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Measurement of fundamental physical quantities in the framework of the Lab2Go project

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Summary. — To establish a closer contact between school and experimental sciences, Sapienza Università di Roma and the Istituto Nazionale di Fisica Nucleare (INFN) launched the Lab2Go project. Lab2Go has the goal of spreading laboratory practice among students and teachers in high schools. In this article, a measurement is presented, carried out in the framework of the Lab2Go project, of the ratio $\frac{hc}{e}$ where h, c and e are respectively Planck's constant, the speed of light in vacuum, and the electric charge.

1. – Introduction

Modern physics is based on a few key discoveries made across the 19th and 20th centuries: the invariance of speed of light c in different reference frames (Michelson-Morley experiment [1]), the quantisation of the electric charge (Millikan experiment [2]) and the quantisation of the electromagnetic waves energy through the Planck relation [3]

$$E = h\nu. \tag{1}$$

Nowadays, three fundamental constants, c (speed of light), e (electron charge) and h (Planck constant) related to these discoveries define (since May 2019 [4]) the measuring units of length, charge and mass in the International System of units (SI) [5]. These three constants are involved in the relations linking measurable quantities in Light Emitting Diodes (LEDs). LEDs are semiconductor devices emitting light at a given wavelength

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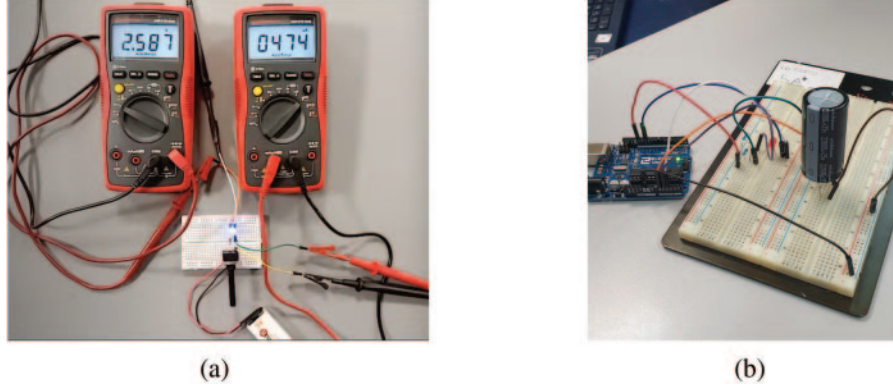[*] Corresponding author. E-mail: `fausto.casaburo@uniroma1.it`

Fig. 1. – Analog (a) and Arduino-based (b) experimental setups.

λ when powered by a potential difference above a minimum threshold value V_g (gap voltage). The minimum energy needed to turn on a LED is given by

$$(2) \qquad\qquad E = eV_g.$$

Current i flowing into the LED as a function of the potential difference V_{LED} (characteristic curve) has an exponential trend, but the region of the curve over the gap voltage can be approximate as a linear function. To estimate gap voltage V_g, we can interpolate data of the approximately linear region of the characteristic curve by linear function $i\,(V_{LED}) = mV_{LED} + q$ and calculate the intersection between the $V_{LED}-$axis and the fit function. Then V_g is given by

$$(3) \qquad\qquad V_g = -\frac{q}{m}.$$

Lastly, by combining eqs. (1) and (2) and solving for V_g, we get the relation between gap voltage V_g, Planck's constant h, speed of light in vacuum c, electric charge e, and wavelength of the LED λ [6]:

$$(4) \qquad\qquad V_g\left(\frac{1}{\lambda}\right) = \frac{hc}{e}\frac{1}{\lambda}.$$

In this paper we present the measurement of physical quantity $k = \frac{hc}{e}$ made in the framework of the Lab2Go project [7].

2. – Experimental setup and procedure

We present here two different approaches to perform the measurement of k with instruments and methods available in secondary schools. In the first one (analog approach), LEDs are powered by a battery, the potential difference is varied by a potentiometer, and data of both the potential difference and the current are measured by two multimeters (fig. 1(a)). In the second version (Arduino-based approach) a $22\,\text{mF}$ capacitor, and an

TABLE I. – *Gap voltages of LEDs V_g.*

Method	$V_{g_{Red}}$ (V)	$V_{g_{Yellow}}$ (V)	$V_{g_{Green}}$ (V)	$V_{g_{Blue}}$ (V)
Analog	1.85 ± 0.33	1.90 ± 0.74	2.34 ± 0.42	2.59 ± 0.87
Arduino	1.859 ± 0.083	2.009 ± 0.067	2.335 ± 0.060	2.569 ± 0.059

Arduino board [8] are used. Arduino is used both to charge/discharge the capacitor, and for Data AcQuisition (DAQ) purposes (fig. 1(b)). The code (sketch) for Arduino starts charging the capacitor. When the capacitor is fullycharged, by an automatic switch, it is discharged powering the LED [9]. In both versions, data of the current as a function of the powering potential difference have been stored for several LEDs colors (red, yellow, green, and blue), corresponding to different wavelengths.

3. – Data analysis and results

Data of the current flowing into the LEDs as a function of the potential difference have been interpolated (fig. 2), as described in sect. **1**, allowing estimating values of the gap voltages that are summarized in table I. The higher uncertainties on the values of V_g obtained by the analog method (fig. 2(a)) with respect to the Arduino-based one (fig. 2(b)), just depend on data not fully contained into the fitting line. In turn, the gap voltages (table I) have been interpolated (fig. 3) by eq. (4) as a function of λ^{-1} using values of the wavelengths declared in the datasheets of the LEDs.

The slope resulting by interpolation represents the estimated value of parameter k. Results are $k_{Analog} = (1.22 \pm 0.16) \cdot 10^{-6}$ Vm and $k_{Arduino} = (1.197 \pm 0.019) \cdot 10^{-6}$ Vm, respectively, for the analog and the Arduino-based methods. These values agree respectively within approximately 1σ and 2σ with the theoretical value of approximately $1.23984 \cdot 10^{-6}$ Vm calculated by the accepted values of h, e and c [5].
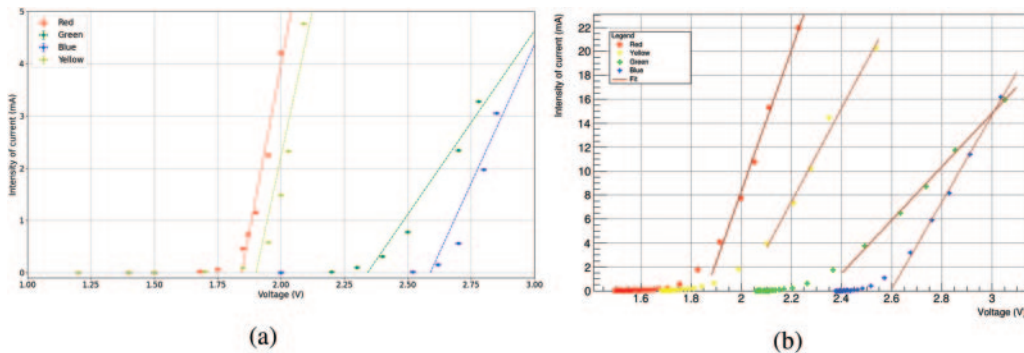

Fig. 2. – Characteristic curves of LEDs obtained by the analog (a) and Arduino-based (b) methods. From left: red, yellow, green, and blue LEDs.
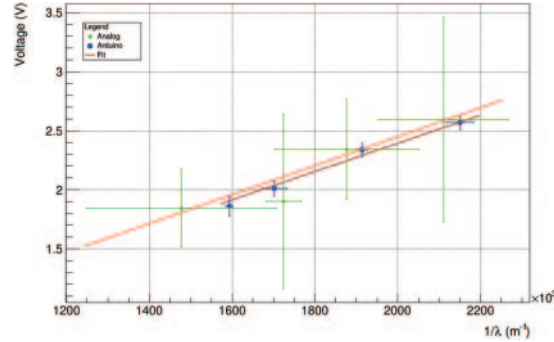
Fig. 3. – Interpolation of data of V_g as a function of λ^{-1}, both for analog (green, on the top), and Arduino-based (blue, on the bottom) methods.

4. – Conclusions

During the school year 2020/21, in the framework of Lab2Go, the measurement of fundamental physical quantities using LEDs has been proposed to high school students. Despite the caveat of Planck's constant being a fundamental constant since 2019 used as a reference to define other units of measurement and for the calibration of instruments, this experiment can not be made in the future using new instruments; this proposed activity has the advantage of illustrating "quantum mechanics in action" to students.

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