1. Heat Conduction in a Copper Rod

Experimental Examination

Report: ***Reza M. Namin***,

Experiment Design: ***Alireza Noroozshad***

Setup Production: ***Ava Smart World Co.***

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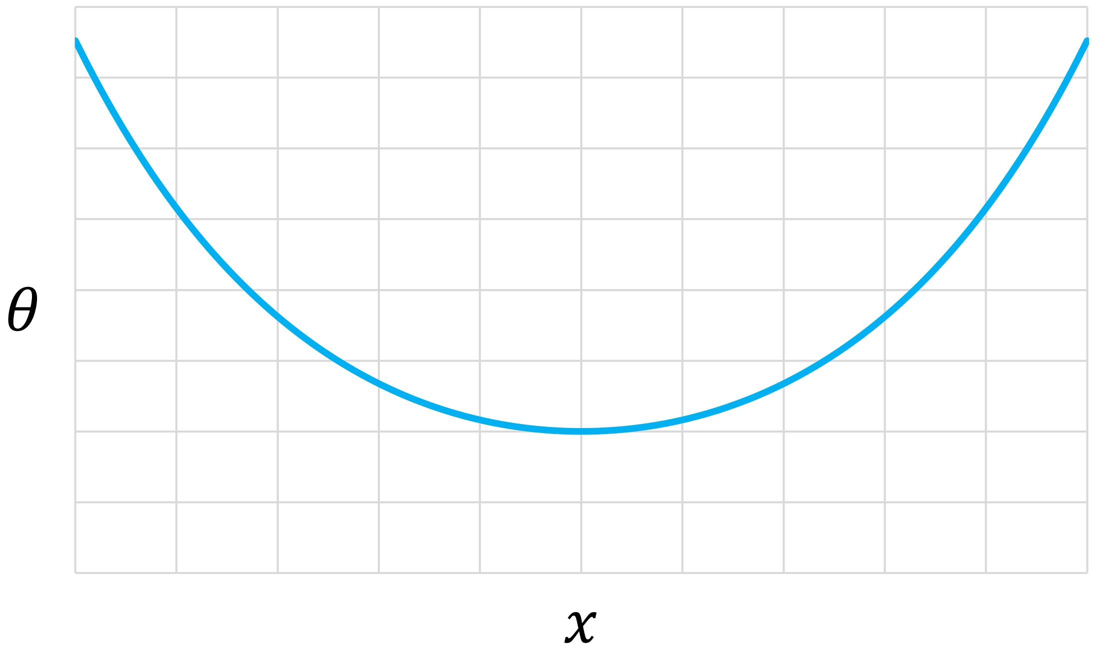
Introduction

- ***Thermodynamics*** does not often make its way to our Experimental Exams ☹

- *But*… It's quite important!
  - It provides a foundation for **understanding energy**; its transfer, conversion, conservation, etc.
  - It paves roads to understanding the **laws of thermodynamics**, which is… well… a big deal!
  - Has **numerous applications** in a variety of fields of applied physics and engineering…

- So, ***let's propose a problem in Thermodynamics!***

Problem Core



$$\theta - \theta_{en} = A\cosh\left(\lambda(x - x_0)\right)$$

$$\lambda = \sqrt{{}^{2h}\!/_{kr}}$$

h: Convection Coef.
k: Conduction Coef.
r: Rod Radius

Analysis of this **temperature profile** with **Energy Equations** could lead us to find several parameters such as the conduction coefficient (***k***) and convection coefficient (***h***)

Requirements in this Thermodynamics Problem

Box & Forced Convection	**Innovation in Part C**	**Low Temp, Restricted Access**
Create a Controlled Environment	**Include Innovation**	**Resolve Safety Concerns**
Shouldn't Require High Power	**Enable Reasonable Precision from Measurements**	**Enhance Keeping Track of Numerous Measurements**
Accurate Sensor, Low Power	**Accurate Calibrated PTC & NTC Thermistors**	**Effective User Interface**

The Setup

Well-Crafted Setup

Several Fast Accurate Sensors

Controlled Forced Convection

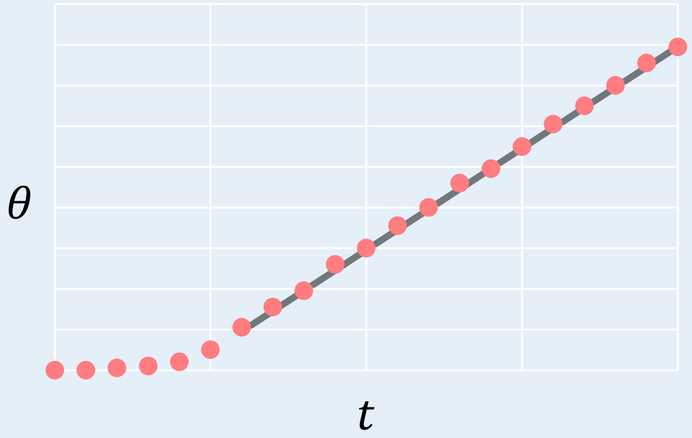
Convenient User Interface

All data Saved with a Button

Safe and Low Power

Problem Outline

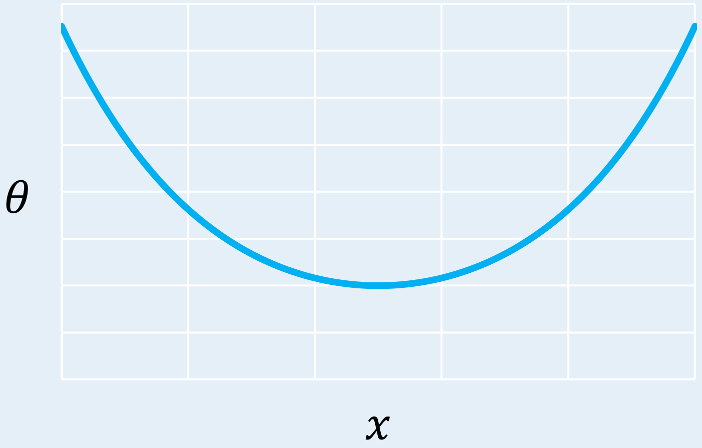
Preliminary Steps – Part A



Evaluation of setup parameters

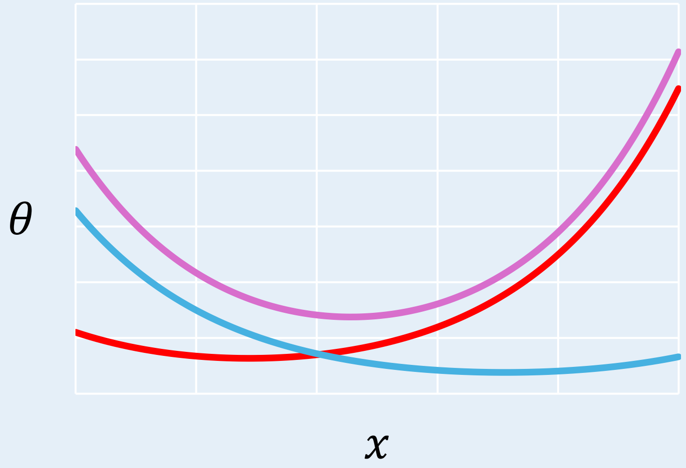
Calibration of a sample sensor

Problem Core – Part B



Calculation of ***Convection*** and ***Conduction*** coefficients from steady-state temperature profile

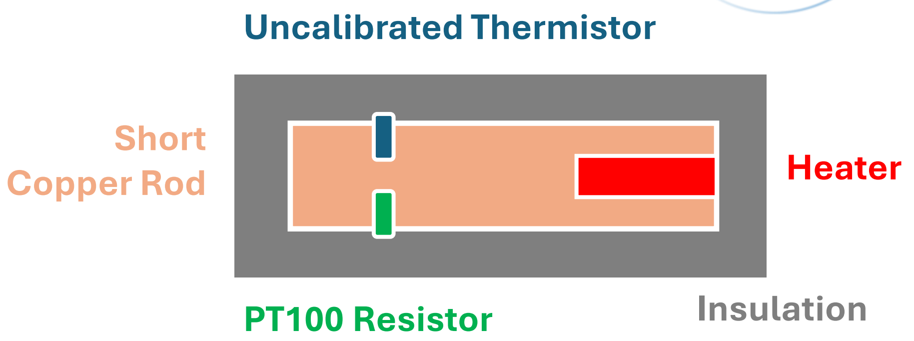
Innovative Step – Part C



Use students' ***own method*** to estimate an unknown power

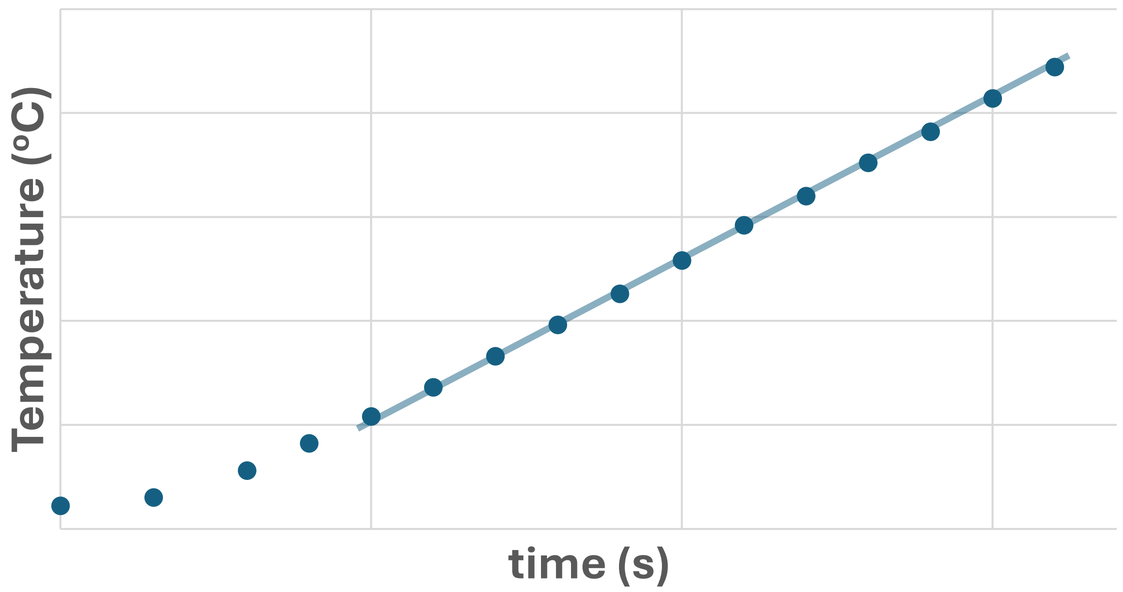
Problem Walkthrough – Part A (A1-A3)

- Use PT-100
  - ➔ Find Temperatures
  - ➔ Calculate $\boldsymbol{C_s}$



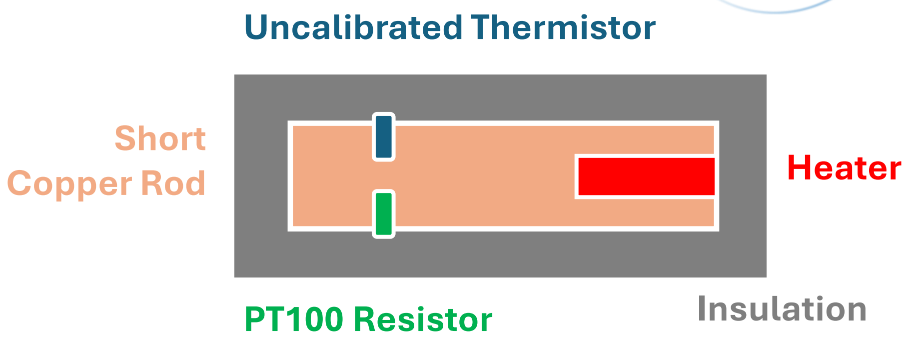
- Knowing the input power, the heat ***capacity*** can be calculated from the linear slope

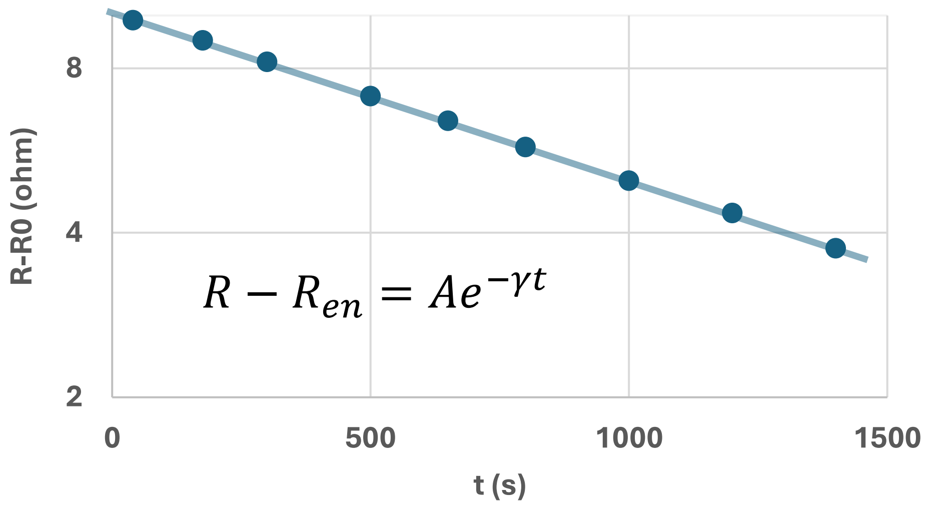
- Important to consider the ***linear region*** of the plot

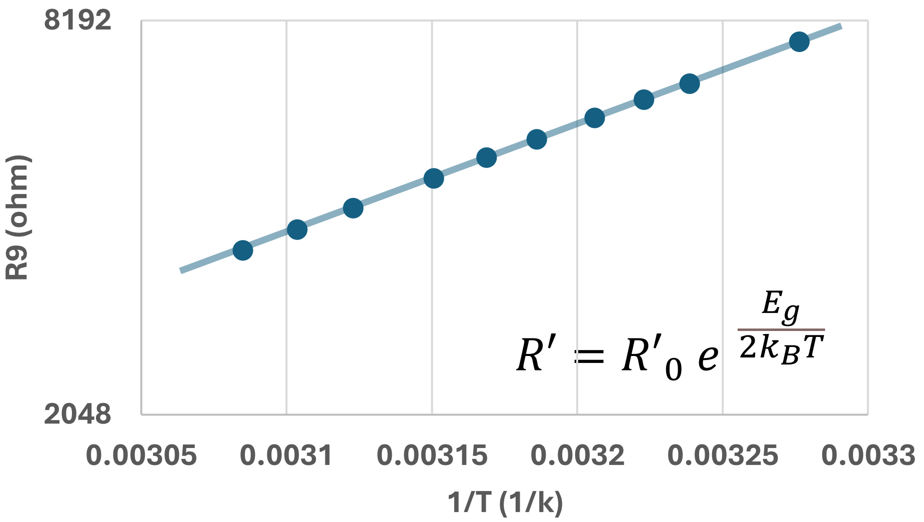


Problem Walkthrough – Part A (A4-A7)

- Cooldown Measurements:
  - Use PT-100 ➔ Find gamma using a semi-log plot
  - ***Calibrate the Thermistor*** using a semi-log plot (R vs $1/T$) ➔ Calculate Energy Gap (E_g)



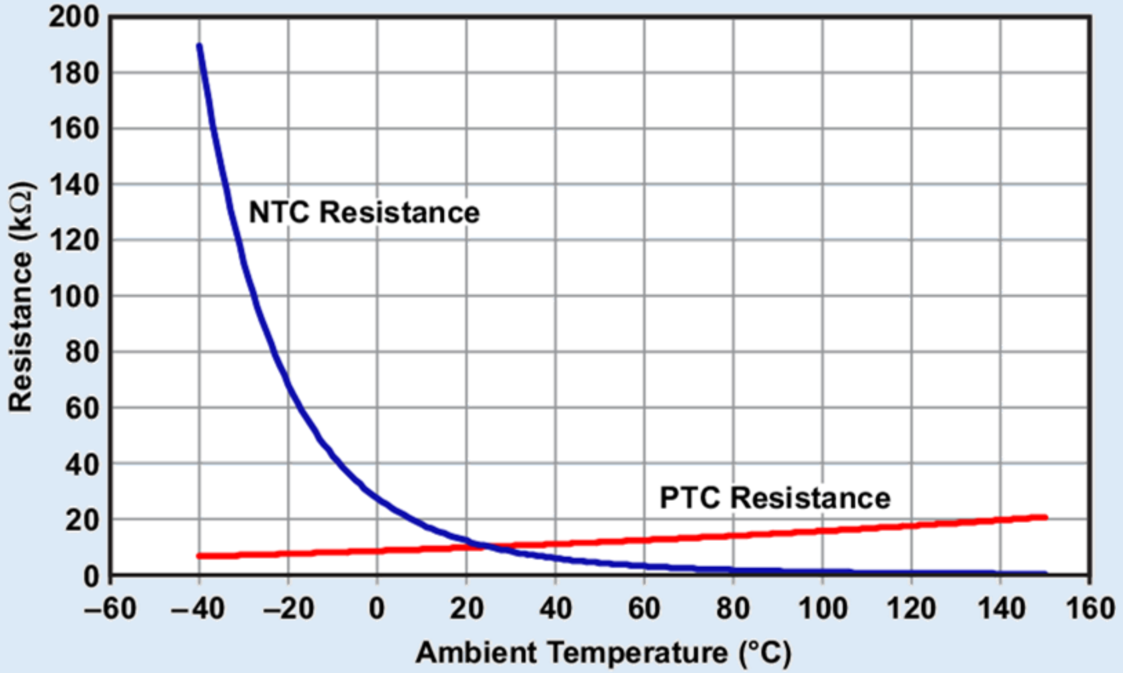


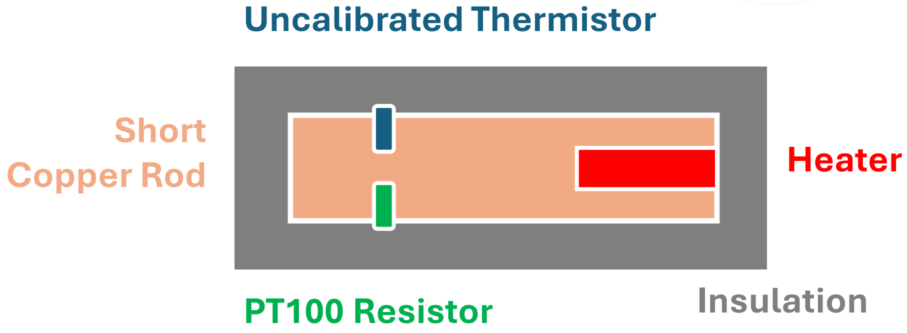


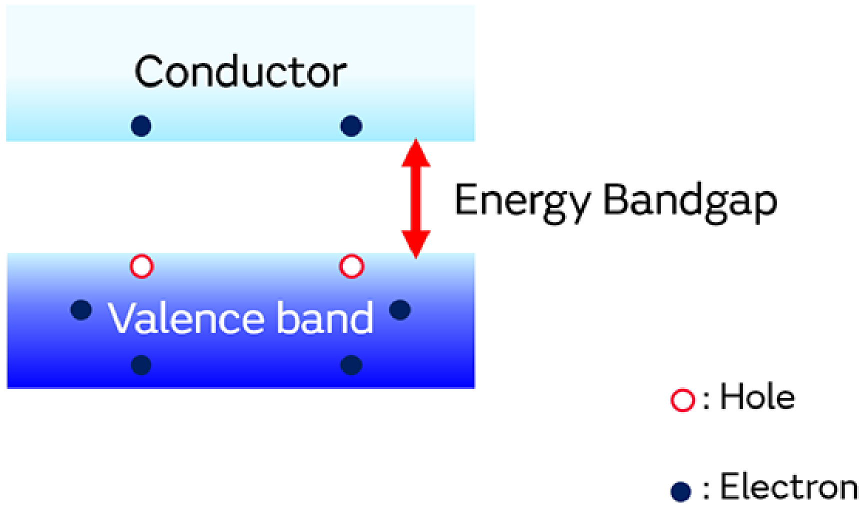
Problem Walkthrough – Part A (A4-A7)

Interesting Concept:

NTC and PTC Thermistors

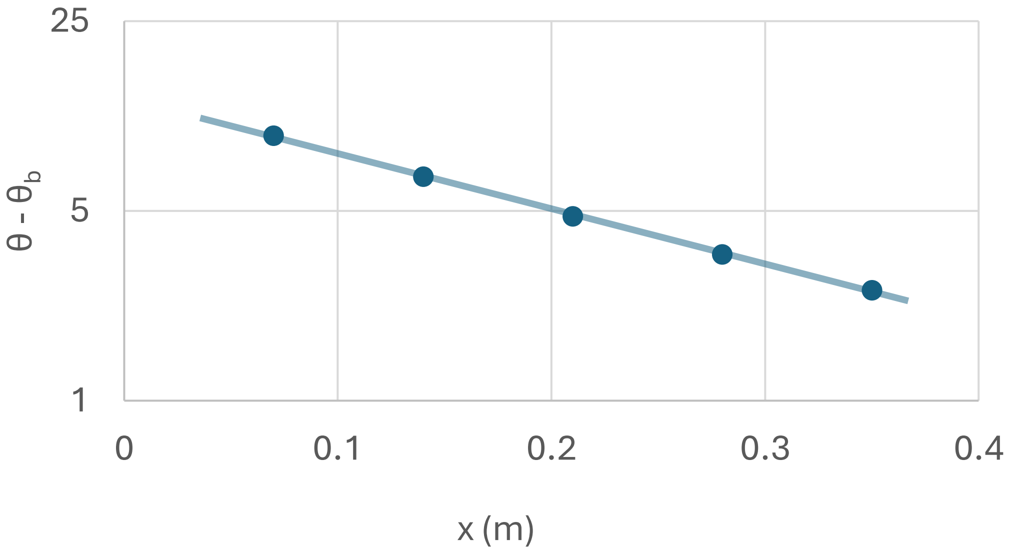


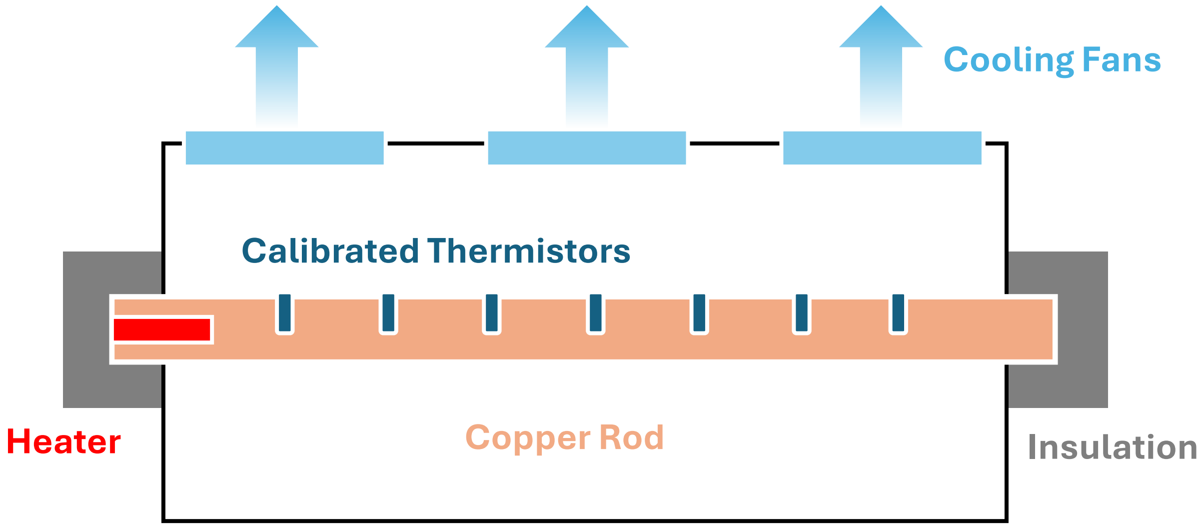




Problem Walkthrough – Part B (B1-B3)

- The Long Rod Setup:
  - Turn On Heater 2;
    ➔ Wait for Steady Temperatures
    ➔ Measure and Plot Temperatures
    ➔ Estimate $\boldsymbol{A^{(0)}}$ and $\boldsymbol{\lambda^{(0)}}$

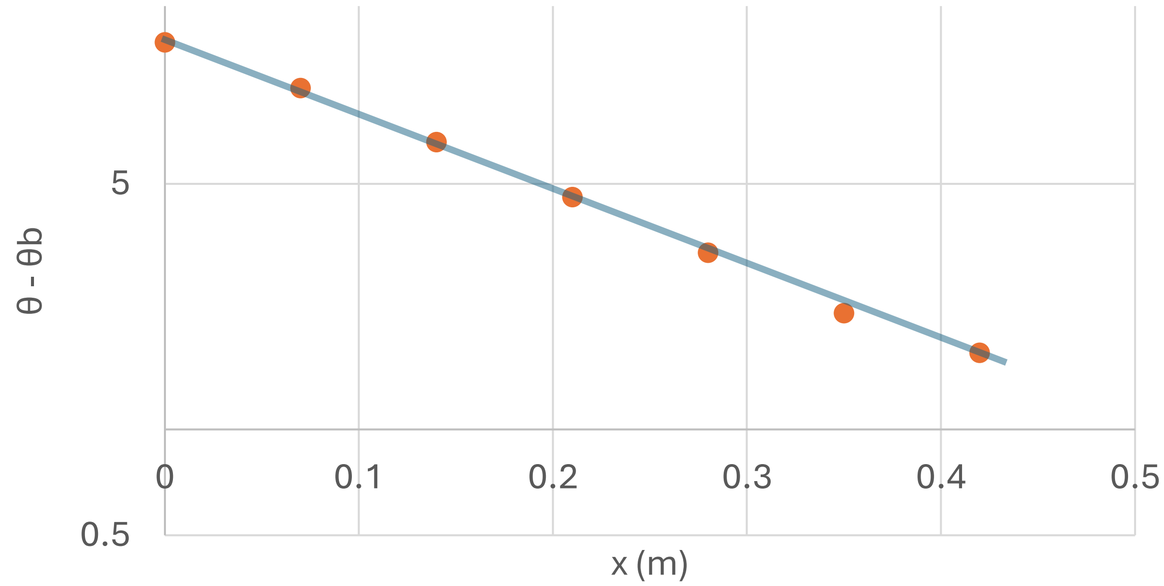


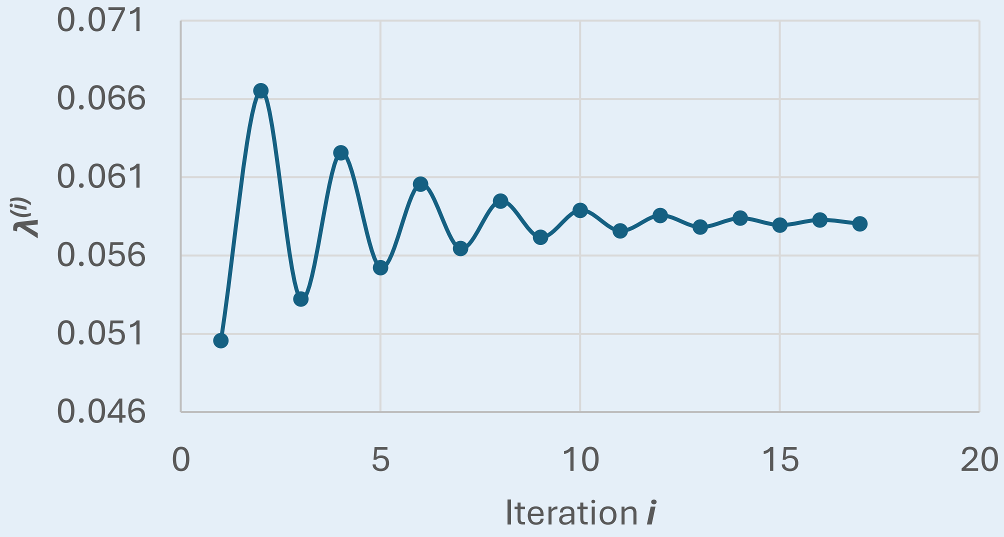


$$\theta_x = \theta_b + \boldsymbol{A}\boldsymbol{e}^{-\boldsymbol{\lambda x}} + Be^{\lambda x}$$

Problem Walkthrough – Part B (B4-B7)

- Correct Calculations by Considering B
  ➔ Repeat Calculations to Estimate $\boldsymbol{A^{(1)}}$ and $\boldsymbol{\lambda^{(1)}}$
  ➔ Final Estimation by Averaging (0) and (1)
  ➔ Calculate ***h*** and ***k*** by balancing input & output powers





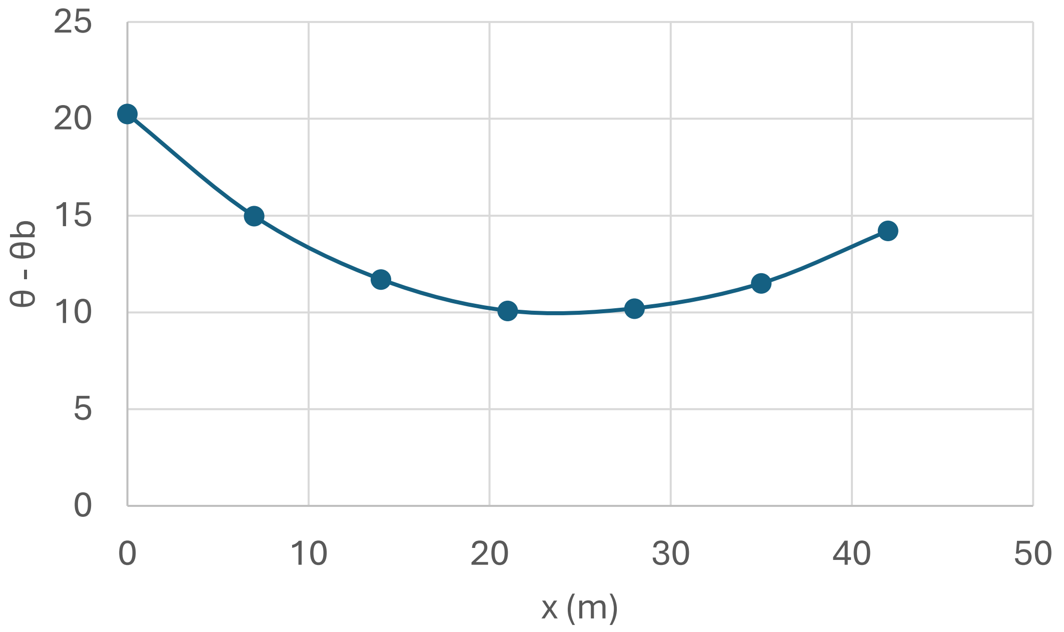
$$\lambda^{(17)} = 0.05803$$

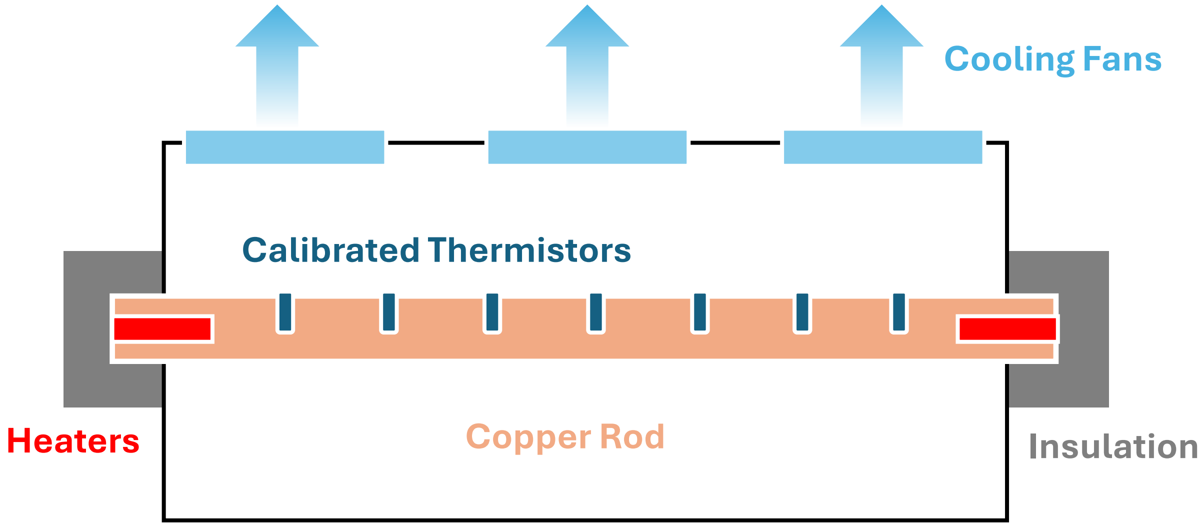
$$(\lambda^{(1)}\lambda^{(0)})/_2 = 0.05855$$

Difference < 1%

Problem Walkthrough – Part C

- Same Setup with Heater 3 on:
  - Draw ***θ*** vs ***x*** and find x_0





x0 can be calculated by curve fitting (preferred), or visually using the plot

Problem Walkthrough – Part C: Innovation

Estimation of Temperature Slope at the two Ends

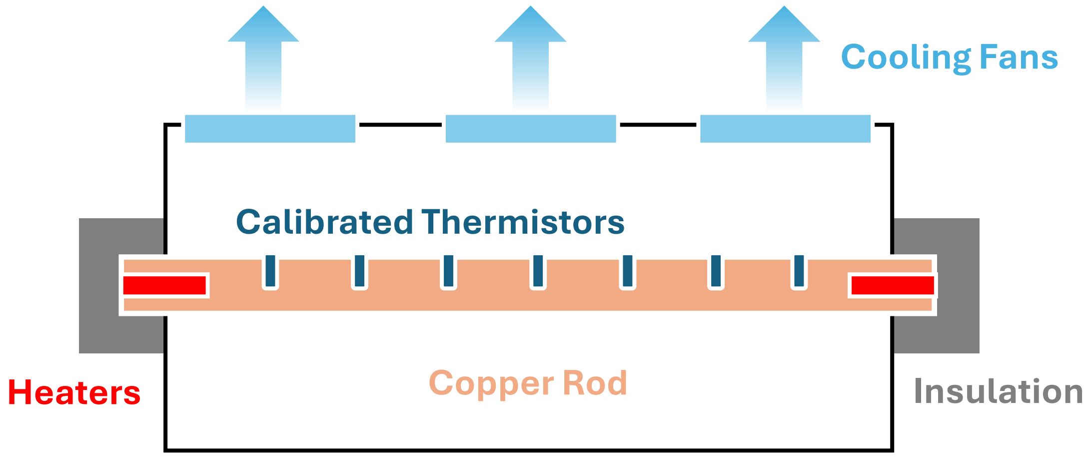
- Numerical Differentiation
- Estimation via Curve Fitting
- Calculate Using the Formulations and $\boldsymbol{x_0}$

Separation of the Temperature Profiles via Superposition

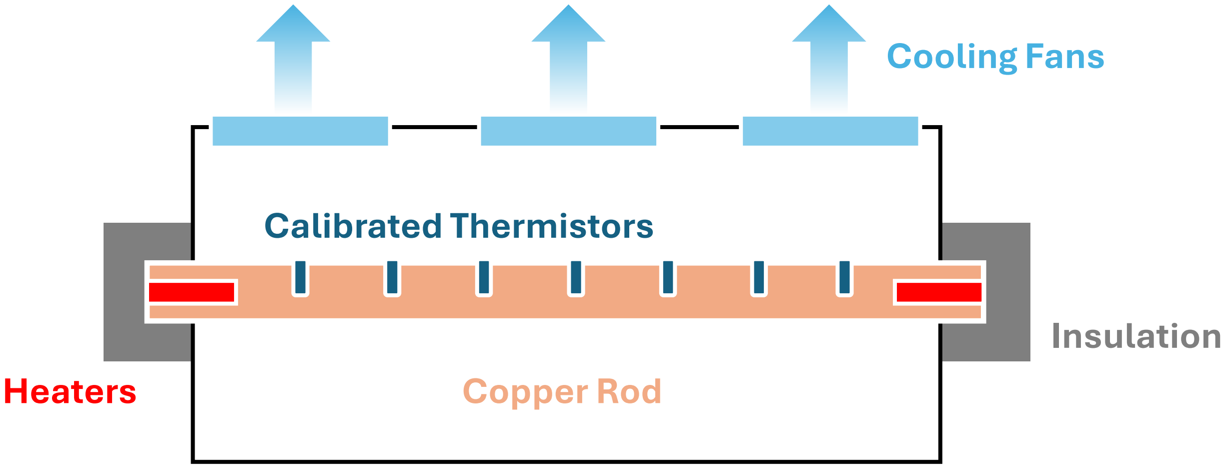
- Subtract the Temperatures from Part B to find the Temperature Effects of Heater 3
- Use the Same Formulations of Part B to find the Power

Estimation of the Total Convective Power via Integration

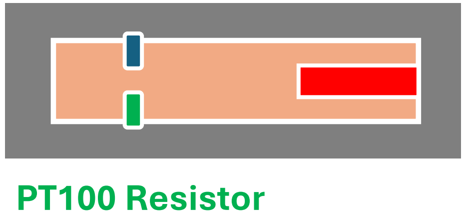
- Integrate the Total Convection Power to find all the Input Power
- Balance Input and Output Powers to find Heater3 Power



The Setup



Internal Experimental Setup



External Experimental Setup

The Setup

Internal Setup

User Interface

External Setup

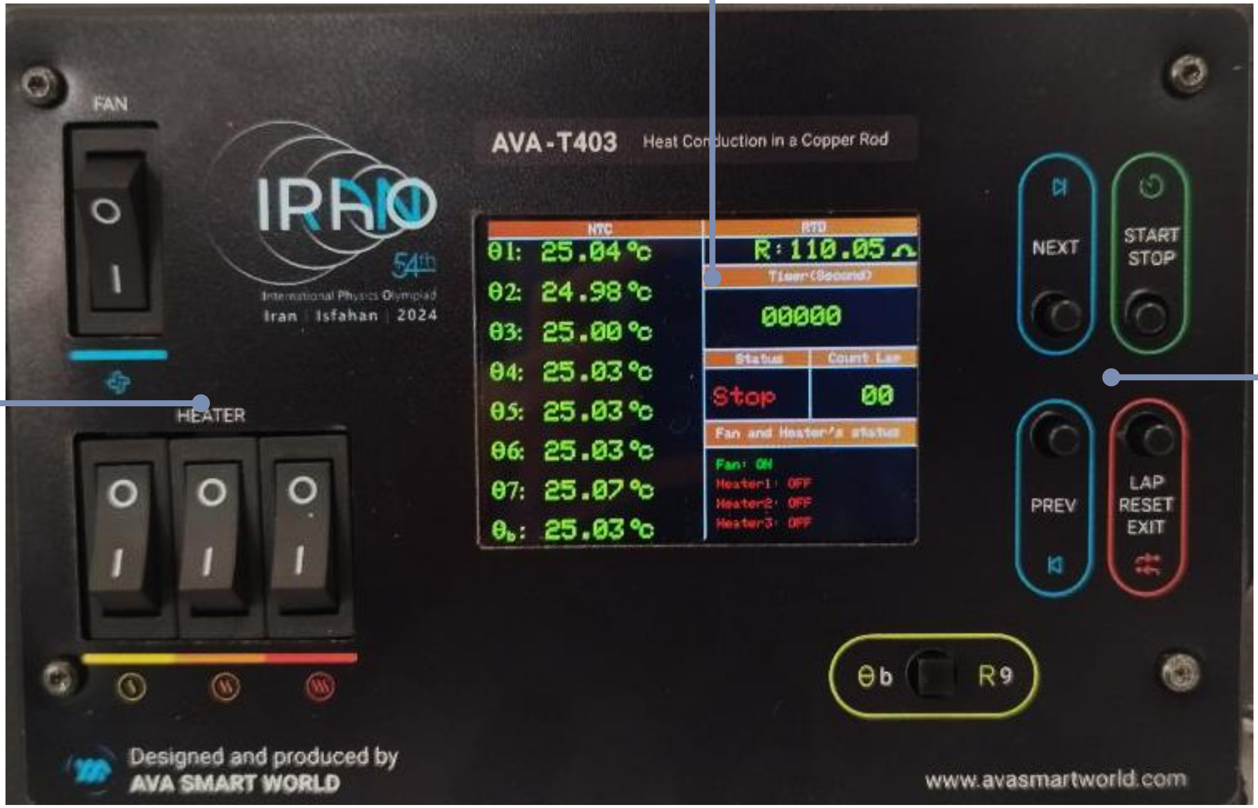
The Setup – Internal Parts

The Setup – User Interface

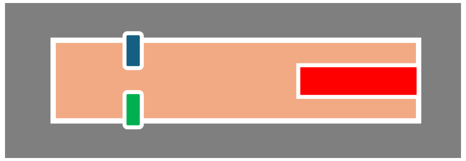
Display

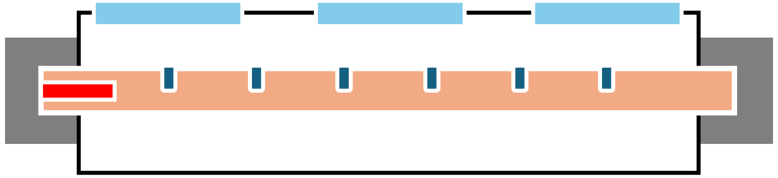
System Control

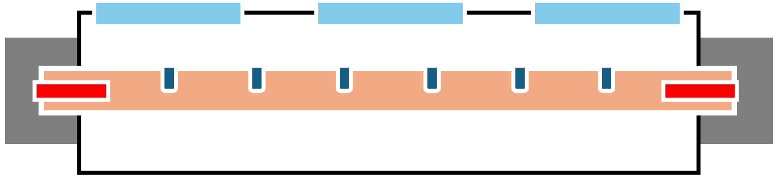
Interface Control



Main Question Parts:







Part A:

Using The External Setup

Measure parameters in rising and falling temperatures

Calibrate and calculate parameters e.g. ***the energy gap***

Part B:

Using The Internal Setup

Measure temperatures in the steady state with heater 2 on;

Follow an interesting line of calculations to find ***convection*** and ***conduction*** coefficients

Part C:

Using The Internal Setup

Measure temperatures in the steady state with heaters 2&3 on;

Using your own method estimate the power of heater 3

Syllabus

Syllabus – Theoretical Skills

- 2.1 General
  - The ability to make appropriate approximations, while modelling real life problems (Parts 1-3). Recognition of and ability to exploit symmetry in problems (Part 3).

- 2.7. Thermodynamics and Statistical Physics
  - 2.7.1. Classical thermodynamics
    - Concepts of thermal equilibrium, internal energy, heat, Kelvin's temperature scale, Specific Heat (Parts 1-3).

Syllabus – Experimental Skills (1/2)

- 3.3 Measurement techniques and apparatus
  - Knowing commonly used simple laboratory instruments and digital and analog versions of simple devices, such as thermometers.
  - In the case of moderately sophisticated equipment, instructions must be given to the students.

- 3.4. Accuracy
  - Being aware that instruments may affect the outcome of experiments.
  - Being familiar with basic techniques for increasing experimental accuracy
  - Expressing the final results and experimental uncertainties with a reasonable number of significant digits, and rounding off correctly

Syllabus – Experimental Skills (2/2)

- 3.5 Experimental uncertainty analysis
  - Identification of dominant error sources, and reasonable estimation of the magnitudes of the experimental uncertainties of direct measurements
  - Finding absolute and relative uncertainties of a quantity determined as a function of measured quantities using any reasonable method

- 3.6. Data analysis
  - Transformation of a dependence to a linear form by appropriate choice of variables and fitting a straight line to experimental points
  - Finding the linear regression parameters either graphically, or using the statistical functions of a calculator
  - Selecting optimal scales for graphs and plotting data points with error bars

Syllabus – Mathematics

- 4.1. Algebra
  - Simplification of formulae by factorisation and expansion
- 4.2. Functions
  - Basic properties of exponential and logarithmic functions
- 4.7. Calculus
  - Finding derivatives of elementary functions
  - Integration of elementary functions
- 4.8 Approximate and numerical methods
  - Using linear and polynomial approximations based on Taylor series. Linearization of equations and expressions

Thank You

Some Interesting Concepts

Using of a ***specially designed*** experimental setup for a thermodynamics problem, enabling **accurate** measurements in a controlled system

Introduction of an interesting ***iterative experimental process*** in part B, with its rather surprising shortcut

Calculation of a rather complex property of material i.e. ***the Energy Gap*** from simple plotting of transient temperature data in part A

An innovative step to find the unknown power in part 3, for which several methods can be explored with significant differences in the final accuracy!