

Object: Using a current balance, measure the magnetic force between two parallel current-carrying wires, and thereby determine the magnetic permeability constant, μ_o .

Theory: A magnetic field \mathbf{B} will exert a force on a wire carrying a current I according to the relation

$$\mathbf{F} = I\mathbf{L} \times \mathbf{B} \quad (1)$$

where \mathbf{L} is the vector in the direction of I and the magnitude L is the length of the wire segment.

Also, according to Ampere's Law, an electric current produces a magnetic field at point P with a magnitude of

$$B = \frac{\mu_o I}{2\pi r} \quad (2)$$

where μ_o is the magnetic permeability constant and r is the perpendicular distance from the current to P .

Combining these two relations (and changing variables from r to d) results in the force between two parallel current-carrying wires in the form

$$F = \frac{\mu_o L I_1 I_2}{2\pi d} \quad (3)$$

where d is the distance between the currents. We will route the same current through both wires so that $I_1 = I_2 = I$. A plot of F vs. I^2 should be a straight line whose slope involves μ_o .

If the currents flow in the same directions the force is attractive; if in opposite directions, repulsive. (Use this to your advantage to create a stable equilibrium with the current balance.)

There is a second method of obtaining μ_o . When wire is wound around an air-core solenoid and a current I is established in the windings, a magnetic field \mathbf{B} is produced inside the hollow solenoid which can be measured with a gaussmeter and has magnitude

$$B = \mu_o n I \quad (4)$$

where n is the number of windings per unit length.

Procedure:

1. Set up the Coulomb Balance with the straight rods (wires) rather than the plates used to obtain ϵ_0 . Examine the rods for straightness and align them by placing a coin on the scale pan to bring the rods into contact. Check alignment from various perspectives. Remove the coin.

2. This experiment may be done in either DC or AC modes of operation. When done with direct current the Earth's field will cause erroneous results. This may be compensated for by switching the direction of the current and averaging the values obtained, or by orienting the instrument at right angles to the Earth's field.
3. First measure the center-to-center distance d between the wires in a zero-current equilibrium position. Note the position of your laser beam on the wall.
4. With the current routed to go one way in one wire and then the opposite way in the other wire so the force is repulsive, turn up the power supply so the rods separate. (Always keep the current below the rated value of the power supply, usually about 4–7 A.)
5. Add small weights to the scale pan to bring the rods back to their original equilibrium separation (*i.e.*, the laser beam returns to its original position on the wall).
6. Starting each time with the same zero-current d , vary I and note the amount of weight needed in each case to restore the balance to the original separation. Plot F vs. I^2 and compute μ_0 from the least squares slope (see equation 3). Compare with the exact defined value of $\mu_0 = 4\pi \times 10^{-7} \text{ T}\cdot\text{m/A}$.
7. Repeat the whole experiment with a different starting separation d by adjusting the counterpoise.
8. Use the second method of determining μ_0 by plotting the magnetic field inside a solenoid (as measured by a gaussmeter) vs. the current in the windings for various values of the current (don't use as much current as in the previous procedures). Subtract the contribution from the Earth's field. Calculate μ_0 from the least squares slope of B vs. I . Report your error.

Questions:

1. Why is the force between currents method of determining μ_0 more fundamental than the solenoid method?

Conclusions: