Classroom Experiment to verify the Lorentz Force

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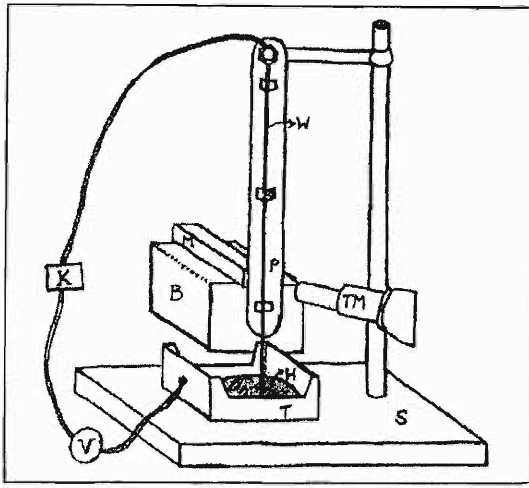
Introduction

The Lorentz force is a phenomenon of fundamental importance in electricity and magnetism for it gives a law for the interaction between a magnetic field and a current i.e. a charge in motion. This interaction between a magnetic field and a moving charge, first discovered by Faraday, and expressed mathematically as the Lorentz force is the basis of many devices (the most popular being an electric motor). It also provides explanation of many electromagnetic phenomena. Yet, as far as we are aware, very little is done in undergraduate laboratories to demonstrate this force in a quantitative or semi-quantitative way. While setting up a new laboratory for the mathematics students, studying the BMath course of the Indian Statistical Institute, Bangalore, it was felt that verification of Lorentz formula could be a viable experiment for the undergraduate level for one can not only demonstrate the existence of this force but also find the means to quantify it by a very simple method. In the absence of a teaching lab and workshop facilities it was decided to set up the equipment with the material available and with minimum effort at fabrication. The aim was to generate innovative ideas through stronger interactions between the students and the instructor. What is described below is a first attempt. We feel that with further improvement the same set-up can be used to obtain more accurate results and shows that for teaching physics, a simple experimental set-up can often be employed not only for demonstration of phenomena but also for quantitative verifications.

Instrumental Set-up

The essentials of the set-up are shown in *Figure* 1, while *Figure* 2 shows the real set-up. A pair of bar magnets,



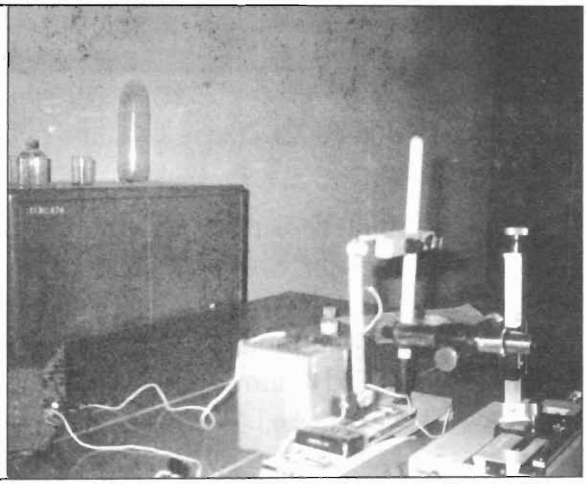


Figure 1 (left). Schematic diagram of the set-up. K: key, V: voltage source, W: wire attached to the frame, M: magnet, H: mercury, B: Base, P: plastic frame, T: trough, S: stand, TM: travelling microscope.

Figure 2 (right). Photograph of the laboratory set-up.

of which only M is shown was used to generate a fairly uniform magnetic field and the other equipment were a travelling microscope, a battery eliminator, a mercury trough and a very light plastic frame, which can easily swing if hinged. The idea was to drive a current I through a wire W perpendicular to the direction of the magnetic field and to measure the deflection θ of the wire to verify whether $\theta \propto I$ is followed. First the magnet was held horizontally and the plastic frame (with the wire adjoined with it by tape) was freely suspended such that it was free to execute oscillations in the vertical plane. The arrangement was such that one end of the wire was made to touch the mercury in the trough. In this set-up, the current was allowed to flow through the wire W, (attached to the plastic frame P) and the current was altered by changing the driving voltage in the battery eliminator, in steps of 2 volts.

Experiment and Results

The system was first allowed to come to rest in the absence of any current through the wire W The frame P was found to be vertical in the absence of any current I through the wire. The field lines of the magnet M were plotted with the help of a magnetic needle, with the north pole of M pointing towards the north direction. This allowed us to identify the region close to the N pole of M, over which the magnetic field could be assumed to be uniform.

The typical dimensions of the magnet M were 1.19 cm x 1.34 cm x 10.37 cm. Our observations showed that with the N pole of M pointing towards north (checked independently by a magnetic needle), one could consider the magnetic field to be uniform up to about 0.75 cm from the pole. In suspending the frame P (with the wire W attached to it) care was taken to ensure that W was within 1 cm from the N pole of M. At this stage, the wire W was viewed through a focussed travelling microscope TM such that its vertical cross wire coincided with W

The emf (V) driving the current $I(=\frac{V}{R}, R$ being the resistance of the circuit) was increased in steps of 2 volts. It was observed that the frame P was deflected in a direction consistent with the Lorentz force (or Fleming's left hand rule), i.e.

$$\vec{F} \propto \vec{I} \times \vec{H}\, \delta\ell.$$

Our next objective was to verify the linear dependence between $|F|$ and $|I|$, for which we tried to accurately measure the deflection θ (see *Figure* 3) as the current I was changed. Considering that the total mass of the frame P with the wire W is M, then on the element $\delta\ell$ of the wire the components of the force on the x (horizontal) and y (vertical) directions are, as seen in *Figure* 3,

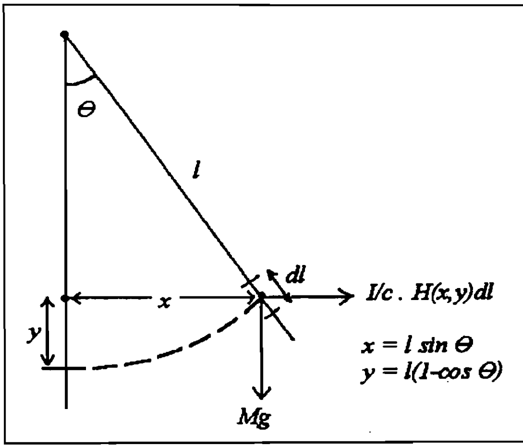
$$F_y = Mg \tag{1}$$

$$F_x = \frac{I}{c}H(x,y)\delta\ell = \frac{V}{Rc}H(x,y)\delta\ell, \tag{2}$$

where

$$x = \ell \sin\theta \tag{3}$$

$$y = \ell(1-\cos\theta) \tag{4}$$



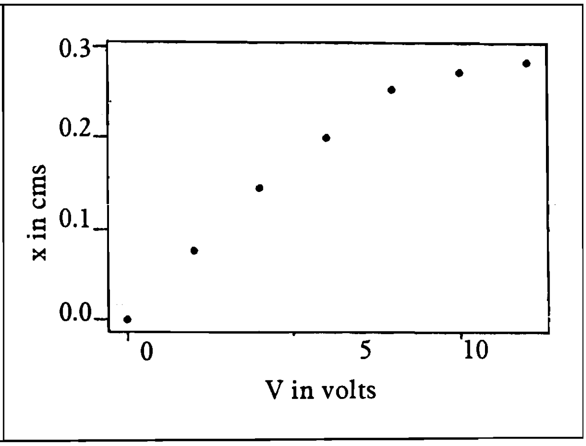


Figure 3 (left). Components of the forces in x and y directions are shown.
Figure 4 (right). x versus V plot (see equations (3-5).

and $H(x, y)$ being the magnetic field at (x, y), being directed perpendicular to the plane of the paper.

At equilibrium, we must have,

$$\tan\theta = F_x/F_y = \frac{H(x,y)}{RcMg}\delta\ell V. \qquad (5)$$

From the geometry in *Figure* 3 we note $\tan\theta \sim x/\ell$, so that (5) implies that the horizontal deflection must follow,

$$x \propto V. \qquad (6)$$

By changing V we noted the deflection x in the horizontal direction with the help of a travelling microscope TM, with a least count 0.001 cm. The variation of x with V is shown in *Figure* 4 and the regression plot is given in *Figure* 5. The results of the regression plot can be found in *Figure* 5. The linearity with respect to V is clear. In the absence of an independent measurement of H, we cannot however establish the relationship between the coefficient of V and the magnetic field H. We, however, observe that the deflection x saturates for higher values of V This saturation of x with V is understood from the fact that the magnetic field distribution of M falls off beyond a region 3 mm x 3 mm x 3 mm from the pole of M. This shows that the visual examination of the

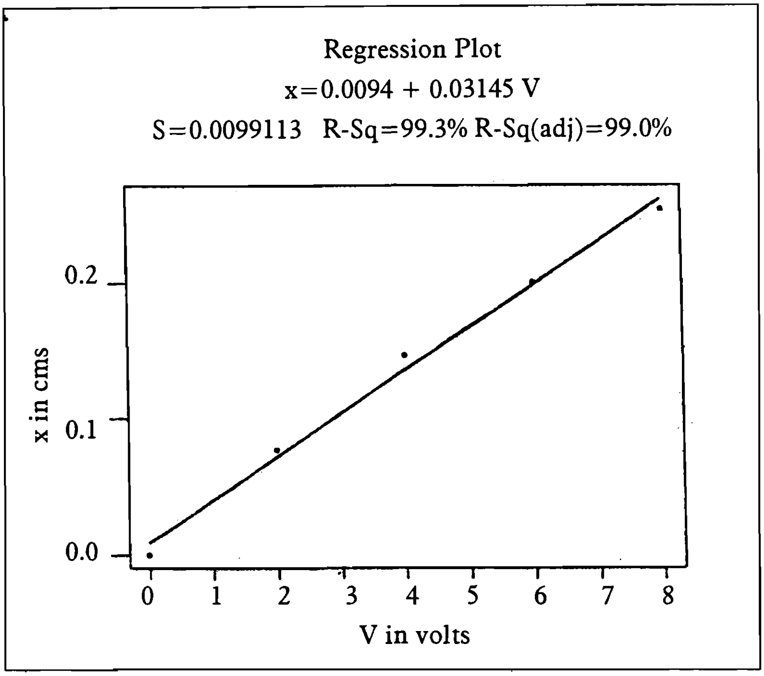


Figure 5. Linear regression analysis of x versus V in the low V regime.

the field lines gives the region of field uniformity to be larger than what it actually is. We repeated the experiment many times on every occasion similar (x vs V) dependence was seen and the deflection was also seen to reduce as W was placed further away from M indicating a lower value of the Lorentz force due to the reduction of H with distance.

Discussions

With a simple experiment we have not only demonstrated the existence of the Lorentz force – its direction being given by the Fleming's left hand rule, but also shown its linear dependence with I. The basic consideration in formulating this experiment was to try something novel, simple and yet obtain the basic understanding of a fundamental physical law. In devising this experiment we also took note of the absence of a workshop for fabrication of instruments. As ideas evolved through interactions between the students and the instructor, it was decided to substitute fabrication by using components from children's Mechano set – available in any toy shop. A plastic mechano was chosen, to avoid magnetic materials, since such materials could offset the limited magnetic field uniformity we had at our disposal. The travelling microscope, battery eliminator and the voltmeter were already available in the lab. It is of interest to us to suggest that this experiment is feasible in any BSc laboratory and its simplicity can be understood from the photograph in *Figure* 2. In order to have improvements, we suggest that the following changes be made. Firstly the frame P can be made of aluminium. This ensures that P is non-magnetic and also light so that in view of small M (see (3)) changes in x are detectable even for small changes in I. Secondly the frame P could be suspended from a knife edge and also the system could be covered by a glass enclosure and the deflection x be seen through a focussed cathetometer, away from close proximity of the working table. These changes are suggested in order to avoid stray deflections that may arise while handling the travelling microscope TM. The experiment could be repeated with a system with a better uniformity of magnetic field. For this purpose, we plan to use the commercially available pole pieces that come with standard equipment for the study of Zeeman effect and magnetoresistance. Also, the circuit must be accompanied by an ammeter (a digital multimeter can also be used) so that the current I can be read directly. The system also has the potential for the study of uniformity in d.c. magnetic field for which too we plan to use our system in future.

Readers are also requested to repeat our experiment and communicate their results and comments through the pages of *Resonance*, which we look forward to.

Acknowledgment

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