UM-SJTU Joint Institute

Physics Laboratory

(Vp241)

Laboratory Report

Excercise 1

Basic Characteristics of Magnetic Materials

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Date: October 17, 2024

[rev4.1]

1 Introduction

The goal of this exercise is to study the shape of the magnetic hysteresis loop and the magnetization curve, and understand how to use these characteristics to discuss properties of ferromagnetic materials. For calculation, the magnetization curve and the magnetic hysteresis loop will be visualized on the oscilloscope.

2 Experimental setup

2.1 Conceptual Questions

Before going on with the experiment, we first answer the following concepts:

- **Magnetic Dipole Moment**: It is a vector quantity that represents the strength and orientation of a magnetic source, such as a current loop or a magnet. It measures the tendency of a system to align with a magnetic field.
- **Magnetization**: It refers to the degree to which a material becomes magnetized when exposed to a magnetic field. It is defined as the magnetic moment per unit volume of a material.
- **Antiferromagnetic vs. Ferromagnetic Ordering**:
  - **Antiferromagnetic Ordering**: In this type of magnetic ordering, adjacent atomic spins align in opposite directions, resulting in no net magnetization.
  - **Ferromagnetic Ordering**: In ferromagnetic materials, atomic spins align parallel to each other, leading to a strong net magnetization even without an external magnetic field.
- **Hysteresis Loop**: A curve showing the relationship between the magnetic field applied to a ferromagnetic material and its resulting magnetization. It demonstrates the material's magnetic memory, showing how magnetization lags behind changes in the applied field.
- **Curie Temperature**: The temperature above which a ferromagnetic material loses its permanent magnetic properties and becomes paramagnetic, meaning that thermal energy disrupts the alignment of magnetic moments.

2.2 Equipments used in the experiment

Devices used in this experiment include the following: a signal generator, an oscilloscope, a digital multimeter, a voltage/current source, a wiring block, a capacitor, and two resistors with resistance value of 10Ω and 1000Ω.

2.3 Measurements used in the experiment

There is only one measurement to do in this lab: the Magnetic Hysteresis Loop Measurement. To carry out the measurement, we build a circuit shown in the Figure 1:

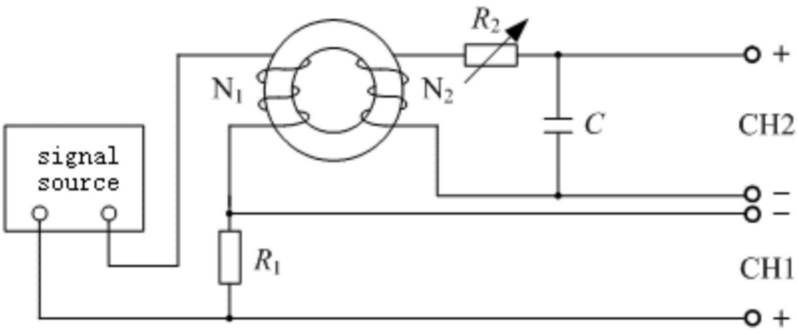


Figure 1: Circuit setup

Before measuring the desired U_C and U_R, we need to measure the two values of resistance and capacity using the multimeter. After measuring, take down the values for further calculations.

The voltage of the capacitor and the 10Ω resistor is displayed on the oscilloscope for further measurement. After adjusting the amplitude and frequency of the output signal, we take 18 points on the loop as 18 groups of data to record. Using these groups of data, we calculate 18 groups of value of H and B using the following equation:

$$H = \frac{N_1}{R_1 L} U_{R_1} \tag{1}$$

$$B = -\frac{R_2 C}{N_2 S} U_C \tag{2}$$

Finally using the data of H and B we plot the graph of H-B curve and find $\pm B_s$, $\pm B_r$, $\pm H_s$ and $\pm H_c$.

3 Measurements and Results

3.1 Magnetic Hysteresis Loop Measurement

Using the measurement method described above, we obtain the following data table:

N_1	100	N_2	100
R_1	10.17Ω	R_2	0.9968 kΩ
L	3.61×10^{-2} m	S	1.25×10^{-5} m²
		C	4.43 μF

Table 1. Parameters of circuit components.

U_{R_1} [mV]	0	32	76	93	130	94
U_C [mV]	93	113	134	136	143	122
U_{R_1} [mV]	67	60	37	0	−39	−100
U_C [mV]	44	0	−60	−93	−112	−129
U_{R_1} [mV]	−133	−186	−128	−77	−48	−26
U_C [mV]	−135	−141	−130	−104	0	63

Table 2. Measured values of U_{R_1} and U_C in the circuit.

H [A·m^{-1}]	0	8.72	20.70	25.33	35.41	25.60
B [T]	-3.29×10^{-1}	-3.89×10^{-1}	-4.73×10^{-1}	-4.8×10^{-1}	-5.05×10^{-1}	-4.31×10^{-1}
H [A·m^{-1}]	18.25	16.34	10.08	0	−10.62	−27.24
B [T]	-1.55×10^{-1}	0	2.12×10^{-1}	3.29×10^{-1}	3.96×10^{-1}	4.56×10^{-1}
H [A·m^{-1}]	−36.23	−50.66	−34.86	−20.97	−13.07	−7.08
B [T]	4.77×10^{-1}	4.98×10^{-1}	4.59×10^{-1}	3.67×10^{-1}	0	-2.23×10^{-1}

Table 3. Calculated values of B and H.

Figure 2: Data tables of the experiment

Table 1 is the data table of some essential parameters we will be using in the later calculation. In table 2 are the original groups of data obtained from the oscilloscope. Table three contains the calculated H and B using the equations 1 and 2.

4 Conclusions and discussion

4.1 H-B Curve and desired values of data

In this experiment, we will plot the graph of H-B curve based on the data groups obtained above. We will use python to do the plotting. The curve is shown below:

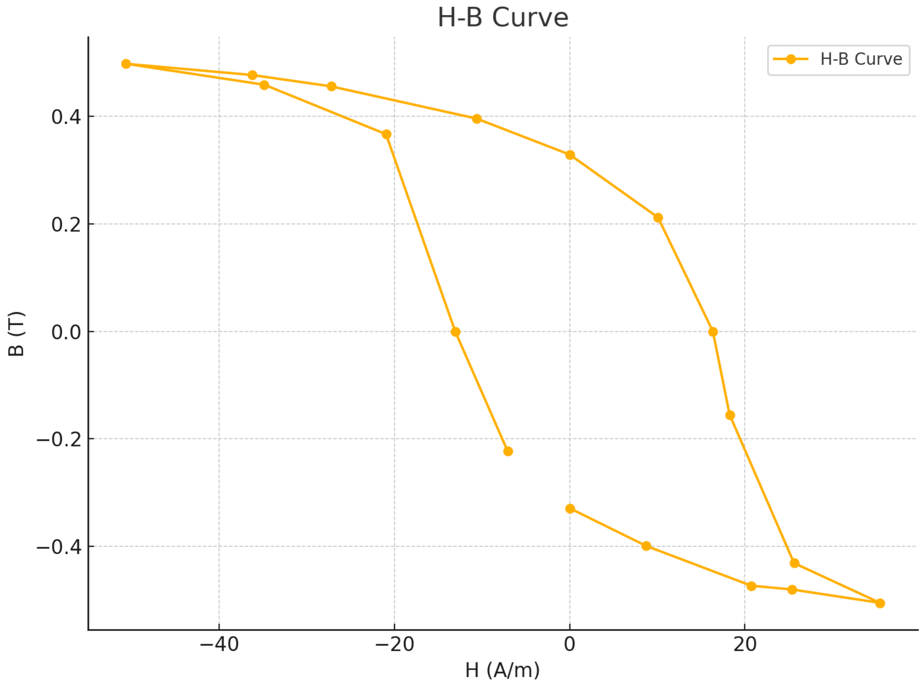


Figure 3: H-B curve

From the graph we can find the values of $\pm B_s$, $\pm B_r$, $\pm H_s$ and $\pm H_c$ as following:

- $\pm B_s$: $B_s^+ = 0.498\,\mathrm{T}$, $B_s^- = -0.505\,\mathrm{T}$
- $\pm B_r$: $B_r^+ = 0.329\,\mathrm{T}$, $B_r^- = -0.329\,\mathrm{T}$
- $\pm H_s$: $H_s^+ = 35.41\,\mathrm{A/m}$, $H_s^- = -50.66\,\mathrm{A/m}$
- $\pm H_c$: $H_c^+ = 16.34\,\mathrm{A/m}$, $H_c^- = -13.07\,\mathrm{A/m}$

4.2 Discussion

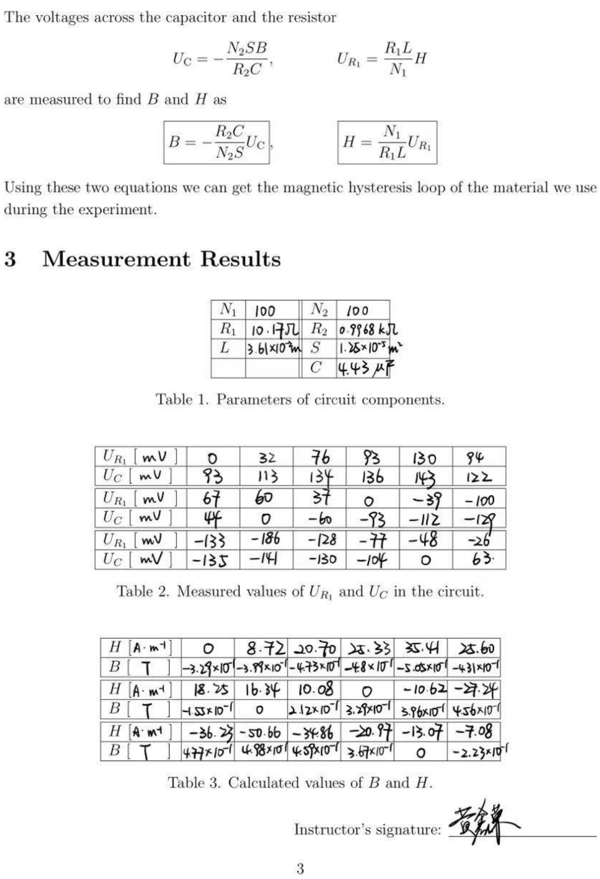
From the final output of rthe graph we may see some steps that can be further improved. The shape of the curve is similar to what we desire as a Magnetic Hysteresis Loop, but it is still not symmetrical enough (or say, not smooth enough). This indicates some probable inaccuracy in calculation or the process of data obtaining. One ideal solution to this problem is to take more groups of data to make up for the loss of accuracy. Also, the whole measurement process is done manully choosing data points, which may also make the distribution of data not even or average. It would be great if there are some automatic programs that help choose data points at higher accuracy for better data distribution.

5 Works cited

Department of Physics, Shanghai Jiaotong University, Exercise 1 (Basic Characteristics of Magnetic Materials) - lab manual [rev. 2.4], 2024
Python Software Foundation. (2020). Python Language Reference, version 3.9. Available at http://www.python.org

All the figures displayed in the article (excluding the appendix) are given using Python 3.9.

A Datasheet



The voltages across the capacitor and the resistor

$$U_C = -\frac{N_2 S B}{R_2 C}, \qquad U_{R_1} = \frac{R_1 L}{N_1} H$$

are measured to find B and H as

$$\boxed{B = -\frac{R_2 C}{N_2 S} U_C}, \qquad \boxed{H = \frac{N_1}{R_1 L} U_{R_1}}$$

Using these two equations we can get the magnetic hysteresis loop of the material we use during the experiment.

3 Measurement Results

N_1	100	N_2	100
R_1	10.17 Ω	R_2	0.9968 kΩ
L	3.61×10^{-2} m	S	1.25×10^{-5} m²
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Table 1. Parameters of circuit components.

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Table 3. Calculated values of B and H.

Instructor's signature:

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Figure 4: Datasheet 1