E&M Lab
Current Balance

1. Objectives:

To measure the force between two current-carrying wires, as a function of the current, and obtain an experimental value for permeability of free space.

2. Theory:

The magnitude of the magnetic field around a long, straight current-carrying wire is given by the formula:

$$B = \frac{\mu_0 I}{2\pi a}$$

where μ_0 is $4\pi \times 10^{-7}$ Tesla·meter/Ampere (the permeability of free space) and a is the radial distance from the center of the wire. The direction of this field is circular around the wire, with the sense given by a right-hand rule: point the thumb of the right hand in the direction of the current; then the fingers will point in the direction of the magnetic field.

If a second wire of length L is placed parallel to the first, and carries the same current in the opposite direction, then the two wires will repel each other with a force of magnitude

$$F = \frac{\mu_0 I^2 L}{2\pi d}$$

where d is the distance between the central axis of the wires.

3. Procedure:

1. Verify the current balance set-up that has already been wired for you. Ensure that all wires leaving the balance do so at right angles. (Note: AC is used because it is readily available for large currents; the results are the same as for DC.)

2. Set up the laser pointer and white sheet a distance of at least one meter from the mirror, in such a way that when the laser is activated a red dot is visible on the sheet. (This step may already be done for you.) The red dot on the white sheet is the laser's reflected image.

3. Measure the length L of the upper front bar from center-to-center of its two supporting arms. Also measure the lever arm, l, which is the distance from the knife-edge to the center of the front bar, obtained by measuring each side and taking the average. Then measure the distance S from the mirror to the white sheet (with a string).

4. Because the separation of the two front bars is small, the distance must be measured very carefully. Firstly, note the position of the laser's reflected image when the bars are in equilib-

rium position. Secondly, very gently place a coin on the pan to bring the bars in contact and note the new position of the laser's reflected image. Measure the distance, *D*, between these two positions on the white sheet.

5. Using a vernier caliper, measure the diameters of each of the bars, and obtain and record the corresponding radii r_1 and r_2.

6. Since the angle of incidence of a light beam equals the angle of reflection, it may be noted that the light beam between the mirror and white sheet (formed by the incident and reflected laser beam) rotates through twice the angle of rotation of the mirror. Hence, a little geometry will show that the equilibrium separation, d_0, between the two bars is given by:

$$d_0 = \frac{D\ell}{2S}$$

The center to center distance of the two bars, *d*, is then given by:

$$d = d_0 + r_1 + r_2$$

Take note of the value of *d* and use it for the rest of the lab as the distance between the bars.

7. Remove the coin and re-record on the white sheet the position of the red dot for equilibrium. You must re-record since the equilibrium position may have changed slightly from step 4. If the change is more than a couple of millimeters then you must repeat steps 4, 6 and 7.

8. With the auto-transformer (giant knob that controls AC voltage) set at zero, plug in the transformers. Turn the voltage up slightly to see if a current will flow in the circuit (read the current from the analog ammeter).

9. Place a 50 mg mass on the pan. USE THE TWEEZERS; do not touch the small masses with your fingers.

10. Increase the current until the bar is back at its original position, i.e., the laser's reflected image should return to its original equilibrium position as marked in step 7. Record the current (in Amperes) and weight (in Newtons). Use $g = 9.80665$ m/s2.

11. Repeat for masses of 70, 100, 120 mg, and so on, until the current reaches about 20A. Do not exceed 20A.

12. Plot *F* vs. I^2 and determine the slope. Prove that the slope of such a graph should be

$$\frac{\mu_0 L}{2\pi d}$$

Solve for μ_0 and compare with theory.