

The image shows two toroidal inductors, which are coils of red copper wire wound around a grey metal core. The coils are positioned on either side of a vertical metal rod, creating a clear air gap between them. Each coil is connected to a black plastic terminal block. The background is a blurred industrial or laboratory setting with various equipment and a yellow object on the right.

Toroidal inductor with an air gap

equipped to class
me you practice
particularly

recent notes, toytome,
ime diary, pens, pencils,
ator, ruler, geometry
urface (charged!), perhaps a
Quite a lot to think about yes?
out that pre-packed bag.....

9. Aspire to be a good experim

- Setting up equipment safely
- Making precision measurements, and recording them clearly
- Quantifying *uncertainty*
- Analysis using straight line graphs. Does your model *correlate?*

For physics success

When we go through toytome, use the Windows Snip screenshot of my answers to the question you are we answers in OneNote so you can see (i) the question (

- When we go through work, annotate it! Be active
- Make small corrections yourself – can you debug
- Highlight key phrases, explain terms in equations something means in your own words, Diagrams
- Try to understand the solution first. Write down
- Use both your original work, and my solutions w
- They need to write a solution out again later

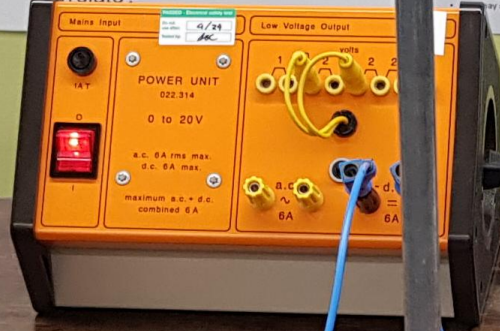
What to copy a
of your
answer.

What
good idea.
recation.
to you

Ammeter



Power supply
4V DC

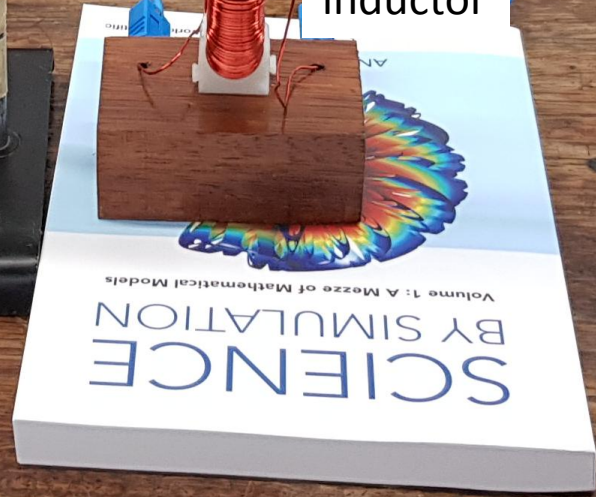
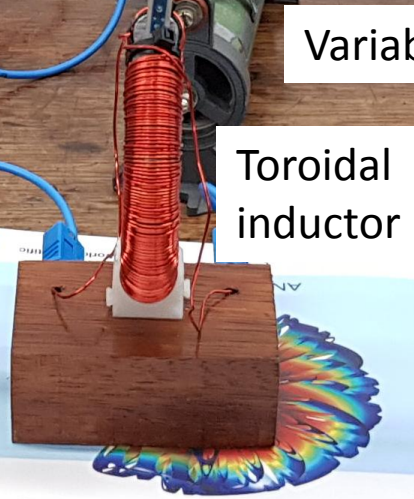


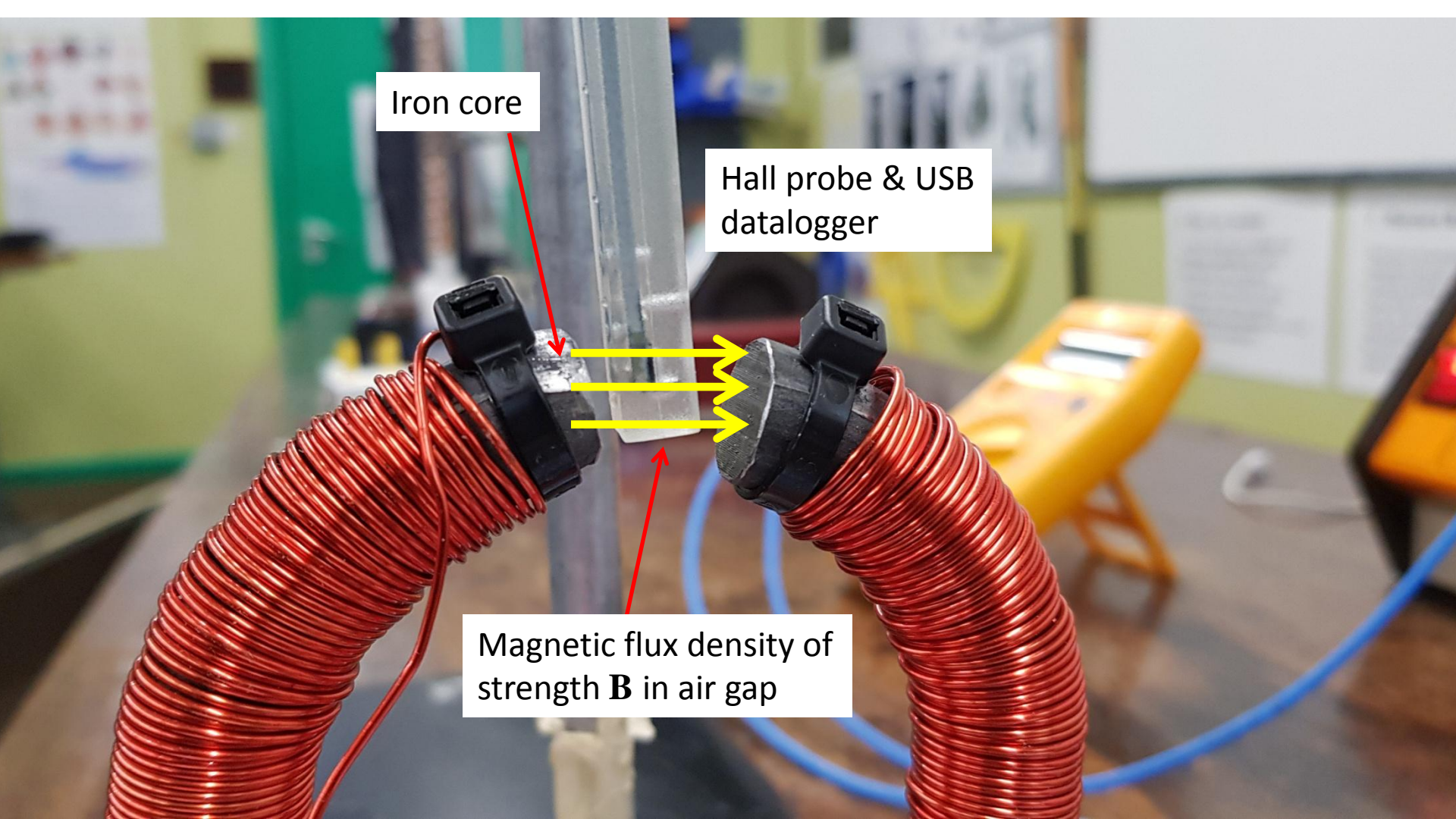
Hall probe & USB
datalogger



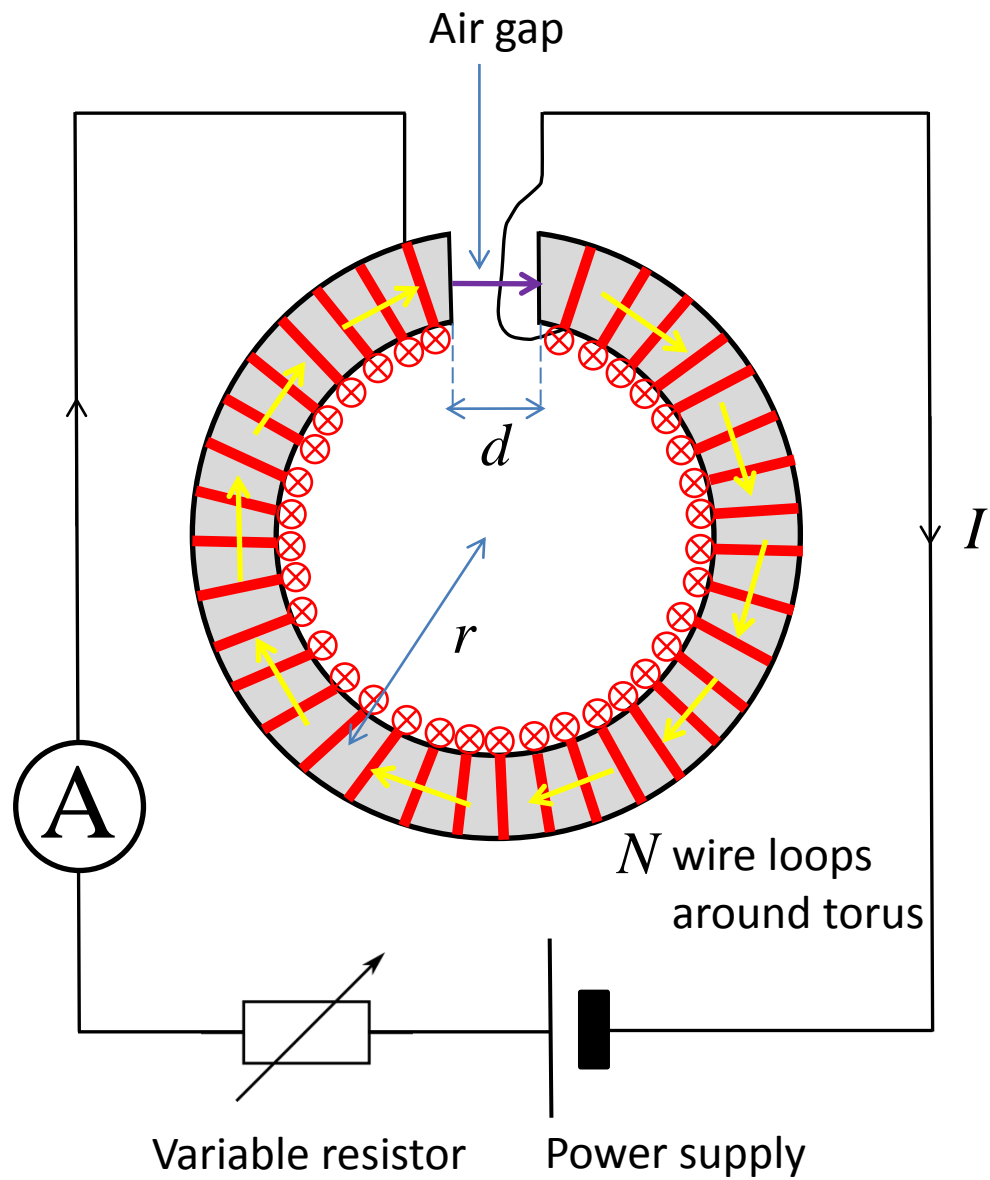
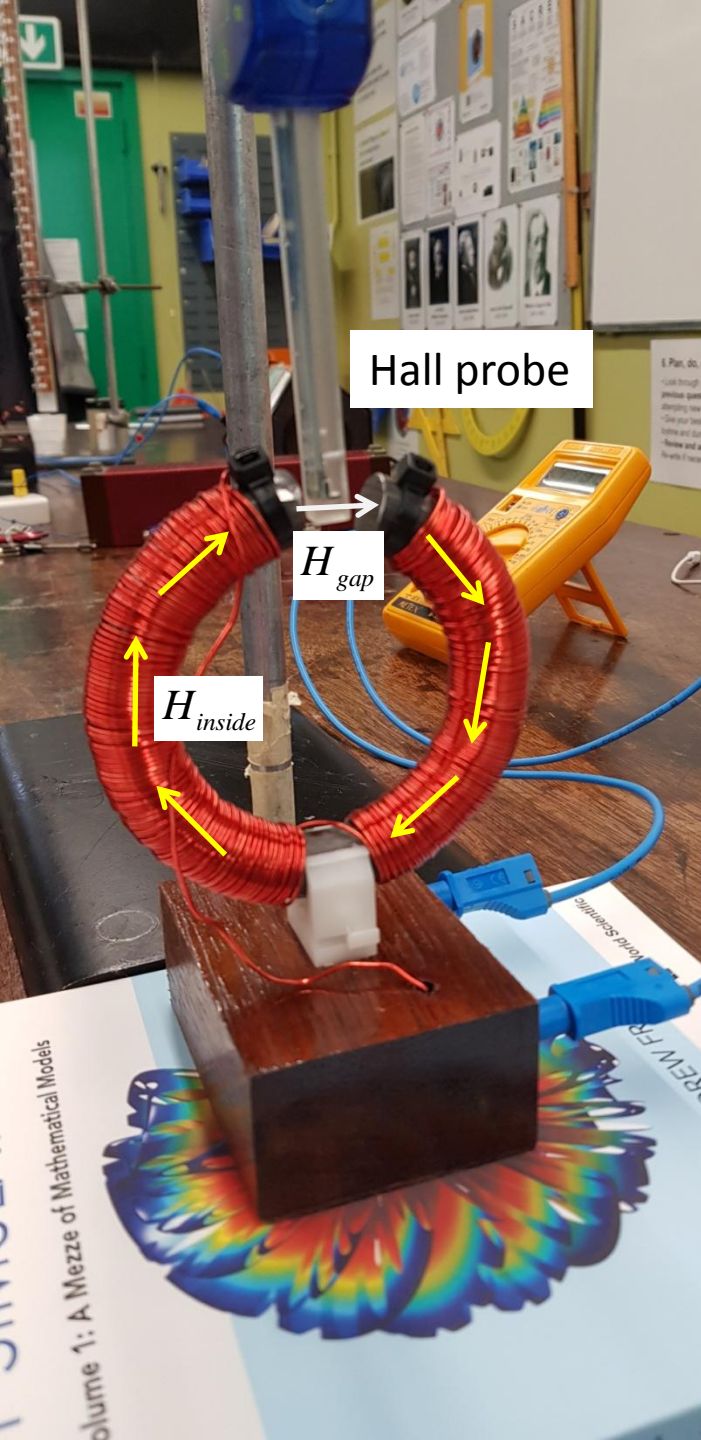
Variable resistor

Toroidal
inductor





1. Vary current (range 0.4A to about 2.0A) in toroidal inductor by changing resistance of variable resistor.
2. Use Hall Probe and datalogger to measure magnetic flux density B in air gap.
3. Plot magnetic flux density (in T) vs current (in A). Use the graph to calculate the relative permeability μ of the iron core.



Application of the Lorentz force – the Hall Effect

A semiconductor of width w and height h is placed in a magnetic field B . Current I passes through the semiconductor as shown. The Lorentz force on charges will cause a charge separation, which in turn will result in an electric field E perpendicular to both the magnetic field and the current direction.

Equilibrium is reached when the electric force and Lorentz magnetic forces balance.

$$qE = qvB$$

$$\therefore E = vB$$

$$E = \frac{V_H}{w}$$

$$I = qnwhv$$

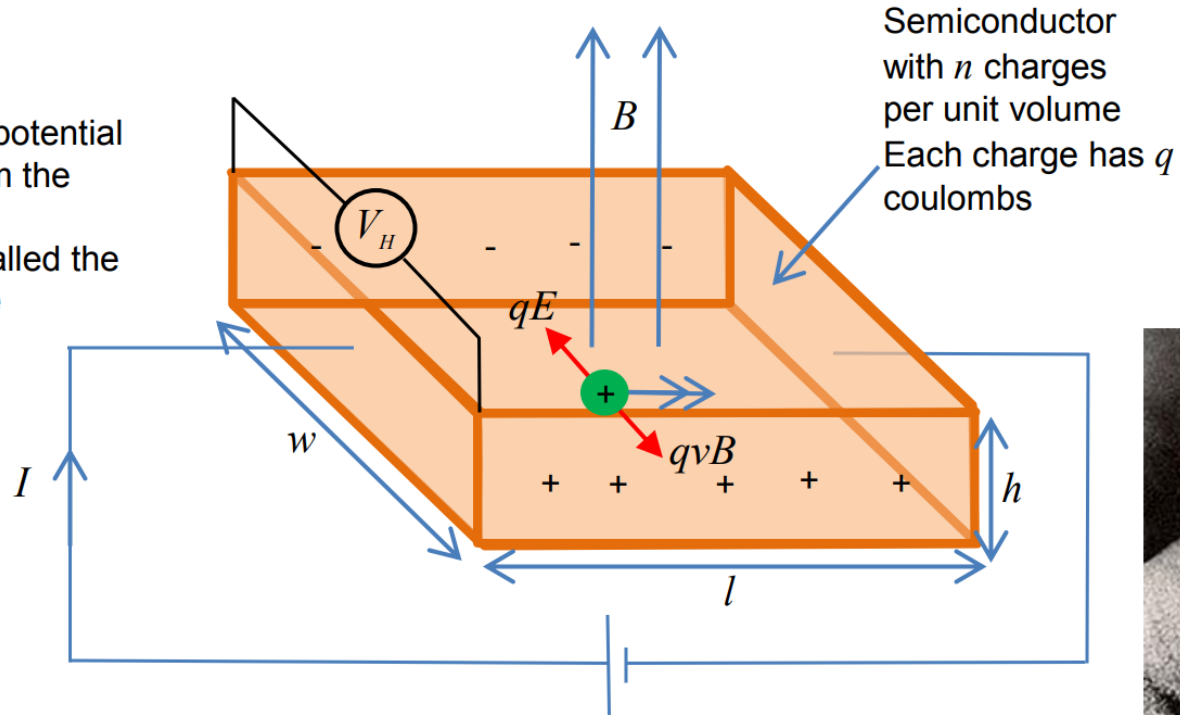
$$\therefore v = \frac{I}{qnwh}$$

$$\therefore \frac{V_H}{w} = \frac{IB}{qnwh}$$

$$V_H = \frac{IB}{qnh}$$

$$B = \frac{qnhV_H}{I}$$

The electric potential resulting from the separated charges is called the **Hall Voltage**



Example calculation:

$$n = 7 \times 10^{21} \text{ m}^{-3}$$

$$q = e = 1.6 \times 10^{-19} \text{ C}$$

$$h = 0.1 \text{ mm}$$

$$\therefore qnh = \boxed{0.112}$$

$\therefore \frac{V_H}{I}$ can be a ratio of near-unity quantities, which are readily measurable i.e. B fields not too many orders of magnitude less than 1.0T can be easily measured.



Edwin Hall
1855-1938

It is possible to measure the Hall effect in a small semiconductor, so the effect can be used to determine the how a non uniform magnetic field varies in time and space.

Ampère's Theorem:

$$\oint_{loop} \mathbf{H} \cdot d\mathbf{l} = NI$$

Magnetic field strength inside torus is tangential to circular loop

$$\therefore H_{inside} (2\pi r - d) + H_{gap} d = NI \quad \text{if gap is small } d \ll 2\pi r$$

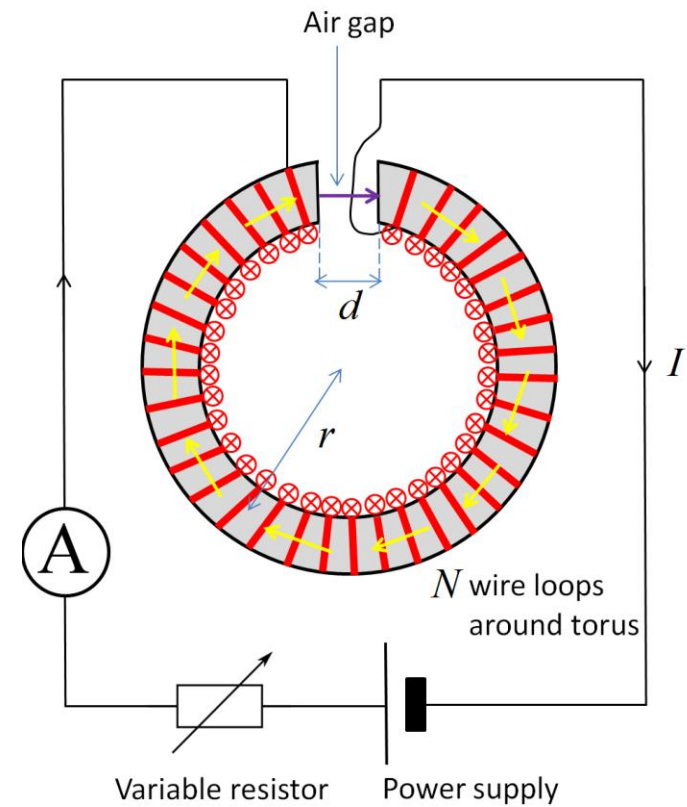
$$B_{gap} = \mu_0 H_{gap}$$

Permeability of free space

$$\mu_0 = 4\pi \times 10^{-7} \text{ Hm}^{-1}$$

$$B_{inside} = \mu\mu_0 H_{inside}$$

Magnetic flux density \mathbf{B} is continuous perpendicular to the iron, air boundary. (Maxwell Equation result).



Hence:

$$B_{gap} = B_{inside} = B$$

$$\therefore H_{inside} (2\pi r - d) + \mu H_{inside} d = NI$$

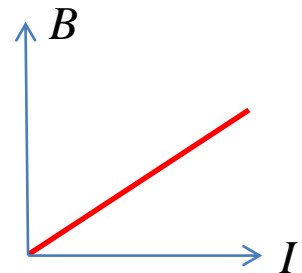
$$\therefore H_{gap} = \mu H_{inside}$$

$$\rightarrow \therefore H_{inside} (2\pi r - d + \mu d) = NI$$

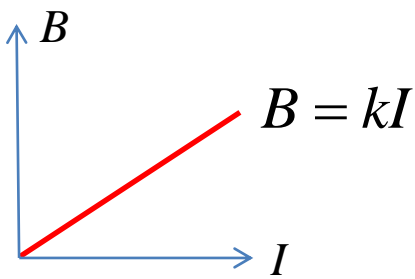
$$\therefore H_{inside} = \frac{B}{\mu\mu_0}$$

$$\therefore \frac{B}{\mu\mu_0} (2\pi r - d + \mu d) = NI$$

$$\therefore B = \frac{N\mu\mu_0}{2\pi r - d + \mu d} I$$



André-Marie Ampère
(1775-1836)



$$k = \frac{N \mu \mu_0}{2\pi r - d + \mu d}$$

$$k(2\pi r - d + \mu d) = N \mu \mu_0$$

$$k(2\pi r - d) = \mu(N \mu_0 - kd)$$

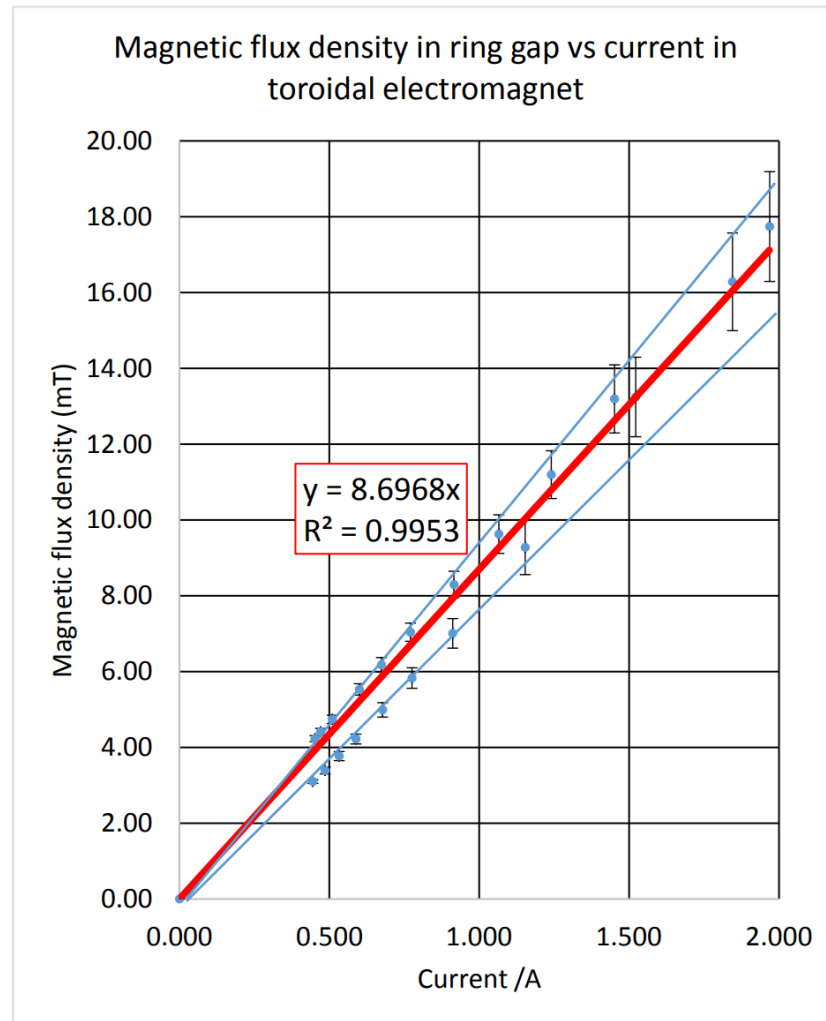
$$\therefore \mu = \frac{k(2\pi r - d)}{N \mu_0 - kd}$$

TOROIDAL ELECTROMAGNET EXPERIMENT
21/11/2022

Radius of ring /m	0.08
Gap in m	0.018
Number of coils N	220
μ_0	1.25664E-06
$k = dB/dI$	0.00870
k_{max}	0.00950
k_{min}	0.00775
μ_{mean}	35.15
μ_{max}	43.66
μ_{min}	27.42

Magnetic flux density
B in air gap (mT)

B (mT)	B error /mT	I (A)
0.00	0.01	0.000
3.10	0.05	0.445
3.39	0.09	0.486
3.77	0.12	0.533
4.22	0.13	0.589
4.99	0.19	0.678
5.83	0.27	0.776
7.01	0.39	0.912
9.28	0.72	1.154
13.25	1.05	1.523
16.29	1.29	1.846
17.75	1.45	1.970
13.20	0.90	1.452
11.20	0.63	1.241
9.63	0.51	1.066
8.30	0.35	0.916
7.04	0.24	0.771
6.18	0.19	0.674
5.53	0.15	0.600
4.74	0.11	0.510
4.41	0.09	0.471
4.23	0.08	0.452



In many literature sources μ is quoted as being about 1,000.

So the ring metal is probably not pure iron!

Current raised then lowered to investigate *hysteresis* - only very marginal in this experiment.