EXPERIMENT 9

Magnetic Field of Helmholtz Coils

Purpose:

- To investigate the spatial distribution of the magnetic field strength between a pair of coils in the Helmholtz arrangement for different separation distances
- To investigate the spatial distribution of the magnetic field strength between a pair of coils when the currents in the coils flow in parallel and in opposite directions

Experimental Instruments:

- 1 pair of Helmholtz coils
- 1 power supply (12 V and approx. 2A DC)
- 1 digital multimeter
- 1 teslameter (0-100mT/3000mT)
- 1 Hall probe
- 1 barrel base, 1 support rod, 1 right angle clamp, 3 G-clamp
- Connection cables

Theoretical Information:

Magnetic field at a distance s from the center of a uniformly wound one coil with length l containing N turns can be calculated by the Biot-Savartz law as given in Eq. (9.1). In this equation, r represents the radius of the coil, I is the current in one loop and μ_0 is the magnetic permeability of free space (μ_0=1.26×10^{-6} H/m).

$$B = \frac{\mu_0 N I r^2}{2(r^2+s^2)^{3/2}} \tag{9.1}$$

A pair of flat circular coils with equal numbers of turns and equal radius, arranged with a common axis, and connected in series is referred to as **Helmholtz coils**. A nearly uniform magnetic field can be formed with Helmholtz coils. When the distance between the two coils equals to the radius of one of the coils, the magnetic field between the coils becomes totally uniform.

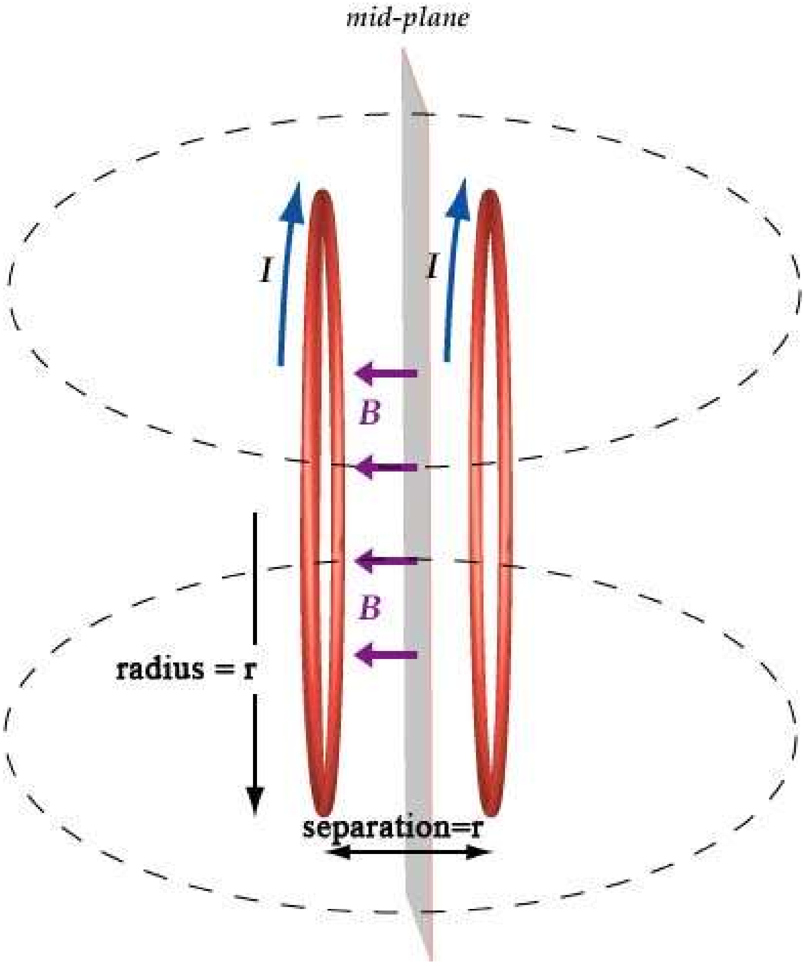

Figure 9.1 Magnetic field lines for Helmholtz coils separated by a distance r

Magnetic field at any point along the central axis of Helmhotz coils can be found by summing the individual magnetic fields of each coil via the superposition principle. For example, the magnetic field at the center of the Helmholtz coils is two times the magnetic field of a single coil.

If the two coils lie on the center axis with a distance *a*, the magnetic field at a distance *s* away from the center of the coils (Figure 9.2) can be calculated by Eq. (9.2) and (9.3).

$$B=\frac{\mu_0 N I r^2}{2}\left[\frac{1}{\left(r^2+\left(s-\frac{a}{2}\right)^2\right)^{3/2}}+\frac{1}{\left(r^2+\left(s+\frac{a}{2}\right)^2\right)^{3/2}}\right] \tag{9.2}$$

$$B=\frac{\mu_0 N I}{2r}\left[\frac{1}{\left(1+\left(s-\frac{a}{2r}\right)^2\right)^{3/2}}+\frac{1}{\left(1+\left(s+\frac{a}{2r}\right)^2\right)^{3/2}}\right] \tag{9.3}$$

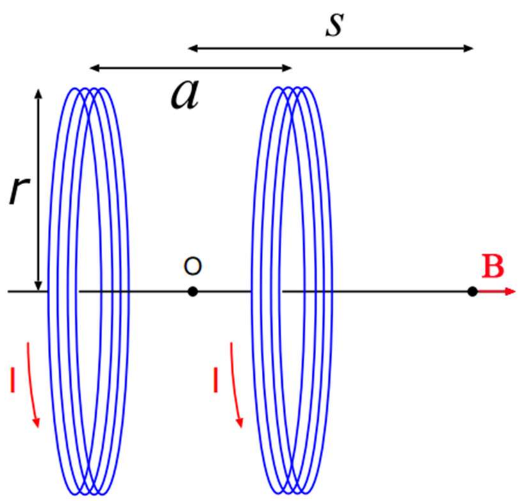

Figure 9.2 Magnetic field vector component along the central axis of Helmholtz coils at distance s.

Experimental Procedure:

1. Connect the coils in series and in the same direction as seen in **Figure 9.3**.
2. Place the coils with $a = r = 6.8$ cm separation. Note that the radius, r, of the coils is also 6.8 cm.
3. Calibrate the Teslameter and Hall probe by using a calibration coil. Do the zero setting of the Teslameter and Hall probe.
4. Increase the voltage of the power supply until you read 1 A from the multimeter.

WARNING: The coils withstand maximum to 1.5 A current. Therefore, avoid increasing the current more than 1 A. Set the current to zero after each step of measurement before moving the Hall probe for the next measurement.

5. Move the Hall probe along the axis of the coils and notice the variation of the magnetic field. Check whether the magnetic field has its maximum value in the middle.
6. Measure the magnetic field with 5 mm steps along the axis of the coils starting from the end of the first coil to the beginning of the second coil.
7. Note the measured values in **Table 9.1**.
8. Change the separation distance between the two coils to $a=2r$ and note the measured magnetic field of the Hall probe with 5 mm steps to **Table 9.2**.
9. Turn the pair of coils through 90° so that the current direction of one coil becomes opposite to the other one. The separation distance of two coils is again $a=2r$. Move the Hall probe along the axis of the coils and note the measured magnetic field in 5 mm steps to **Table 9.3**.

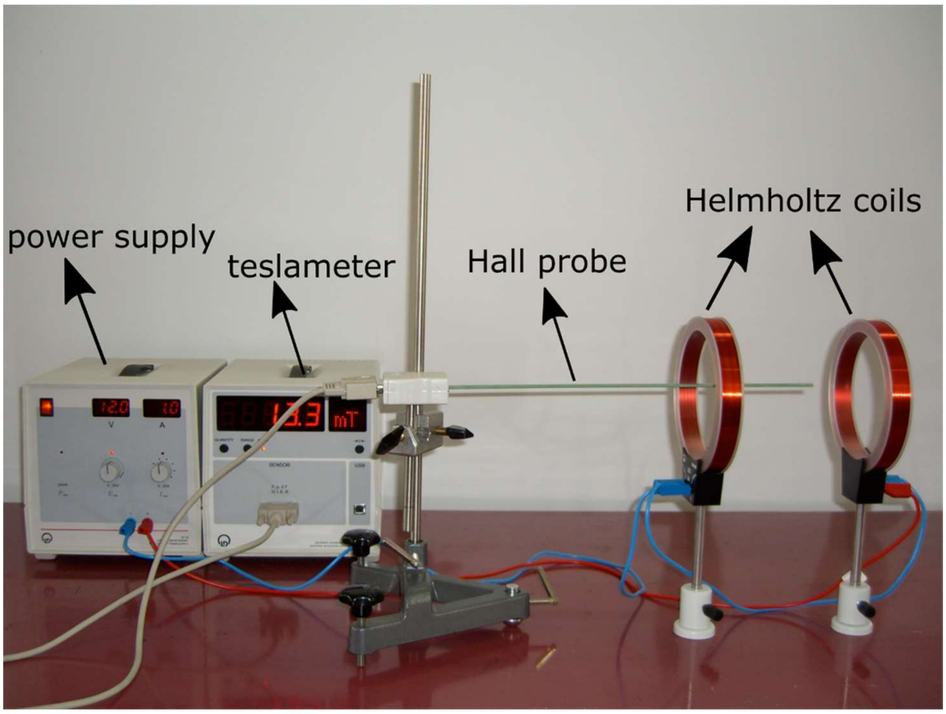

Figure 9.3 Experimental setup

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DATE :

GROUP ID :

Student ID	**Name Surname**	**Signature**

Experiment Expectation	

CALCULATIONS AND RESULTS:

Table 9.1 Measured magnetic field values when a = r and the currents in the two coils are parallel

x (mm)	**B (mT)**

- Plot a graph of the magnetic field B versus distance x by using your data.

Table 9.2. Measured magnetic field values when a = 2r and the currents in the two coils are parallel

x (mm)	**B (mT)**

- Plot a graph of the magnetic field B versus distance x by using your data.

Table 9.3. Measured magnetic field values when *a* = 2r and the currents in the two coils are in opposite direction.

x (mm)	**B (mT)**

- Plot a graph of the magnetic field versus distance by using your values in Table 9.3.

DISCUSSION AND COMMENTS:

1) Calculate the magnitude of the magnetic field for the middle point between the coils used in this experiment for *a*=r and *a*=2r arrangements. Compare your answer with your measured value and compute the percent error between the measured and theoretical values. What factors may have caused the difference, if any?

2) How does the magnetic field change as the separation distance between the coils increase? Why?

3) If we reverse the direction of the current in one coil, how will this affect the magnetic field at the center of the two coils? Explain your reason.