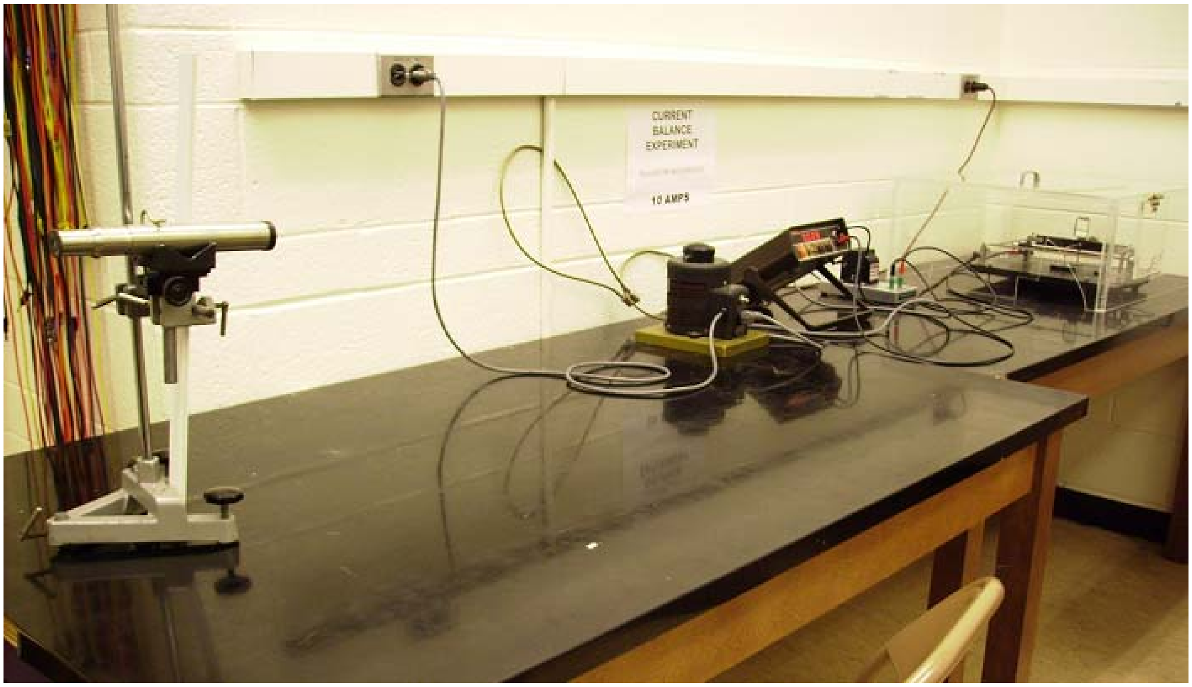
THE CURRENT BALANCE (2 weights)

REFERENCES

Physics for Scientists and Engineers: A Strategic Approach with Modern Physics by Randall D. Knight, 1st edition (Pearson, 2004), Chapter 32.



I. INTRODUCTION

This fundamental experiment defines the unit of current – the **ampere**. Andre Marie Ampere (1777-1863) showed that two parallel currents attract each other if the currents are in the same direction and repel each other if the currents are in opposite directions. The magnitude of force per unit length of the wire between two current-carrying wires is given by:

$$\frac{F}{l} = \frac{\mu_0}{2\pi}\frac{I_1 I_2}{d} \qquad (1)$$

where I_1 and I_2 is the current through each wire, d is the distance between the wires and μ_o is called *permeability of vacuum*. It is the fundamental physical constant to be determined in this experiment. In SI, μ_o is related to *permittivity of vacuum* ε_0 and the speed of light c as c = $(\mu_o\varepsilon_o)^{1/2}$. Equation (1) gives the unit for μ_o as N/A^2, however, T·m/A is used more often.

II. EXPERIMENT

In this experiment you will use a current balance in which the upper conductor is free to pivot on knife edges. The upper conductor is balanced so that the wires are a small distance apart. The conductors are wired in series to carry the same current but in opposite directions, so that the wires rather repel than attract. The force of repulsion can be measured indirectly by placing weights on the upper conductor pan.

Note that alternating current, rather than direct current, is used in the system. With the alternating current, the transformers can be used to adjust the voltage applied to the circuit, thus changing the current passing through it (Fig.1). There is another reason to use AC, not DC, in this experiment: think of the effect of the Earth's own magnetic field on a current-carrying conductor.

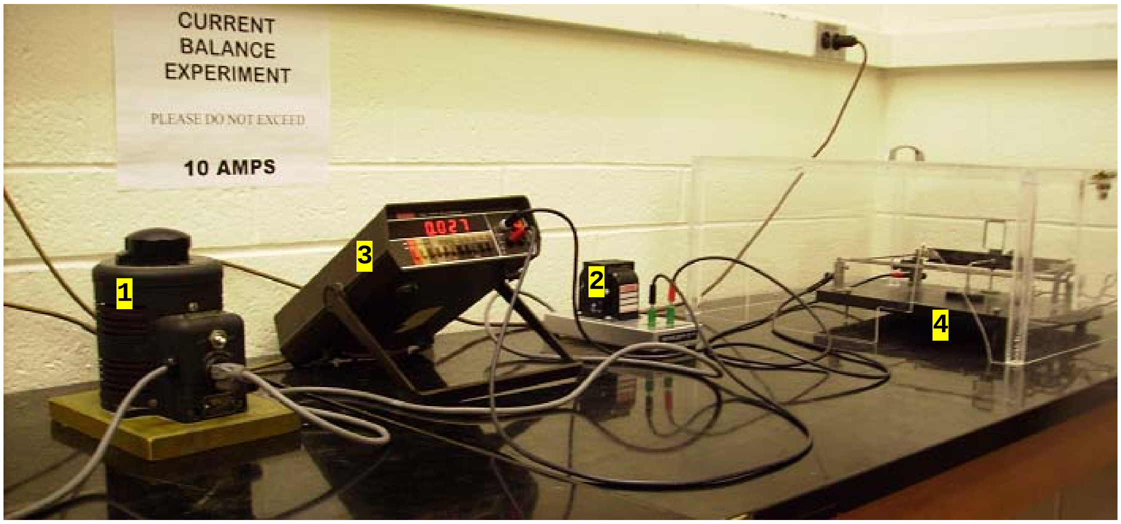


Fig. 1. Current balance circuit: 1 – autotransformer, plugged into the network with 120 V and 15 A; 2 – step-down transformer with output voltage of 6 V; 3 – ammeter; 4 – current balance in a protective box.

The variable transformer (an *autotransformer* in our setup) supplies a voltage to the *step-down transformer*, which in turn supplies the input voltage to the current balance circuit.

Examine the balance. The force between the conductors exerts a torque on the movable frame, which is balanced, by the torque of the unbalanced weight of the frame. The deflection of the movable frame is measured indirectly by observing the image of the scale reflected by the mirror attached to the frame.

First, be clear how any balance works. Knife edges never have exactly zero radius of curvature. Thus, a balance will come to rest at a continuum of positions, depending on both the loading difference and the mass distribution in the moving arm. Therefore, to obtain precise results, data must be taken **at a constant deflection**.

A. Deflection Measurements

In this experiment the deflection of the movable conductor is measured by an optical system. A small mirror is attached to the base of the frame. This mirror is tilted at small angles when the movable frame is deflected due to the magnetic force between two current-carrying wires. The deflection is measured indirectly by the displacement of the ruler’s scale reflected by the mirror. Figure out how to calculate the distance between the two conductors from the displacement of the image of the ruler observed in the eyepiece. Discuss the procedure with your TA if in doubt.

B. Procedural Notes

1. When the load is placed on the pan, the two wires should only be separated by a small distance; if the separation is too large, when the weights are removed and/or current is applied, the frame will

tip backward. Begin your measurements with the unloaded frame in a tilted position. Plot the deflection of the unloaded frame versus current.

2. Plot the deflection of the loaded frame versus current for various values (5-50 mg) of load on the pan of the moving conductor to obtain the family of curves of deflection versus current for various loads. Then take points from these curves to determine the relationship between the load and current at a constant deflection. (Since formula (1) is accurate only when the distance between the wires is much larger than their diameter, take points where the distance between the wires is relatively large.)

Note that in order to calculate the distance between two wires you also need the reading of the ruler's scale in the position when the two wires are touching each other (non-deflected frame). Hold the top wire down against the bottom wire, and read the ruler's scale in the eyepiece in this position. Remember that even when touching, the distance between the wires is non-zero *(2r)* because of the finite thickness of the wires.

Confirm that the load is proportional to the square of the current, and extract the value of μ_0 from your graph. Check the accuracy of the relationship $F \propto 1/d$.

C. Hints and Suggestions

- In this experiment, relatively large currents are used. If the equipment does not work, check fuses.

- Cover the current balance with the protective box during your measurements. The current balance is very sensitive even to the air circulation in the room.

- Never exceed 10 A current, or you may burn out the step-down transformer.

III. DISCUSSION

How does your value of μ_0 compare with the accepted value $\mu_0=4\pi x10^{-7}$ N/A^2 ≈ 1.26x10^{-6} N/A^2? In fact, if μ_0 is assigned this value, the force acting between currents in two parallel wires is the basis for the definition of one of the seven SI base units, **ampere**. The unit of electric current (**ampere**) can be defined as follows:

If two very long parallel wires one meter apart carry equal currents, the current in each is defined to be one ampere if the force per unit length on each wire is 2x10^{-7} newtons per meter of length.

This definition of the ampere makes the magnetic constant appearing in the Biot-Savart law for the magnetic induction $k_m=\mu_o/(4\pi)$ exactly equal to 10^{-7} T·m/A. The definition was adopted in 1946. It allows the unit of current, as well as the unit of electric charge, to be determined by a mechanical experiment. In practice, as you already know, the wires are chosen to be much closer together than 1m so that they do not need to be so long, and the force is large enough to be measured accurately.

(GMG:amk- Dec. 82, amk -Dec. 92, ta Aug.-2000, Dec. 2002)
(Updated by Dr. N.Krasnopolskaia, March 2008)