

## EXPERIMENT 7: THE CURRENT BALANCE

In our physics experiments we are not often able to calculate directly the value of fundamental constants, such as speed of light or one of the electromagnetic constants. However, by use of magnetic forces we are able to calculate the so-called magnetic permeability constant,  $\mu_0$ .

### ADVANCE STUDY ASSIGNMENT

1. Using the equation in the second paragraph of the background section, derive an expression for  $\mu_0$  from the slope of  $F$  vs  $i^2$  graph (see procedures 10 and 11) and the constants in the equation for  $F$  in the second paragraph.
2. Make a sketch of two parallel rods with opposite currents and show that the magnetic force between the rods is repulsive.

### BACKGROUND

The magnetic field due to a very long straight wire carrying a current  $i$  is given by  $B = \mu_0 i / (2\pi s)$ , where  $s$  is the perpendicular distance from the wire to the point at which the magnetic field is measured and  $\mu_0$  is the magnetic permeability constant. The value of  $\mu_0$  in free space is  $4\pi \times 10^{-7}$  Tm/A. The magnetic field direction is tangent to concentric circles about the wire, with the direction along the tangent given by the right hand rule. The magnetic force between a current carrying conductor also carrying a current  $i$  and of length  $L$  is  $\mathbf{F} = i \mathbf{L} \times \mathbf{B}$ , and is attractive for parallel currents and repulsive for antiparallel currents. Thus the force between two parallel conducting wires or rods carrying a common current  $i$ , both of length  $L$ , is given by  $F = \mu_0 Li^2 / (2\pi s)$ . In this experiment the two currents are actually alternating currents and the wires repel each other. The force may be experimentally determined by placing small masses on top of the upper rod, so that the repulsive magnetic force is balanced by the gravitational force pulling down on the small masses. Plotting  $F$  as a function of  $i^2$  using the equation above can experimentally determine the value of the magnetic permeability constant. The slope of the graph can be determined from that equation.

### PROCEDURE A

1. Place the current balance on a box on the table with rods in the East-West direction (parallel to the width of the table), near the center of the room. Level the apparatus using a circular level.
2. Make sure that the two conducting rods are in the same vertical plane, and are touching uniformly along their lengths. Adjust if necessary with adjusting thumbscrews, but DO NOT BEND the rods.
3. Check that the damping paddle is in the center of the magnet poles. Use the lifting mechanism (the large rotating silver knob opposite the rods) to test. The assembly should pivot freely without the paddle rubbing magnet poles.

- Measure the length of the rods  $L$ , between the centers of their supports, using a meter stick and two calipers, and measure the diameters,  $d$ , using a micrometer. Record in Data Table A.

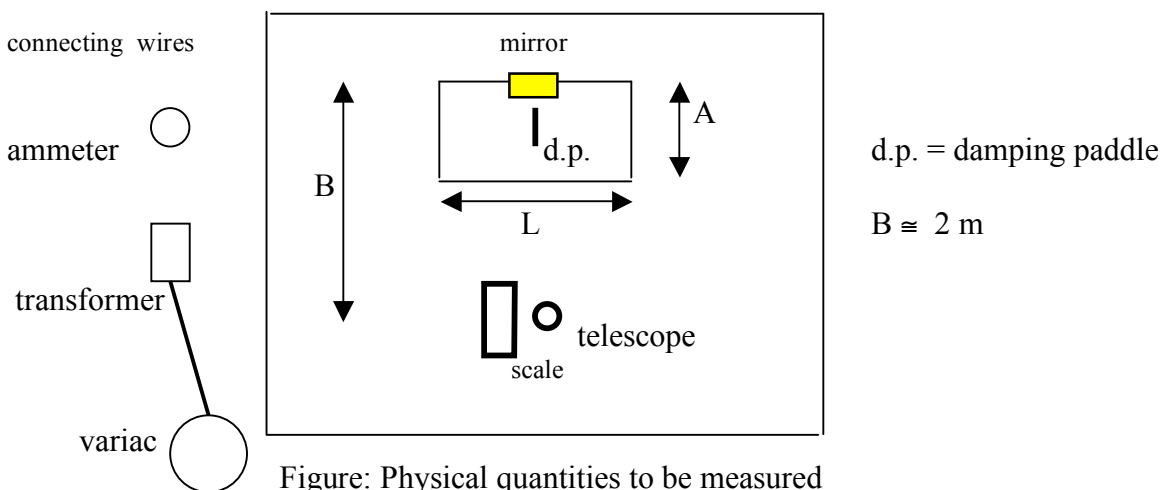


Figure: Physical quantities to be measured

- Measure the length of the lever arm,  $A$ , and the distance from the mirror to the scale,  $B$ . Obtain scale readings through the telescope at contact (two rods touching, using the small weight provided) and at equilibrium (with no weights on the small pan). The equilibrium position should be adjusted by moving the counterweight so the rods are separated by 1 to 2 cm. Record all measurements in Data Table A.

## PROCEDURE B

- Connect the apparatus to a transformer (plugged into the variac, a variable ac transformer with know on top) and AC ammeter, all in series connections, as shown in the figure above. Trace with your finger to see that the same current goes through both rods and ammeter. Place the variac at the opposite end of the table from the current balance, next to the telescope, which is mounted on a ring stand, with the scale.
- CAUTION: You will be using milligram masses which are easy to lose or misplace. Put the masses only in the box holding them or on the pan on the top rod.
- Place one or more milligram mass(es) on the top rod, with the size of the mass chosen so that it takes about 14 A to return the rod to equilibrium position, by adjusting the current with the variac. Divide this mass by 5, and place multiples of this quotient on the pan (first  $1/5m$ , then  $2/5m$ , etc.), and determine the current needed to return the rod to equilibrium position each time. Record on Data Table B. (The masses do not need to be exactly  $1/5 \text{ m}$ . Any masses approximately spaced between 0 and  $m$  will do; for example if  $m = 17 \text{ mg}$ , use 3, 6, 9, 12 and 17.)
  - Calculate  $d_0$ , the distance from top of bottom rod to bottom of top rod at equilibrium, by using  $d_0 = DA / (2B)$
  - Calculate  $s$ , the center to center distance of the rods by  $s = d_0 + d$ .
  - Graph the applied force  $F=mg$  vs  $i$ , and also  $F$  vs  $i^2$ .
  - Use the information from the  $F$  versus  $i^2$  graph (that is, the slope) and the values of  $s$  and  $L$  to determine  $\mu_{0(\text{exp})}$ .
  - Calculate a percent error.

**DATA TABLE A**

Length of lever arm, A _____	Average rod diameter, d _____
Distance from mirror to scale, B _____	Average rod length, L _____
Scale reading at contact _____	$d_0$ _____
Scale reading at equilibrium _____	s _____
Difference in scale reading, D _____	

**DATA TABLE B**

M (kg)	F = mg (N)	i (A)	i <sup>2</sup> (A <sup>2</sup> )

Slope \_\_\_\_\_

$\mu_0$  \_\_\_\_\_

**QUESTIONS**

1. What is the shape of the F vs i graph and the F vs i<sup>2</sup> graph? Is this justified from the theory? Explain.
2. Derive the equation  $s = d_0 + d$  with an end-on sketch of the rods at equilibrium separation..
3. Derive  $d_0 = DA / (2B)$  by drawing a sketch of the apparatus and mirror and using a small angle approximation  $\tan \theta = \text{arc length} / \text{radius}$ . Hint: for the reflection in the mirror, angle of reflection = angle of incidence, and the angle is 2 $\theta$  for D and B, compared to  $\theta$  for  $d_0$  and A.)