SIMPLE, CHEAP, AND PORTABLE COLORIMETER FOR INTRODUCTORY ANALYTICAL CHEMISTRY LABORATORIES

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Abstract. The construction and application of a cheap, simple and portable colorimeter is presented. The system employs an LED as a light source and a common photocell (photoresistor) as a detector. The device functions based on the level of light received by photocell, which is connected to a digit multimeter yielding resistance readings. Resistance increases with increasing the sample absorption. Due to the simplicity of the instrument it can be constructed in a laboratory or a classroom. The fabricated device is applicable to calculate the molar absorption of colored species and demonstrates the basics of the instrumentation of spectrophotometers.

Keywords: colorimeter, light emitting diode (LED), photoresistor, spectrophotometry, laboratory demonstration

Introduction

In introductory analytical chemistry courses, the components of a spectrophotometer and the Beer-Lambert law are introduced as an important concept. According to the literature (and our own experience), there are occasions when demonstrations are used for teaching instrumental analytical chemistry because they are a less expensive or a safer way of providing students with practices of instruments' components [1]. The analytical instruments, e.g. spectrophotometers, are often expensive and complex to operate, hence not suitable for introductory chemistry experiments. Therefore, it is helpful to build a simple and cheap device for demonstrating basic principles, functions, and components of the spectrophotometer. Devising portable and simple colorimeter faces some challenges. The first is providing a simple light source with a monochromatic light and the second is adopting a cheap and simple detector. The electronic industry within few past decades has created a great variety of devices that are of considerable advantages when applied in chemical instrumentation. These devices could help to overcome the challenges in devising cheap and simple colorimeters. Light emitting diodes (LEDs) received a great interest in analytical applications and for use as a light source in commercial portable absorption devices [2]. LEDs with colors ranging from the blue to the infrared are available and cover almost all the wavelength ranges required for the analytical spectrophotometers. Since these light sources emit light of relatively narrow band widths (ca. 20-100 nm) they have been used as a monochromatic light source. Another challenge in the development of portable analytical devices is to reduce detector size. Common photoresistors (small, cheap and accessible device) which are other newly devised electronic products can be used as detector in portable colorimeters.

In the last three decades many LED-based colorimeters have been described in the literature [3]. In the proposed colorimeters the detectors (photodiodes or phototransistors) have usually been connected to operational amplifiers for amplifying the out put current. In most cases, either the optical fiber bundles are employed to guide light radiation of LED to the measuring cell [4] or the instruments controlled by a microcomputer [5] or software and complicated circuits employed to acquiring and processing data [6]. A few of these are relatively simple and devised for educational purposes [7,8]. Although the reports in the literature reveals a great deal of advances on colorimeters, still efforts for simplifying the colorimeters seems to be of importance.

It was intended to devise a very simple colorimeter for demonstrating the spectrophotometer components and its use for analytical determinations. The present work describes an LED-photoresistor based colorimeter which directly uses resistance values without any need to transform current values or voltages (which is a common practice) or for a computer or a minicomputer to control the device. The proposed device is very cheap, light in weight, compact, and portable. It does not involve complicated components, employs an inexpensive photoresistor as a detector, and is easy to operate. Since it is capable of being operated by small dry batteries, it is a suitable device for use in classroom or laboratory for demonstration of spectrophotometer's components and functions.

Experimental

Construction of the colorimeter

Fig. 1a shows a schematic diagram of the constructed colorimeter and Fig. 1b shows the commercial components used in the colorimeter construction. A common green-color LED (Shenzhen Mingxue Optoelectronic Co., Ltd., China), emitting a continuous spectrum ranging from 520-620 nm, band width 25 nm and maximum wavelength of 565 nm, was operated by two 1.5-volt dry battery, was used as light source. A cheap common photoresistor (Xiamen Xinpulong Semiconductor Co., Ltd., China) was employed as a detector. The LED and the photoresistor were glued to the two opposite end windows of a sample cell (a plastic semi micro cuvette with path length 10 mm) with a transparent quick two-component adhesive. All outer surfaces of cuvette, LED, and photoresistor were coated with a layer of black oil color. Light emitted from LED passed through the plastic cuvette containing colored sample and transmitted light intensity was detected with the photocell. A digit multimeter connected to the photoresistor poles was used for the resistance reading.

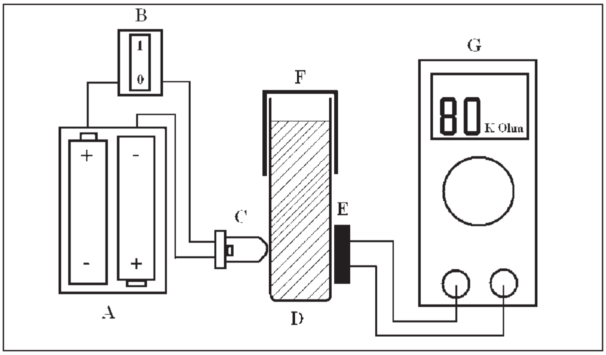

Fig. 1a.

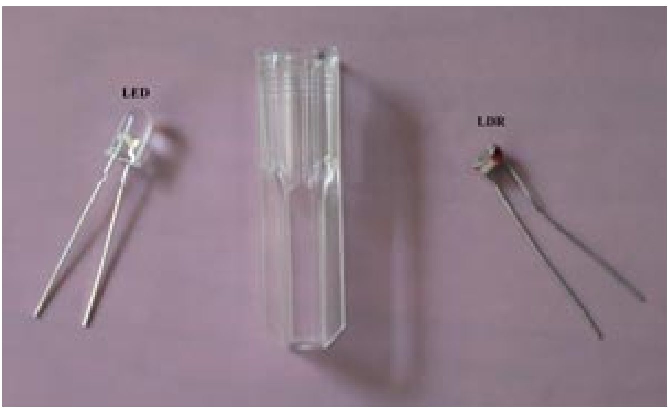

Fig. 1b.

Determination procedure

A photoresistor is made of a high-resistance semiconductor whose resistance decreases with increasing the incident light intensity. Light absorption by analyte decreases incident light intensity and increases resistance value represented by multimeter, which means that there is a direct relation between analyte concentration and photoresistor resistance.

Measurements of resistance were substituted for transmittance. A resistance measurement corresponding to the 100% transmittance value (R_{water}) was made with the LED on and the cuvette filled with water. Solutions of colored species were added to the cuvette. After the addition of each solution, the black cover was placed onto the cuvette to provide a stable dark background and the resistance was measured using the multimeter. Since the resistance of photoresistor is inversely proportional to light transmittance, to calculate the absorbance the following relationship was used:

$$A = -\log\left(T / T_0 \right) = -\log\left(R_{water} / R_{sample} \right)$$

where R_{samle} is the resistance resulting from analyte solution and R_{watery} is the resistance measurement corresponding to the 100% transmittance. Analyte concentration was determined from a calibration graph of resistance (and/or calculated absorbance) values versus concentration.

Results and discussion

The demonstration of spectrophotometer components in classroom or laboratory provides an excellent opportunity for students to realize the principle of spectrophotometry.

The basic parts of a spectrophotometer are a light source, a wavelength selector, a sample container, a radiation detector, and a signal-processing/readout unit [9]. These parts could be demonstrated by the proposed fabricated device for introductory analytical chemistry students. As described earlier, in the proposed device LED used as light source and monochromator, cuvette as sample cell, LDR as detector and multimeter as signal processing/readout unit.

In addition to that, the fabricated device could be applied as an analytical device for determination of molar absorptivities (ε) of colored species. Using equation 1, the plots of absorbance versus concentration of some colored species were presented and from the obtained data, the values of molar absorptivities were calculated. The results of these experiments were compared with those obtained at 565 nm from a Shimadzu UV-265-FW type UV-Vis spectrophotometer. Figs. 2-4 are plots of absorbance versus concentration of permanganate, eriochrome black T (ECBT), and Fe^{II}-1,10-phenanthroline complex solutions using the fabricated colorimeter and the commercial spectrophotometer.

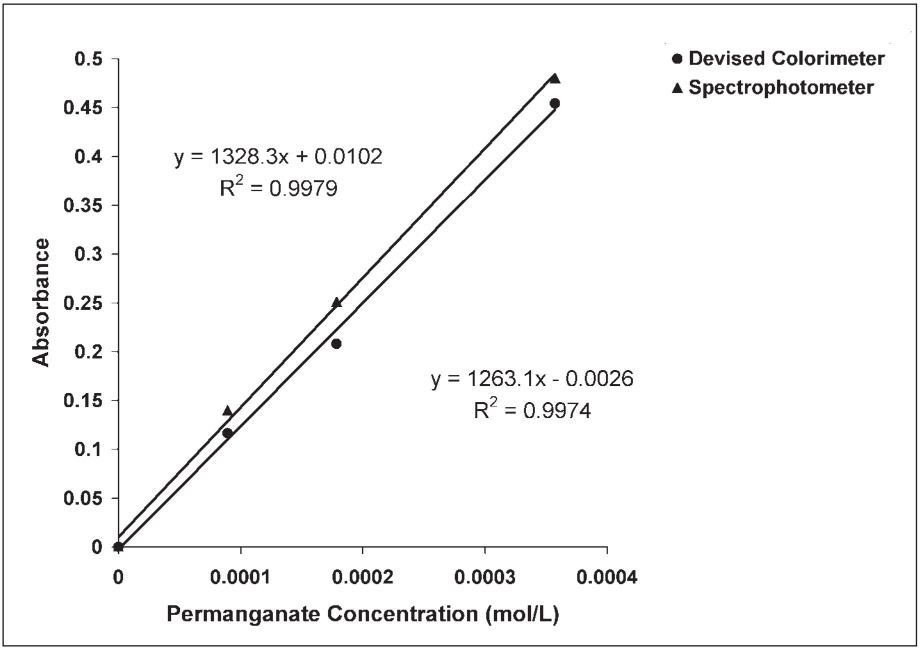
Devised Colorimeter
Spectrophotometer
y = 1328.3x + 0.0102
R2 = 0.9979
y = 1263.1x - 0.0026
R2 = 0.9974
Absorbance
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.0001
0.0002
0.0003
0.0004
Permanganate Concentration (mol/L)

Fig. 2.

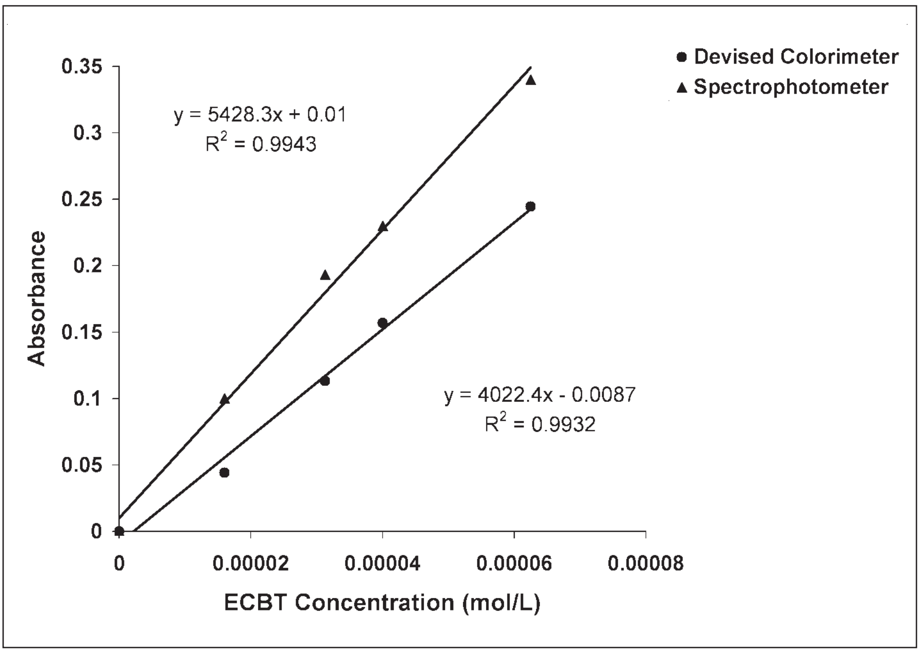
Devised Colorimeter
Spectrophotometer
y = 5428.3x + 0.01
R2 = 0.9943
y = 4022.4x - 0.0087
R2 = 0.9932
Absorbance
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.00002
0.00004
0.00006
0.00008
ECBT Concentration (mol/L)

Fig. 3.

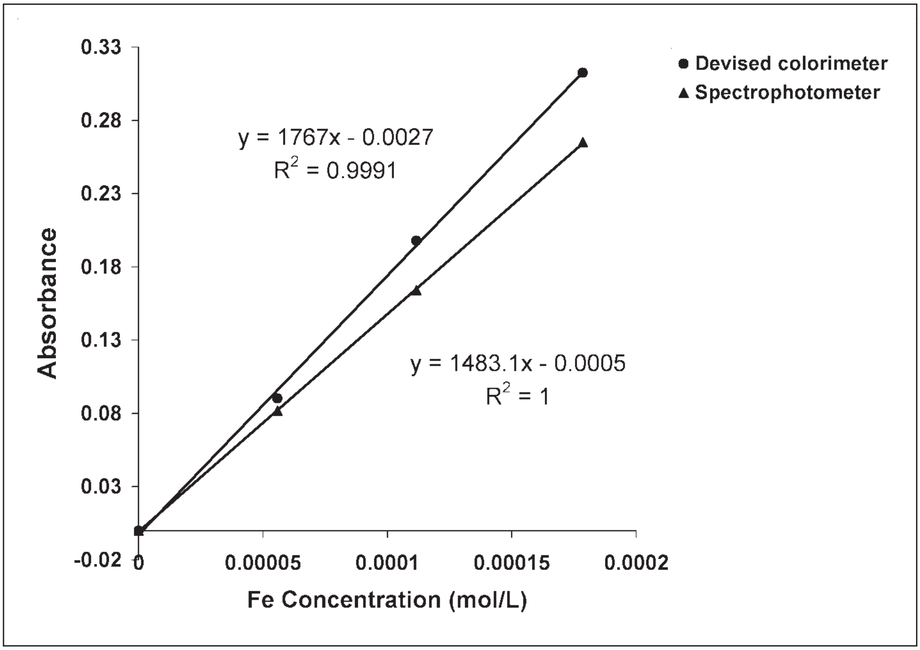

Fig. 4.

The molar absorptivities comparing obtained from each of the two methods are presented in Table 1. The differences between the results of the two instruments are attributed to the LED's polychromatic character.

Table 1.

Colored species	Spectrophotometer	Devised Colorimeter
Permanganate	1.32×10^3	1.26×10^3
ECBT	5.42×10^3	4.02×10^3
Fe^{II}-1,10-Phenanthroline	1.48×10^3	1.76×10^3

Hazards

The potentially hazardous materials used were the oxidizing solutions of permanganate, which should be handled with care and disposed of properly, the 1,10-phenanthroline and eriochrome black T those may cause skin and/or eye irritation. In case of contacting skin or eye with these materials, washing immediately with plenty of water is recommended.

Conclusion

The low cost and the simplicity of colorimeter construction and operation offers a practical alternative for the demonstration of spectrophotometry in the classroom. The fabricated device is able to show students a spectrophotometer's basic components, help in learning and teaching the fundamentals of spectroscopy and use as an analytical device.

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