Lab 14

Lorentz Force and Current Balance

A. Purpose

To study the Lorentz forces acting on current-carrying wires of different lengths under the magnetic field and to apply the principle of current balance formed by two current loops to measure the magnetic force.

B. Introduction

A current-carrying wire in a magnetic field experiences a force that is usually referred to as a magnetic force. The magnitude and direction of this force depend on four variables: the magnitude of the current I, the length of the wire L, the strength of the magnetic field B, and the angle θ between the field and the wire.

The magnetic force can be described mathematically by the vector cross product:

$$\mathbf{F_m} = I\mathbf{L} \times \mathbf{B} \quad (1)$$

Or in scalar terms,

$$F_m = ILBsin\theta$$

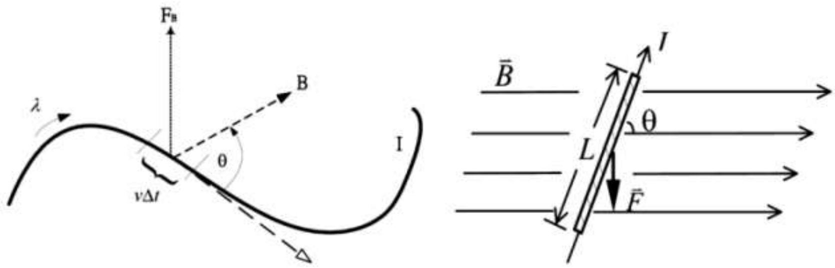


Fig. 1. Schematic of a current-carrying wire in a magnetic field

A current balance is used to measure the force of repulsion between identical, oppositely-directed currents in parallel conductors. This experiment focuses on Lorentz force, trying to discuss the Lorentz force acting on the current-carrying wires under the magnetic field and to further determine the unknown mass of a small object by the current balance.

C. Apparatus

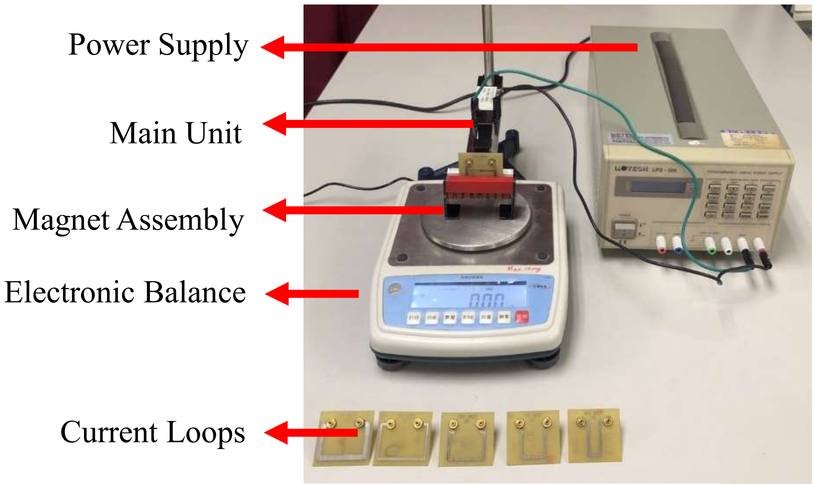


Fig. 2. Setup and apparatuses of Exp. 1

Fig. 3. Magnetic Assembly

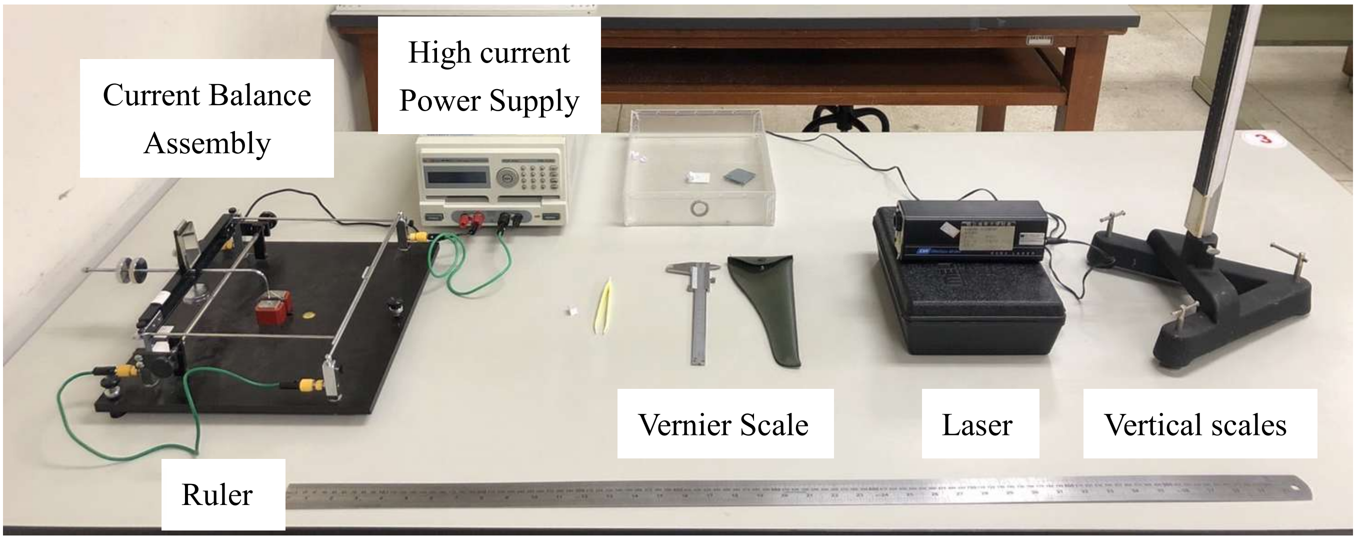


Fig. 4. Setup and apparatuses of Exp. 2

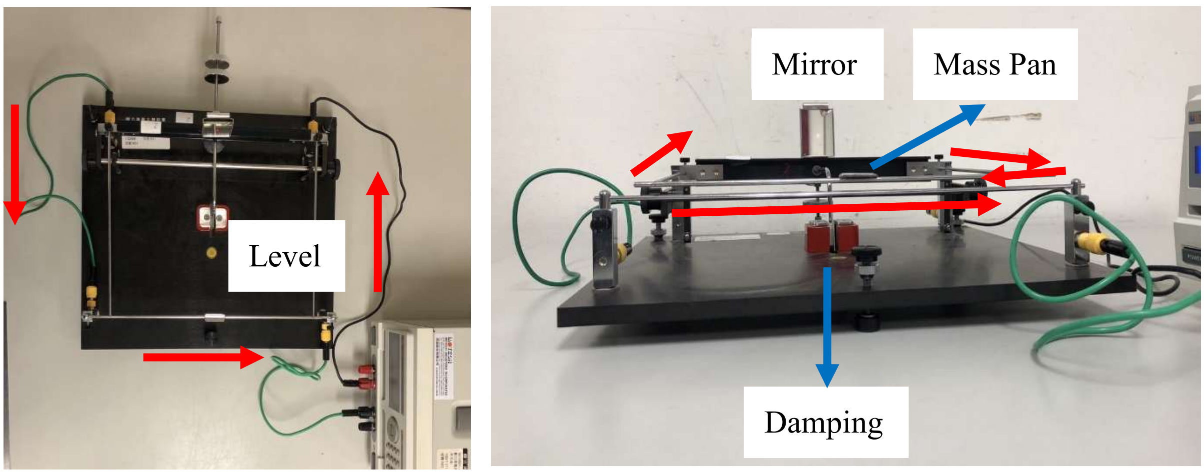


Fig. 5. Top view and Side view of current balance assembly. Red arrows show the direction of the current provided by the power supply. Two conducting wires are repulsed with each other due to the Lorentz force. Damping magnet makes the equilibrium more easily reached. The magnitude of Lorentz force can be obtained by putting the mass on Mass Pan.

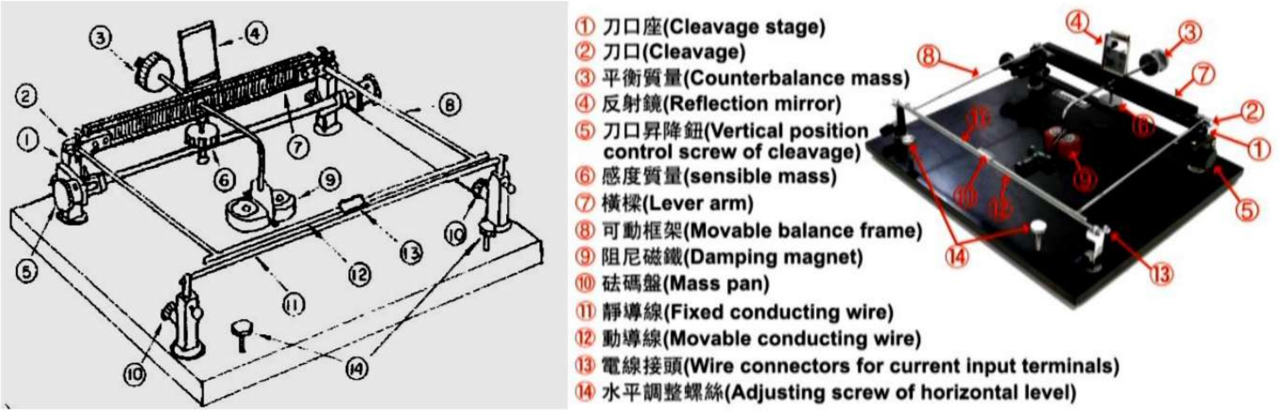


Fig. 6. Current balance assembly. Before the experiment, one should use adjusting screws of horizontal level to make the assembly horizontal and check by the bubble level. Movable balance frame is used to ensure two conducting wires are parallel.

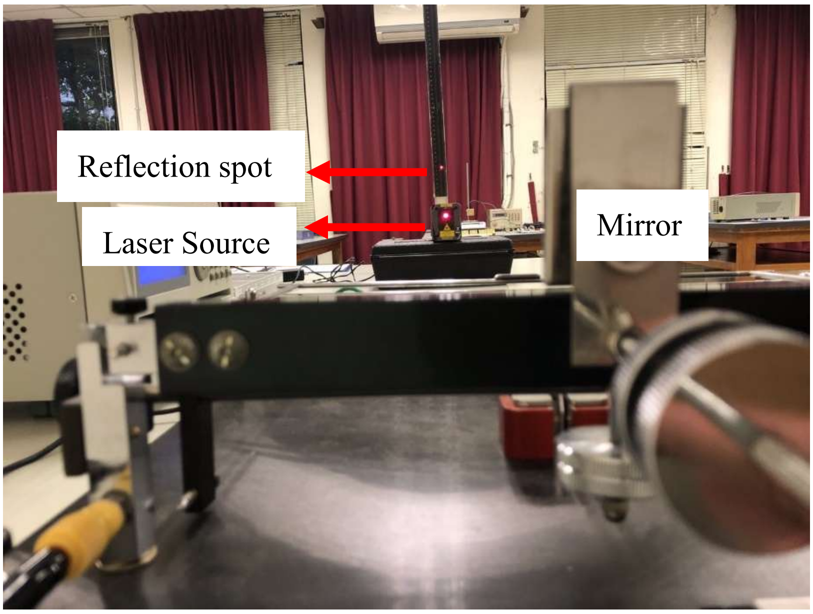
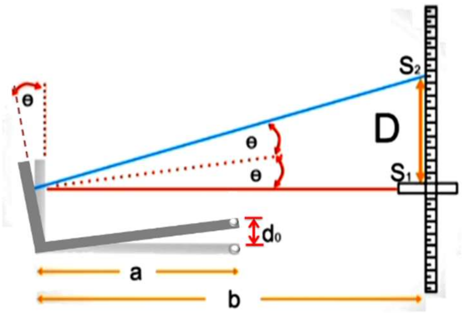


Fig. 7. Laser source and its image reflected by the mirror. Since the distance between two conducting wires is very small, here we use the "optical lever method" to enlarge the difference. (See pre-lab)

D. Procedures

1. Pre-lab assignments (hand in before the experiment)
   (1) Make a flowchart of this experiment and answer the questions below.
   (2) The SI unit of current is Ampere. What is the definition of one Ampere? Can Ampere be expressed in mass $\mathbf{M}$, length $\mathbf{L}$, and time $\mathbf{T}$? Explain in your own words.
   (3) In Fig. 3, eight magnets are used to form a large magnetic field. Describe the poles, N and S, for each magnet given the poles of the first magnet shown in the figure.
   (4) An optical lever is a convenient device to magnify a small displacement and thus to make possible an accurate measurement of the displacement. During the experiment, you will use an optical lever to magnify the extension of a wire produced by a series

of different loads. As Fig. 6 shows, a laser beam is reflected in the mirror and makes a light spot on the scales.



θ: deflected angle due to Lorentz force
d_0: displacement of the wire
D: displacement of the reflected spot
a: distance between mirror and current wire
b: distance between mirror and the scales

Refer to the picture above, and prove that if θ (or d_0) is small,

$$d_0 \approx \frac{aD}{2b}$$

Note that during the experiment, the radius r_0 of the wire should be considered so that the real distance is

$$\mathrm{d} = 2r_0 + d_0 = 2r_0 + \frac{aD}{2b}$$

(5) Prove that **the repulsion force per unit length** between two current-carrying wires is

$$f = \frac{\mu_0 I_1 I_2}{2\pi d} \left(\mathrm{N}/\mathrm{m} \right)$$

where I_1 and I_2 are the currents of the wires, d is the distance between them, and μ_0 is permeability of vacuum $\left(=4\pi\times10^{-7}\ \mathrm{N}/\mathrm{A}^2\right)$.

(6) Following Q6, how to use the formula to design an experiment of obtaining μ_0 by the current balance? Describe your idea in details. (Hint: Five different small objects are provided during the experiment. Also, how to fix d during the experiment?)

(7) Tesla and Gauss are common units of the magnetic field. Explain their definitions and find their relationship. Also, find the approximate value of magnetic field of the earth.

2. In-lab activities

(1) Measurement of Lorentz force

In this experiment, five wire loops of different lengths are used as shown in Fig. 2. Be careful of the arrangement of the magnets attached to the holder. **(pre-lab Q3)**

(i) To set up the experiment

(a) Mount the Main Unit on a lab stand having with a rod

(b) Select a Current Loop, and plug it into the ends of the arms of the Main Unit

(c) Place the Magnet Assembly on a balance with at least 0.01 gram sensitivity. Position the lab stand so the horizontal portion of the conductive foil on the Current Loop passes through the pole region of the magnets. ***The current Loop shouldn't touch the magnets and should be perpendicular to the direction of the magnetic field.***

(d) Connect the power supply as shown in Fig. 2.

(ii) To measure the force

(a) With the magnet assembly sitting on the balance, tare the reading by pressing the appropriate switch on the balance so that only the force caused by the current will be measured.

(b) Turn the current on. If the reading is negative, reverse the leads where they plug into the arms of the Main Unit. **(Why?)**

(iii) Varying the wire length L under the constant current $I = 2$ A

Five different trials are needed in this experiment. Make a graph of resulting Lorentz force F and the length of the wire L. Use the graph to estimate the magnitude of the magnetic field and compare the result with the measurement of Gauss meter. You would notice that the current loop is of a specific width. *Should the wire length be the maximum length L_1 of the current-carrying wire foil, the minimum length L_2, or the average $(L_1 + L_2)/2$?* **Measure the lengths and compare the results obtained from different lengths.**

(iv) Varying the magnetic field B under the constant current $I = 2$ A

Use the current loop of the longest length to do the experiment. The magnetic field is varied by changing the number n of magnets mounted on the Magnet Assembly. Five different trials are needed for this experiment. Make a graph of F and n, and explain the meaning of the result. ***(If the magnetic field is the measure of the magnetic flux density, why can we vary the magnitude of the B-field by changing the number of magnets?)***

(2) Measurement of a small unknown mass by Current Balance

(i) Set up the experiment as shown and described in Fig. 4, 5, 6. Notice that **the laser should be directed toward the wall** as shown in Fig. 4, and ***the power supply is on only when you are doing the measurement.***

(ii) Design an experiment to obtain the permeability of the air and compare the result with the standard value $(\cong \mu_0)$. Note that the working principle of the current balance is mentioned in the pre-lab Q5, Q6, and Q7.

(iii) Use the current balance to determine the mass of a small object and compare the result with the measurement of precision balance. The difference percentage between them should be **less than 5%.** Try to adjust the apparatus to reach this goal, and explain the uncertainty that occurs in your post-lab report.

3. Post-lab report

1. Recopy and organize your data from the in-lab tables in a neat and more readable form.
2. Analyze the data you obtained in the lab and answer the given questions

E. Questions

1. During the experiment, we don't bother with the influence of the earth's magnetic field. Estimate the effect of the earth's magnetic field for each experiment in this lab.

2. Following (1), find a way to erase the influence of the earth's magnetic field. (Hint: the power supplies used in the experiment both give **direct current (DC)** voltage to power the device. *What if we have used a AC power supply?*)
3. Explain the working principle of Gauss meter in your own words.
4. During the experiment, we use a small angle approximation while calculating the distance between two wires by the optical lever method. Estimate the percentage difference resulting from this approximation.
5. Find a way to measure the magnitude of the effective magnetic field in the lab by the current balance. (Hint: *change the direction of the current*)
6. **(Optional)** During the experiment of the current balance, we use the repulsion force of two conducting wires to obtain the unknown mass of a small object. Can we instead adjust the current so that two wires attract each other and obtain the unknown mass by this attraction force? What is the difference between these two methods? Which way is more practical?
7. **(Optional)** During the experiment of measurement of Lorentz force, it's obvious that the wire loop is of some specific width w. Find the theoretical value of the Lorentz force considering the width.

F. References

K. A. Fletcher, S. V. Iyer, and K. F. Kinsey , "Some Pivotal Thoughts on the Current Balance", The Physics Teacher 41, 280-284 (2003) https://doi.org/10.1119/1.1571263