Evaluation of Boltzmann's constant: Revisit using interfaced data analysis

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Abstract

The evaluation of Boltzmann constant using V-I characteristics of diodes has been used to understand various aspects of fundamental physics. The use of diodes for analog and digital applications is based on the basic diode characteristics. The use of low-cost devices and tools for interfaced experiments in contrast to traditional methods provide new levels of understanding of the physical concepts. In the present report, the evaluation of Boltzmann's constant has been carried out with the help of an interfacing device, EXPeyes junior (Experiments for Young Engineers and Scientists junior) (IUAC). This device in conjunction with a laptop is well suited to measure, record and analyzedata. The Python has been used for coding. The data has been analyzed with the Xmgrace. The V-I data of the silicon diode IN4001 has been obtained. The value of Boltzmann constant is in agreement with the standard value. This unique way of performing the experiment supplements as well as complements the traditional way of performing experiment. This also emphasizes the use of inexpensive devices, power of computing and analysis using easily accessible open software for better performing and understanding of physics experiments.

1. Introduction

The use of ICT and interfacing of experiments is paving way for better visualization and understanding of physics as well as mathematical equations. These provide better description of various phenomena, states and processes. It is also coupled with better accuracy and precision as compared to conventional instruments. The errors in data collection are minimized in comparison to manual collection of data. The inherent features of low- cost and flexibility widen the prospects of inclusion for marginalized societies.

With the accessibility of computers and mobiles, low cost interfacing devices are improving the teaching-learning processes. The EXPeyes junior (Experiments for Young Engineers and Scientist) [1] also offers advantages such as open ended learning, interfacing of various branches such as Physics, Electronics, Computers and Mathematics for real-life applications.

The conventional way of performing V-I characteristics needs power supply, voltmeters and ammeters. The applied voltage and current are measured in the circuit.

The V-I characteristics of diodes are non-linear in nature. The variation between applied voltage and current in the circuit does not obey ohm's law. The data analysis of V-I measurements also provide useful information. The knee voltage, reverse saturation current and Boltzmann's Constant can be evaluated by performing this experiment.

The forward characteristics of a p-n junction diode traditionally are obtained by connecting the positive of the battery to the p side and negative of the supply to the n side of the p-n diode [2]. Voltage is measured across the diode using a voltmeter (0-1 V) and current is measured in the circuit using an ammeter (0-100 mA). The manual measurements are limited by the least count of the instruments and it affects calculation of Reverse saturation current (~ Microamperes) due to very low value [2].

In contrast, the interfaced experiment can be performed using EXPeyes junior, required components and a laptop/desktop. This method can be used for obtaining better data and accuracy. The details are given as below.

Description of Expeyes Junior

EXPeyes Junior has been developed by Inter University Accelerator Center(IUAC) and it is interfaced and powered by the USB port of the computer. It has programmable digital and analog inputs, current source and can perform measurements with Pythonas an interface between the hardware and user [3]. It is worth to mention that coding in Python is quite simple yet apt in performance [3]. It can be downloaded freely on various platforms. A number of experiments can be performed using various features integrated on the EXPeyes junior board. In the present investigation a detailed study is carried out to measure, record and analyze the data for determining Boltzmann's constant. In contrast to conventional ways of performing experiment, this method offers many advantages and help the students to understand the basics of Physics with the aid of electronics, computer and simulations. The data has been fitted using Xmgrace [4] using the standard Diode Equation and various parameters such as Reverse Saturation Current and Boltzmann Constant have been evaluated.

Circuit Diagram

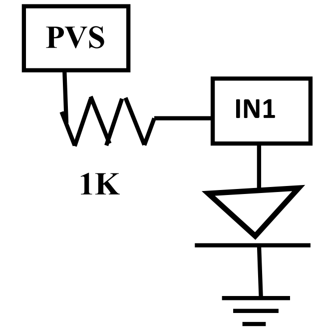

Figure 1. The Circuit Diagram (using EXPeyes junior)
PVS - Programmable Voltage Source
IN1- For reading Voltage

#Code in Python (iv.py)

```
frompylab import *
importexpeyes.eyesj, time
p=expeyes.eyej.open()
voltage =[ ]
current= [ ]
f=open('diode_iv.dat', 'w')
v=0.0
while v<= 5.0:
        va=p.set_voltage (v) #  set voltage
        time.sleep(.001)
        vd=p.get_voltage(3) # read voltage
(IN1)
        i=(va-vd)/1.0        #    current    in
milliamps
        voltage.append (vd)
        current.append (i)
        ss= '%5.3f\t%5.3f'%(vd,i)
        printss
        f.write(ss+'\n')
        v=v+.050   (# 50 mV step size for
va)
plot (voltage, current)
show( )
```

2.Conventional Vs. Automated data

The EXPeyes junior can conveniently sets the voltage of PVS (Programmable Voltage Source) in the steps using the python coding (in place of manual variation of voltage). The voltage is read by IN1 as shown in Fig.1 and the python coding, 'iv.py'.The current measurement is done by observing the voltage drop across 1Kresistor. The measured current has been calculated by dividing the voltage drop by 1 Kohm resistor value.

Results

The a forward biased diode, the Voltage-Current Equation[5] is governed by the following expression

$$I = I_0\,[\exp(\frac{qV}{\eta k_B T}) - 1] \qquad \text{(Eq. 1)}$$

For a forward biased region, the Equation reduced to

$$I = I_0 \exp(\frac{qV}{\eta k_B T}) \qquad \text{(Eq. 2)}$$

Where

I_0 = Reverse Saturation Current

I = Measured Current; V= Applied Voltage; q = electronic charge; η = Ideality Factor = 2 (for Si Diode [6]) ;k_B = Boltzmann's Constant ; T= 300 K

After making the circuit (Figure 2), the program was run on the Linux terminal with the following command $ python iv.py.

The graph started showing the V-I characteristics of the diode instantaneously on the screen. The data of the experiment was obtained in a file. The V-I characteristics of the diode are shown in Figure 3. The data was exported to Xmgrace (an open access software) and fitting was done using the Equation,

Figure 2. Automated Set-up. The circuit, Expeyes and Data acquisition on the computer

The representative of the Diode Equation as

$$y = a_0 \exp(a_1 * x)$$ (Eq. 3)

A comparison of Eq.3 with Eq.2 provides the following values

$a_0 = I_0$ (Eq.4)

$a_1 = \frac{q}{\eta k_B T}$ (Eq.5)

The initial guess was inserted for the values of a_0 and a_1 with tolerance of 0.01. The fitting was done using Xmgrace and a0 and a1 were evaluated using the fitting.

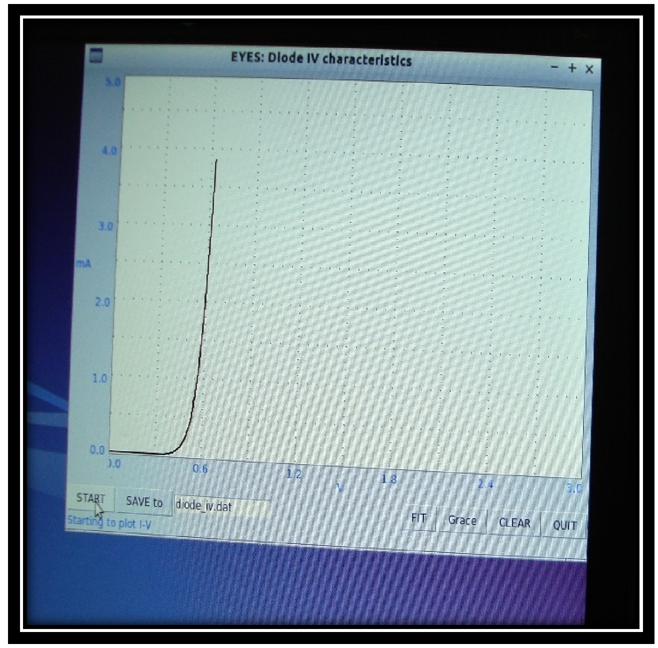

Figure 3. V-I characteristics acquired

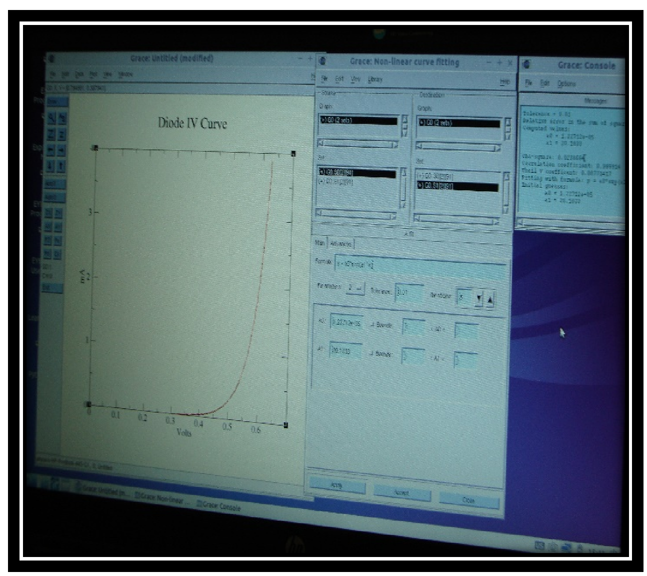

Figure 4 : Fitting using Xmgrace

The following characteristics typical of a diode were observed

1. Upto a certain voltage, there is no increase in current with increase in voltage.

2. After onset voltage, the current increases exponentially.

3. The knee voltage has been calculated by extrapolating the straight line to meet the x-axis. (0.54 volts)

Xmgrace facilitates the fitting of observed data into exponential form a_0*exp(a_1*x). This yields two parameters as follows

a_0 = 1.227e-05 mA

a_1 = 20.1033

Chi-square: .0238664

Correlation coefficient: 0.999914

$$k_B = \frac{1.6 \times 10^{-19} C}{20.1033 \times 2 \times 300\ K} = 1.326 \times 10^{-23} \frac{J}{K}$$

By substituting these values in Eq.2, the value of Boltzmann's constant was calculated, which is in good agreement with the standard value of 1.38×10^{-23} J/K.

Discussion:

The interfacing of experiments reconsolidates the theoretical knowledge. The errors incorporated in acquiring the data are minimized with the automated data. The programming in Python provides a versatility due to simple syntax. The usability of such low-cost devices and other freely available software & tools could be well exploited further for improving physics education mediated through more visualization.

Acknowledgments

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