# Physics practical report

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Part IB Physics Report

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**Abstract**

## 1 Introduction

Transformers form a core part of modern technology, being used for impedance matching within electronics and electricity transmission on the grid. In both systems, the efficiency and performance are determined by how the transformer responds to an applied magnetic field.

This response is described by the relationship between the magnetic flux density $B$ and the magnetising field $H$, known as the $B$-$H$ curve. By altering the core of the transformer its properties can be changed. For ferromagnetic materials, the $B$-$H$ curve is non-linear and exhibits hysteresis (**Figure 1**) due to magnetic subdomains in the material.

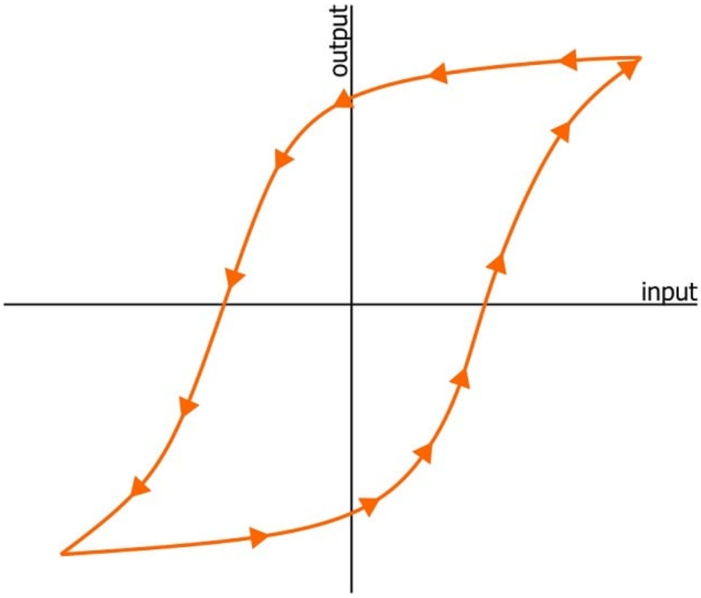


Figure 1: A typical hysteresis curve for a ferromagnetic material, showing the relationship between $B$ and $H$. [1].

The most efficient transformers are made by having a high magnetic susceptibility ($\mu_r$) and low energy loss per cycle. This experiment aims to quantify the usability of different materials as transformer cores, by measuring the energy loss per cycle per unit volume (given by the area of a hysterysis loop) and the maximum magnetic susceptibility (given by the gradient). Section 2 of this report will go through the relevant theory. Section 3 outlines the experimental setup, and Section 4 shows the results obtained. This data is analysed and compared against theoretical expectations in Section 5. The overall conclusions are then presented in Section 6.

# 2 Theoretical background

The magnetising field $H$ inside a solenoid is given by

$$H = \frac{nI}{L} \tag{2.1}$$

Where $n$ is the number of turns, $I$ the current, and L the solenoid length.
This gives rise to the magnetic flux density $B$ For solenoids, with non-magnetic media in their core, there is a linear relationship:

$$B = \mu_0(H + M) \tag{2.2}$$

$$M = \chi H \quad \Rightarrow \quad B = \mu_0(1+\chi)H \tag{2.3}$$

$$\mu_r = 1 + \chi \quad \Rightarrow \quad B = \mu_0\mu_r H \tag{2.4}$$

However, when using magnetic materials, $\mu_r$ is not a constant and so:

$$B = \mu_0(H + M) \tag{2.5}$$

$\mu_0$ is the permeability of free space ($4\pi \times 10^{-7}$ H/m $\approx 1.257 \times 10^{-6}$ H/m),
$\mu_r$ is the relative permeability of the material.
$M$ is the magnetisation of the core material.
$\chi$ is the volume magnetic susceptibility

By using different materials within the centre of the solenoid different values of $mu$ are used resulting in different hysteresis loops being formed. These B and H values cannot be measured directly. But if you arrange 2 solenoids as in (**Figure 2**).

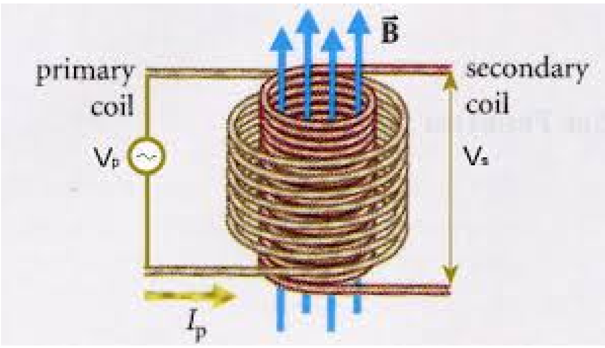


Figure 2: Interlinked solenoids [2].

the variance of the magnetic field in one (the primary solenoid) results in an induced $emf$ in the other coil. This is given by Faraday's law of induction:

$$\mathcal{E} = -N_s \frac{d\Phi}{dt} \tag{2.6}$$

Where: $\mathcal{E}$ is the $emf$ induced in the secondary coil $N_s$ is the number of turns of coil And $\frac{d\Phi}{dt}$ is the rate of change of flux
$\Phi$, the magnetic flux given by:

$$\Phi = BA_s \tag{2.7}$$

Where $B$ is the magnetic flux density inside the coil and is provided by the primary coil and $A_s$ is the area of the secondary coil.

$A_s$ is the Crossectional area of the material in the core.

This secondary coil then allows us to calculate $B$ by integrating $\mathcal{E} = -N_s \frac{d\Phi}{dt}$ to give:

$$B = -\frac{1}{N_s A_s} \int \mathcal{E} dt \tag{2.8}$$

Then through the use of an integrator circuit we can let $V_{out} = -\frac{1}{R_i C} \int \mathcal{E} dt$ and then calculate B using:

$$B = -\frac{R_i C}{N_s A_s} V_{out} \tag{2.9}$$

Our loop allows us to calculate the energy loss per cycle from the area under the $B$-$H$ curve and the $\mu_r$ values at different points. In this case, $\mu_r = \frac{1}{\mu_0} \frac{\partial B}{\partial H}$ as linear dependence is assumed in the localised region.

# 3 Experimental Setup

# 4 Results

# 5 Discussion

# 6 Conclusion

# References


[1] Robert Keim. What is hysteresis? an introduction for electrical engineers, 2023.

[2] Knoxville University of Tennessee. Mutual and self inductance.