

This document has been created as a part of the Erasmus+ -project “Developing Digital Physics Laboratory Work for Distance Learning” (DigiPhysLab). More info: [www.jyu.fi/digiphyslab](http://www.jyu.fi/digiphyslab)

# Smartphone thermometer?

Instructor version

6.2.2023



Co-funded by the  
Erasmus+ Programme  
of the European Union



This work is licensed under a [Creative Commons Attribution-ShareAlike 4.0 International License](https://creativecommons.org/licenses/by-sa/4.0/).

## Smartphone thermometer? – Instructor version

### Overview of the experiment

- Topic: Thermodynamics, temperature, limitations of experiments.
- Target group: Physics and physics teacher training students. Suitable for various phases of studies with varying openness of the experiment.
- Timeframe: The task can be assigned in two ways: as an at-home project spanning for example a week, or as an on-campus assignment. If the task is done on campus, two hours should be reserved at minimum for the planning, measurements, and analysis.
- Done individually, in pairs, or small groups.

This experimental task engages students in an investigation with a rather unconventional point of view. The attempted goal of measuring temperature with a smartphone is, frankly, doomed to fail. However, this is an example of figuring out an experimental solution to an authentic problem, and it is not always easy to spot the limitations of an experimental idea before trying it out. Many of the methods that can be used to measure temperature with smartphone sensors seem sensible at a first glance, but they all fall apart on closer inspection, at least to some extent.

It is thus important to not walk into this task with the expectation of obtaining precise or even reliable results. This has been explicitly stated in the student document as well. The most important thing in this task is to spot the limitations and the largest sources of uncertainty in the experimental setup. Students design the experiments themselves, so they know the reasoning behind the experimental choices. As the limitations of the experiment are typically not subtle in this task, it provides a good opportunity to practice identifying and discussing limiting factors in an experiment.

### Required equipment

Smartphones (with a measuring app, for example phyphox or Physics Toolbox Suite). Students can use any other equipment that they wish, barring the use of external temperature sensors.

If the task is done on-campus, one might have to provide a set of available equipment for the students to use. To enable several possible ways to conduct the task, some ice, water, and sealable containers should be provided, as well as some pipes or test tubes of various length, bottles, and tape measures.

### The measuring app

In this task students typically need to measure pressure (barometer), time (stopwatch, acoustic stopwatch), or sound frequency (microphone). Data from smartphone sensors can be accessed via free mobile apps, such as phyphox or Physics Toolbox Suite. These apps are intuitive and easy to use. Any tools available in a smartphone can be used.

### Example narrative with comments and suggestions

There are several ways to carry out the task. The two main branches that students can choose are to measure either pressure in a sealed container and find the relationship to temperature (gas thermometer), or to measure the speed of sound (many ways to do this exist) and relate that to temperature.

#### *Gas thermometer*

**Safety notice:** The method described below includes exposing the phone to a low temperature. If the seal of the container is not adequate, the phone can also get wet. Experimentation should be done with care and on one's own responsibility.

Making a gas thermometer requires the phone to have a barometer. iPhones typically have barometers, but Android phones seem to quite often lack one. One also needs a sealable container, like a glass jar, that holds a constant volume. To calibrate the instrument one can dunk the phone-and-jar system into ice water to find the pressure  $p_0$  at  $T_0 = "273.15\text{ K}"$  (why the air quotes? see limitations below). Then one can measure the pressure  $p$  at the wanted temperature  $T$  and use ideal gas law to find the temperature

$$T = \frac{p}{p_0} T_0.$$

A major limitation in this method is the heat generated by the smartphone. It is quite impossible to say how much heat the smartphone produces, but the temperature in the glass jar will not reach  $0\text{ }^\circ\text{C}$  when submerged in ice water. This unquantifiable uncertainty makes it difficult to evaluate the reliability of the result.

#### *Temperature via the speed of sound*

It is worthy to note, and to discuss with students, that the idea of measuring temperature via the speed of sound actually has some serious applications. See here for examples of acoustic thermometry <https://www.nist.gov/programs-projects/acoustic-thermometry> and ocean acoustic tomography [https://en.wikipedia.org/wiki/Ocean\\_acoustic\\_tomography](https://en.wikipedia.org/wiki/Ocean_acoustic_tomography). Efforts exist also to utilize this idea in a smartphone app <https://doi.org/10.1145/3384419.3430714>.

With a smartphone as the experimental tool, there are at least a couple of ways to measure the speed of sound. One way is to make a basic time-of-flight measurement using regular smartphone stopwatches or the tool Acoustic stopwatch found in the app phyphox. Here the variability between measurements is typically huge, and students choosing this method need to evaluate the limitation that the precision of the stopwatch sets on the accuracy of the obtained temperature. It is downright impossible to get an accurate measurement with this method, so one might be tempted to engage in questionable practices like cherry picking from the data or other convenient data handling tricks to obtain "The Correct Result", so this is something to look out for.

A more refined method is perhaps to use some sort of resonance phenomenon to obtain the speed of sound. One can measure frequencies of standing waves forming in an open-closed tube

$$f = \frac{c_{\text{air}}}{4L},$$

where  $c_{\text{air}}$  is the speed of sound in air, and  $L$  is the length of the air column in the tube. One can also use a bottle which can be modeled as a Helmholtz resonator and the frequencies obtained when blowing on the bottle are then related to the speed of sound as

$$f_H = \frac{c_{\text{air}}}{2\pi} \sqrt{\frac{A}{VL_{\text{neck}}}},$$

where  $A$  is the cross-sectional area of the opening of the bottle neck,  $L_{\text{neck}}$  is the length of the bottle neck, and  $V$  is the volume of air in the bottle cavity (not including air in the neck).

To refine the measurements, one might need (or want) to invoke an effective value for the length of the tube or bottle neck so that

$$L_{(\text{neck})}^{\text{eff}} = L_{(\text{neck})} + ar,$$

where  $a$  is a dimensionless parameter and  $r$  is the radius of the tube (here bottle neck). Suitable values of  $a$  can be found from literature for an open-closed tube and a Helmholtz resonator.

Limitations of this method include the measuring uncertainties of the dimensions of the tube or bottle, and the modeling error arising from the idealizations made in modeling the equipment as a narrow tube or an ideal Helmholtz resonator.

## Assessment

We have suggested this task to be assessed via a discussion with an instructor. The discussion is guided by the following questions:

- What was your experimental setup like, especially if you made changes in your initial plan?
- How did you obtain the ambient temperature from your measured data?
- How accurately and precisely were you able to determine the temperature?
- What choices did you have to make which were not optimal? How does this reflect on your results?
- What shortcomings can you identify in your experiment, and in determining temperature with smartphone sensors in general? What would be required to overcome them?

Due to the unconventional point of view of the task, we feel like having a conversation is the natural way of assessing the task. The experimental goal is virtually unattainable, and most likely different groups will make different decisions about the experiment, and it makes sense to be able to explain and discuss these decisions in person. The definition of success in this task is not the accuracy and precision of the results, but rather the identification and discussion of the limitations and uncertainties present in the selected experimental method.

## Possible modifications

- One could use the idea of this task as quick lecture demonstration by measuring the speed of sound (roughly) and determining the room temperature (badly). Group discussions can be had of the limitations of the experiment and how it can be improved.
- This task can also be suitable for the high-school level if students are provided with a set of available equipment to use, and some hints and instruction are readily available.
- Students can be asked to make a more detailed prediction about the precision and accuracy of their experiment before making any measurements, and they can later reflect upon whether their prediction was correct, or whether improvements to the method were made during experimentation.