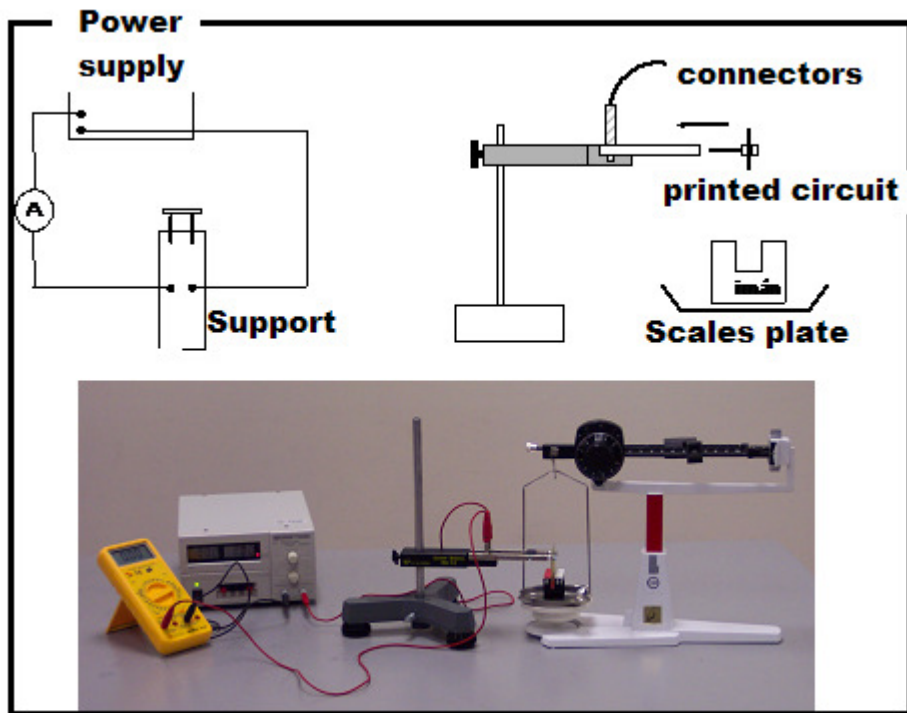

Figure 8

6

Figure 9: Schematic of experimental setup

We start by connecting the circuit to the support as shown in Figure 9. Then, we connect the support to the 0-5 A power supply including also an ammeter to measure the current. Remember to use the 20 A connections to connect the ammeter to the circuit (not mA connections!). And it should be made sure that no current flows in the circuit.

Next, the support height must be adjusted until the bottom part of circuit is in the magnet. It is VERY IMPORTANT that at no time the printed circuit board is in contact with the magnet. At this time, the scale must be balanced. We call m_0 the measurement obtained with the scale in the absence of current in the circuit. Next, we adjust the power supply to allow for a 1A current to circulate through the circuit. 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 of the sense of the field (i.e., the position of the magnet respect with to the current) and the current sense (i.e., how the circuit has been connected to the source). 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, we re-balance the scale arm and take a new measurement, denoted by m_I. The magnitude of the magnetic force is then given by:
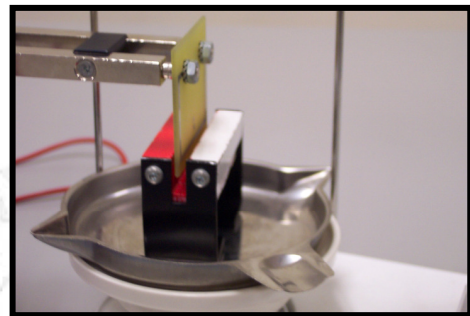
$$F_m = |m_I - m_0| g \qquad \text{[5]}$$

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 <u>experimental procedure</u> to follow is:

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

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

   WARNING: Never exceed the value of 5 A

3. Repeat the above steps (parts 1 and 2), so that two different values are available for both m_0 and m_I for each current. With these two experimental values, calculate the mean value of m_0 and m_I for each current and its corresponding uncertainties.

4. Using these average values, calculate in each case the value of the magnetic force according to equation [5]

5. Plot **F$_m$** against **I**. Fit the data using the least squares formulas.

6. Interpret the values of the fit parameters using equation [2]. Get the value of **B** inside the magnet from the fit parameters.

7. Perform in all cases the corresponding calculation of uncertainties.

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

To perform this study, we will use the reference circuits PCB SF40, SF37, SF39, SF38, SF41 and SF42. The length of the lower part of these circuits is 1, 2, 3, 4, 6 and 8 cm, respectively.

The experimental procedure is the following:

1. <u>In all cases will use a current value of I = 3 A</u>

2. For each circuit we will measure the **m$_I$** value according to the experimental procedure explained above.

3. Plot **F$_m$** as a function of the length of the conductor. Perform a least squares fit of the data.

4. Interpret the values of the fit parameters using equation [2]. Get the value of **B** inside the magnet from the fit parameters.

5. Perform in all cases the corresponding calculation of uncertainties.