# Physics 2049C Laboratory 6
# The Current Balance

## Purpose

To use a current balance to measure the permeability of free space.

## Apparatus

Current balance, laser, power supply, ammeter, resistor, reversing switch, 10 mg weights, transparent ruler.

## I. Preliminary Discussion

If a current I is passes through an infinitely long straight wire, the resultant magnetic field produced outside the wire is given by

$$B = m_0 \frac{I}{2pd} \qquad (1)$$

where $d$ is the radial distance from the center of the wire and $m_0$ is the permeability of free space. If a second wire of length $L$ carrying the same current is placed parallel to the first wire it will experience a force given by

$$F = BIL = \frac{m_0 L I^2}{2pd} \qquad (2)$$

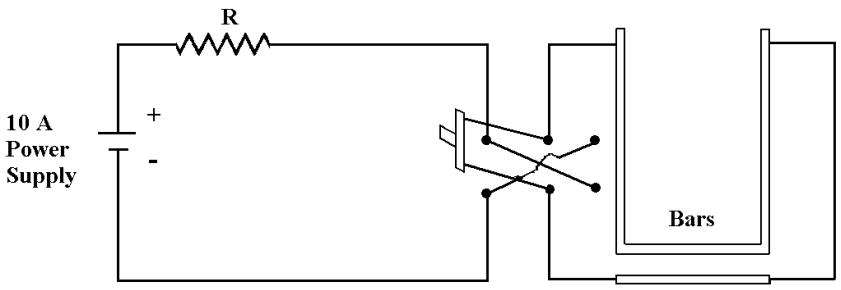
If the two currents are in opposite directions, then the two conductors will repel one another. The above expression will hold exactly only if the conductor setting up the magnetic field is infinitely long, but it will be sufficiently accurate for our experiment.

The above expression is used to define the ampere in the SI system. The definition of the ampere is as follows: "One ampere is the current which, if in a vacuum, causes each conductor, one meter apart, to experience a force of exactly $2 \times 10^{-7}$ newton per meter of length".

In this experiment, you will pass a current $I$ in opposite directions through two parallel horizontal metal rods which are connected in series. The lower rod is fixed, while the upper one is balanced a few millimeters above it by adjusting a counterweight. Attached to the upper rod is a small metal pan onto which analytical weights may be placed, thereby causing the upper rod to drop down toward the lower one.

When the current is turned on and carefully adjusted, repulsion between the two rods causes the

upper rod to return to its initial equilibrium position. The position of the upper rod is observed by utilizing a mirror attached to upper rod carriage assembly. A laser beam is reflected off the mirror and observed on a sheet of paper taped to the wall of the laboratory. With this experimental arrangement, you will be able to determine the relationship between the force on the upper conducting rod and the current passing through the conductors. You will then be able to determine the permeability of free space.




**Wiring diagram for the current balance**

## II. Experimental Procedure

- Align the two rods to be parallel by carefully observing their spacing from the front and top. Adjustment screws are provided for making the rods parallel in both directions. Do not bend the rods

- Connect the apparatus as shown in the diagram. Then insert an ammeter in the circuit in such a way that it measures the current leaving the power supply. (Hint: All the charge in the circuit must pass through the ammeter in order for it to indicate the number of coulombs/second.) DO NOT TURN ON THE POWER SUPPLY UNTIL YOUR INSTRUCTOR HAS CHECKED YOUR CIRCUIT.

- Clamp the laser at the end of the lab table so that the beam reflects off the mirror. Rotate the current balance so that the reflected laser beam passes directly back over the center of the laser and hits the wall. Tape up a sheet of paper where the laser beam strikes the wall. **Caution: Do not look directly into the laser beam**.

- Adjust the leveling screws in the base of the current balance so that it rests firmly on the table.

- Adjust the horizontal counterweight (at rear) until the upper rod is about 2mm above the lower fixed rod at equilibrium. Then place a transparent ruler on the piece of paper to draw a horizontal line passing through the center of the laser beam.

- Drop a 10 mg weight on the pan. Adjust the current (use white knob on the power supply)

until the laser beam returns to its equilibrium value on the sheet of paper and record the current. Do this as you approach equilibrium from above and below. Reverse the current and repeat (Why? ). Average these four current readings.

- Add 10 mg weights one at a time and record the currents as above. Do this until you have 100 mg. Should it be necessary to remove any weights, this should be done with great care with tweezers so as not to disturb the equilibrium position.

- Measure the length of the upper rod. The length $L$ is the distance between the supporting rods.

- You will need to know $d$, the center-to-center distance between the rods at equilibrium. This is measured as follows: Depress the upper rod by placing a 500 mg weight on the pan. Draw a point on the paper at the new position of the laser beam center. Measure the distance $D$ between the dot and the horizontal line. Measure the distance $b$ from the mirror to the horizontal line on the sheet of paper. Measure the lever arm $a$, which is the distance from the knife-edge to the center of the upper (moveable) rod. Do this at each side and take the average. Measure the diameters of the upper and lower rods at several places and take an average. Calculate the average rod radius $R$.

The distance $d_0$ between the surfaces of the two rods at the equilibrium position is given by (show why with a diagram)

$$d_0 = \frac{Da}{2b}.$$

The center-to-center distance $d$ is given by $d = d_0 + 2R$. (Show why with a diagram)

- Use your current data obtained above to plot the force $F$ as a function of $I^2$, and determine the slope of the resultant curve. (The magnetic force is just equal to the gravitational force mg which was required to balance it.) From this slope determine the value of the permeability of free space by using Eq. (2).