10+10+10+10+10+10 = 60

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TECHNOLOGY BOMBAY	NAME KHYATI SINGH	
	EXPT. No. 05	LABORATORY
PHYSICS DEPT.	DATE 4/09/23	

Helmholtz Coils

Aim: (a) To measure the magnetic field produced by the Helmholtz coil.

(b) To determine the torque experienced by a current carrying loop, suspended between the Helmholtz coils, as a function of:

(i) the strength of the magnetic moment (by varying current 'i_L' through the loop).
(ii) the angle (α) between the magnetic field and the axis of the loop.
(iii) the no. of turns (n) in the current loop.

Apparatus: Helmholtz coils, digital Gaussmeter, Hall probe, Torsion dynamometer, power supply with inbuilt digital ammeter, connecting wires, supporting stand and two small coils having n=1 and 3.

Theory: Helmholtz coils consist of a pair of identical coils (each having N number of turns and radius R) placed coaxially and separated by a distance R. Such a pair produces a fairly uniform magnetic field B_0 in the region between the coils, provided the sense of current 'I' through the coils are such that the two magnetic fields add.

$$|B_0| = \frac{8}{5\sqrt{5}} \mu_0 \frac{NI}{R} \quad \text{——} \ (1)$$

In the laboratory set up; R=0.2m, N=154 and 'I' may be varied up to 3A.
Note $\mu_0 = 4\pi \times 10^{-7}$ Henry/m.

When a current (i_L) carrying conducting loop of radius 'r' with 'n' turns, is placed in the uniform magnetic field B_0 between the Helmholtz coils, it experiences a non-zero torque T, provided the axis of the loop makes a non-zero angle 'α' with B_0. The magnetic moment of the loop is m;

$$|m| = \pi r^2 i_L .$$

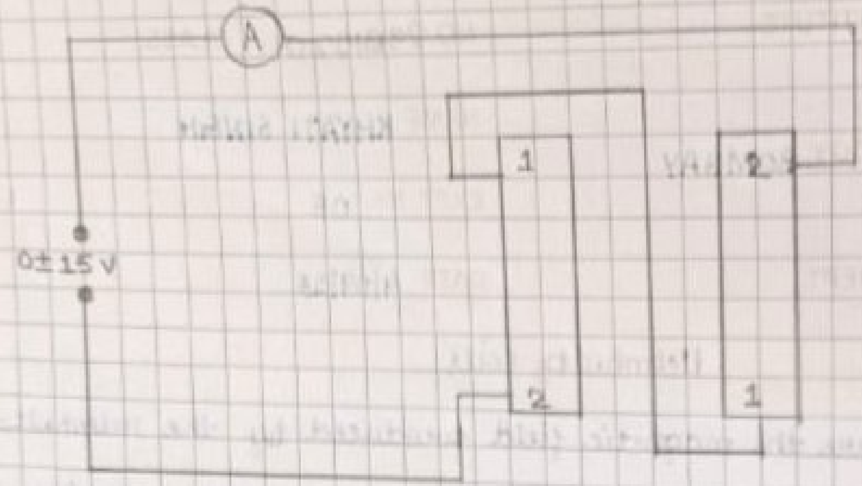
$$T = m \times B_0 \quad \text{——} \ (2)$$

and

$$|T| = \pi r^2 i_L n |B_0| \sin\alpha \quad \text{——} \ (3)$$

where r = 6cm.

Circuit Diagram:



$\frac{60}{60}$ Good. [signature]

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Experimentally, the torque experienced by the coil, transfers to a torque on the lever arm, which can be measured directly from the force experienced by a dynamometer.

$$|T| = |F|L \quad \text{——} \ (4)$$

where $|F|$ is the force measured by the force indication knob of the dynamometer, and L is the half length of level arm ($L = 12cm$). The angle between F and L is 90°.

Precautions:

1) While connecting and changing the circuit, the power supply must be switched off. If at any time, the red light on the power supply glows (indicating overload), immediately switch off the power supply and check any possibility of short circuit.

2) Make sure that no other magnetic material is placed in the vicinity of the coils, while measuring the magnetic field.

3) Align the lever arms very carefully, it is very delicate and should be handled with extreme care.

4) Rotate the force indication knob very carefully, while measuring the deflection on torsion dynamometer.

Observations:

TABLE 1.

S.No.	Helmholtz coil current (I) (in A)	Measured magnetic field B_o (in G)	Calculated magnetic field $B_c = \frac{8}{5\sqrt{5}} \mu_0 \frac{NI}{R} = 6.924 \times 10^{-4} I$ (in G)
1.	2	15.7	$13.8 \times 10^{-4}\ T = 13.8\ G$
2.	3	23.1	$20.8 \times 10^{-4}\ T = 20.8\ G$

for (1); $B_c = \frac{8}{5\sqrt{5}} \times 4\pi \times 10^{-7} \times \frac{154 \times 2}{0.2} = \frac{30947.84 \times 10^{-7}}{11.15 \times 0.2} = \frac{30947.84 \times 10^{-7}}{2.23}$

$\Rightarrow$ [illegible]

TABLE 2:

$I = 3$ amp.
$\alpha = 30°$
$n = 3$
$B_0 = 20.8\ G = 20.8 \times 10^{-4}\ T$
$L = 12$ cm.

S.No.	Loop current (i_L) (in A)	Measured force (F) (in mN)	Measured Torque $T = FL = F \times 10^{-3} \times 0.12$ (Nm) $= 1.2 \times 10^{-4} F$ (Nm)	Calculated torque (T_c) $T_c = \pi r^2 i_L n \lvert B_0 \rvert \sin\alpha$ $= 1.696 \times 10^{-2} B_0 i_L$ (N m)
1.	2	1.2	14.4×10^{-5}	7.05×10^{-5}
2.	3	1.7	20.4×10^{-5}	10.5×10^{-5}
3.	4	2.1	25.2×10^{-5}	14.1×10^{-5}
4.	5	2.6	31.2×10^{-5}	17.6×10^{-5}

for ①; $T = F.L = (1.2\,mN).(12\,cm)$
$= (1.2 \times 10^{-3} N)(0.0012\,m)$
$T = 14.4 \times 10^{-5}$ N-m

$T_c = \pi r^2 i_L n \lvert B_0 \rvert \sin\alpha$
$= 3.14 \times \frac{6 \times 6}{10^4} \times 2 \times 3 \times 20.8 \times 10^{-4} \times 0.5$
$= 1.696 \times 2 \times 20.8 \times 10^{-6}$
$= 70.55 \times 10^{-6}$
$T_c \Rightarrow 7.05 \times 10^{-5}$ (N-m)

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TABLE 3:

$I = 3$ amp
$i_L = 4$ amp
$n = 3$

S.No.	Angle between magnetic field & axis of loop (α)	$\sin\alpha$	Measured force (F) (in mN)	Measured Torque $T = 1.2 \times 10^{-4} F$ (N-m)	Calculated Torque (T_c) $T_c = \pi r^2 i_L n \lvert B_0 \rvert \sin\alpha$ (N-m) ~~$= 1.696 \times 10^{-2} \times B_0 \times i_L$ (N-m)~~ $= 1.356 \times \lvert B_0 \rvert \sin\alpha \times 10^{-5}$
1.	15°	0.25	1.4	16.8×10^{-5}	~~0.88×10^{-5}~~ 7.05×10^{-5}
2.	30°	0.50	2.0	24.0×10^{-5}	14.1×10^{-5}
3.	45°	0.70	2.6	31.2×10^{-5}	19.7×10^{-5}
4.	60°	0.86	2.9	34.8×10^{-5}	24.2×10^{-5}

for ①; $\because T = F.L$
$= (1.4\,mN)(12\,cm)$
$= (1.4 \times 12) \times 10^{-3} \times 10^{-2}$ N-m
$T = 16.8 \times 10^{-5}$ N-m

$\because T_c = \pi r^2 i_L n \lvert B_0 \rvert \sin\alpha$
~~$= 1.696 \times 10^{-2} \times 20.8 \times 10^{-4} \times \sin 15°$~~
~~$= 1.696 \times 20.8 \times 10^{-6} \times 0.25$~~
~~$= 8.81 \times 10^{-6}$~~
~~$\therefore T_c = 0.88 \times 10^{-5}$ N-m~~

$T_c = 1.356 \times 10^{-5} \times 20.8 \times \sin 15°$
$= 1.356 \times 20.8 \times 0.25 \times 10^{-5}$
$= 7.05 \times 10^{-5}$ N-m

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Calculation:

from Graph ①

$\Delta B_0 = B_0 - B_{calculate}$

$$\frac{\Delta B_0}{B_0} = \left| \frac{B_0 - B_{cal.}}{B_{cal.}} \right| = \left| \frac{37.14 - 20.8}{20.8} \right|$$

$$= \frac{\cancel{20.65}}{20.8} \Rightarrow \frac{16.38}{20.8}$$

$$= \cancel{0.99}\ 0.78$$

$$\left(\frac{\Delta B}{B}\right)_1 = 78\%$$

from Graph ②

$$\frac{\Delta B_0}{B_0} = \left| \frac{B_0 - B_{cal.}}{B_{cal.}} \right| = \left| \frac{34.6 - 20.8}{20.8} \right|$$

$$= \frac{13.8}{20.8}$$

$$\Rightarrow 0.66$$

$$\left(\frac{\Delta B}{B}\right)_2 \Rightarrow 66\%$$

using formula;

$$\frac{\Delta B}{B} = \left|\frac{\Delta F}{F}\right| + \frac{\cos\alpha}{\sin\alpha} |\delta\alpha|$$

$$= \left|\frac{0.1}{1.2}\right| + \left|\frac{\cos 30^\circ}{\sin 30^\circ}\right| \cdot \frac{\pi}{180}$$

$$\Rightarrow |0.08| + \left|\frac{0.86}{0.5}\right| \cdot \frac{3.14}{180}$$

$$\Rightarrow |0.08| + \left|\frac{1.72 \times 3.14}{180}\right|$$

$$\Rightarrow 0.08 + 0.03$$

$$\Rightarrow 0.11$$

$$\left(\frac{\Delta B}{B}\right)\% = 11\%$$

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Calculation:

Slope of T vs i_L graph = ~~2.6×10⁻³~~ 6.3×10^{-5} $\frac{N\text{-}m}{amp.}$

$\tau = \pi x^2 n \sin\alpha |B_0| i_L$

$|B_0| = \frac{\text{slope}}{\pi x^2 n \sin\alpha}$

$\Rightarrow \frac{\cancel{2.6}\,6.3 \times 10^{-5}}{3.14 \times 36 \times 10^{-4} \times 3 \times 0.5}$ $\Rightarrow \frac{\cancel{2.6}\,6.3 \times 10}{169.56}$

$\Rightarrow \cancel{0.15}$ ~~0.37~~ 0.0371×10^{-1}

$= 37.14 \times 10^{-4}$ T

$\Rightarrow 37.14$ G.

T vs sin α :-

$T = \pi x^2 i_L n |B_0| \sin\alpha$

slope of T vs sin α graph $= 0.47 \times 10^{-3}$ N-m.

$|B_0| = \frac{\text{slope}}{\pi x^2 i_L \cdot n}$.

$\Rightarrow \frac{0.47 \times 10^{-3}}{3.14 \times 36 \times 10^{-4} \times 4 \times 3}$ $= \frac{0.47 \times 10^{1}}{1356.4}$

$\Rightarrow 3.46 \times 10^{-3}$ T.

$\Rightarrow 34.6 \times 10^{-4}$ T

$\Rightarrow 34.6$ G.

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Results:

from Graph 1;

$$B_o = 37.14\,G$$

$$\left(\frac{\Delta B}{B}\right)_1 \% = 78\%$$

from Graph 2;

$$B_o = 34.6\,G$$

$$\left(\frac{\Delta B}{B}\right)_2 \% = 66\%$$

from formula ; $B_o = 20.8\,G$

$$\left(\frac{\Delta B}{B}\right) \% = 11\%$$

$B_{graph2} > B_{calculate} > B_{graph1}$.

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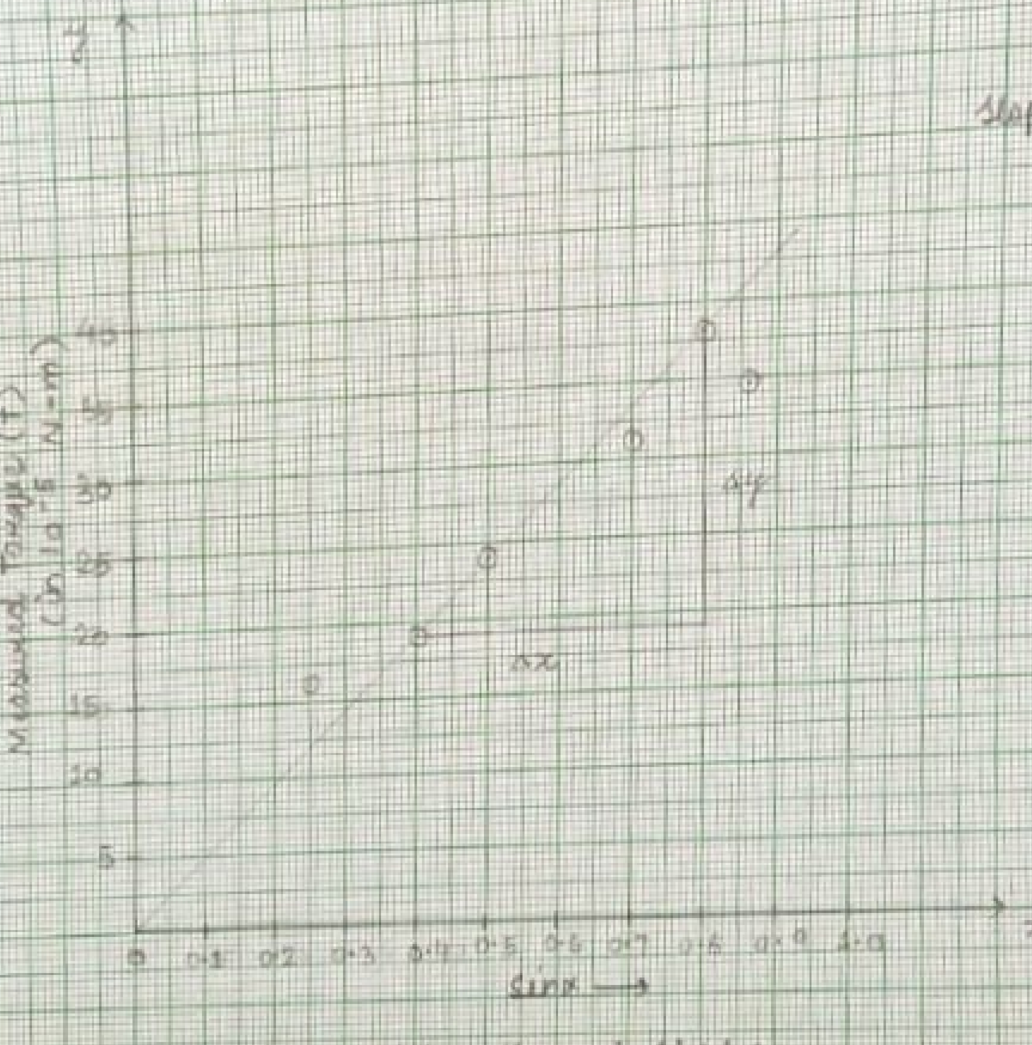
Graph for Torque (τ) vs $\sin\alpha$ (Table 3)

Scale:

on y axis; 1cm = 5×10^{-5} N-m

on x axis; 1cm = 0.1



$$\text{slope} = \frac{38 - 19}{0.8 - 0.4}$$

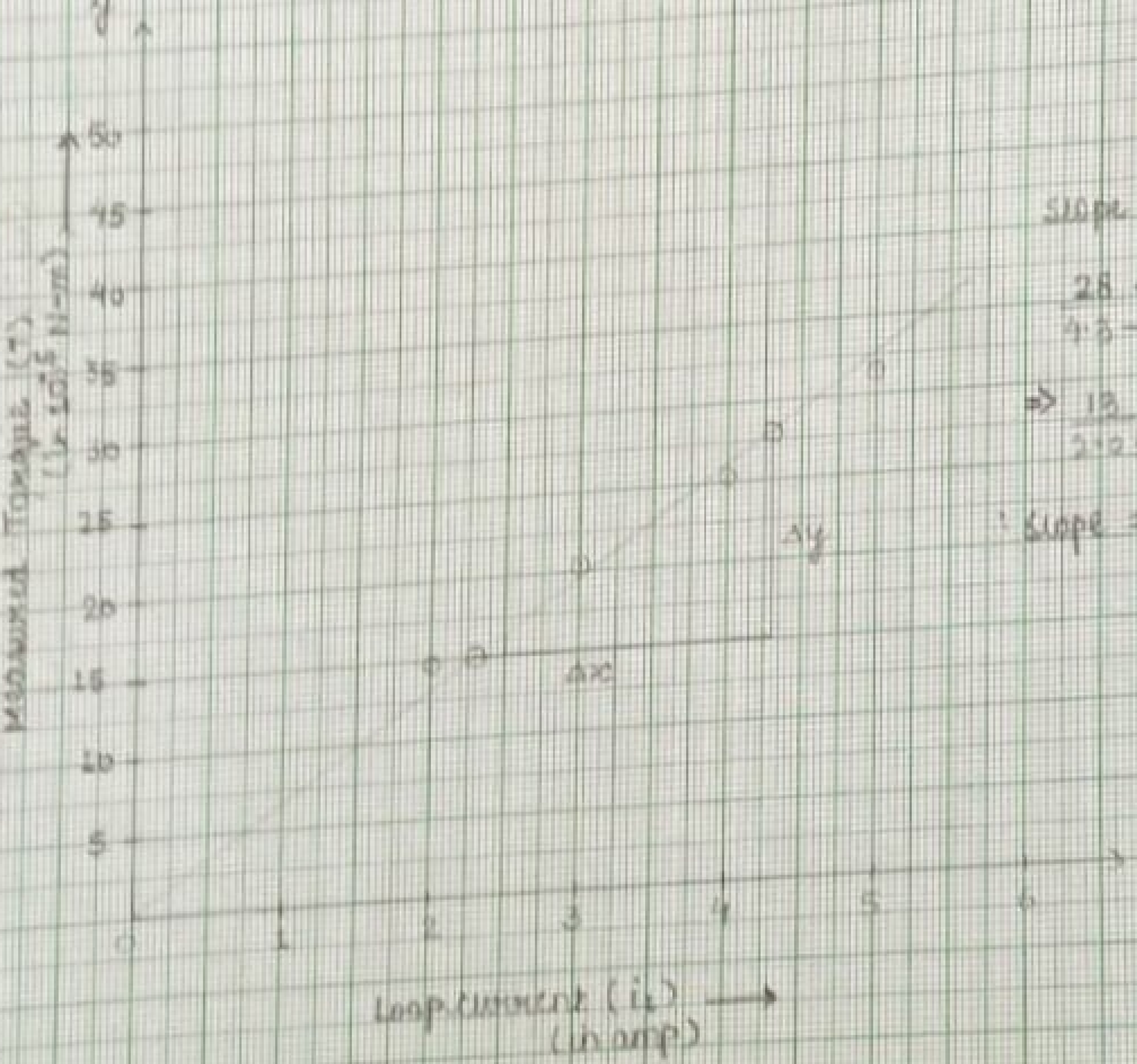
$$= \frac{19}{0.4}$$

$$= 0.475 \times 10^{-3} \text{ N-m}$$

sine of angle b/w magnetic field & axis of loop.

(a) Graph for τ vs i_L (Table 2)

Scale:
on x axis, 2cm represents 1amp
on y axis, 1cm represents 5×10^{-5} N-m



Slope:

$$\frac{28 - 15}{4.5 - 2.25}$$

$$\Rightarrow \frac{13}{2.25}$$

$\therefore$ Slope $= 5.8 \times 10^{-5} \frac{N\text{-}m}{amp}$