SCHOOL OF PHYSICS
UNIVERSITI SAINS MALAYSIA

ZCT191/192 PHYSICS PRACTICAL I/II

ERROR ANALYSIS

Lab Manual

OBJECTIVES

1. *To understand how to correctly present a physical quantity with its error;*
2. *To estimate the resistivity of a copper wire and its error by measuring its length, resistance and diameter; and*
3. *To study the probability distribution function of the diameter of a copper wire.*

THEORY

Introduction

This experiment is the first experiment that you will conduct in your *first year undergraduate physics laboratory* (also known as *first year lab* or *lab 100*). Before you start, please read and understand the *Introduction to Error Analysis* guidebook given as it contains the fundamentals required to conduct all physics experiments from this point onwards.

This experiment is divided into two parts. **Part A** is about measuring the resistivity of copper, where the variables used to determine the resistivities are measured and their respective errors estimated. Subsequently, the resistivities are calculated and their related errors computed using the *propagation of errors*. In **Part B**, a statistical analysis on wire diameters will be performed to confirm that you understand basic error analysis, which has been covered in the guidebook mentioned. Just like all other experiments, two practical sessions are required to perform this experiment.

This experiment is a little different from the others, in the sense that all you need to do is to fill up the blanks and tables, cross out incorrect statements, analyse and comment on the experimental aspects in the worksheets given. No report submission is required for this experiment, unlike all other experiments in this lab. Remember to write your answers in the correct units and significant figures.

Resistivity

The resistance (R) for a conductor in cylindrical form is given by:

$$R = \rho \frac{l}{A} \tag{1}$$

where ρ, l, and A are the *resistivity*, length, and cross-sectional area of the conductor, respectively. Thus, the resistivity of a conductor can be calculated once l, R and A are known.

In this experiment, an SWG36 copper wire will be used as the conductor. Here, SWG stands for *standard wire gauge*, which is a unit for denoting wire size, while the number 36 is a code corresponding to a thickness of 0.1930 mm.

EQUIPMENT

1. SWG36 copper wire (length ~130 cm)
2. Micrometer
3. Metre rule
4. Multimeter
5. Sandpaper

PROCEDURE

Part A: Resistivity of A Copper Wire

In this experiment, you are required to make a few measurements on the length, resistance and diameter of a copper wire and calculate its resistivity.

A1: Length of Copper Wire

1. Measure the length (l) of the copper wire with the metre rule.
2. Repeat the measurement so that 8 readings are obtained, and record them in **Table 1**.
3. Calculate the average value of the length ($\bar{l}$) and its corresponding error.

A2: Resistance of Copper Wire

1. Remove the enamel coating at both ends of the copper wire to obtain better electrical conductivity.
2. Measure the resistance (R) of the copper wire with a multimeter. Ensure that you turn knob and read the scale carefully.
3. Repeat the measurement so that 8 readings are obtained, record them in **Table 2**.
4. Calculate the average value of the resistance ($\bar{R}$) and its corresponding error.

A3: Diameter of Copper Wire

1. Record the zero error of the micrometer up to 3 decimal places.
2. Remove a small part of the enamel coating until the bare copper wire is observed.
3. Measure the diameter of the copper wire with a micrometer.
4. Repeat **Step 3**, each time at a different area of the copper wire, until 8 readings are collected. Record your measurements in **Table 3**.
5. Calculate the average value of the diameter ($\bar{d}$) and its corresponding error.
6. Compare the measured value with the diameter d_0 given by the laboratory reference book, and find the percentage discrepancy between them.

Analysis

1. Compute the resistivity (ρ) of the copper wire using **Equation 1**, and find its corresponding error using the propagation of errors.
2. Measure the temperature of the laboratory.
3. By using the standard values of the resistivity of the SWG36 copper wire at temperatures $T = 0$ °C and 100 °C obtained from the laboratory reference book, plot a graph of ρ vs. T.
4. From the graph, obtain the standard resistivity at the laboratory temperature (ρ_0) and find its percentage discrepancy with the measured value.

Part B: Probability Distribution of Wire Diameter

In this part, you are required to perform statistical error analysis on a distribution of data.

Measurement

1. Obtain 8 readings of the diameter of the copper wire using the micrometer, each time at a different location.
2. Repeat **Step 1** twice, such that you have obtained 3 samples of diameter measurements (you can use your data obtained for **Part A3** as one sample). Record your data in **Table 4**. Note that samples $j = 4$ to 40 has been generated for you, thus you have a total sample size of $N = 40 \times 8$.

Analysis

1. Using an interval of $d = 2 \times 10^{-3}$ mm, divide each reading into bins of data, and record the number of readings (n) for each bin in **Table 5**. Choose a suitable starting point and bin interval ranges such that all the readings could be included.
   [*Hint: you can sort the data and produce the graphs required using Microsoft Excel.*]
2. Plot a histogram of n/N vs. d.
3. Estimate the mean diameter of the copper wire, ($\bar{d}$), its standard deviation (s), and its standard error (s_{m}).
4. Sketch a smooth Gaussian curves that could represent the data distribution given by the histogram. This can be done by equating the maximum value of the histogram $(n/N)_{\max}$ with the peak of the Gaussian function (at $x = \mu$), such that

$$\left(\frac{n}{N}\right)_{\max} \frac{1}{\Delta x} = \frac{1}{\sigma\sqrt{2\pi}}, \qquad (2)$$

   where Δx is the bin interval, required to adjust the area of the Gaussian curve. Sketch the Gaussian curve $f(\mu, \sigma)$ using $\mu = d_{\max}$, the centre point of the bin with $(n/N)_{\max}$ and the value of σ obtained from **Equation 2**.
5. Calculate the resistivity $\bar{\rho}$ of the copper wire by using the values of R and l obtained from **Parts A1** and **A2**, but d obtained from **Part B**.
6. Estimate the error $\delta\rho$ using propagation of errors.
7. Compare the $\bar{\rho}$ obtained from this experiment (ρ_{B}) with the standard value ρ_0 and the value of $\bar{\rho}$ obtained from **Part A** (ρ_{A}).

REFERENCES

1. School of Physics, USM (2021). *Introduction to Error Analysis*. Universiti Sains Malaysia.
2. Taylor, J. R. (1997). *An introduction to Error Analysis: The Study of Uncertainties in Physical Measurements (2nd Ed.)*. University Science Books.

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