Teaching Physics by Arduino during COVID-19 Pandemic: Measurement of the Newton's cooling law time-constant

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Abstract. Due to the COVID-19 pandemic, schools and universities had to the shift from face-to-face to distance teaching, organizing on-line lectures. Easily accessible materials, smartphones physics apps, on- line tools and devices can be used to perform laboratory practice even in this period. In this paper a method to measure the Newton's cooling law time-constant by Arduino board is presented.

Keywords: Arduino board, COVID-19, Physics teaching.

Contents

Introduction

The COVID-19 pandemic is influencing the teaching worldwide. Indeed, the educational system had to shift from face-to-face to distance learning [1, 2].

Due to the restrictions introduced by the COVID-19 pandemic, to preserve the leaboratory course, many educational institutions enabled the students to perform physics experiments at home [3].

For example, in Italy, the Lab2Go project [4, 5, 6, 7, 8] proposed on-line seminars aimed at showing experiments that can be made at home using easily accessible materials and exploiting resources as the Arduino board [9].

Arduino is an open source platform made of electronic boards, sensors and expansion boards. By Arduino, students can acquire additional competences, as for example coding and programming [10, 11]. The original Arduino board can be bought for as low as about few tens of euo, but there are also cheapest clones. Both the board and the sensors can be easily bought on-line or in electronics stores [11]. There are also many kits including the board and common sensors available for just 50-60 euro. Thanks to the low cost, the Arduino board and related component can be bought directly by students or by schools/universities to be provided to students.

In this paper an Arduino-based physics experiment regarding of the Newton's cooling law will be presented. It consists in a liquid cooling and measuring the temperature in function of the time by Arduino to estimate the time-constant of the cooling.

The experiment can be proposed both to high school and university students.

1. Theory

The Newton's law of cooling (Eq. 1) describes the rate at which an exposed body changes temperature by radiation. According to this law, the trends over time of the temperature depends on the initial temperature of the body T_0 and the enviroment temperature T_{env} as:

$$T\left(t\right) = T_{env} + \left(T_0 - T_{env}\right) e^{-t/\tau} \tag{1}$$

where

$$\tau \propto mc \tag{2}$$

is a time-constant depending on the body (and eventually by its box), m and c are respectively the mass and the specific heat of the body [12, 13]. The esponential dependence of the temperature by the time can be verified and the time-constant τ can be estimated measuring the temperatures of body and enviroment.

2. Experimental setup and procedure

In this paper, the measure of the time-constant of water ($m = (9.9 \pm 0.1) \cdot 10^{-2}\,\mathrm{kg}$, $c = 4186\,\frac{\mathrm{J}}{\mathrm{kg \cdot K}}$) is presented; the enviroment temperature was $T_{env} = (300 \pm 1)$ K. The experimental setup (Fig. 1) is made of an Arduino UNO R3 board, a temperature sensor DS18B20 (the range of operation is $[218.15\,\mathrm{C}; 398.15\,\mathrm{C}]$ and the sensitivity is $\pm 0.5\,\mathrm{K}$ in the range $[263.15\,\mathrm{K}; 358.15\,\mathrm{C}]$) a $10\,\mathrm{k\Omega}$ resistor, a thermometer to check that the enviroment temperature is constant during the experiment, a stove to heat the water, a computer, a breadboard and Dupont cables for connections.

The resistor, the breadboard and the Duponts cables could be found in a typical Arduino kit. On the contrary, the sensor temperature must be bought separately.

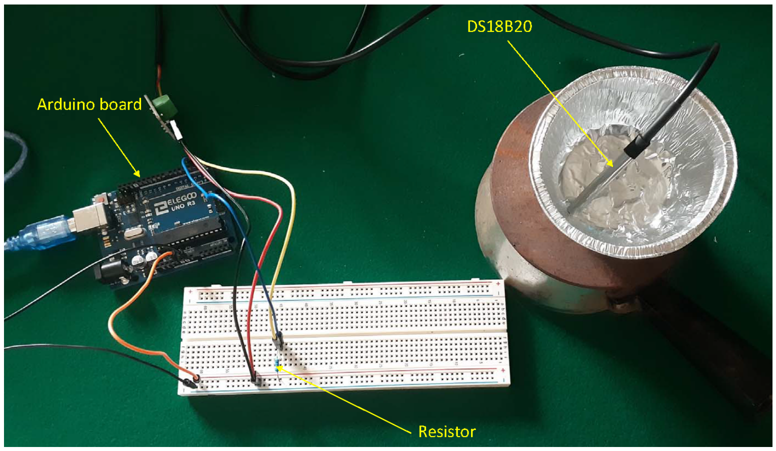

Figure 1: Experimental setup.

The temperature sensor is connected to Arduino by Dupont cables; the sensor has three cables: the first one to be connected to the GND pin of Arduino, the second one to the V_{cc} pin (both the 3.3 V or 5 V can be used) and the last one to be connected to a digital pin. The resistor is inserted between the digital and the V_{cc} pins as shown in figure 1 .

The overall setup is connected to the computer for data acquisition by the USB cable.

The water has been heated up to $T_0 = (349.0 \pm 0.5)$ K, then it has been left cooling up to $T_f = (300.2 \pm 0.5)$ K measuring the temperature and the time by Arduino.

3. Data analysis and results

Equation 1 has been linearized by calculating the logarithm, then data have been interpolated (Fig. 2) using ROOT [14] by a linear function:

$$y = kx \tag{3}$$

where

$$y = \ln\left(\frac{T(t) - T_{env}}{T_0 - T_{env}}\right) \tag{4}$$

$$k = -\frac{1}{\tau} \tag{5}$$

Thefore, the time-constant is given by:

$$\tau = -\frac{1}{k} \tag{6}$$

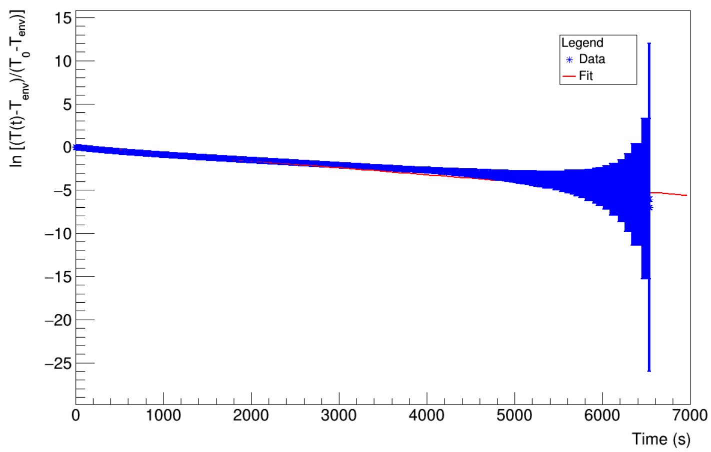

Figure 2: Fit.

The slope k got by fit and the obtained τ value are given in Tab. 1

Table 1: Fit result slope and obtained τ value.

k (s^{-1})	τ (s)
$(-8.0067 \pm 0.0073) \cdot 10^{-4}$	1249.0 ± 1.1

Conclusions

Due to COVID-19 pandemic, laboratories of schools and universities weren't accessible. To overcame the problem it's possible to organize laboratory activities made at home using easily accessible materials and exploiting resources as smartphones physics apps, on-line tools and devices, as for example, the Arduino board.

In this paper it has been shown a technique to measure the Newton's cooling law time-constant by Arduino. The article goal is to encourage teachers to propose the experiment to their students in order to carry on the laboratory practice even in this pandemic period. In particular we encurage to repeat the experiment changing the body (water in this case) and enviroment conditions, in order to estimate the time constant for several materials and conditions.

Lastly, thanks to its low-cost, the usage of Arduino for physics experiments can also be useful in school laboratories not adequately equipped (obsolete or non-functioning instrumentation, poor assortment, lack in maintenance, missing catalog) even when the COVID-19 emergency is over.

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