Physics instruction for undergraduate college courses through the design of an experimental device

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Abstract: - During experimental sessions for science related students, different measurement instruments and equipment are used, but in most occasions its mechanism is ignored. This turns the device into a “black box” which seems to receive some kind of impulse and transforms it into measurement estimations. By not being able to comprehend the means used by the instruments to determine a measure, the students lack from the required information to identify the different factors that can affect the measuring process, thus they are forced to accept the outcome as true.

Moreover, ignorance towards the basic functioning principles of a device leads students into damaging the measurement instruments. This is why the authors’ proposal is for students to carry out an experimental session where the main goal is acknowledging Physics by building a measuring device. The outcome of a related experience that was carried out by the authors in the Physics Laboratory of the School of Chemistry in the UNAM is presented trough this work.

Key-words: - Physics acknowledgement, Electromagnetic balance, experimental weight measuring instrument, teaching in undergraduate courses.

1 Introduction

The teaching of experimental Physics in university courses is generally developed under predetermined protocols or scripts, written by those who impart the subject. In order to accomplish the objective of each experimental session, students make use of different measuring instruments whose functioning principle is not familiar to them in most cases, especially when it is about electronic devices. These events are more common in experimental experiences among students from the first terms of university.

By misunderstanding, and even ignoring how this measuring devices work, students are forced to accept the results obtained during the measuring process, without understanding the actual process. This converts those instruments into something similar to “black boxes” that appear to give results without a clear explanation.

This usually leads students to ignore certain agents, related to the handling of the instrument that may be at some point an important source of error in the outcome data. Furthermore, this may cause severe damage in the device. A clear example of this is the number of broken devices kept in laboratories storerooms, due to irreversible damage or high reparation costs.

For this reasons, the authors of the present paper consider important that students of the experimental Physics courses execute an experiment whose main objective is the design and construction of a measuring instrument.

At the same time, the construction of this measuring device pursues two central goals that will be explained in brief.

1.1 Extensive study of the related concepts.

In order to be able to construct an instrument, students are required to posses a deep knowledge of the conception and evolution of its operation principles, as well as the application of the scientific models for the device's development.

1.2 Promoting awareness about the use of the instrument.

When constructing a measuring instrument, the student becomes aware of the care that should be taken during the utilization of the instrument. Furthermore, he can determine in subsequent measurements the variables that affect its performance. In this article the construction of an electromagnetic balance is thoroughly described as one of the experiments of the Laboratory of Physics, which is attended by undergraduate students of second semester from the School of Chemistry at the UNAM.

2 Assembling of the device

2.1 Fundamental principles of the device

The setting up of the electromagnetic balance was based on the application of the following principle [3]: The magnetic force (F_b) exerted on the electrical charge that travels through the surface of a conductor is equal to the product of the intensity of circulating current (*i*), the length of the conductor (L), and the modulus of the magnetic field (B) around it.

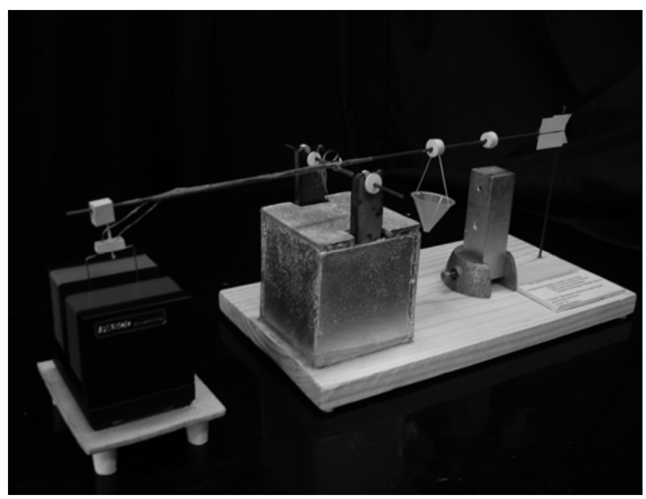
$$F_b = iLB \qquad \dots (1)$$

This magnetic force can be applied to counter the weight of an object with a specific mass (*m*). Analyzing the generated torques, the following relation between the electric current traveling through the conductor and the mass of the weighted object can be established as follows:

$$i = m\left(\frac{g}{LB}\right) \qquad \dots (2)$$

2.2 Device description

The design of the electromagnetic balance was based on the structure of a balance of equal beams. The balancing force is generated by the electromagnetic field around a conductive coil which transports an electrical current. This force counters the weight of the object placed on the opposite end of the arm. For the construction of the mechanism we used a PASCO SCIENTIFIC magnet as the source of the magnetic field. The coil was constructed with copper wire with a diameter of 1.06mm, a width of 3.4cm and a length of 7.4cm. The circulating electrical current was provided using a GW DC power source model GPR-30ÓD connected to the coil. On the opposite end of the balance, a container was placed as well as an equilibrium indicator. The container was elaborated with fabric and its height reached 8.66cm below the balance's main axis. The balance indicator was constructed with two independent segments of horizontal straight line: a dynamic and a static one (independent of the balance's beam); this way the equilibrium was defined when both segments met, creating a single straight line. Zero was established as the equilibrium without any object in the container. In order to help the zero adjustment of the balance, 6 steel beads of 0.5cm of diameter with mobility were introduced. The axis of the balance was elaborated with a stainless steel rod with a thickness of 2,74mm and a length 50cm placed on a ceramics stand. The complete device is shown in Figure 1.



Electromagnetic Balance
Fig.1

2.3 General operation of the device

Once the zero of the balance is adjusted, an object is placed in the container, thus moving the beam's position from its previous position (adjusted as zero). Later, the intensity of electrical current in the coil is adjusted until the magnetic force on it counters force generated by the weight of the object and the dial returning to the equilibrium position.

3 Calibration

The calibration of the electromagnetic balance for zero mass took place using a mass standard, calibrated by the Metrology Laboratory of the School of Chemistry, UNAM, with report number FINUM-PTEUM-M-002-021 and traceability to CENAM; several currents associated to each mass standard were obtained. The value of the electrical current associated to each mass standard, was repeatedly determined until achieving regular outcomes.

The average values of electrical current for each known mass are shown in Table 1.

Table 1	
Mass Standard (g)	Average electric current (A)
0	0
0,5±3,5X10^{-5}	0,54±5,64X10^{-2}
1,0±3,5X10^{-5}	1,16±1,248X10^{-1}
2,0±3,6X10^{-5}	2,37±2,433X10^{-1}
3,0±4,2X10^{-5}	3,52±3,528X10^{-1}
4,0±6,1 X10^{-5}	4,84±4,844X10^{-1}

3.1 Treatment of experimental data

The use of a force analysis determined a relationship between the mass placed in the electromagnetic balance, and the electric current used to put its beams into equilibrium. This led to the creation of a graph using the data obtained during the experiment, and that defines the electric current as a function of the mass standard (Fig. 2). The obtained graph was used as a calibration curve for the electromagnetic balance.

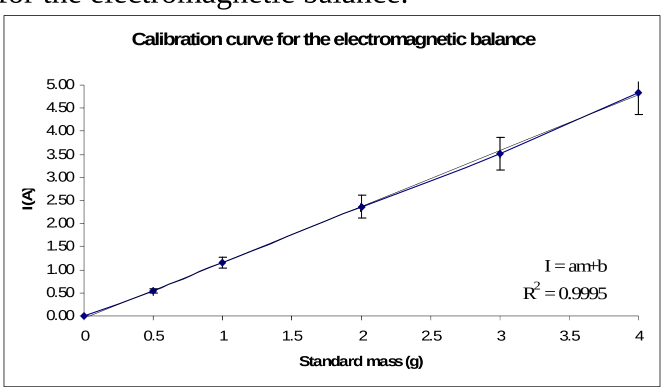


Figure 2

Trough a linear regression, a mathematical model was obtained. This model describes the calibration graph:

$$I = (1{,}2084 \pm 0{,}0831)\left[\frac{A}{g}\right] m - (0{,}0418 \pm 0{,}0282)[A] \qquad (3)$$

The estimated value of the correlation coefficient of this regression was:

R^2 = 0,9995

3.2 Analysis of the obtained model

In order to estimate the uncertainty related to the electromagnetic balance, a second experiment was performed. It consisted in placing different known masses and recording the electric current required to put its beams in its original place. Afterwards the calibration graph was used to calculate the electrical current needed to poise the balance in the same mass values. The outcomes of the second experiment are shown in Table 2.

Table 2		
Mass Standard (g)	Theoretical Current (A)	Experimental Current (A)
0	0	0
0,5±3,5X10^{-5}	0,5624±0,0279	0,54±0,1173
1,0±3,5X10^{-5}	1,1666±0,0624	1,18±0,1854
1,5±3,6X10^{-5}	1,7708±0,1204	1,78±0,2735
2,0±3,6X10^{-5}	2,3750±0,1204	2,31±0,2913
2,5±4,2X10^{-5}	2,9792±0,1764	2,94±0,3772
3,0±4,2X10^{-5}	3,5834±0,1764	3,50±0,3909
3,5±6,1X10^{-5}	4,1876±0,2422	4,20±0,4915
4,0±6,1X10^{-5}	4,7918±0,2422	4,77±0,5023
4,5±1,2X10^{-4}	5,3960±0,4000	5,39±0,7359
5,0±1,2X10^{-4}	6,0002±0,4000	5,89±0,7423

By subtracting the experimental values of electric current to the theoretical ones, the error related to the experiment was obtained (Table 3).

Table 3	
Mass Standard (g)	Error (A)
0	0
0,5±3,5X10^{-5}	-0,0224
1,0±3,5X10^{-5}	0,0134
1,5±3,6X10^{-5}	0,0092
2,0±3,6X10^{-5}	-0,0650
2,5±4,2X10^{-5}	-0,0392
3,0±4,2X10^{-5}	-0,0834
3,5±6,1X10^{-5}	0,0124
4,0±6,1X10^{-5}	-0,0218
4,5±1,2X10^{-4}	-0,0060
5,0±1,2X10^{-4}	-0,1102

3.3 Uncertainty of the device

Using the information obtained through the second experiment, the measured mass (the one reported trough the device) was estimated (Table 4). After that, a graph showing the relation between the measured mass and the mass standard was elaborated (Fig. 3).

The correlation coefficient for the least-squares method applied was 0,9996 and the linear fitting is described by the following mathematical equation.

$$M_t = (0{,}9909 \pm 0{,}0831) M_p - (0{,}0009 \pm 0{,}0282)[g] \quad (4)$$

Table 4	
Mass standard (g)	Theoretical Mass (g)
0	0,0009±0,0282
0,5±3,5X10^{-5}	0,4814±0,0586
1,0±3,5X10^{-5}	1,0110±0,0927
1,5±3,6X10^{-5}	1,5076±0,1367
2,0±3,5X10^{-5}	1,9462±0,1456
2,5±4,2X10^{-5}	2,4675±0,1886
3,0±4,2X10^{-5}	2,9309±0,1954
3,5±6,1X10^{-5}	3,5102±0,2457
4,0±6,1X10^{-5}	3,9819±0,2511
4,5±1,2X10^{-5}	4,4950±0,3679
5,0±1,2X10^{-5}	4,9088±0,3711

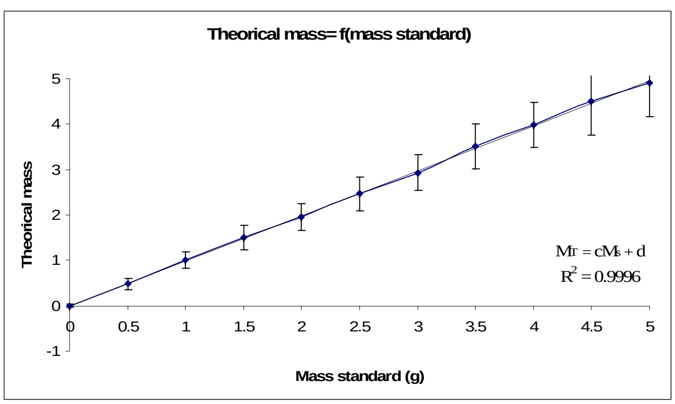


Fig. 3

This model represents the difference between the measured mass value obtained by the electromagnetic balance and the value of the reference standards.

At last, the expanded uncertainty related to the measuring of each standard mass by the electromagnetic balance was estimated. The results are shown in Table 5.

Table 5	
Mass standard (g)	Expanded Uncertainty
0	±0,0378
0,5	±0,1173
1,0	±0,1855
1,5	±0,2736
2,0	±0,2913
2,5	±0,3772
3,0	±0,3910
3,5	±0,4915
4,0	±0,5024
4,5	±0,7360
5,0	±0,7424

4 Conclusions

As a result of this experience, the students were able to acknowledge the interaction of a magnetic field and a moving electric charge that enables the electromagnetic balance to work.

Furthermore, the students became familiar with the procedure to obtain uncertainties as well as with agents that affect measurements, in such a level that they were able to develop a proposal to decrease in a great deal the uncertainties that the electromagnetic balance informed (Table 4).

It is important to highlight the achievement that represents the construction of an electromagnetic balance with the materials and instruments previously described. Even more if the uncertainty of its related data is less than 8%, making it a reliable device in different applications.

Despite the limited measurement range (0g to 5g), it was not transcendental to build a balance with exceptional qualities. The most relevant aspect of this experiment was that students achieve a better and more detailed understanding about the measurement process. Undoubtedly, metrology related activities will be involved in their future professional living.

At last, it should be pointed out that this kind of activity contributes to the development of teamwork skills, practical experience sharing, and activity planning. All these enable the achievement of a single goal throughout experimental activities, which overall, are vital aspects in the instruction of Physics.

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