Magnetic field variation along the axis of a circular coil and a Helmholtz coil

Aim: 1) To study the variation of magnetic field along the axis of a circular coil

2) To study the principle of superimposition of magnetic field using a Helmholtz coil

Apparatus:

Constant current Power supply DC 0-16 V, 5 Amp, Digital Gauss meter with Axial Hall Probe (Transducer), Current carrying coil with 390 turns (N), Diameter 150 mm, support base and stand, Deflection compass, multimeter and connecting leads

Theory: The intensity of magnetic field at a point 'P', lying on the axis of a circular coil 'AB' or radius 'a' having 'n' turns at a distance 'x' from the centre 'O' of the coil in S.I. units, is given by

$$\vec{B} = \frac{\mu_0}{4\pi} \cdot \frac{2\pi n I a^2}{(a^2 + x^2)^{3/2}} \hat{x}$$

Where I is the current flowing through the coil, μ_0 is the permeability of free space, which is equal to $4\pi \cdot 10^{-7}$ H/m.
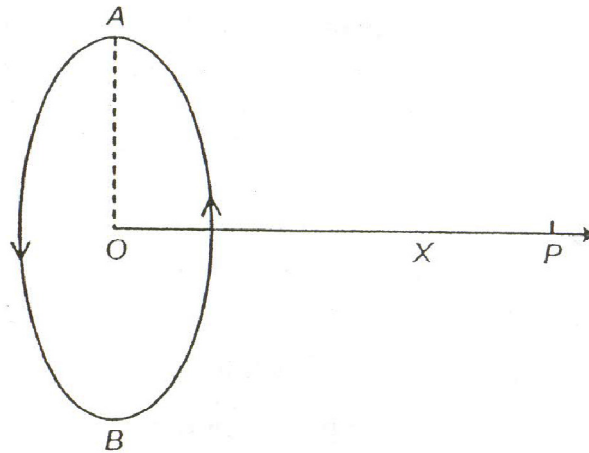

Fig. 1

The direction of the magnetic intensity at P is along OP if the current flows through the coil in the anti-clock-wise direction as seen from P. If the direction of the current is clockwise the field at P is along PO.

The value of the magnetic intensity is maximum at the centre of the coil and is given by

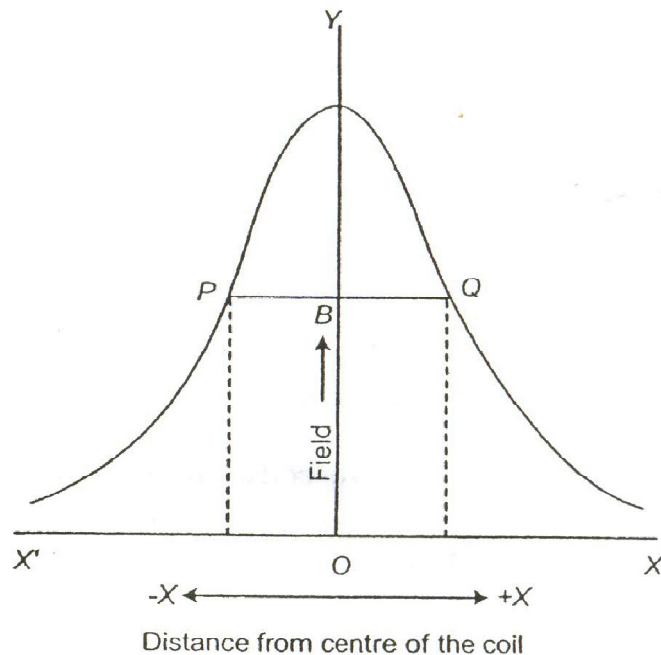$$\vec{B} = \frac{\mu_0}{4\pi} \cdot \frac{2\pi n I}{a} \hat{x}$$

Fig.2

If we move away from O towards the right or left, the intensity of the magnetic field decreases. A graph showing the relation between the intensity of the magnetic field B and the distance x is given in Fig.2. The curve is first concave (towards O) but the curvature becomes less and less, quickly changes sign at P and Q and afterwards becomes convex towards O. It can be shown that the points of inflexion P or Q where the curvature changes its sing lie at distances 'a/2' from the centre. Hence the distance between P and Q id equal to the radius of the coil.

A pair of current carrying coils connected in series and separated by radius of the coils is known as Helmholtz coil. Helmholtz coil produces a uniform magnetic field between the coils, which is given by

$$\vec{B} = \frac{8\mu_o NI}{\sqrt{125}R} \hat{x}$$

Procedure

i. Using spirit level verify and adjust that track for moving the Hall probe is horizontal and track is at the centre of the current carrying coils.

ii. Connect the DC supply, Ammeter (Multimeter in current mode), first circular coil in series as shown in the figure 3. **Get the circuit checked by T.A. before switching on the power supply.**

iii. Adjust zero knob such that magnetic feild is zero at the centre of the coil without switching on the power supply.

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iv.   Switch 'ON' the DC supply. Rotate the current knob to 1/3 rd of full movement and then increase the voltage. Check the current. Increase the voltage till current is 0.5 Amp. If needed, rotate current know slightly to get 0.5 Amp.

v.   **Note that current should be constant throughout the experiment. Check it before taking each reading in the multimeter.**

vi.   You are provided with an axial Hall probe connected to a Gauss meter. End portion of the probe detects magnetic field. Move it to centre of the coil and check the position at which magnetic field is maximum.

vii.   Place the given compass on the track and find the direction of magnetic field. Then determine the current direction in your coil (clock wise/Anticlock wise)

viii.   Remove the compass from the track and move the Hall sensor to 10 cm left of the left coil.

ix.   Take readings of magnetic field for each 0.5 cm from 10 cm left to 10 cm right of the coil and tabulate. Magnetic field in Gauss meter fluctuates due to electronics used. At each step, wait for few seconds and note down the average value.

x.   Switch off the supply and place the second coil at a distance equal to radius of the coil.

xi.   Disconnect the first coil and make connections to second coil and repeat the measurement as above.

xii.   Third measurement is for Helmholtz coil setup. Make connections as in Figure 2. Check with compass that magnetic field is in same direction for both the coils.

xiii.   Measure magnetic field from 10 cm left of the first coil to 10 cm right of the second coil for each 0.5 cm.

xiv.   Draw the graphs between distance and magnetic field due to COIL 1, COIL 2 and BOTH along the axis of coils in a single graph and estimate the radius of the coil.

xv.   Calculate the radius of coil to verify with the given value

$$a = \frac{2\pi nI \times 10^{-3}}{B}$$
    where B is field of the coil the centre of the coil.

xvi.   Calculate magnetic field at the centre of the Helmholtz coil using $\vec{B} = \frac{8\mu_o NI}{\sqrt{125R}}\hat{x}$
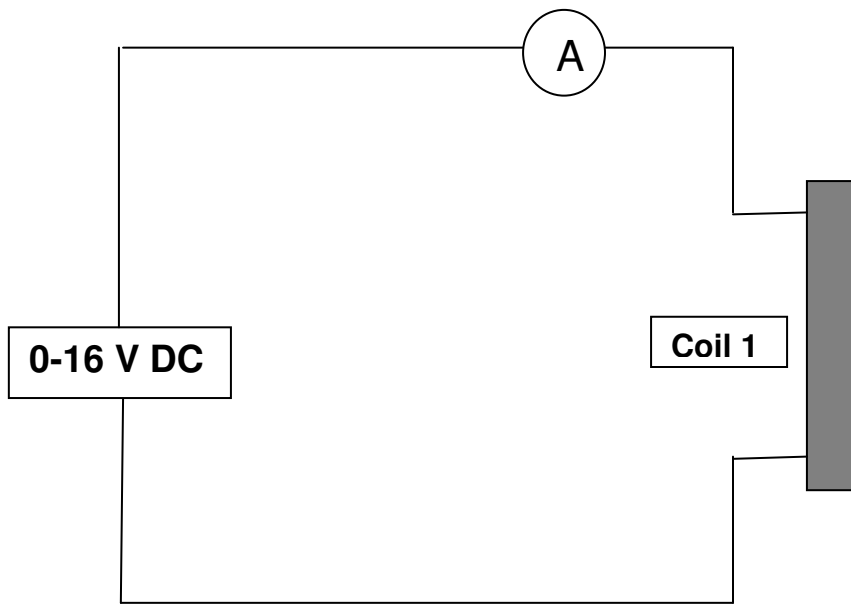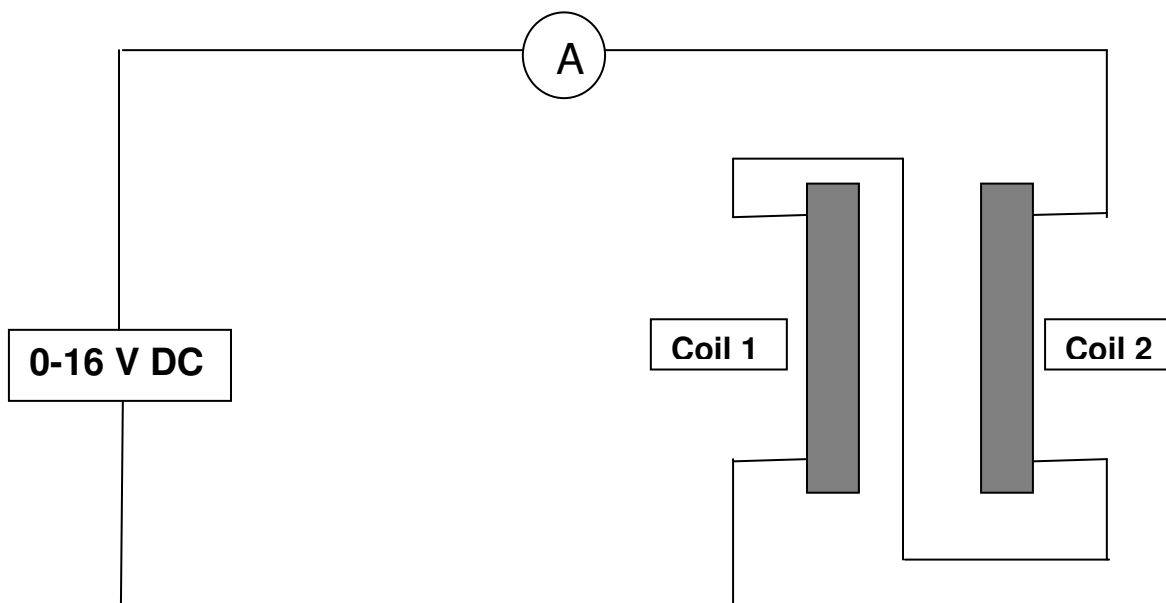
Fig. 3: Experimental Arrangement for single coil

Fig.4: Experimental Arrangement for Helmholtz coil

Observations

Sensor position (cm)	COIL 1 field (Gauss)	COIL-2 field (Gauss)	Both coils field (Gauss) Helmholtz arrangement

Precautions

1) Care should be taken that there is no stray magnetic field or ferromagnetic material, such as keys, screwdriver etc. near the setup, while performing the experiment.

2) The radius of the coil is calculated from the centre of winding and not from the inside edge of the coil bobbin.

3) The Zero of the Gauss meter should be adjusted each time before beginning the experiments and verified after the completion of experiment by reducing the current in both the COILS to zero.

Questions: 1) What is a solenoid? What is the variation of magnetic field along the axis of solenoid?