1. Experimental Contents

1) Measure the magnetic field intensity point by point along the axis of a single current-carrying coil, and compare results with theoretical values.
2) At fixed current, measure on-axis magnetic field intensities $B(a)$ and $B(b)$ of two single coils a and b, and compare with the magnetic field intensity $B(a+b)$ of Helmholtz coils.
3) Measure the magnetic field distribution along the axis of Helmholtz coils with different coil spacing of $R/2$, R, and $2R$, and verify the magnetic field superposition principle.
4) Plot the magnetic field distributions of a single current-carrying coil and Helmholtz coils, respectively.
5) Measure the horizontal component of the earth's magnetic field.

2. Experimental Procedure

A. Measure magnetic field intensity on central axis of a single coil and Helmholtz coils

1) For a single coil, refer Figure 1 to connect wires of coil a and set the current of the coil to I=100 mA. Move the probe and measure magnetic flux density $B(a)$ along the axis of coil a by recording data in every 1.0 cm. **Note**: prior to measurement, turn off current (I=0 mA) and zero the Tesla meter.
2) Compare the measured magnetic field intensity at the center of the coil with theoretical value.
3) Rotate the Tesla probe at a point along the axis while observing the direction of the magnetic field at this point.
4) For Helmholtz coils, adjust the spacing between the two coils to 10.0 cm for the formation of Helmholtz coils.
5) Set current at I=100 mA to single coil a and b, respectively, while measuring magnetic field intensities $B(a)$ and $B(b)$ along axis, respectively. Next, apply current to both coils simultaneously while measuring magnetic field intensity $B(a+b)$ along the axis. Verify $B(a+b)=B(a)+B(b)$, the magnetic field intensity at any point along the axis of Helmholtz coils is the summation of that of two single coils.
6) Adjust the spacing of the two coils at $R/2$ and $2R$, respectively while measuring the magnetic field intensity along the axis at current I=100 mA.
7) Plot magnetic field intensity B of the Helmholtz coils versus position z (B~z graph) at $d=R/2$, $d=R$, and $d=2R$, respectively. Verify the magnetic field superposition principle.

B. Map the magnetic induction lines on a plane through the axis of a current-carrying coil

Place a piece of coordinate paper on the board which is through the axis of the Helmholtz coils, select a proper point, aim the probe at the point, and apply current I=100 mA to the Helmholtz coils. Rotate the probe while observing the change in magnetic field intensity. The normal direction of the sensor at which a maximal reading is observed from the sensor is the direction of the magnetic field at this point. Compare the directional change in magnetic field between on-axis points and off-axis points. Approximate the distribution map of the magnetic field lines of current-carrying Helmholtz coils.

3. Examples of Data Recording and Processing

Note: Following data are for reference purposes only, not the criteria for apparatus performance.

1) Measure the magnetic field intensity $B(a)$ on the axis of a current-carrying coil (a) are shown in Table 1, where current I=100 mA, coil average radius R=10.00 cm, number of turns of the coil N=500, and the permeability in vacuum $\mu_0=4\pi\times10^{-7}$ H/m.

Table 1

x (cm)	-1.00	0.00	1.00	2.00	3.00	4.00	5.00
$B(a)$ (mT)	0.300	0.316	0.312	0.297	0.278	0.251	0.225
x (cm)	6.00	7.00	8.00	9.00	10.00	11.00	12.00
$B(a)$ (mT)	0.198	0.173	0.150	0.130	0.113	0.097	0.083

According to formula (2), the magnetic field intensity at the center of coil a is as follows:

$$B_0(a) = \frac{\mu_0}{2\overline{R}} N \cdot I = \frac{4\pi\times10^{-7}\times500\times0.100}{2\times0.1000} = 0.314 \text{ mT}$$

In Table 1, the measured result at the center is $B_0(a)$=0.316 mT, yielding a measurement error of 0.64%.

According to formula (1), the magnetic field intensity at x=5.00 cm is calculated as:

$$B_5(a) = \frac{\mu_0 \cdot \overline{R}^2}{2(\overline{R}^2 + x^2)^{3/2}} N \cdot I = \frac{4\pi\times10^{-7}\times0.100^2\times500\times0.100}{2(0.100^2+0.0500^2)^{3/2}} = 0.2248 \text{ mT}$$

In Table 1, the measured result at x=5.00 cm is $B_5(a)$=0.225 mT, yielding a small measurement error.

2) Verify magnetic field superposition principle. The current in Helmholtz coils is I=100 mA, and the spacing of the two coils is d=10.00 cm. Set the central point of the two coil axis as the coordinate origin. Measured data are shown in Table 2, where a and b represent single coil a and b, respectively; and *(a+b)* represents Helmholtz coils.

Table 2

x (cm)	-7.00	-6.00	-5.00	-4.00	-3.00	-2.00	-1.00	0.00
$B(a)$ (mT)	0.295	0.309	0.316	0.312	0.297	0.278	0.251	0.225
$B(b)$ (mT)	0.080	0.093	0.112	0.128	0.148	0.172	0.195	0.224
$[B(a)+B(b)]$ (mT)	0.375	0.402	0.428	0.440	0.445	0.450	0.446	0.449
$B(a+b)$ (mT)	0.381	0.408	0.428	0.440	0.448	0.451	0.450	0.451

x (cm)	1.00	2.00	3.00	4.00	5.00	6.00	7.00
$B(a)$ (mT)	0.198	0.173	0.150	0.130	0.113	0.097	0.083
$B(b)$ (mT)	0.251	0.275	0.296	0.308	0.312	0.307	0.394

[$B(a)$+$B(b)$] (mT)	0.449	0.448	0.446	0.438	0.425	0.404	0.377
$B(a+b)$ (mT)	0.451	0.451	0.448	0.441	0.427	0.405	0.379

From Table 2, it is apparent that the values of $B(a)+B(b)$ and $B(a+b)$ are consistent within error limit, proving the magnetic field superposition principle. Range from -2.50 cm to 2.50 cm has a uniform magnetic field. At x=0.00 cm, the measured magnetic field intensity is B_0=0.449 mT while the corresponding theoretical value can be calculated using formula (4):

$$B_0^{'} = \frac{8}{5^{3/2}} \cdot \frac{\mu_0 \cdot N \cdot I}{\overline{R}} = \frac{8}{5^{3/2}} \frac{4\pi \times 10^{-7} \times 500 \times 0.100}{0.1000} = 0.450\,\mathrm{mT}$$

Therefore, the error limit is within 1%.

3) Change the spacing between the two coils, at $d=R/2$, $d=R$, and $d=2R$, respectively, while measuring the magnetic field intensity at various positions along the axis. Measured data are plotted as shown in Figure 2.

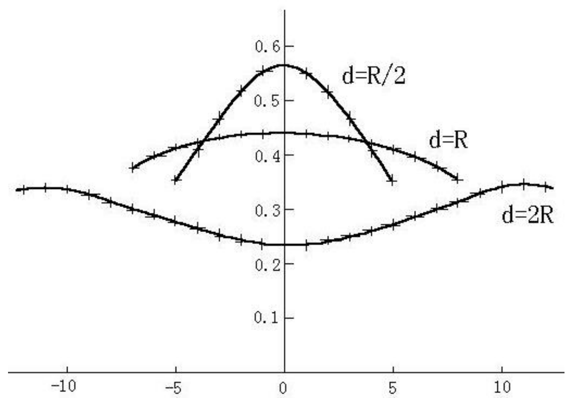

Figure 2 Magnetic field intensity distributions with different coil spacing