LAHORE SCIENCE FOUNDRY
مشاہدہ
phenomenon lab

Phenomenon# 16 مشاہدہ#١٦

A mathematical model for the response of a thermistor

تھرمِسٹر کے ردِ عمل کے لیے ایک ماڈل کی تیاری

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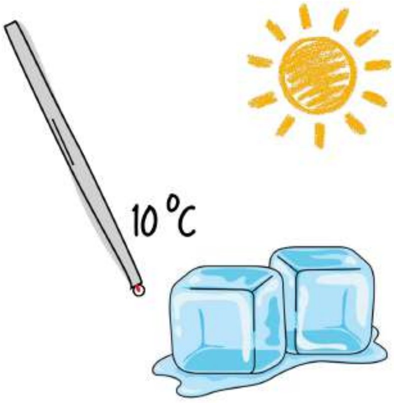
May 18, 2026

Have you ever thought how do household devices, such as refrigerators, air conditioners, electric irons and water heaters sense a change in temperature? This is realized by a tiny electronic component, a thermistor.

Thermistor is a specialized semiconductor and is temperature sensitive. Unlike a traditional mercury thermometer, which respond linearly to temperature changes, the thermistor resistance changes non-linearly with a change in temperature.

In this lab investigation, you will go a step beyond measurements. You will learn how a thermistor physical behavior can be described using a mathematical model. What begins as a simple measurement becomes an interesting exploration of curves, and the connection between physics and mathematics. So let's get started.



کیا آپ نے کبھی سوچا ہے کہ گھریلو آلات جیسے ریفریجریٹر، ایئر کنڈیشنر، الیکٹرک آئرن اور واٹر ہیٹر درجۂ حرارت میں تبدیلی کو کیسے محسوس کرتے ہیں؟ یہ کام ایک چھوٹے سے الیکٹرانک جزو کے ذریعے کیا جاتا ہے جسے تھرمسٹر کہا جاتا ہے۔

تھرمسٹر ایک خاص قسم کا سیمی کنڈکٹر ہوتا ہے جو درجۂ حرارت کے لیے حسّاس ہوتا ہے۔ روایتی پارہ والے تھرمامیٹر کے برعکس، جو درجۂ حرارت میں تبدیلی کے ساتھ خطی انداز میں ردِعمل دیتے ہیں، تھرمسٹر کی مزاحمت درجۂ حرارت میں تبدیلی کے ساتھ غیر خطی انداز میں بدلتی ہے۔

اس لیب تحقیق میں آپ پیمائش سے ایک قدم آگے بڑھیں گے۔ آپ یہ سیکھیں گے کہ تھرمسٹر کے طبیعی رویّے کو ایک ریاضیاتی ماڈل کی مدد سے کیسے بیان کیا جا سکتا ہے۔ جو عمل ایک سادہ پیمائش سے شروع ہوتا ہے، وہ آگے چل کر منحنی خطوط کے ایک دلچسپ مطالعے میں تبدیل ہو جاتا ہے، اور اس کے ذریعے طبیعیات اور ریاضی کے درمیان تعلق کو سمجھا جا سکتا ہے۔ تو آئیے، آغاز کرتے ہیں۔

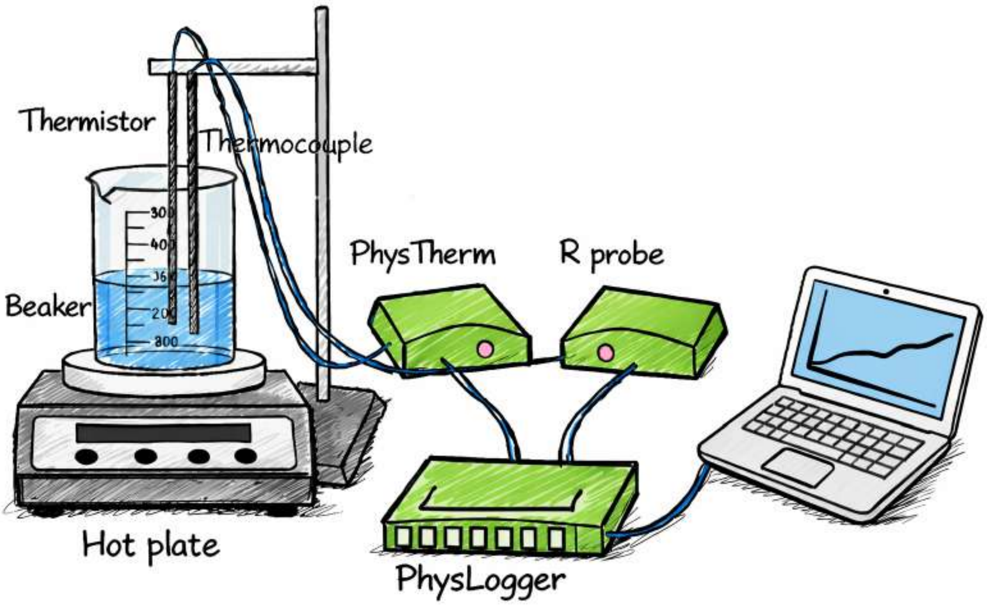


Figure 1: Scheme of the experiment to model the response of a thermistor.

Let's make sure we have everything we need to make our setup which is shown in Fig. 1.

1. Thermistor
2. Thermocouple
3. Hot plate
4. Beaker
5. R probe
6. PhysTherm
7. PhysLogger
8. Retord stand

The setup for this experiment consists of a thermistor and a calibrated thermocouple placed in a beaker filled with water. The beaker is placed on a hot plate. A thermocouple that measures temperature is connected to a PhysTherm to record and transfer temperature data to a desktop using PhysLogger for further analysis. At the same time, the resistance of a thermistor is measured using an R-probe connected in a similar fashion to the thermocouple.

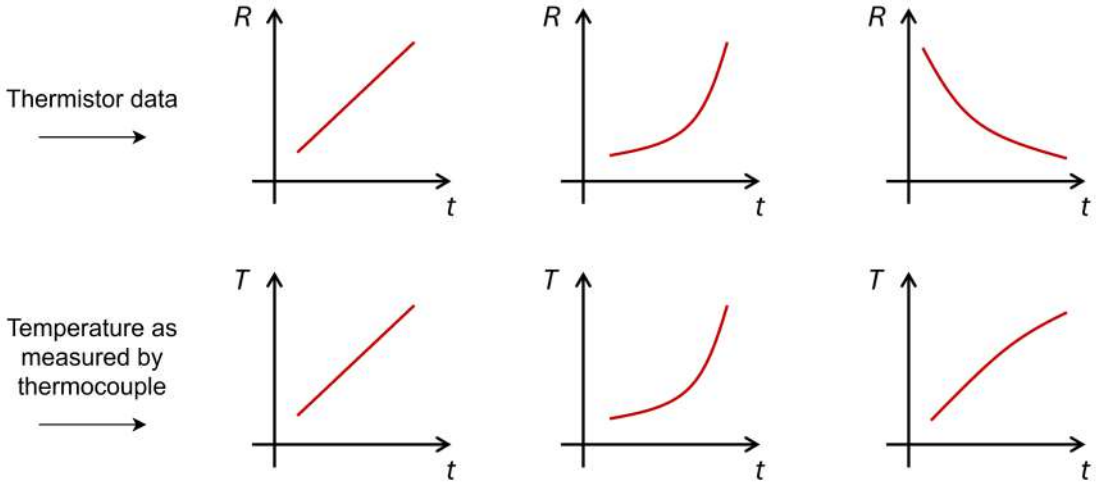
The thermocouple measure the temperature. However, we have a secondary sensor called the thermistor that measures resistance R which changes with temperature T. The purpose is to use R as a measure of the temperature when the thermistor is used stand-alone. This process is called calibration. For this purpose, we need to build a model $R(t)$ which relates the measured resistance to the temperature. This mean that if we know R, we can tell what T is. So this experiment helps us build a model for an incalibrated sensor (the thermistor) by comparing against a known sensor (the thermocouple).

What does the data say?

Let's turn on the hot plate, and proceed with settings provided in Appendix to measure change in temperature (T) and resistance (R) over time.

For your interest, thermistors are semiconductors where resistance changes with temperature. Now let's try to make a few predictions.

[Q 1]. Make a sketch of your predictions for the R and T behavior with time (t) for the present setup as the water is heated. Is your answer any one of the following? Or any thing else?



To validate your intuition, answer the following questions.

[Q 2]. Plot the measured T versus t (from the thermocouple).

[Q 3]. Plot the measured R versus t (from the thermistor).

[Q 4]. Plot R versus T.

[Q 5]. Plot $\frac{1}{T}$ versus R.

[Q 6]. Plot $\frac{1}{T}$ versus $\ln R$.

The key ideas is that the same data when plotted differently, can provide different shapes of graphs. One shape can be more intuitive than another. The previous questions indicate various ways on how the data can be plotted. We wish to develop a model between T and R, say

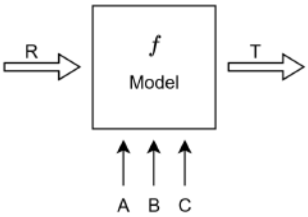
$$\frac{1}{T} = f(R) \tag{1}$$

so that in future, whenever we measure R of the thermistor, we can “apply” the formula given in Eq. (1) and determine T. The graph between $\frac{1}{T}$ and $\ln R$ shows that this is a very good starting point.

In industrial setting, the thermistor response is generally fitted by a Steinhart non-linear relationship between $\frac{1}{T}$ and $\ln R$, given by

$$\frac{1}{T} = f(R) = A + B\ln(R) + C[\ln(R)]^3 \tag{2}$$

where A and B are some constants specific to the thermistor. Knowing A, B and C, therfore completely determine the model.



[Q 7]. From the data plotted in Q.6, estimate coefficients A, B, C in Eq. (2) using the custom curve fitting method to model thermistor response. You can seek help from the associated Jupyter NoteBooks.

What have we done?

It is nice to step back and recount what has been acheived. We have created a model for the thermistor, means that whenever we measure its resistance, we can estimate what the temperature is. A key in this process is to find the temperature, at the same time, with another sensor (a thermocouple). So we have calibrated one sensor (the thermistor) with respect to another sensor (the thermocouple). We have also designed a mathematical model $\frac{1}{T} = f(R)$ for the thermistor.

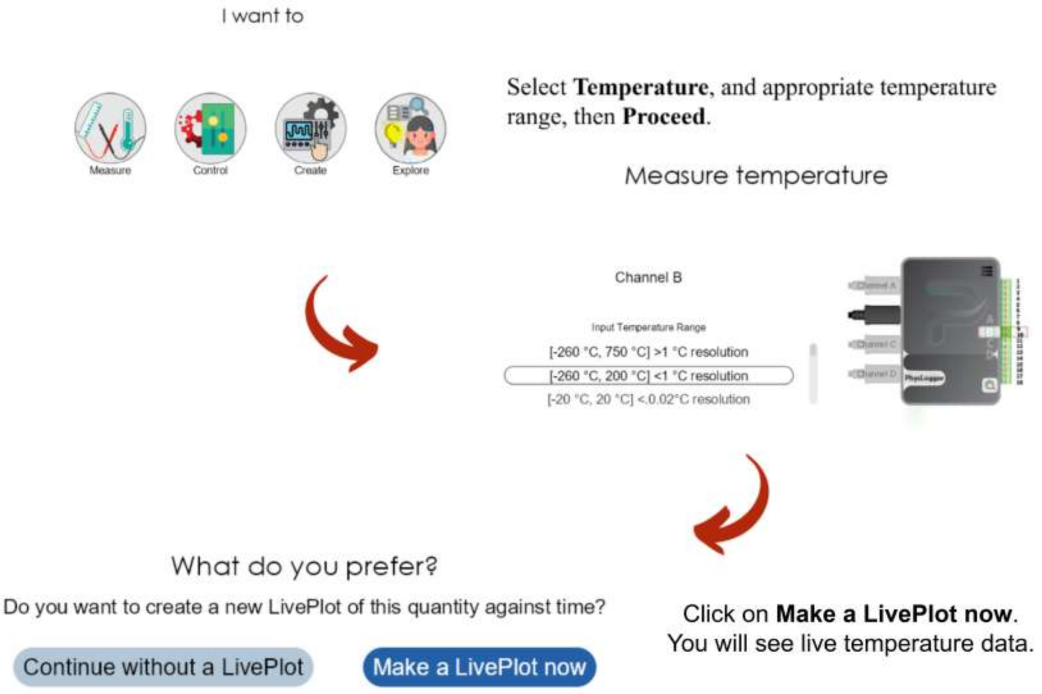
References

[1] M. Boleman, Mechanical Equivalent of Heat—Software for a Thermistor, The Physics Teacher **46**, 92–94 Feb. 2008.

Appendix

PhysTherm and R Probe setting

To setup, the PhysTherm, make sure its is connected to one of the analog input channels of PhysLogger and follow the steps below:



Select **Temperature**, and appropriate temperature range, then **Proceed**.

Measure temperature

Channel B

Input Temperature Range

[-260 °C, 750 °C] >1 °C resolution

[-260 °C, 200 °C] <1 °C resolution

[-20 °C, 20 °C] <.0.02°C resolution

What do you prefer?

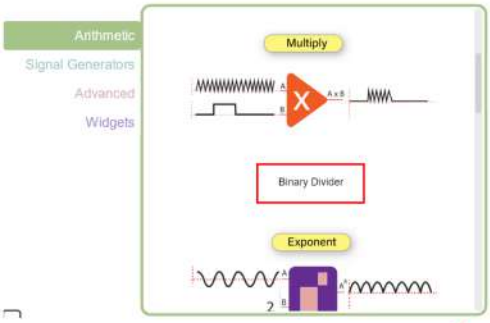
Do you want to create a new LivePlot of this quantity against time?

Click on **Make a LivePlot now**.
You will see live temperature data.

Now, to setup R-Probe connect it to one of the analog input channels and follow the following steps:

Go to **Extensions Menu**.

Select **Build from scratch**.

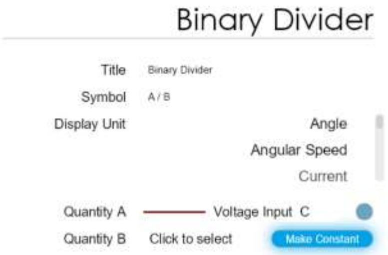


In **Arithmetic**, select **Binary Divider**.

Binary Divider

Title Binary Divider
Symbol A / B
Display Unit Angle / Angular Speed / Current
Quantity A Voltage Input C
Quantity B

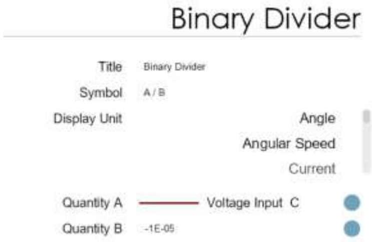
In **Quantity A**, select the **Voltage Input** channel at which **R-Probe** is connected.



Binary Divider

Title Binary Divider
Symbol A / B
Display Unit Angle / Angular Speed / Current
Quantity A Voltage Input C
Quantity B Click to select

In **Quantity B**, make it constant and type **-10uA** current (**-1E-5**).



Binary Divider

Title Binary Divider
Symbol A / B
Display Unit Angle / Angular Speed / Current
Quantity A Voltage Input C
Quantity B -1E-05

Add graph using the shown icon on live data plotting window.

Navigate to **Quantities menu**.

Drag the soft quantity (**Binary Divider**) and drop on the y-axis of added graph in live plotting widow.