

Magnetic field strength vs current for a short coil

Richard Walding – Nov 2024

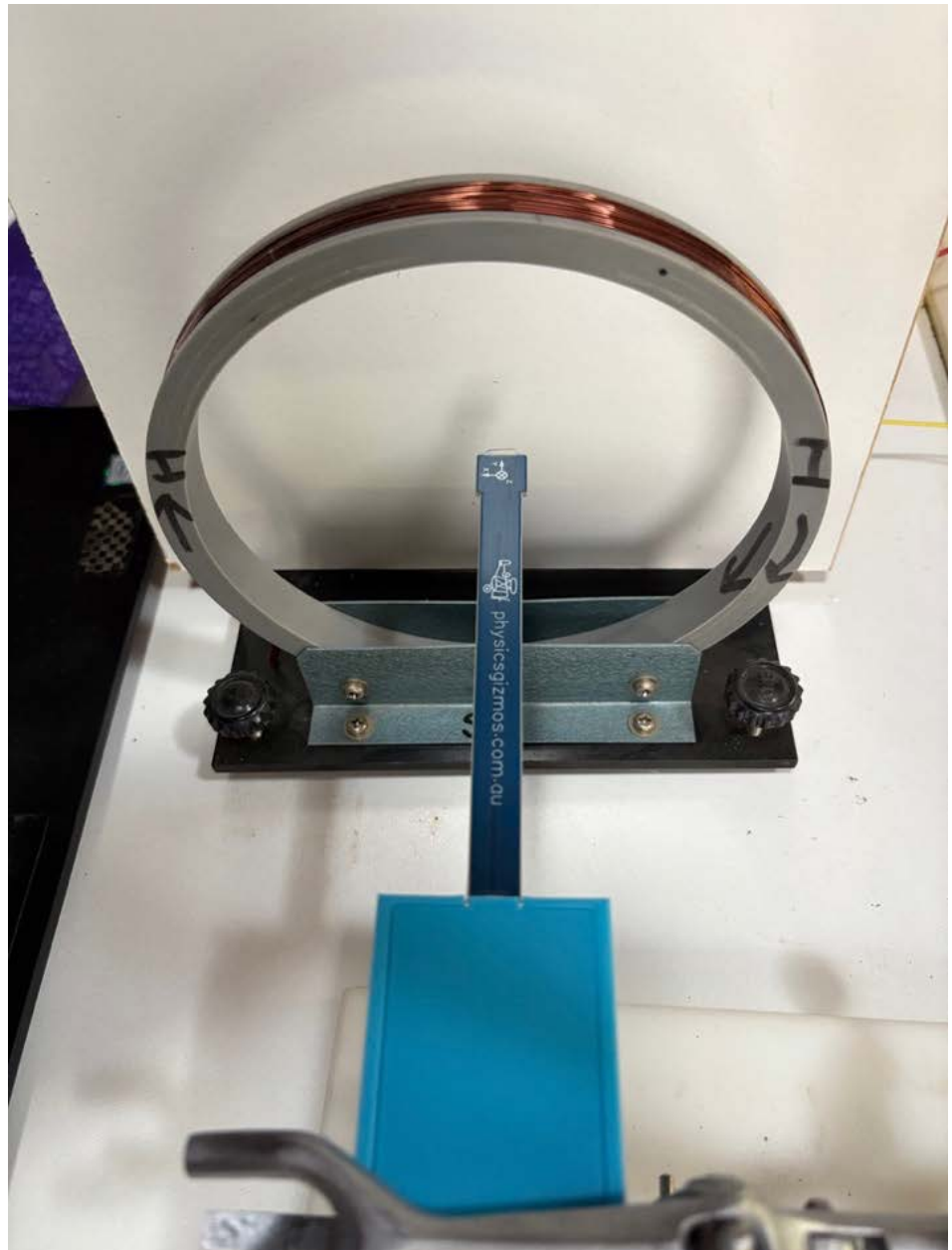
As a modification of an experiment on the field strength about a current-carrying wire or solenoid, I tested how the field varies with current inside a “short coil”. Unlike a solenoid where $L \gg d$, a short coil is one where $L \ll d$. On page 214 of the Oxford U3&4 text I posed a Challenge comparing the different formulas for a solenoid ($B = \mu_0 n I$) and a single loop $B_{\text{loop}} = \frac{\mu_0 I}{2R}$. For N turns of a loop the formula becomes $B_{\text{short coil}} = N \frac{\mu_0 I}{2R}$.

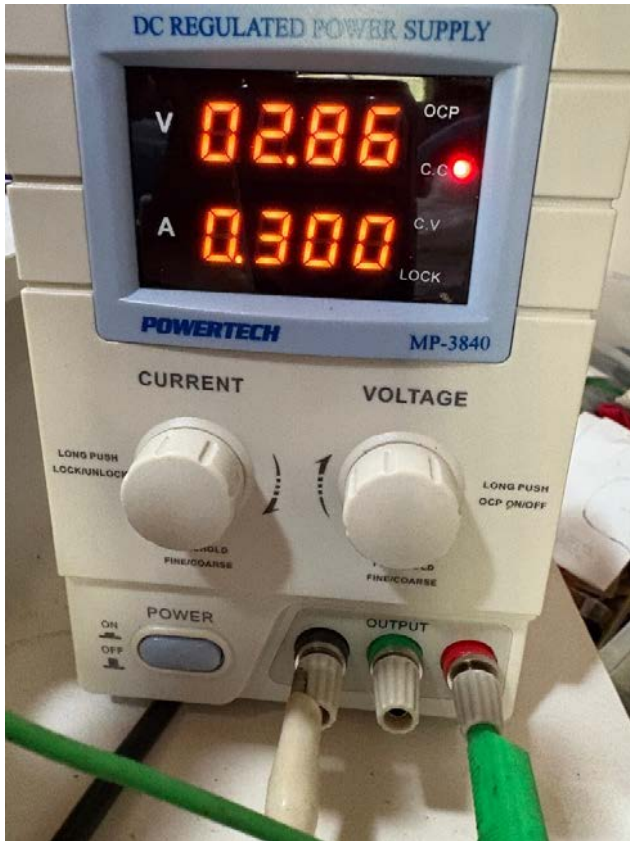
I wanted to see if B was proportional to I for a short coil, and I wanted to test the accuracy of the formula against the experimental data in the determination of μ_0 – the permeability .

SETUP

I used a 200-turn coil with a radius of 8.0 cm from an old current balance.

I was fortunate enough to have Ian Thompson’s *Magnetic Field Sensor* (physicsgizmos.com.au). They cost about \$75 and I know they give great results. I connected it to the USB port (COM3) set it to display readings in microtesla with a range up to 12G. The axis of the magnetometer had to be orientated along the y-direction at right angles to the plane of the loop. See photo opposite.

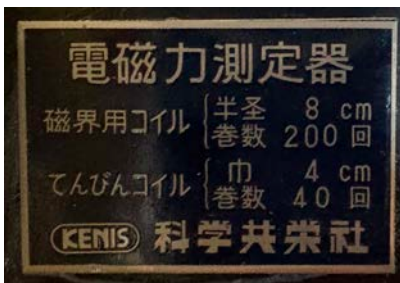




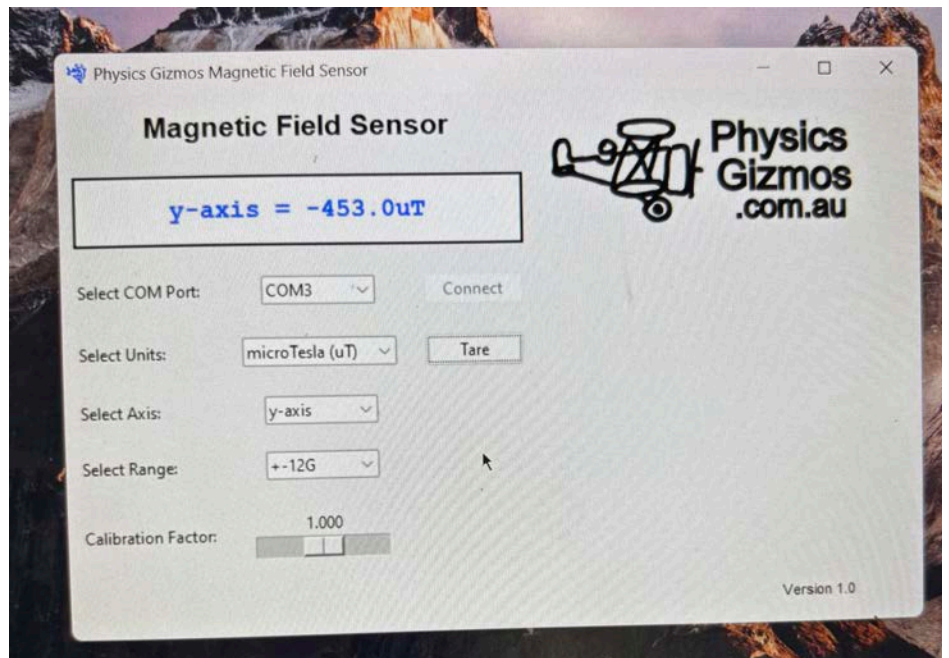
I set the power supply to a constant current (CC). In this case 0.300 A. The coil was getting hot over 1 A.



You can choose the field direction for the sensor. I used the y-direction at right angles to the plane of the loop (parallel to the field).



I assume it means 8 cm radius and 200 turns



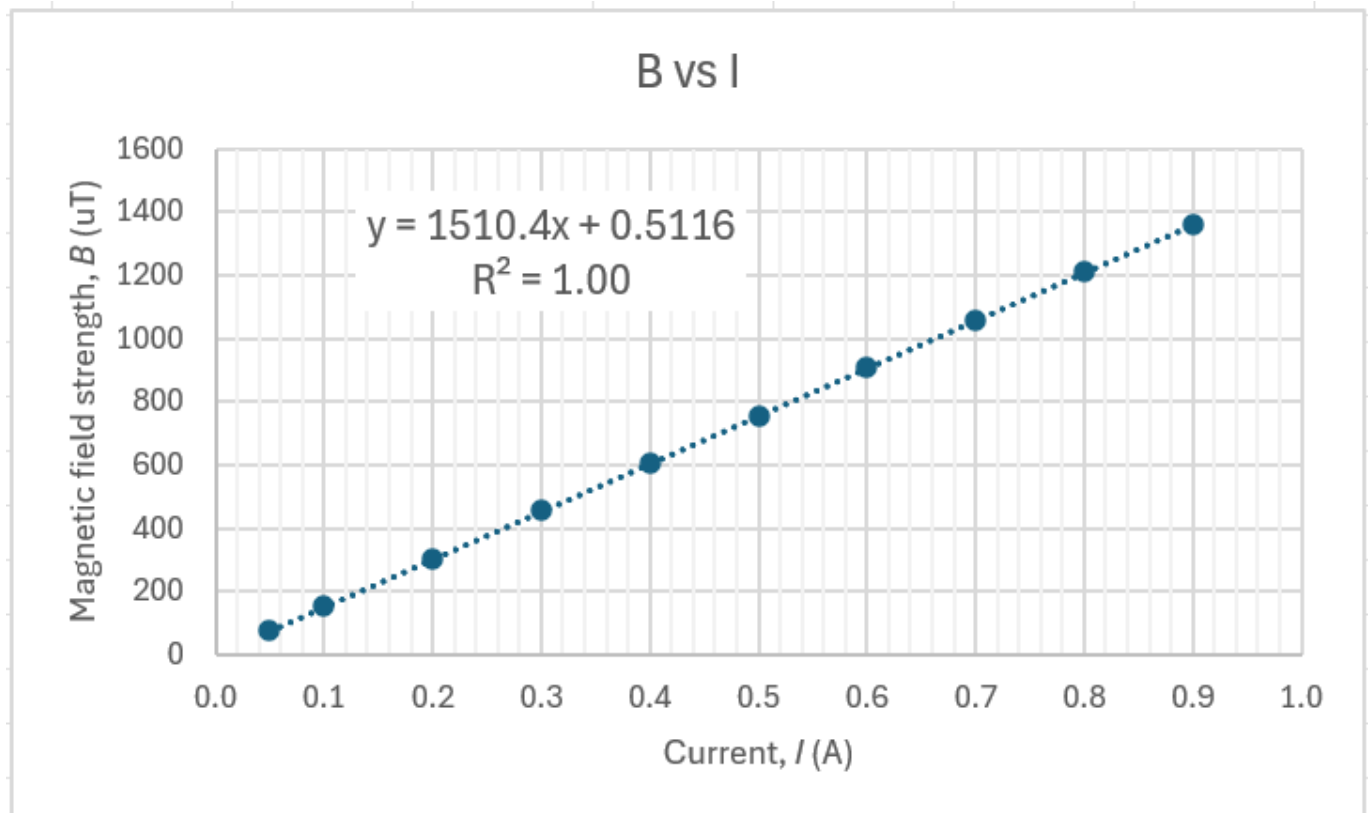
Here's the display for 0.300 A

RESULTS

I (A)	B (μT)				$\bar{\delta x}$ (μT)	$\delta\%$	B theoretical (μT)	Error E%
	Trial 1	Trial 2	Trial 3	Av				
0.05	74.9	75	74.9	74.9	0.05	0.1	79	4.7
0.10	151	152.0	153.0	152.0	1.00	0.7	157	3.9
0.20	302	303	304	303.0	1.00	0.3	314	3.9
0.30	453	455	455	454.3	1.00	0.2	471	3.9
0.40	603	605	606	604.7	1.50	0.2	629	4.1
0.50	755	755	756	755.3	0.50	0.1	786	3.9
0.60	906	907	907	906.7	0.50	0.1	943	3.9
0.70	1057	1059	1058	1058.0	1.00	0.1	1100	3.9
0.80	1209	1209	1210	1209.3	0.50	0.0	1257	3.8
0.90	1359	1359	1360	1359.3	0.50	0.0	1414	3.9

You'll notice straight away how little deviation there is. The % uncertainty is about 0.2% which is amazing. I think that is due to the stability of the magnetometer (well done Ian) and the stable output from the power supply. I'm just using a Jaycar DC Regulated Power Supply (about \$200).

GRAPH



ANALYSIS

I'm amazed at the R^2 of 1.00. I didn't rig these results. They were that consistent.

I calculated the theoretical value of B using the short coil formula and found that it was very accurate with the percentage error being about 3.7%. I'm still amazed.

ERROR in μ_0

Probably the most straightforward thing to compare is the experimental and accepted values of μ_0

$$\begin{aligned} \text{gradient} &= \frac{B}{I} = \frac{N\mu_0}{2R} \\ \mu_0 &= \frac{2R \times \text{gradient}}{N} \\ &= \frac{2 \times 0.08 \times 1510.4 \times 10^{-6}}{200} \\ &= 1.208 \times 10^{-6} \text{ TmA}^{-1} \\ \text{E}\% &= \frac{|1.208 \times 10^{-6} - 1.257 \times 10^{-6}|}{1.257 \times 10^{-6}} \times 100 \\ &= 3.7\% \end{aligned}$$

SUMMARY

This would make a great student experiment. It doesn't stray out of Unit 3 topics and is quick to do. I did the data collection (3 trials) in about 15 minutes. I must congratulate Ian on producing such an easy-to-use magnetometer that is very stable – and cheap. I also tried using a \$1000 Kanetec teslameter and was no better off.

OTHER INVESTIGATIONS

I'm going to try:

1. Measure B and as a function of the radius. Keep I , N constant
2. Measure B across the diameter of the coil. Keep B , I , N constant. There was a question similar to this for parallel wires on the EA a couple of years ago. Worth a shot.

All-in-all a great result.

Cheers

Richard