Measuring the refraction index of luminescent carbon nanodots forming Gaussian beam using the tracker software

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Nanotechnology is currently regarded as one of the fastest-growing technologies. Equipping students with some understanding of nanotechnology in relation to physics ideas may trigger their interest and inspire them to learn physics. This study is aimed to measure the refraction index of Cdots solution using the Gaussian beam and Tracker software. The method used in this research is quantitative descriptive method with the stages of research that include designing, construction, developing, and testing the measuring instrument. The procedure in this study begins by preparing the Cdots solution from cajuput oil (CJO) distillation wastes. The Cdots are then characterized using the UV-visible (UV-Vis), photoluminescence (PL), time resolved-PL (TRPL), and Fourier transform infrared (FTIR) spectroscopies. The Cdots solution is then put into a reaction tube with solution height variation. The violet/UV laser pointer is exposed upward towards the Cdots solution from the bottom of the reaction tube producing a Gaussian beam inside the reaction tube. The Gaussian beam is then photographed, which then the format is converted into a video format. The video format of the Gaussian beam is analysed using the Tracker software. The characterizations of the Cdots show i) an absorption peak at a wavelength of 216.0 nm, ii) an emission peak at 512.29 nm indicating cyan luminescence, iii) an electronic lifetime of 51.3 ns, and iv) functional groups of O-H; C=C; and C=O. Moreover, the Gaussian beams are formed for various heights of the Cdots solution, *i.e.*: from 5.364 cm to 13.000 cm. Using the Tracker software, the value of the Cdots' refraction index is 1.29 ± 0.03, which is comparable to the refraction index of water. This measuring instrument has the potential to be used in high school physics classes and/or first-year university physics courses.

Keywords: Refraction index; luminescent carbon dots; Gaussian beam; tracker software.

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1. Introduction

Physics is the science that seeks to understand the beautiful rules and/or patterns of nature and describe them in mathematical forms. Hence, physics itself explores and describes phenomena that occur in everyday life via mathematical descriptions that can be learned by students [1]. Thus, physics teachers are naturally able to instil physics concepts that are combined with various daily phenomena to their students in a way that is fun and easy to understand. In order to realize this, a supporting learning media is needed in the form of measuring instruments and/or teaching aids [2]. Moreover, physics teachers must also provide opportunities for students to use the measuring instruments and/or teaching aids directly, hence adding to their learning experiences.

The learning of physics concepts for students tends to be lagging behind the rapid advancement of technology [3]. Moreover, the learning of physics concepts to students is often detached and separated from the latest technological advances, which causes students to be left behind from technological advances related to the physics concept being taught. An example of this is that although most students are familiar with the use of electronic gadgets, however they are not familiar with the physics concept behind the workings of these gadgets. Therefore, there needs to be a bridge between physics concepts learned by students with the advancement of technology. One way to realize this is by creating measuring instruments and/or teaching aids that can relate physics concepts and the latest technological advancement.

Nanotechnology is considered as one of the fastest-growing technology at the moment. Nanotechnology has reached everyday products, such as kitchen appliances, clothing, vehicles, and housing materials [4]. Hence, equipping students with some knowledge of nanotechnology in connection with physics concepts may stimulate students' curiosity and motivate students to learn physics.

A nanomaterial that is currently being studied and developed as it has novel properties, such as excellent luminescence, biocompatible, and non-toxic is carbon nanodots (Cdots) [5, 6]. This nanomaterial was discovered in the purification of single-walled carbon nanotubes (CNT) [7]. Cdots have been utilized for various applications including bioimaging [8], screen display [9], photocatalysts [10], energy storage [11], and drug delivery system [12]. The advantages of Cdots include easy preparation using daily appliances, simple preparation methods [13, 14], and inexpensive precursor materials [15]. Moreover, the Cdots used in this study were made from cajuput oil (CJO) distillation wastes. CJO was produced from the cajuput (*Melaleuca cajuputi*) plants, which grow naturally in Indonesia and other South-

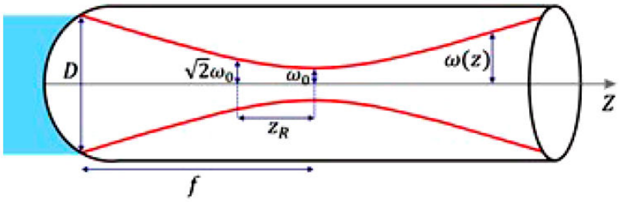

FIGURE 1. Transmission of Gaussian beam through a thin convex lens.

east Asia countries. Hence, Cdots can be used as teaching aids in the form of experiments or practicum activities.

Gaussian beams are the most basic and in many cases, the most desirable form of laser beam. The ray transforms into a beam, with the width parameter defining its transverse reach [16]. Transmission of Gaussian beam through a thin convex lens is described in Fig. 1.

At the direction of propagation z along the beam (measured from the focus), the formula of the spot size parameter ω was described by the hyperbolic equation [17]:

$$\omega(z) = \omega_0\sqrt{1+\left(\frac{z}{z_r}\right)}, \qquad (1)$$

where ω_0 is the beam waist. The parameter of z_R is defined as the Rayleigh range and can be determined using the equation [18]:

$$z_R = \frac{\pi\omega_0^2 n}{\lambda}, \qquad (2)$$

where n is the refraction index and λ is the wavelength of the laser beam. The parameter of beam waist can be obtained from by the formula given by [19]:

$$\omega_0 = \frac{2\lambda}{\pi}\left(\frac{f}{D}\right), \qquad (3)$$

where f represents the focal length of the lens. Here, D is the diameter of the incident beam. By substituting Eq. (3) into Eq. (2), the refraction index may be obtained using the formula given by:

$$n = \frac{z_R\pi}{4\lambda}\left(\frac{D}{f}\right)^2. \qquad (4)$$

The parameters of D and f can be observed using the Tracker software. z_R can be obtained by measuring the distance from the beam waist to the point when the width ω of the beam is $\sqrt{2}$ larger than ω_0 [18].

Tracker software is an open source video analysis and modeling tool built with a Java framework [20,21]. The software may be freely downloaded via a computer device [22]. The Tracker software analyzes videos about physical phenomena, especially those related to the motion of an object, *e.g.*: speed, velocity, acceleration, force, gravitational field, conversion, and energy conservation [23]. Moreover, this software has the ability to provide users with many ways of representing data, as well as providing tools for multi-representation of experimental data [24]. In addition, the ability to track the movement of objects can display results in the form of pictures, tables, and graphs [25]. In this study, we utilize the Tracker software to track an analytical model of light rays forming a Gaussian beam in Cartesian coordinate. Moreover, we use a ratio factor, M, in order to calculate the refraction index of a sample. In this case, M is a ratio between the true and the measured (using Tracker) lengths of the parameters, *i.e.*: ω_0 and z_R, of the Gaussian beam.

Here, we explore one of the characteristics of Cdots, *i.e.* their excellent luminescent to be connected to the physics concept of refraction index in geometrical optics. This study can be used to show the concept of refraction index of nanomaterials, especially Cdots, for senior high school students and/or first-year university students. Moreover, we also give partial characterizations of the Cdots, especially their optical properties using ultraviolet-visible (UV-Vis) spectrophotometer, photoluminescence (PL), time-resolved PL (TRPL), and Fourier transform infrared (FTIR). In this case we do not focus on the Cdots materials and hence the detailed properties of the Cdots are not provided as these need advanced physics concepts. In this study, we use the fact that Cdots have excellent luminescent property, which can be used to show a Gaussian beam in order to calculate the refraction index of the Cdots solution assisted by the Tracker software.

2. Research method

This study aimed to measure the refraction index of Cdots solution using the Gaussian beam assisted by the Tracker software. Furthermore, this study also examined the implementation of the refraction index measurement activity as a topic that can be delivered in a physics classroom. The processes of designing, developing, and testing the refraction index of the measuring equipment were described in this research, which can be considered as a quantitative descriptive research.

The procedure in this study consisted of five steps, *i.e.*: i) preparing the Cdots from CJO wastes; ii) characterizing the Cdots using UV-Vis, PL, TRPL, and FTIR; iii) designing the measurement set-up; and iv) testing the measurement set-up by measuring the refraction index of Cdots. The procedure of this study is described as follows.

2.1. Preparation of Cdots from CJO wastes

The Cdots were prepared by low heating method by adapting the procedure designed by Dwandaru *et al*. [26] with some modifications as needed. CJO distillation wastes were heated in an oven (Mitseda Electric) for 2 hours at a temperature of 250°C to become carbon or charcoal. The CJO wastes, which have become charcoal, were mixed with distilled water and left alone for 4 days. The CJO wastes solution was filtered using Whatman filter paper 40 and poured into a beaker glass. The beaker glass containing 50 ml of brown solution was put in the microwave for 40 minutes. The remaining material was the crusts or sediments at the bottom and sides of the beaker glass. The crusts were cooled and 100 ml of distilled water was added. The sample was shaken until it was well-mixed and left no residue. The Cdots solution was ready to be characterized.

2.2. Characterizations of the Cdots

The characterizations of Cdots were carried out using the UV-Vis spectrophotometer, PL, TRPL, and FTIR. The UV-Vis (Shimadzu UV-2450) spectroscopy was used to determine the absorption of visible and UV spectra of light by the sample [27]. The PL test was utilized to determine the emission spectrum of the sample. The TRPL measurements were used to determine the sample's lifetime decay curve. The time it takes for electrons to undergo de-excitation is called the lifetime decay [28]. The FTIR (Thermo Nicolet Avatar 360IR) characterization was used to determine the functional groups formed in the Cdots. The FTIR spectrum was the result of the interaction between the sample with the IR radiation [29].

2.3. Design of the cdots refractive index measurement set up using the Gaussian beam and tracker software

The equipment needed in this study consisted of a stand with clamps and bossheads, a ruler, a reaction tube, and a violet/UV laser ($\lambda = 532$ nm; power 5 mW). The design of the measurement set up is shown in Fig. 2. The Cdots was poured into the reaction tube. Then, the laser pointer was turned on so the laser beam passed upward through the Cdots. The bottom of the reaction tube served as the convergent lens such that it can focus the rays of light producing the Gaussian beam.

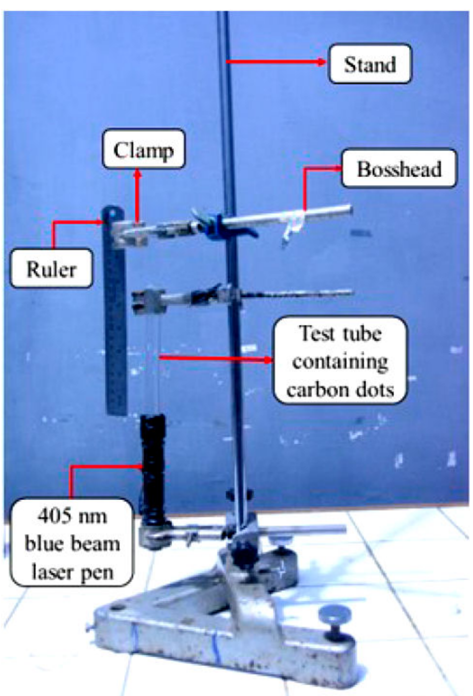

FIGURE 2. Set up design of the measuring instrument.

Photo documentations were carried out at each data collection and produced files in .jpg format. The parameters needed for calculating the refraction index can then be determined using the Tracker software. In order that the photos can be analyzed using the Tracker software, the photos in the .jpg format were then converted into videos in .mp4 format.

2.4. Calculating the Refractive Index of the Cdots

The main equation to determine the refraction index of the Cdots is Eq. (4). The values of D and f can be measured using the Tracker as they were clearly visible. Furthermore, as mentioned above, the ratio factor, M, was used to determine z_R. Here, M is given by

$$M = \frac{\omega_{0,T}}{\omega_0}, \tag{5}$$

where $\omega_{0,T}$ is the length of ω_0 measured from the Tracker, whereas ω_0 can be determined using Eq. (3). Hence, the length of Z_R can be obtained using M from Eq. (5), that is:

$$z_r = \frac{z_{0,T}}{M}, \tag{6}$$

where $z_{R,T}$ is the length of z_R observed from the Tracker software. Finally, the refraction index of Cdots can then be obtained using Eq. (4).

The measurement of Cdots' refraction index was done by varying the height of the Cdots solution (h). The data from the measurement results of the refraction index from Eq. (4) were analysed on average using equation:

$$\overline{n} = \frac{\sum_{i=1}^{m} n_i}{m}, \tag{7}$$

where $\overline{n}$ is the average refraction index and $\sum_{i=1}^{m} n_i$ is the total refraction index of Cdots from $i = 1$ to the $m - th$ measurement. The precision of the refraction index measurements were determined using standard deviation, *i.e.*:

$$\Delta n = \sqrt{\frac{\sum_{i=1}^{m} (n_i - \overline{n})^2}{m-1}}, \tag{8}$$

where Δn is the standard deviation of the refraction index.

3. Results and analysis

Firstly, we describe the characterization results of the Cdots. Figure 3 shows the results of the UV-Vis (dotted-blue line) and PL (red line) spectral of the Cdots. There is one absorption peak at a wavelength of 216.0 nm, showing that the Cdots solution absorbs UV spectrum. The PL characterization aims to determine the spontaneous emission of light from an excited material [27, 28]. The emission peak of the Cdots is obtained at a wavelength of 512.29 nm. This indicates that the Cdots emit visible light of cyan wavelength.

Figure 4 shows the electronic lifetime curve of the Cdots. We use the exponential decay fitting to match the observed

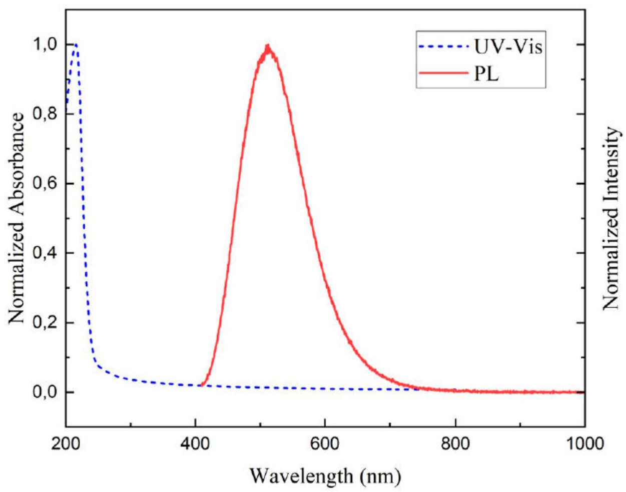

FIGURE 3. Absorbance and emission spectra of the Cdots.

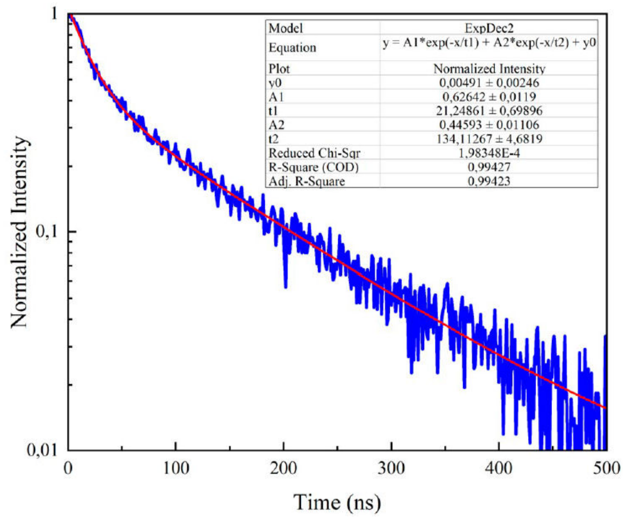

FIGURE 4. Electronic lifetime decay of the Cdots.

data. Based on the curve fitting employed, the curve intensity (y) is formulated as follows:

$$y = y_0 + A_1 e^{\frac{-x}{\tau_1}} + A_2 e^{\frac{-x}{\tau_2}}, \tag{9}$$

where A and τ are the curve fitting parameters. Thus, the electronic lifetime decay (τ) of the Cdots can be calculated using [28]:

$$\tau = \frac{(A_1\tau_1)^2 + (A_2\tau_2)^2}{A_1\tau_1 + A_2\tau_2}. \tag{10}$$

From the result of the calculation, the Cdots has an electronic lifetime of around 51.3 ns. This shows that the electronic lifetime of the Cdots is in the order of ns, hence indicating a form of fluorescence [30]. This means that the Cdots solution does produce luminescence.

The FTIR spectrum result can be seen in Fig. 5. From the FTIR spectrum result, we can see that the Cdots produce transmittance bands at 3396 cm^{-1}; 2042 cm^{-1}; and 1624 cm^{-1}; that correspond to O-H; C=C; and C=O functional groups, respectively. The C=C bond shows the core

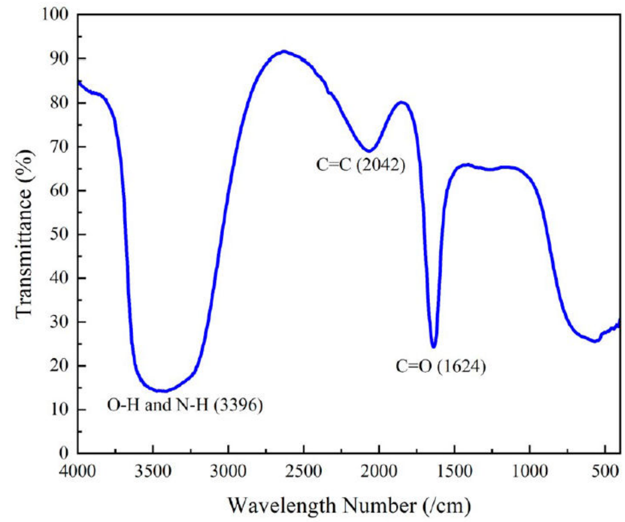

FIGURE 5. Functional groups of the Cdots.

of the Cdots, whereas the O-H and C=O bonds indicate the surface state [31] of the Cdots.

The characterization results from the UV-Vis, PL, TRPL, and FTIR spectroscopies only partially indicate that the solution consists of Cdots. Moreover, these characterizations focus on the optical properties of the solution, which is useful in this study as we use the luminescence property that can be observed as Gaussian beam when the laser is exposed to the solution. However, in order to give a stronger justification of the Cdots' existence further characterizations are needed, *e.g.*: using transmission electron microscope (TEM), high-resolution scanning electron microscope (HRTEM), and X-ray photoelectron spectroscopy (XPS). In this study, the TEM, SEM, and XPS data are not yet provided, as it is not our main objective. For pedagogical purposes, it is sufficient to show partial evidence of the Cdots, especially the optical properties.

The Gaussian beams produced by exposing the violet/UV laser pointer towards the solution can be observed in Fig. 6. The Gaussian beams show cyan luminescence in accordance to the PL characterization. Full Gaussian beams can be seen from the height of the solution of 5.364 cm to 13.000 cm. However, if the height of the solution is less than 5.364 cm, *i.e.*: 3.605 cm to 0.306 cm, partial Gaussian beams are observed. Hence, the formation of the Gaussian beams depends on the height of the solution being exposed by the laser.

The data of the measurement results using the Tracker software are shown in Table I. It can be observed from Table I that from the height of 0.306 cm to 2.774 cm, only the data of D is available. Other data is not available because the Gaussian beam of each height, which can be observed in Fig. 6 , is incomplete. However, from the height of 3.605 cm to 13.000 cm, the data is complete as the Gaussian beam of each of the height is complete. Moreover, it can be observed that the values of the Cdots' refraction index are in the range of 1.241 to 1.319. Hence, the average value of the

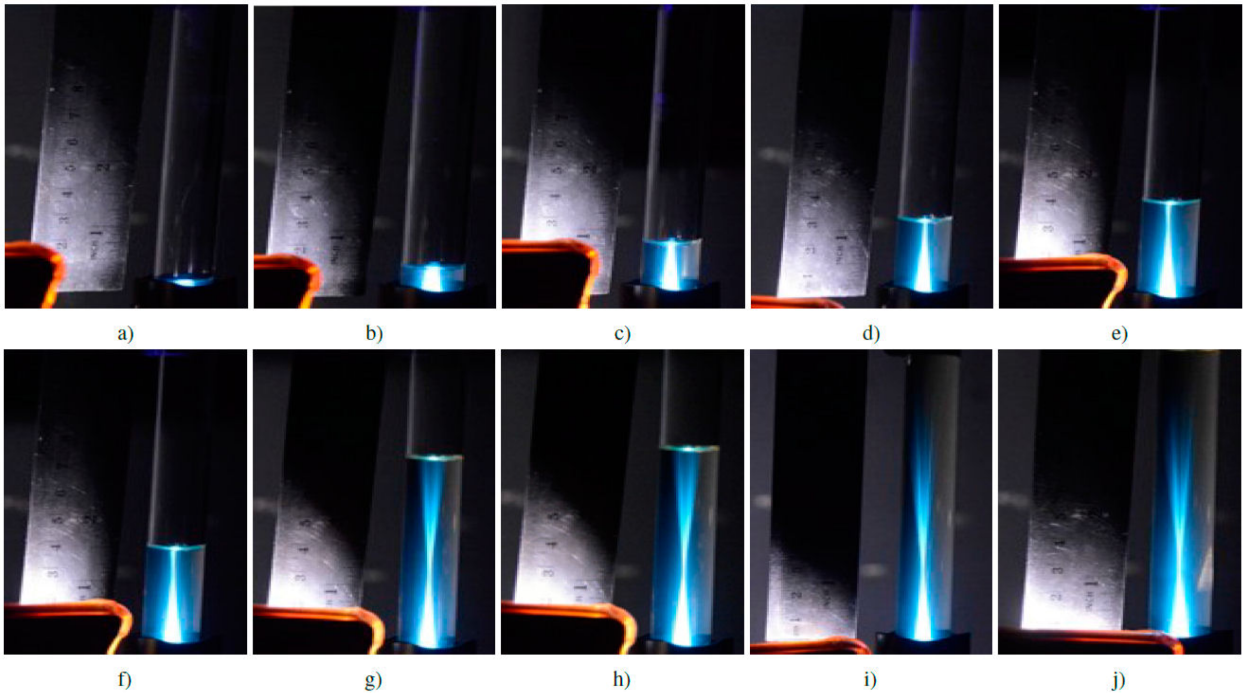

FIGURE 6. Gaussian beams of the laser to determine the refractive index of the Cdots with height variation of the solution (in cm): a) 0.306; b) 1.000; c) 1.908; d) 2.774; e) 3.605; f) 5.364; g) 7.004; h) 9.002; i) 11.007; and j) 13.000.

TABLE I. The measurement results of the Cdots refraction index.

h (cm)	f (cm)	D (cm)	ω_0 (μm)	$\sqrt{2}\omega_0$ (μm)	$z_{r,t}$ (cm)	$\omega_{0,T}$($\times 10^{-2}$ cm)	M	z_r (μm)	n
0.306	-	0.500	-	-	-	-	-	-	-
1.000	-	0.493	-	-	-	-	-	-	-
1.908	-	0.490	-	-	-	-	-	-	-
2.774	-	0.490	-	-	-	-	-	-	-
3.605	2.632	0.498	1.363	1.928	0.402	3.012	22092.408	18.1963	1.263
5.364	2.583	0.493	1.351	1.911	0.475	3.653	27028.181	17.5742	1.241
7.004	2.687	0.497	1.394	1.972	0.428	3.031	21732.980	19.6936	1.306
9.002	2.713	0.494	1.417	2.003	0.432	3.089	21804.177	19.8127	1.273
11.007	2.775	0.496	1.443	2.041	0.435	2.947	20419.422	21.3032	1.319
13.000	2.643	0.491	1.389	1.963	0.462	3.259	23470.012	19.6847	1.317
Average of Refraction Indeks									1.286
Standard Deviation									0.029

refraction index is 1.29 ± 0.03. Although the refractive index of the Cdots solution has not been studied much, so that it is not clearly known, the value of the refraction index in this study is comparable to the refraction index of water, *i.e.*: 1.33 [32, 33]. We argue that this may be caused by the low concentration of the Cdots in the sample, such that the refraction index of the sample is effectively the refraction index of the distilled water.

This measuring instrument has the potential to be used in high school physics classes or first-year University physics courses. It can be utilized as a demonstration experiment or as a "home lab experiment" practicum activity. The experiment and the data analysis provided in this research show an interesting and accurate method for determining the refraction index of the Cdots solution. Despite the fact that this experiment and analysis might be more challenging and advance than the common high school and/or university experiment, we believe that the advantages of conducting this experiment will improve students' interest in learning physics. This measuring instrument can also be used as an example of nanotechnology advancement to students. Moreover, this experiment also shows the beauty of physics in motion through the luminescence of the Cdots solution in the form of Gaussian beams. The implementation of the physics learning using this measuring instrument can be done by the following steps: i) the teacher gives a brief definition to nanotechnology, especially in this case is Cdots; ii) the teacher gives the novel properties of the Cdots; iii) the teacher then gives a brief explanation in the application of the Cdots; iv) the teacher gives a task for students to prepare the Cdots in groups using various organic wastes that can be found in students' local environment; v) each group observes the Gaussian beam using the measuring instrument; vi) each group determines the refraction index of the Cdots solution from various precursors; and vii) each group presents the result in front of the class.

This learning activity can be conducted even without doing the characterization process. Then, the procedure in this experiment should be straightforward. There are mainly three steps in conducting this experiment, *i.e.*: i) preparing the Cdots sample; ii) setting up the tools and materials according to Fig. 2, and lastly, iii) calculating the refraction index assisted by the Tracker software. In the first step, the main technique used is heating using an oven. The tools and material used in this experiment (see Fig. 2) are commonly found in physics laboratories. Moreover, there is no special technique needed to set up the experiment. Finally, students are required to be able to use the Tracker software in order to execute the last step. Hence, a Tracker software tutorial should be given to students. In addition, the steps and techniques in the experiment can also be adjusted to the needs or level of the students, *e.g.*: by simplifying the experimental procedure and/or the objectives of the experiment. Therefore, this shows that high school, college, and/or university students may conduct the entire experiment.

4. Conclusion

Gaussian beams can be constructed via exposing violet/UV laser pointer towards the Cdots solution. Assisted by the Tracker software, the refraction index of the Cdots solution can be calculated and yielded a value of 1.29 ± 0.03. The Cdots solution is characterized using the UV-Vis, PL, TRPL, and FTIR spectroscopies, which indicate the optical properties of the Cdots. The Tracker software is used to analyze the Gaussiam beams such that the refraction index of the Cdots can be determined. This experiment can be used in the physics learning process in high school classes and/or first-year University physics courses to improve students' interests in physics, while also familiaring the advancement of nanotechnology to students. Further study can be conducted by extending the characterization of the Cdots using TEM, SEM, and XPS.

Acknowledgments

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