

Magnetic Balance

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Object:

To study the forces between two magnetic poles as a function of the distance from one another, to measure their magnetic strengths, and to determine the effect of current loops on a magnetic pole.

Apparatus:

A magnetic balance set, 1 gm counterweights, a Helmholtz coil, a rheostat, voltage source, and connecting wires.

Please make sure that you have graph paper (10 mm to 1 cm).

Theory:

Part 1

Two magnetic poles of strengths M_1 and M_2 placed in air exert forces upon one another according to the relationship

$$F_{\text{mag}} = \mu_0 M_1 M_2 / (4\pi d^2) \quad (1)$$

where F_{mag} is the force in newtons (N),

$\mu_0 = 4\pi \cdot 10^{-7}$ N/A² is the permeability of free space;

the M_1 and M_2 are the pole strengths in ampere-meters,

and d is the distance between the poles in meters.

It is possible to validate this relationship without specifically knowing the magnitudes of M_1 and M_2 . This is done by plotting the force versus the reciprocal of the distance squared (F_{mag} versus $1/d^2$). If this results in a straight line, then the relationship has been verified. The slope of this line is $\mu_0 M_1 M_2 / 4\pi$. If we assume that M_1 and M_2 are equal, then the slope of the line is equal to $\mu_0 M^2 / 4\pi$, where M is the pole strength of either pole.

A magnetic balance, such as the one diagrammed at Fig. 1, may be used to investigate this relationship. The force is not measured directly but may be calculated from measurements made with the apparatus. When set up properly, there is a counterclockwise torque on the balance arm from the magnetic forces on one end and a clockwise torque resulting from the added mass on the other. When the balance arm is at the equilibrium point, the clockwise torque about the fulcrum is equal the counterclockwise torque. (The balance arm and the masses which are attached to its ends produce no net torque since they are distributed symmetrically about the fulcrum, therefore they need not be considered). The weight due to the added mass, m_A , and the magnetic force, F_{mag} , are the forces which affect the equilibrium of the balance. Equating the counterclockwise torques with the clockwise torques results in

$$F_{\text{mag}} L = m_A g L_A \quad (2)$$

where g is the gravitational constant and L_A is the moment arm of the force $m_A g$, $L=10$ cm=0.1 m for the apparatus used. Solving for F_{mag} gives

$$F_{\text{mag}} = m_A g L_A / L. \quad (3)$$

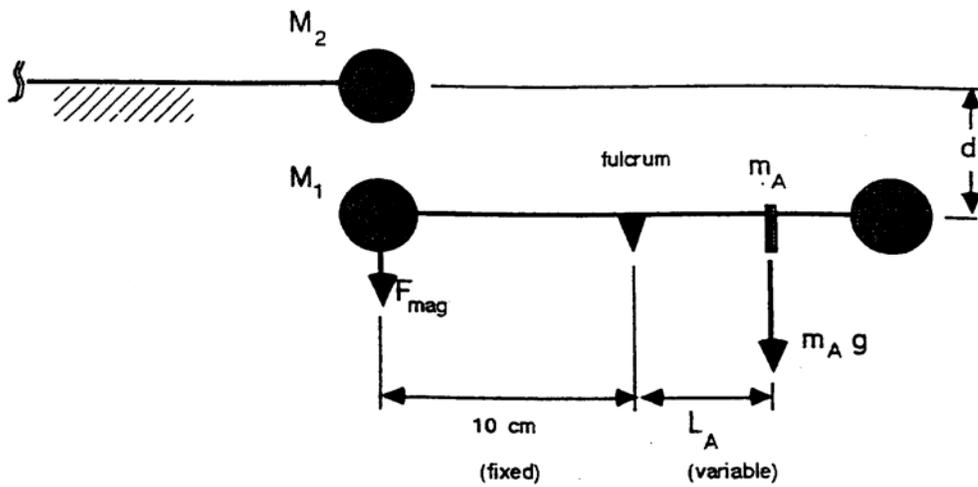


Figure I. Magnetic Balance

Part 2

In the first part of this experiment, we observed the repulsive force between magnetic poles of opposite polarity. This repulsive force results from the magnetic field of one pole acting on the other pole. If the magnetic field is represented by \mathbf{B} , in (N/A m), the force on a single magnetic pole is represented by the following equation.

$$\mathbf{F} = \mathbf{MB} \quad (4)$$

The magnetic field acting on \mathbf{M}_1 in part one can be generated without the use of \mathbf{M}_2 but by placing \mathbf{M}_1 in the center of what is known as a Helmholtz coil (see Figure II).

Two coils which are separated by a distance equal to their radius and carry equal currents such that their axial fields add are called Helmholtz Coil. The magnitude of the magnetic field in the center of a Helmholtz coil is given by the following equation:

$$\mathbf{B} = 8\mu_0 \mathbf{N I} / [a (125)^{1/2}] \quad (5)$$

Where \mathbf{N} is the number of turns of one coil, \mathbf{I} is the current through the coil, and \mathbf{a} is the radius of the coil.

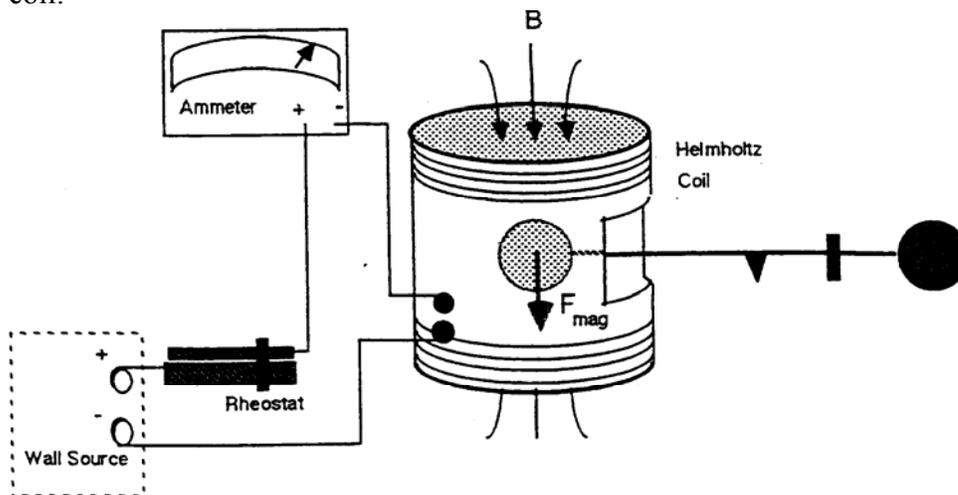


Figure II. Magnetic Balance With Helmholtz Coil

Procedure:

Part 1

1.

- With the magnetic poles, \mathbf{M}_2 , removed from the apparatus and placed away from \mathbf{M}_1 , use the fine adjustment screws to set the pointer on the balance at the equilibrium point.
- With \mathbf{M}_1 balanced, measure its equilibrium height, h_0 . This is used as the reference point for determining the distance d between \mathbf{M}_1 and \mathbf{M}_2 . (Keep in mind that d represents the distance from center to center; but since the dimensions of \mathbf{M}_1 and \mathbf{M}_2 are the same, d may be measured from any point on \mathbf{M}_1 to the corresponding point on \mathbf{M}_2 . This may simplify further measurements.)
- Weigh the counterweight m_A .
- Replace \mathbf{M}_2 on the apparatus. Make sure it is oriented such that \mathbf{M}_1 deflects downward. Align \mathbf{M}_2 so that its right hand pole (sphere) is directly over the left hand pole of \mathbf{M}_1

2.

- Place the counterweight in the 1 centimeter slot and adjust the height of \mathbf{M}_2 until the pointer is at the equilibrium point. Record the height of \mathbf{M}_2 on your data page.
- Repeat step 2a. with the counterweight in the 2 centimeter through 9 centimeter slots, respectively.

Part 2

- Connect the circuit as shown in Figure II. The polarity should be such that a current through the coil forces \mathbf{M}_1 downward.
- Place the counterweight in the 5 centimeter slot and adjust the current until the balance is at the equilibrium point. Record the current I .
- Repeat step 2 with the counterweight at two (or more) other positions.

Data Analysis

Part 1

- Plot F_{mag} versus $1/d^2$ from the data obtained above on linear graph paper and draw your best straight line through the points as discussed previously in the theory section.
- Assuming that \mathbf{M}_1 is equal to \mathbf{M}_2 , calculate the magnetic pole strength \mathbf{M} from the slope of this line.

Part 2

As in the first part, when the balance arm is at the equilibrium point when the clockwise and counterclockwise torques are equal, and the following expression may be written:

$$\mathbf{M}_1 \mathbf{B} L = m_A g L_A.$$

- Calculate \mathbf{B} using equation 5. Using the value for \mathbf{B} , calculate the value for \mathbf{M}_1
- Calculate average \mathbf{M}_1 for all measurements.
- Compare your average value for \mathbf{M}_1 in this part with the value of \mathbf{M}_1 from the first part. Discuss possible sources of disagreement between these two values.