PHY 132 – Summer 2000
LAB 7: Current Balance[1]

Introduction

In this lab we look at the magnetic force between currents in long straight wires. We will see that this is proportional to the product of currents and inverse with their separation. This force in fact is used as an operational definition of the Sl unit of current: "The ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross section, and placed 1 meter apart in vacuum, would produce between these conductors a force equal to $2\pi\ 10^{-7}$ Newton per meter of length."

THEORY

The theory corresponding to this experiment is discussed in all physics textbooks. A wire of infinite length generates a magnetic field of magnitude B varying with the distance d from the wire as

$$B=\mu_0 I/(2\pi d) \qquad \text{Eq. 1}$$

and the force on a parallel wire of length L is given by

$$F = I\ L\ B \qquad \text{Eq. 2}$$

Combining these we have the magnetic force exerted by an infinite wire on a length L of another infinite wire parallel to it, carrying the same current I, is

$$F = \frac{\mu_0 L I^2}{2\pi d}, \qquad \text{Eq. 3}$$

where d is the distance between the two wires. The force is attractive if the currents are parallel, repulsive if the currents are antiparallel. The constant μ_0 is the so-called vacuum permeability constant. Since this is the definition of the ampere, we obtain

$$\mu_0 = 4\pi \times 10^{-7}\ \text{N/A}^2 \qquad \text{Eq. 4}$$

[1] Adapted by R. J. Jacob from P. Bennett, PHY-132 Lab Manual© (ASU)

In this lab, we will invert the logic, assuming we have valid calibrations of current (using current meters) and force (using calibrated weights), and thereby measure μ_0.

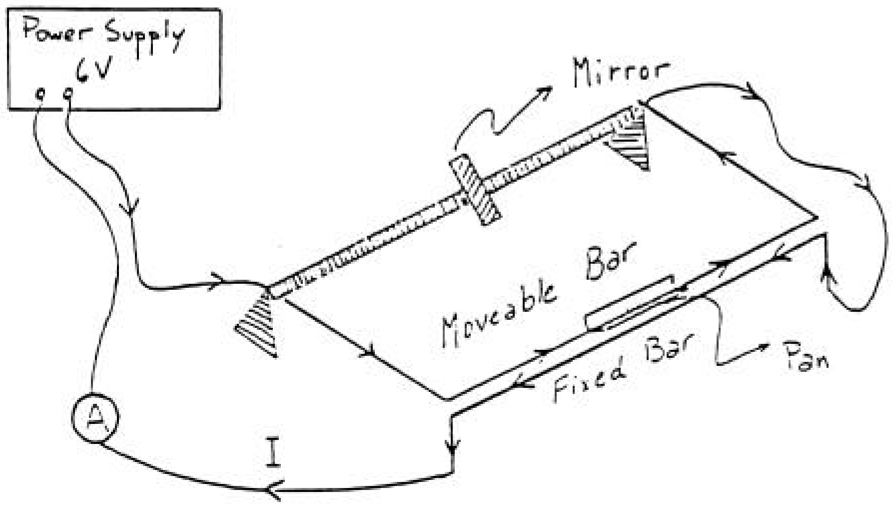


Fig. 1. The current balance apparatus.

You will use the current balance depicted schematically in Fig. 1. In this experiment, the current I is passed in opposite directions through the horizontal bars. The lower bar is fixed. The upper one is moveable and can be brought to a distance of a few millimeters from the fixed bar by means of an adjustable counter-weight. Once an equilibrium position (with no current) is reached, a small mass is added to the upper bar. To compensate for the added weight, a current I is circulated till the moveable bar returns to its original position. At this point, the magnetic force is equal to the weight of the added mass, so that you know all parameters of Eq. 1, except the distance d between wires. This distance can be measured with an "optical lever".

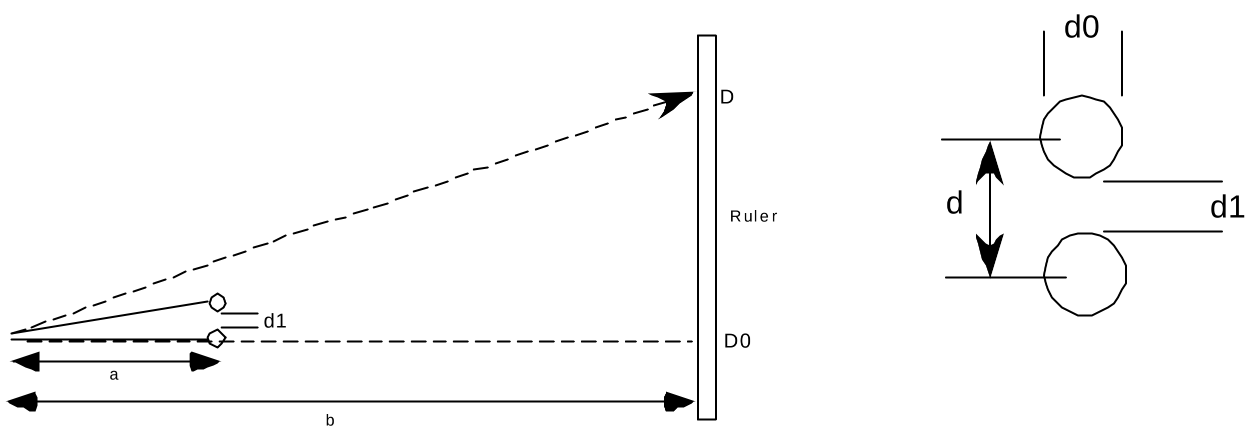
A mirror is attached to the moveable pan of the current balance. The image of a scale is reflected at this mirror and observed with a telescope. Small angular changes in the mirror produce large observable shifts in the image at the telescope, so that very small displacements of the moveable bar can be measured with precision. The parameters of the optical lever are shown in Figure 2. The physical lever has a pivot radius a. It and the radius of the optical lever , b, must be measured to within 1/10 mm. Note that the optical path has twice the deflection angle due to the mirror. Then, by "similar triangles", we have

$$2(d1/a) = (D-D0)/b \qquad \text{Eq. 5}$$

or

$$D = (2b/a)d1 + D0 \qquad \text{Eq. 6}$$

Note that D0 is the ruler reading when the rods are touching (d1=0). Note also that eq. 3 refers to the separation of rod *centers* given by d=d1+d0, where the rods have diameter d0=0.318cm.



Procedure

1. Measure a, b and L.
2. Adjust the balance to make d1 approximately 2 mm with no weight added.
3. Find D0 by setting I = 0 and sufficient weight that the rods touch (d1=0).
4. Now record (F, I) data for a range of forces (weights), starting with 0. Add masses and adjust I to bring back to original D. Take data both for increasing weights (up to 15 Amps) and repeat as you take off weights. This set of paired values serves to establish errors. CAUTION! Do not leave the power supply at high current for more than a minute.
5. Reverse both currents and repeat. This clever procedure allows you to compensate for the Earth's field (see below).

Analysis

1. Find μ_0 from linearized plots of your data. Do this separately for the two directions of current, then average these values. The net uncertainty is the average of the individual uncertainties in this case.
2. Is eq. 3 a good model for F(I)?
3. How would you modify eq. 3 to include the effect of the Earth's field? (Hint: consider a constant uniform B acting on both wires). How does this affect your determination of μ_0?
4. Does your value of μ_0 agree with the accepted value?