# The determination of the Planck's constant using an experimental approach with arduino

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**Abstract**

In this work we made a experimental approach using Arduino to determinate the Planck's constant. To do so, we made a circuit in series using a 50 k linear potentiometer, a 330Ω resistor and a diffuse LED that related to the Arduino that provide 5 V of voltage for the circuit. To estimate the Planck's constant, we program Arduino to generate the voltage and the current values in real time, as we make the potentiometer varies the voltage in the circuit. In this way, using the data streamer of the Excel we may plot, in real time, the behavior of the current as function of the voltage and estimate de minimal voltage necessary to the current increases rapidly. With these data to the four different colors of the LEDs we may use the Planck's equation to correlate the energy of the emitted photon with the energy of the excited electron. To evaluate the experimental Planck's constant, we needed to know the specific wavelength of the LED that we were used. In this way, we made a diffraction spectroscope by reflection recycled materials. We see that the experimental results are very close to the theoretical Planck's constant value. Besides, this approach shows itself as a gratefully tool to teach physics in high school, turning on the theoretical physics with experimental lessons.

**Keywords:** Planck's constant, Arduino, Physics Education.

**Resumen**

En este trabajo realizamos una aproximación experimental utilizando Arduino para determinar la constante de Planck. Para ello realizamos un circuito en serie utilizando un potenciómetro lineal de 50 k, una resistencia de 330Ω y un LED difuso relacionado con el Arduino que proporciona 5 V de voltaje para el circuito. Para estimar la constante de Planck, programamos Arduino para que genere los valores de voltaje y corriente en tiempo real, a medida que hacemos que el potenciómetro varíe el voltaje en el circuito. De esta forma, utilizando el streamer de datos del Excel podremos trazar, en tiempo real, el comportamiento de la corriente en función del voltaje y estimar el voltaje mínimo necesario para que la corriente aumente rápidamente. Con estos datos de los cuatro colores diferentes de los LED podemos utilizar la ecuación de Planck para correlacionar la energía del fotón emitido con la energía del electrón excitado. Para evaluar la constante de Planck experimental, necesitábamos conocer la longitud de onda específica del LED que estábamos utilizando. De esta forma, realizamos un espectroscopio de difracción mediante reflexión de materiales reciclados. Vemos que los resultados experimentales están muy cerca del valor teórico de la constante de Planck. Además, este enfoque se muestra como una buena herramienta para enseñar física en la escuela secundaria, potenciando la física teórica con lecciones experimentales.

**Palabras clave:** Constante de Planck, Arduino, Educación Física.

## I. INTRODUCTION

When Kirchhoff and Busen deduced from their experiments, in 1859, that each element emits a characteristic spectrum under certain conditions, a fundamental property of matter was discovered and a powerful method of analysis that came to be called spectroscopy. From the middle of the 19th century, advances in spectroscopy techniques made it possible to catalog different wavelengths characteristic of different elements.

In the early twentieth century, with the study of blackbody emission, spectrometry boosted the emergence of what we call modern physics. Blackbodies emit identical spectra, at the same temperature, regardless of their composition. Due to this intriguing feature, the problem of blackbody emission became a major target for physics at that time.

The Planck's constant, $h$, was answered for the first time in 1901 by Max Planck to explain the distribution of the spectral intensity of radiation from a black body and the ultraviolet catastrophe. This work gave him the Nobel Prize in Physics in 1918. To solve ultraviolet problem, Planck had to assume that the energy of the radiation trapped in the blackbody cavity, for a given frequency, is not distributed continuously, as predicted by classical physics, but discretely, with values given at that same frequency, $f$. where, the theoretical accepted value is $h = 6{,}62607015 \times 10^{-34} J \cdot s$ [1].

A few years later, in 1905, Albert Einstein used the Planck's energy quantization principle to explain the photoelectric effect phenomena, which consisted of the emission of electrons by a conductor when exposed to high frequency radiation, observed by A. E. Becquerel, in 1839, and confirmed by Heinrich Hertz, in 1887 which also could not be explained by classical physics [1].

The discovery of the light emitting diode (LED) was due to the contributions of two scientists. The first one is Henry Joseph Round who observed the phenomenon of electroluminescence from silicon carbide crystals [2, 3]. the second was the Oleg Vladimirovitch Losev who discovered the LED [4].

In this work, we presented an experimental approach to estimate the Planck's constant using a circuit based on Arduino programming and the construction of a spectroscope with recycled materials.

## II. HOW THE LED WORKS

An LED is a special type of diode, containing a semiconductor PN junction, which conducts current in one direction only.

The diode becomes conductive above a threshold voltage (threshold voltage) sufficient to force electrons in the N-type region to combine with holes in the P-type region. Whenever this occurs, energy is released, creating a photon, or quantum of light, as we can see in figure 1.

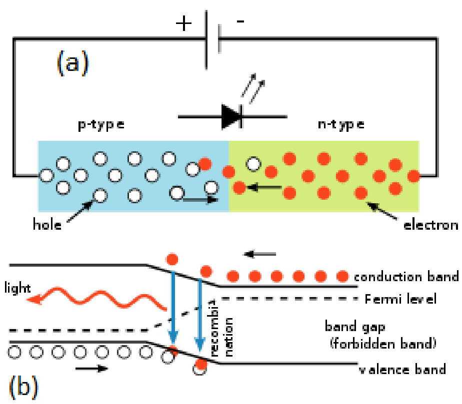


**FIGURE 1.** We see the direct polarization of the P-N junction in an LED diode. In (a) we have a Production of photons because of recombination between electrons and hues. In (b) is shown the phenomenon of recombination observed in an energy band diagram.

The amount of energy released depends on the bandgap, a property of the semiconductor material used. This energy determines the wavelength and thus the color of the indoor light. The bandgap also determines the LED voltage threshold. Therefore, LEDs of different cores suffer very different threshold voltages from each other.

As it is shown in Table I. We see the wavelength for different color of LEDs composed of different semiconductor materials, in special, we presented the only colors that was used in this work.

The Arduino supplies the entire circuit with 5V continuously. While the potentiometer, because it has a variable resistance, controls the flow of current through the circuit, causing the LED brightness to vary according to the variation of the potentiometer.

**TABLE I.** The typical wavelength for different colors of LED [4].

| *color* | *Wavelength (nm)* | *typical material* |
|---|---|---|
| Red | 630 – 680 | GaAsP |
| Orange | 590 – 610 | AlGaInP |
| Green | 520 – 530 | InGaN |
| Blue | 430 – 470 | ZnSe |

According to Oleg [6] the behavior of the LED was called the emission process like a "inverse photoelectric effect". Furthermore, he proposed a relation among the electric energy through the diode poles with the energy of the emitted photon, that is given by:

$$e \cdot U = h \cdot f, \tag{2}$$

where, $e$ is the electron charge, $V$ is the voltage, $h$ is the Planck's constant and $f$ is the frequency of the emitted photon.

## III. EXPERIMENTAL PROCEDURE

The procedure consists on make an electric circuit using a $330\,\Omega$ resistor, an LED, a $50\,k\Omega$ linear potentiometer, a Arduino Uno and a protoboard as follow in figure 2.

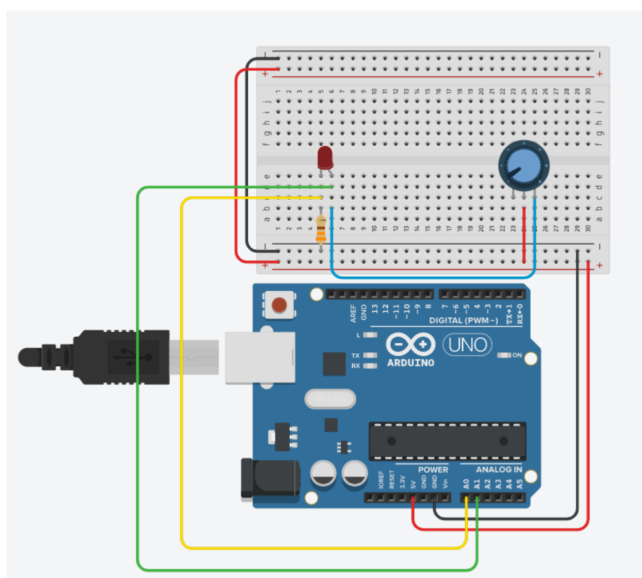


**FIGURE 2.** It is shown the circuit made with the help of the tinkercad. Note that the components of the circuit are disposed in series.

Thus, with the analog ports A0 and A1 we were able to measure, respectively, the voltages on the LED and on the resistor. With this, we can also measure the electric current that pass through the circuit.

All these measurements is made by Arduino programming. But to do this, note that the Arduino, in its analog ports, Arduino uses an AD converter, that is, a 10-bit converter. This converter supports values from 0 to 1023, working between 0 and 5 V. Thus, it is necessary to convert the data obtained through the Arduino as follows:

$$U_{LED} = \frac{5}{1023} \cdot U_l \,, \tag{3}$$

where $U_l \in [0{,}1023]$ is the reading made by the Arduino, 5/1023 is the conversion factor and $U_{LED}$ is the value of the voltage at the LED, now, in units of volts. The Arduino routine is shown in Appendix A. To the current value, following the same procedure to the LED voltage, we have:

$$I_{LED} = \frac{5}{1023} \cdot \frac{V_l}{R} \cdot 10^3 \,, \tag{4}$$

in this case, $I_{LED}$ is the current, $R = 330\Omega$ is the resistance and the result is multiplied by $10^3$ for the current value given in milliampere.

To measure the wavelength to the four LEDs by using a spectroscope. It is seen that there are many works using a CD like diffraction granting involving since the construction of manual spectroscopes [7, 8, 9, 10, 11, 12] to the measurement of wavelengths through rings designed.

How one of goals of this work is bringing this experimental approach to the physics lessons in high school. We made a spectroscope, based on [10], using a cardboard shoe box, as follow in figure 5.

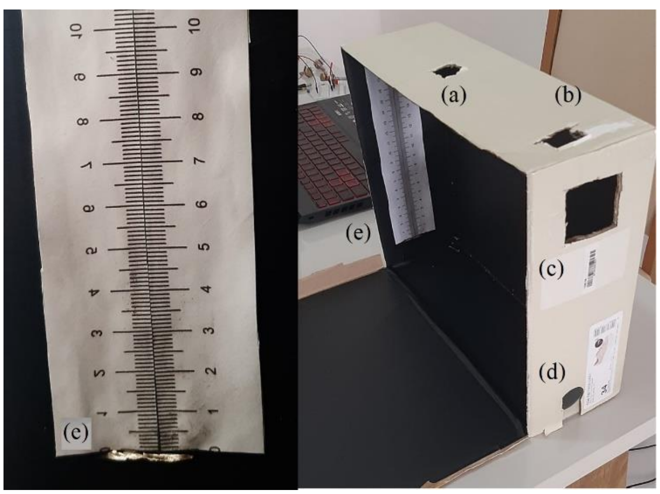


**FIGURE 3.** Homemade spectroscope with dimensions *24x9,5x29 cm*. The holes (a), (b) and (c) are made to let in enough light to see scale (e). Hole (d), 2.5 cm in diameter, is the socket for the diffraction grating. At the beginning of the scale (e) a slit 2.5 cm long and 2 mm thick is made. The inside of the shoebox is covered with a matte black coating to minimize reflective effects.

With the spectroscope ready it is possible to use a cellphone to register the diffraction of the LED. To do so, just position the cell phone camera in front of the diffraction grating, as we show in figure 4

**FIGURE 4.** Measurement of the deviation of the blue LED light by the diffraction grating captured by the cell phone camera positioning in front of the diffraction grating.

Carrying out the procedure presented in figure 4 for the other LED colors, knowing that for the first diffraction maximum, that is, $n$=1, the wavelength ratio is given by [8],

$$\lambda = d \cdot \frac{x}{\sqrt{x^2 + D^2}} \,, \tag{5}$$

where, $d$ = 1/625 mm is the distance between CD slots, $x$ is the deflection of the light LED to the first maximum and $D$ = 29 *cm* is the distance between the projected slit and the diffraction granting that is schematically represented in figure 5.

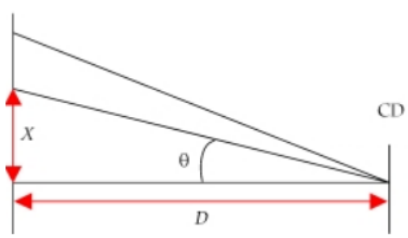


**FIGURE 5.** schematic view inside the spectroscope of the deviation of light caused by the diffraction grating.

## IV. RESULTS

Compiling the routine in the Arduino we obtain a series of data about the current and the voltage through the LED. In this way, it is possible to plot the distributions for the red, orange, green and blue LEDs, as shown in figure 6.

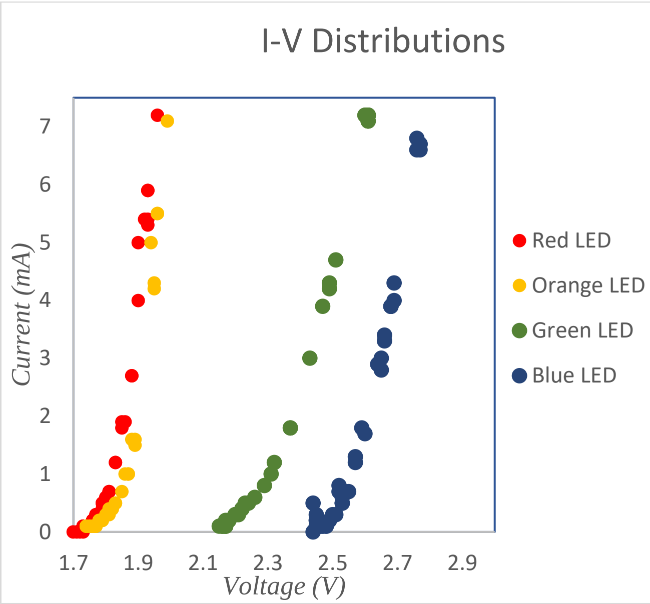


**FIGURE 6.** Distribution of the current through the LED as function of the voltage for the Red LED, Orange LED, Green LED and Blue LED.

As it is shown in figure 3, the barrier potential produces a "knee" in the current-voltage (I-V) curve of the diode and, after that, the current increases rapidly. On the other hand, to find this minimal voltage we make a linear fit to each curve presented. These fist are presented in figure 7.

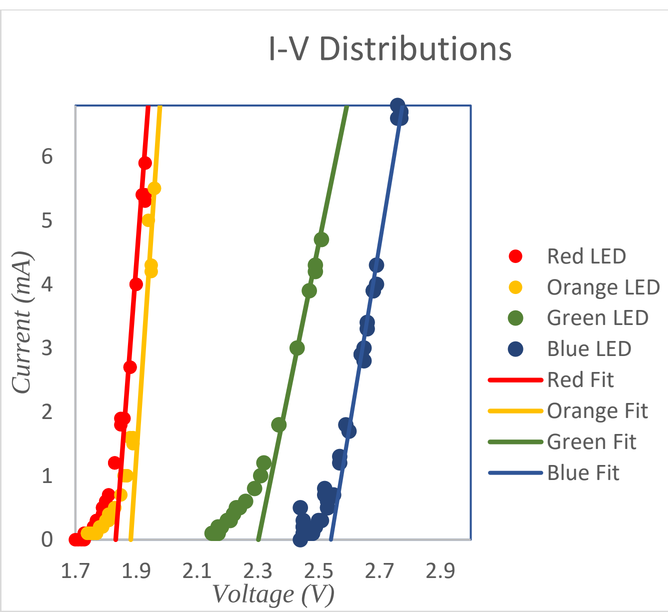


**FIGURE 7.** The behavior of the current through the LED as function of the voltage for the Red LED, Orange LED, Green LED and Blue LED are presented, respectively, by the red-dotted, orange-dotted, green-dotted and blue-dotted distributions. The red line, orange line, green line and blue line are their respective linear fit.

In figure 7 we have, following the order red to blue, the linear fit equations:

$$I_r = 63{,}624 \cdot U - 116{,}59, \tag{6}$$
$$I_o = 70{,}833 \cdot U - 133{,}31, \tag{7}$$
$$I_g = 23{,}261 \cdot U - 53{,}527, \tag{8}$$
$$I_b = 28{,}901 \cdot U - 73{,}414. \tag{9}$$

Using eqs. (6)-(9), taking $I = 0$, we get the knee voltages ($V_0$). In this way, we have:

$$U_{0r} = 1{,}83\,V, \tag{10}$$
$$U_{0o} = 1{,}88\,V, \tag{11}$$
$$U_{0g} = 2{,}30\,V, \tag{12}$$
$$U_{0b} = 2{,}54\,V. \tag{13}$$

Now, using equation (2) and the equations for the wave velocity, $c = \lambda \cdot f$, we have the relation bellow.

$$h = \frac{e \cdot U_0 \cdot \lambda}{c}. \tag{14}$$

To develop equation (14) we used the parameters: $c = 299792458\,m/s$, $e = 1{,}602 \times 10^{-19}\,C$ and $V_0$ given by eqs. (11)-(13). Thus, in question (14), $h$ is expressed as a function of the wavelength.

The deflection light LED to the four LEDs that were used is presented in figure 8 as follow. In this case, by equation (5) we get:

$$\lambda_r = 654{,}5\,nm, \tag{15}$$
$$\lambda_o = 616{,}1\,nm, \tag{16}$$
$$\lambda_g = 535{,}5\,nm, \tag{17}$$
$$\lambda_b = 474{,}24\,nm. \tag{18}$$

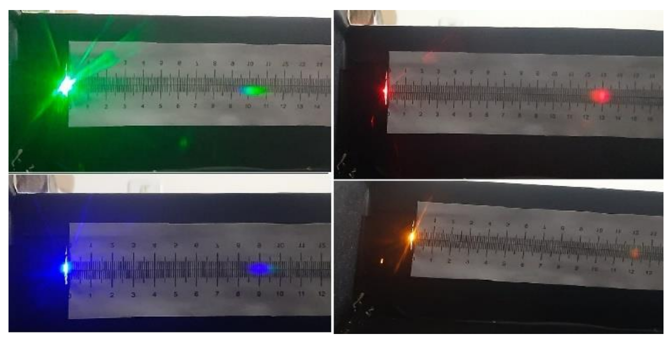

**FIGURE 8.** Measurement of the deviation, $x$, to the four LEDs light by the diffraction grating captured by the cell phone camera. The green LED $x = 10{,}3\,cm$, the red LED $x = 13\,cm$, the blue LED $x = 9\,cm$ and the orange LED $x = 12{,}1\,cm$.

Substituting the results (15)-(18) into eq. (13) we obtained

$$h_r = 6{,}40033269 \times 10^{-34}\,J.s, \tag{19}$$
$$h_o = 6{,}18950974 \times 10^{-34}\,J.s, \tag{20}$$
$$h_g = 6{,}58159610 \times 10^{-34}\,J.s, \tag{21}$$
$$h_b = 6{,}43685472 \times 10^{-34}\,J.s. \tag{22}$$

Assuming that $h = 6{,}62607015 \times 10^{-34}\,J.s$ is the acceptable value on the literacture, we see that our results presented in eqs. (19)-(22) are very close to first one. Besides, we estimate the medium value like

$$\bar{h} = (6{,}40207331 \pm 0{,}0701) \times 10^{-34}\,J.s. \tag{23}$$

Note that our experimental value for Planck's constant differs by only 3,38% under the real value. As well as it is also made in [13] where the authors get an error about 3,9% above the real value.

## V. CONCLUSIONS

In this work we made an experimental approach to calculate the Planck's constant by using an Arduino routine and a homemade spectroscope.

It is seen that the results to the measurement of the LEDs wavelength presented in Eqs. (15)-(18) are closely to these ones in table I, according to [4].

Furthermore, it was demonstrated that the results of Planck's constant for the four different LED colors are close to what is accepted in the literature.

The difference between our results presented in Eqs. (19)-(23), as well as, in Eqs. (15)-(18) to the wavelength, can be explained by several factors such as: a dispersion in the measurement of wavelengths due to the resolution of our scale, the resolving power of the detector (the cell phone camera) and even given the ambient temperature.

However, even disregarding all these variables, all the results obtained are within the expected range, showing the effectiveness of our proposal.

Therefore, this experimental proposal proves to be a great tool that can be used in the classroom to unite theory and practice in physics teaching.

Note that this approach was thought to be done using diffused monochromatic LEDs. In this ways, We will continue with this work making an approach with a RGB LED.

## ACKNOWLEDGEMENTS

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## APPENDIX

In this section we describe the routine that we used to compute the data that we used to calculate the Planck's constant as follow in figure 3.

```
double TensRes = A0; //Resistor voltage
double Vr = 0;
double TensCircuit = A1; // (Resistor + LED) voltage
double Vl = 0;

  void setup(){

Serial.begin(9600);
}

void loop()
{
  Vr = analogRead(TensRes);
  Vl = (analogRead(TensCircuit) - analogRead(TensRes));
 double Iled = Vr*5000/1023/330; // Current through the circuit in milliampere
double VLED = Vl*5/1023; // LED voltage in volts
  //
    Serial.print(VLED);
    Serial.print(",");
    Serial.println(Iled,2);  //

  delay(500);
}

```

**FIGURE 9.** Routine that was used to compute the values of the voltage and the current values through the LED.

To generate the data in a spreadsheet and plot the graphs of the current distribution as a function of the voltage on the LED, we used the Excel Data Stream function.

**Note:** Very large figures and tables should be placed on a page by themselves.