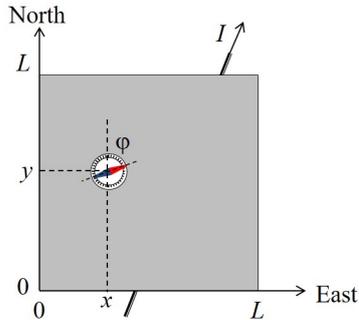


E1: Hidden wire**Experimental setup and tasks**

A very long copper wire runs horizontally at unknown depth h under a horizontal square surface of side length $L = 100.0$ mm. The sides of the square are oriented West-East (the x -axis) and South-North (the y -axis), as shown in the figure. The origin of the coordinate system coincides with the South-West corner of the square.



The wire is connected to an adjustable DC source (not shown in the figure), which can provide a current I in the range from -5 A to 5 A. The reversal of the sign of the current corresponds to a reversal of the polarity of the source. A small compass can be placed on the square surface, (including its circumference) to sense the magnetic field of the wire through the deflection angle φ between the magnetic needle and the North (y) direction. Positive φ values correspond to an Eastward deflection, as shown in the figure, while negative φ correspond to a Westward deflection. You can assume that:

- The magnetic needle is a point-like magnetic dipole, which can rotate freely around the vertical axis, i.e. the compass is sensitive to the horizontal component of the magnetic field only.
- The height of the needle above the surface is negligible compared to the depth of the wire beneath the surface, i.e. the needle is situated in the xy -plane.

Design your experiment and make the necessary simulations to perform the following tasks:

- Determine the orientation of the wire with respect to the coordinate system by specifying its equation in the form: $y = ax + b$, and estimate the uncertainties of the parameters a and b . Draw the wire position on a graph and indicate the direction corresponding to a positive current I .
- Determine the depth h of the wire below the surface and the horizontal component B_E of the Earth's magnetic field. In this task you are not required to calculate the experimental uncertainties explicitly, however, your final results must be represented with an appropriate number of significant digits.

The magnetic permeability of free space is

$$\mu_0 = 4\pi \times 10^{-7} \text{ T m/A.}$$

Description of the simulation software

The command line program simulates the measurement of the deflection angle φ after providing the current I and placing the compass at the coordinates x and y on the surface.

A typical output of a single simulation cycle of the program looks like:

```
Enter I (A) between -5.0 and 5.0: 3.4
Enter X (mm) between 0 and 100: 55
Enter Y (mm) between 0 and 100: 31
PHI = -33 degrees
-----
Enter I (A) between -5.0 and 5.0: _
```

First, you enter the current I in A (the number between -5.0 and 5.0), then coordinates x and y in mm (the numbers between 0 and 100). Each input is confirmed with the **Enter** key. The program will output the value of φ (PHI) in degrees (rounded to 1°) and return to the initial prompt.

The current input I will be rounded to 0.1 A, the coordinate inputs x, y will be rounded to 1 mm before being used in simulation. (There is no point in trying to input more precise numbers).

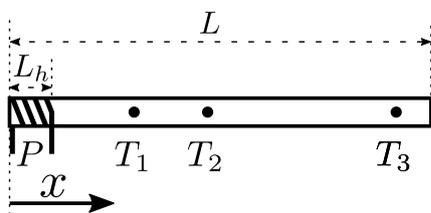
Every time you change the position of a compass, its real position used in simulation differs from the input coordinates with an error about 0.5 mm. (It is a simulation of a limited precision when you place an object).

Any time you need to quit the program, press **Ctrl+C**.

E2: Hot Cylinder

Introduction

A uniform metal rod of length $L = 30$ cm and radius $r = 1$ cm is made of an unknown metal and is kept at room temperature $T_0 = 26.9$ C = 300 K. The metal rod is weighed to be $m = 460$ g. Your task is to determine the thermal properties of the unknown metal. The metal rod can be heated at one of its ends, and temperature measurements can be performed on customizable locations along the rod. The heater is located between $x = 0$ and $x = L_h = 3$ cm (see fig). The heater can be programmed by specifying a fixed power (in watts) and the duration (in seconds) for which the heater is turned on for. Temperature measurements are made by specifying up to five locations for the sensors along the rod, alongside with the frequency, starting time and the ending time of the measurements. The simulation will show the temperature readings in accelerated "real time" (running around 10 times faster than in the real world).



You may assume that all of the heating power goes into the rod, and that the rod loses heat to its surroundings via heat transfer with air and black body radiation. Heat transfer with air is linear in temperature of the rod, and can be described by a coefficient α such that the heat transfer per unit area per unit time is $\alpha(T - T_0)$. The air is well-ventilated such that α can be assumed to be constant throughout the surface of the rod and independent of the temperature of the surface. Heat loss via black body radiation can be described using the Stefan-Boltzmann law modified with emissivity β such that the heat loss to radiation per unit area per unit time is $\beta\sigma(T^4 - T_0^4)$ where $\sigma = 5.67 \times 10^{-8}$ W/(m² K⁴). Similar to α , the emissivity can be assumed to be constant throughout the rod, and independent of temperature. The rod is further characterised by the thermal conductivity k (such that the heat flux density along x is $-kdT/dx$) and the specific heat capacity c .

Task

The task is to determine the specific heat of the unknown metal, c (units J/(K kg)), the thermal conductivity k (units W/(m K)), and the heat loss coefficients α (units W/(m² K)), and β (dimensionless). You should aim to find the values within 10% of the true value. This is because there are various sources of errors, such as Gaussian fluctuations in both defining the locations of the sensors, and the taking the temperature measurements. The sizes of the errors can be found by observing the fluctuations in the output.

As with all experiments, you must provide clearly labelled tables of data, clearly labelled graphs, and suf-

ficient formulae derivations to make it clear what you have measured, and how you are deriving your results.

Program interface

Running the simulation program, named **rod**, allows performing multiple experiments on the rod. The program will ask a sequence of prompts regarding the setup of the experiment. For each prompt, the corresponding value(s) should be entered, followed by pressing **return** to go the next prompt. The prompts are as follows:

1. The heating power of the heater:
Enter P (W), between 0 and 300:
2. The duration after the start of the experiment for which the heater is turned on for (after this time, the heater will be turned off):
Enter heating duration (s), between 0 and 3600s:
3. The starting and finishing times (after the start of the experiment) for the temperature measurements made on the rod:
Enter the starting and finishing time for the measurements (s), separated by a space. Must be between 0 and 3600s:
4. The time interval between two consecutive measurements that are made with the temperature sensors:
Enter dt (s), between 5 and 3600s and a multiple of 5s:
5. The locations of the temperature sensors along the rod. The coordinates are specified with respect to the end with the heater:
Enter up to 5 locations for the sensors (in cm), between L=0 and L=30cm, separated by spaces:
Note that not entering any numbers simply means not taking any measurements.
6. The output file name for the temperature readings. Note that all of the saved readings will also be displayed on the screen:
Enter the output file name:
You are advised to only use Latin letters and numbers for the name. Other characters may or may not be allowed in the filename and in case of an invalid filename, the readings will not be saved. The readings will be saved in a .txt file with the given name in the same folder as the program.

If you enter an invalid input, a clarifying error message will be sent, and an another opportunity for entering the input will be given.

The program will then prompt to press **return** to start the experiment, or typing **restart** and pressing **return** to re-enter all the experimental parameters. After continuing with the simulation, the program will display a summary of the experimental setup, and then start printing out the time elapsed since the heater was turned on (t (s)), and all the sensor readings in the same order they were entered in the prompt (T_i (C), where i corresponds to the i -th sensor).

After the simulation ends, a new experiment can be started by typing **restart** and pressing **return**.