IOP Publishing European Journal of Physics
Eur. J. Phys. 41 (2020) 035101 (6pp) https://doi.org/10.1088/1361-6404/ab6c29

# Determination of absolute zero temperature from thermistor voltage noise

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Received 11 October 2019, revised 23 December 2019
Accepted for publication 15 January 2020
Published 16 March 2020

**Abstract**

We present a simple experiment to determine absolute zero temperature by measuring the Johnson noise of a thermistor. Using the thermistor itself as a temperature sensor, we measure the thermistor voltage noise at different temperatures by submerging the thermistor in hot and cold water contained in a thermally insulated cup. A linear fit of the data yields an absolute zero temperature of $-274 \pm 14\,^{\circ}\mathrm{C}$, agreeing with the accepted value. The experiment is simple enough to be performed at most universities as a part of an undergraduate experimental physics course.

Keywords: thermal noise, absolute zero temperature, Johnson noise, undergraduate experiment

(Some figures may appear in colour only in the online journal)

## 1. Introduction

A resistor with a resistance $R$ develops voltage noise across its two terminals, with the root-mean-square (RMS) of the noise given by the usual Johnson–Nyquist formula:

$$V_{\mathrm{RMS}}^2 = 4k_{\mathrm{B}}TR\Delta f, \tag{1}$$

where $T$ is the temperature of the resistor (in kelvin), $k_{\mathrm{B}}$ is Boltzmann's constant and $\Delta f$ is the noise bandwidth [1, 2]. As the temperature $T$ approaches zero, $V_{\mathrm{RMS}}$ is reduced to zero. Hence, measuring the voltage noise of a resistor as a function of its temperature directly yields the value of absolute zero temperature.

However, it is usually a non-trivial task to measure the temperature of a resistor directly because of a finite thermal resistance between the point of interest (our resistor) and the

  

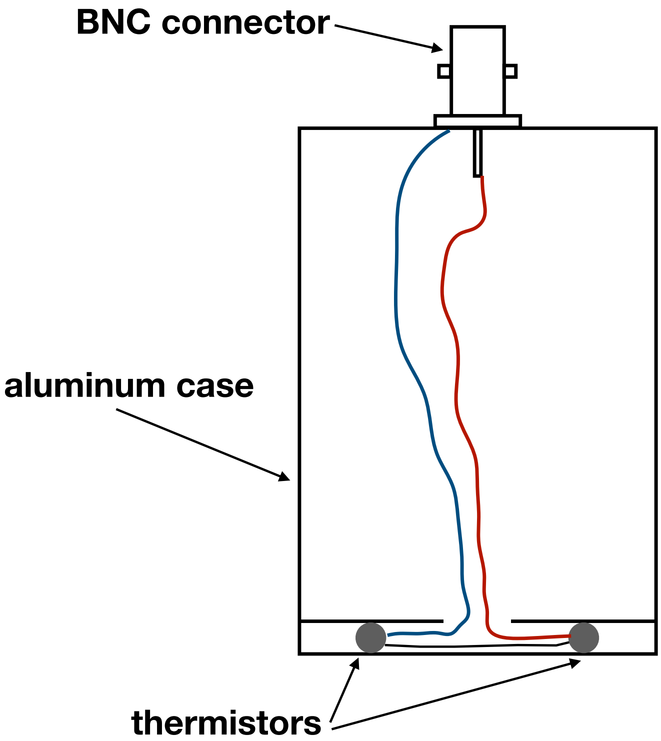


**Figure 1.** Diagram of a thermistor box. Two thermistors are connected in series (to increase the total resistance) and put in a thermal contact with an aluminum casing.

temperature sensor, no matter how closely they are placed. Because of this, one usually relies on putting the resistor in a thermal contact with a large heat bath with a fixed known temperature such as liquid nitrogen or a heated oven [3–5]. In many places, however, liquid nitrogen can be expensive and difficult to find, making this kind of experiment difficult to perform. Alternatively, there are also approaches to measure the absolute zero temperature involving speed of sound and expansion of gas [6–9].

In this manuscript, we present an experiment that measures the voltage noise of a thermistor as a function of its temperature. The resistance of a thermistor yields directly its temperature, eliminating the problem of temperature measurement. By submerging the thermistor in both cold and hot water in a thermally insulated cup, we can vary the temperature from approximately 0 °C to 100 °C. The absolute zero temperature is then determined by extrapolating to the point where the voltage noise vanishes.

## 2. Experimental consideration

We put a thermistor, which consists of two Vishay NTCALUG03 thermistors connected in series to double the resistance, in a water-tight aluminum box where the inner wall of the box is in thermal contact with the thermistor, as shown in figure 1. We use epoxy (not shown in the diagram) to fix the thermistor in place and also to improve thermal conductance. The two terminals of the thermistor are then wired to a grounded BNC connector which is eventually connected to either an amplifier (described in [10]) for voltage noise measurement or an

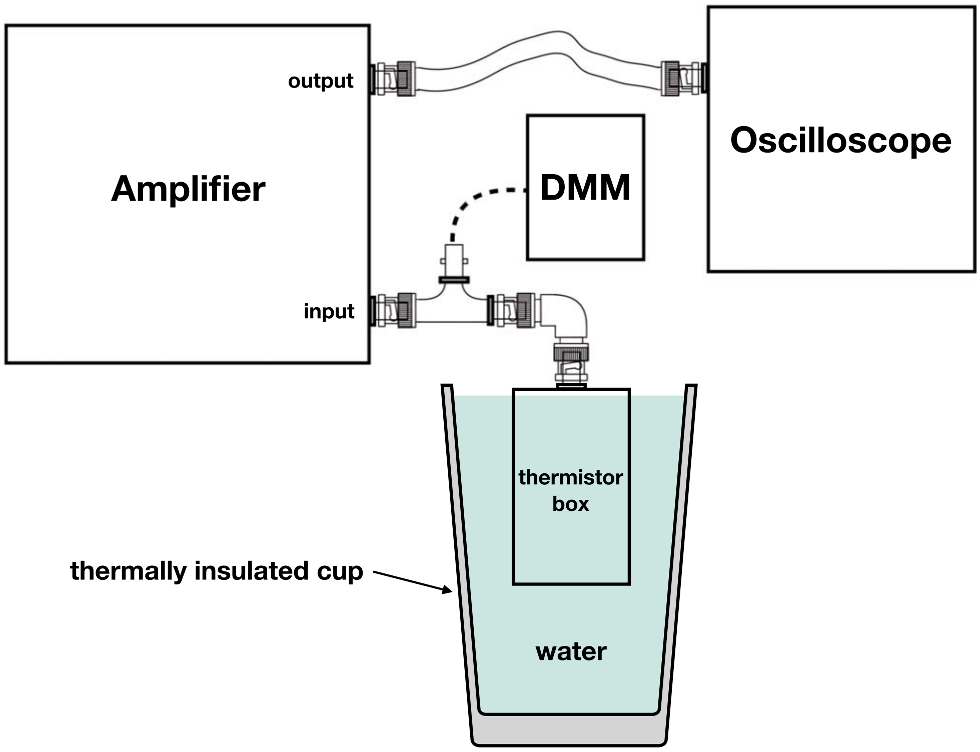


**Figure 2.** Experimental setup. The thermistor box is submerged in either hot or cold water in a thermally insulated cup to slow down the change in the temperature. During the experiment, a digital multimeter (DMM) is connected to monitor the resistance of the thermistor. Once the resistance (or temperature of the thermistor) reaches the desired temperature, the DMM is disconnected to make way for the Johnson noise measurement using an oscilloscope.

ohmmeter (Fluke 115) for temperature measurement[1], as described in figure 2. The aluminum box also acts as a shield for external electrical noise that might interfere with the measurement. In order to change the temperature of the aluminum box, we dip the box into either hot ($\sim$100 °C) or cold ($\sim$0 °C) water contained in a commonly available thermally insulated stainless steel cup, where the change of the water temperature becomes sufficiently slow for our measurements.

The experimental procedure starts with putting boiled water into the cup with the thermistor box partially submerged. At this point, the thermistor box is connected to an ohmmeter in order for us to monitor its temperature. Once the temperature rises to the maximum, we note the reading of the ohmmeter and then switch the BNC coaxial cable to the amplifier and measure the RMS noise on an oscilloscope (Agilent DSO-X 2004A). Once the noise measurement is complete, we switch the cable back to the ohmmeter for the next data point. We proceed until the temperature of the thermistor becomes close to the room temperature ($\sim$25 °C).

[1] It should be noted here that the conversion of the thermistor resistance to its temperature is usually calibrated according to the International Temperature Scale of 1990 (ITS-90) by the manufacturer. So, inherently the thermistor is already measuring the temperature in the absolute scale (which is in kelvin). However, since most published conversion tables are listed in °C, we can treat our thermistors as a °C probe and proceed with the experiment.

**Table 1.** Measured voltage noise for different resistances of the thermistor.

| $V_{RMS}$ (mV) | $\Delta V_{RMS}$ (mV) | $R_{th}$ ($\Omega$) | $\Delta R_{th}$ ($\Omega$) | $T$ ($\pm 0.2$ °C) |
|---|---|---|---|---|
| 2.608 | 0.005 | 175 | 0.02 | 91.3 |
| 2.736 | 0.005 | 200 | 0.02 | 87.0 |
| 2.924 | 0.005 | 250 | 0.03 | 80.0 |
| 3.126 | 0.005 | 300 | 0.03 | 74.5 |
| 3.655 | 0.005 | 450 | 0.05 | 62.8 |
| 3.801 | 0.005 | 500 | 0.05 | 59.8 |
| 4.109 | 0.005 | 600 | 0.06 | 54.8 |
| 4.584 | 0.005 | 800 | 0.08 | 47.2 |
| 5.034 | 0.005 | 10.0k | 0.1k | 41.6 |
| 5.491 | 0.005 | 12.5k | 0.1k | 36.1 |
| 5.915 | 0.005 | 15.0k | 0.2k | 31.7 |
| 6.740 | 0.005 | 20.2k | 0.2k | 24.8 |
| 7.237 | 0.005 | 23.4k | 0.2k | 21.5 |
| 7.853 | 0.005 | 30.0k | 0.3k | 16.0 |
| 10.39 | 0.01 | 56.9k | 0.6k | 2.7 |
| 10.65 | 0.01 | 62.7k | 0.6k | 0.8 |

We then repeat the measurement with cold water (which is essentially water with ice added). This allows us to measure data points in the range of $\sim$0 °C to room temperature. The data collected is presented in table 1, where the resistances of the thermistors are converted to temperatures (in °C) according to the specification.

## 3. Error and data analysis

We first need to calibrate our noise floor by measuring the $V_{RMS}$ of the noise with the input to the amplifier shorted. This is the background noise, which is measured to be $V_{background} = 1.490 \pm 0.005$ mV. We then correct each measured RMS voltage according to

$$V_{RMS\ corrected}^2 = V_{RMS}^2 - V_{background}^2. \tag{2}$$

The uncertainties of $V_{RMS}$ is determined from the fluctuation of the $V_{RMS}$ reading from the oscilloscope. The uncertainties of $R_{th}$ is from the specification of the Fluke 115 multimeter (which is about 1%).

There are two main sources of the uncertainties in the temperature, $T$. The first one is considered from the fact that there is a slight delay between the noise measurement and when the DMM is connected to measure $R_{th}$. The delay is less than 5 seconds. We verified that during this time the temperature change is negligible. The second one is from the uncertainty of the resistance measurement itself because $T$ is converted from $R_{th}$. According to the conversion table, 1% uncertainty of $R_{th}$ translates to about $\Delta T \sim 0.2$ °C.

To find the absolute zero temperature, we plot $V_{RMS}^2/R$ against $T$ (in °C) as shown in figure 3. The vertical error bars are from combining all the uncertainties mentioned above, which yields about 2% uncertainty for each data point. The horizontal error bars (for $T$) are too small to be visible.

To extract the absolute zero temperature, we fit the data using the `lmfit` package in `Python`. The line in figure 3 shows a result of the fit, which yields the absolute zero temperature to be $-274 \pm 14$ °C, agreeing with an accepted value of $-273.15$ °C.

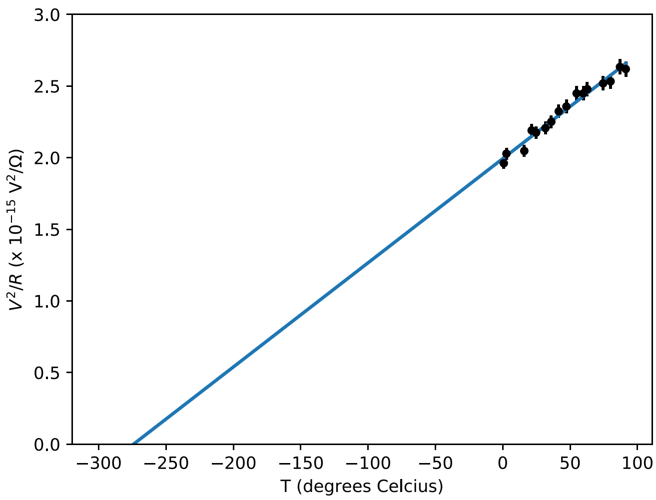


**Figure 3.** $V_{\mathrm{RMS}}^2/R$ plotted against $T$ (in °C). The line is a linear fit to all the data points.

## 4. Summary and outlook

We presented a simple determination of absolute zero temperature by measuring the thermistor noise as a function of thermistor temperature. Since the temperature of the thermistor is determined directly from its resistance, we minimize the discrepancy between the temperature of the probe and the thermistor itself. The thermistor box is submerged in either hot or cold water contained in a thermally insulated cup to slow down the change in the temperature. By fitting a linear relationship between the voltage noise and thermistor temperature, we determined the absolute zero temperature to be $-274 \pm 14$ °C.

To reduce the uncertainty of the absolute temperature, it is imperative to include data points at temperatures as low (or as high) as possible. Since the normal operational temperature of a thermistor is usually rated at $-50$ to 150 °C, the thermistor might not survive dipping in liquid nitrogen. However, the use of dry ice (which is about $-80$ °C) might be possible. Another possible improvement is to employ a resistor/thermistor bridge in the temperature measurement for more accurate temperature data.

This experiment is simple enough to be perform in most university settings, especially as a part of an undergraduate experimental physics course where liquid nitrogen is difficult to obtain.

## Acknowledgments

This project is supported by the Thailand Center of Excellence in Physics (Grant No. ThEP-61-PHY-MU3) and the Faculty of Science, Mahidol University.

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