Effect of carbon dots nanomaterial concentration on luminance spectral bandwidth via Kirchoff-Bunsen spectroscope

P. Wahyu Pradana*, Suparno, E. A. Nurbaiti, and W. S. Brams Dwandaru
Department of Physics Education, Faculty of Mathematics and Natural Sciences, Universitas Negeri Yogyakarta, Jl. Colombo No.1, Karangmalang, Sleman, Yogyakarta, 55281, Indonesia,
e-mail: pramudyawahyu.2021@student.uny.ac.id

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This study aims to determine the effect of the concentration of Carbon Dots on the bandwidth of the Carbon Dots luminescence spectrum. Carbon Dots are produced by ultrasonification method and characterized using UV-Vis spectroscopy, photoluminescence (PL) spectroscopy, scanning electron microscopy (SEM), electron dispersive X-Ray spectroscopy (EDX), X-ray diffraction (XRD), and particle size analyzer (PSA). Measurement of the bandwidth of the Carbon Dots fluorescence spectrum for various concentrations was carried out by irradiating the Carbon Dots sample using a laser with a wavelength of 405 nm and looking at the spectrum of light emitted using a Kirchoff-Bunsen spectroscope.The characterization results show that the resulting Carbon Dots have a light absorption peak at a wavelength of 303 nm, a light wave emission peak at a wavelength of 508.87 nm, the surface structure of the Carbon Dots is in the form of a porous layer, the presence of the dominance of carbon and oxygen atoms in Carbon Dots, an amorphous Carbon Dots structure is observed, and the smallest measured Carbon Dots particle size is 1.12 nm. The results show that increasing the concentration of Carbon Dots causes a tendency to increase the bandwidth of orange, green and blue light spectra emitted by the particles, and in the red color there was no significant effect of increasing the concentration of Carbon Dots on the spectrum. However, increasing the concentration of Carbon Dots actually causes a narrowing of the yellow and violet color spectra.

Keywords: Concentration; luminance spectral bandwidth; carbon dots; Kirchoff-Bunsen spectroscope.

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1. Introduction

Carbon dots are one of the most studied types of nanoparticles today. Carbon Dots is widely studied because it has several unique characteristics. Unlike some other nanoparticles, carbon dots have several properties, for example, they can glow when exposed to light with certain wavelength, environmentally friendly, biocompatible, and have low toxicity [1]. These properties make Carbon Dots usable in various fields. Of the several properties of Carbon Dots, luminescence of Carbon Dots is one of the most prominent properties, so it is widely used in various ways. The luminescence properties and mechanisms of Carbon Dots are widely used, for example, for bioimaging, photocatalysts, sensing, and drug delivery [2, 3].

The luminescence properties of Carbon Dots is one of the most exciting discussions in materials science. Regarding its luminescence properties, some experts state that the luminescence of Carbon Dots is influenced by the size of the particles [4], but on the other hand, some say that its luminescence is influenced by the surface energy level of the particles [5]. The photon emission produced by Carbon Dots is also influenced by several other factors such as pH and the concentration of this carbon particle [6]. These properties have attracted scientists for further application of the Carbon Dots in the future.

One of the luminescence properties of Carbon Dots that has been widely studied is the effect of Carbon Dots concentration on luminescence. Isnaeni et.al studied this effect at room temperature and found that the surface energy of the Carbon Dots shifted when the concentration of Carbon Dots was added [7]. In line with Isnaeni et.al, Meng et. al. found that reducing the concentration of Carbon Dots would reduce the wavelength of light emitted by the luminescence Carbon Dots [8]. In contrast to this study, Su *et al*,. observed that increasing the concentration of Carbon Dots made the particles aggregate and decreased the width of the bandgap so that the luminescence shifted to a red color wave [9]. Based on these findings, there is an effect of the concentration of Carbon Dots on their luminescence properties. However, these studies show different effects of varying the concentration of Carbon Dots on the luminescence spectrum. In addition, research on the effect of Carbon Dots concentration on the bandwidth of the emitted light spectrum is still limited. Furthermore, these studies have only focused on observing the effect of concentration on changes in the spectrum with the highest luminescence intensity. They have not looked at the effect on the entire spectrum of visible light emitted by Carbon Dots.

In this paper, the researchers are interested in observing the effect of Carbon Dots concentration on the spectral characteristics of the visible light they emit. The purpose of this study is to determine the effect of the concentration of Carbon Dots on the bandwidth of the luminescence spectrum. Observation of this effect is carried out using Kirchoff-Bunsen spectroscope. This research is expected to provide new insights into the luminescence properties of Carbon Dots, which in the future can provide greater benefits.

2. Method

Carbon Dots preparation was carried out using the Top-Down method. This study's main ingredient for making Carbon Dots was coffee husk waste. Wet coffee husk waste with a mass of 4 kg was dried in a place that was not exposed to direct sunlight for three days to obtain dry coffee husk waste with a mass of 2.464 kg. Part of the dry mass was precisely 100 gr and then baked in the oven for 2 hours at 250°C to obtain 56.1 gr of coffee husk charcoal. Carbon Dots were produced by adding 56.1 gr of the charcoal to 400 mL of aquadest. The charcoal in the aquadest was sonicated for 1 hour and then filtered to obtain a liquid sample of Carbon Dots. This liquid was then microwaved for 45 minutes to reduce the water content to produce a caramel-like sample of Carbon Dots.

The Carbon Dots samples were then characterized by UV-Vis spectroscopy, photoluminescence (PL) spectroscopy, scanning electron microscopy (SEM), electron dispersive X-Ray spectroscopy (EDX), X-ray diffraction (XRD), and particle size analyzer (PSA). Characterization using UV-Vis spectroscopy was carried out to determine the character of the Carbon Dots' absorption. PL spectroscopy was performed to determine the Carbon Dots's emission during irradiation. SEM was performed to characterize the surface morphology of the Carbon Dots. EDX was used to characterize the elemental composition of the produced Carbon Dots. XRD was carried out to characterize the crystal structure of the Carbon Dots. PSA was performed to determine the particle size distribution of Carbon-Dots.

After characterization, samples were prepared for measurement. Sample preparation was carried out by mixing 0.05 gr of the Carbon Dots in caramel-like form into 10 mL of aquadest. The results of this mixture produce 10 mL of Carbon Dots liquid with a concentration of 5 gr/L. This liquid was then diluted to produce five liquid samples, each with a concentration of 0.05 gr/L, 0.14 gr/L, 0.28 gr/L, 0.36 gr/L, and 0.53 gr/L.

The activity of measuring the bandwidth of the luminescence spectrum is carried out after the sample for measurement is prepared. Measurements were carried out using the Kirchoff-Bunsen spectroscope. The sample that has been prepared and the spectroscope were positioned so that when measurements were made, the luminescence spectrum of Carbon Dots can be observed through the spectroscope. After adjusting the position, each sample was irradiated using a laser with a wavelength of 405 nm, and the luminescence spectrum of the Carbon Dots sample was seen. The researcher then recorded the wavelengths at the lower and upper limits of the luminescence spectral band for each color and then analyzed them to determine the characteristics of the luminescence spectrum bandwidth.

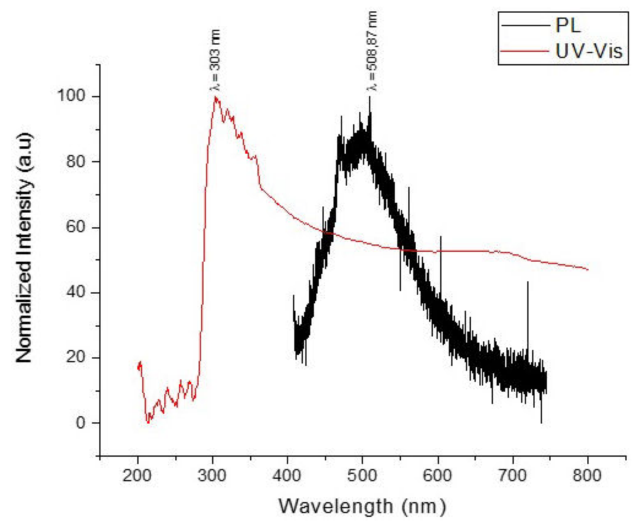

FIGURE 1. Results of UV-Vis and PL spectroscopy.

3. Result and discussion

3.1. Characterizations of carbon dots

In this subsection, we present the characterization results of Carbon Dots. The results of UV-Vis and PL analysis are presented in Fig. 1. Figure 1 shows that the peak of the UV-Vis graph is at wavelength of 303 nm while the peak of the PL graph is at wavelength of 508.87 nm. These peaks show that most photons absorbed by Carbon Dots have a wavelength of 303 nm and most photons emitted by Carbon Dots have a wavelength of 508.87 nm. The different absorption and emission characteristics are shown by Carbon Dots, which are made of watermelon peel. The carbon dots show absorbance and emission peaks at wavelengths of 203.5 nm and 405 nm, respectively [10]. Nonetheless, Guo et. al. reported the presence of Carbon Dots with UV-Vis absorbance peaks in the wavelength range of 250 nm to 305 nm [11].

Figure 2 presents the results of the analysis using XRD. The XRD results show that the diffraction peaks are at $2\theta = 12.089°$ and $2\theta = 29.417°$. The first peak is close to the XRD pattern of graphene oxide, which has a peak at $2\theta = 9.8°$ to $2\theta = 11.8°$ degrees [12–14]. However, in contrast to many graphene oxides with XRD patterns that show a crystal structure as in the research of Al-Ghaasani [15] and Saleem [13], the Carbon Dots produced in this study show an amorphous structure because they have quite broad peaks. Previous studies have reported the presence of Carbon Dots with an amorphous structure [16–18]. The Carbon Dots produced in this study have similarities with the structure of one type of Carbon Dots, namely Carbon Nitride Quantum Dots (CNQDs), which has two peaks at $2\theta = 13.11°$ and $27.41°$ [19]. In addition, Carbon Dots in this study also have similar XRD patterns with one other type of Carbon Dots, namely polymer Carbon Dots (PCDs), which shows a similarity of the structure of the two Carbon Dots [20]. The similarity of the pattern is indicated by the presence of a broad

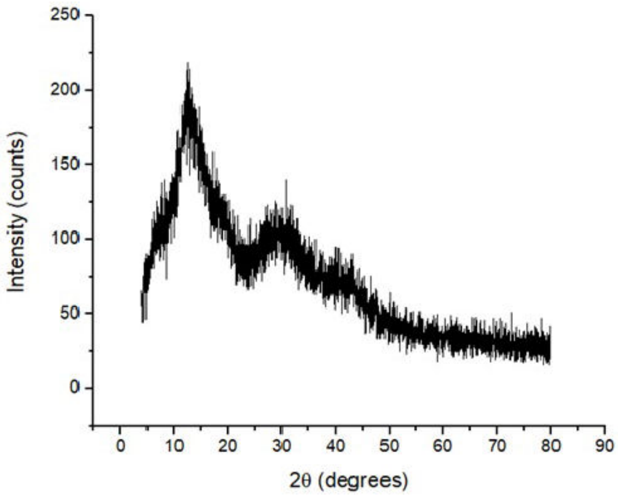

FIGURE 2. Result of the XRD analysis.

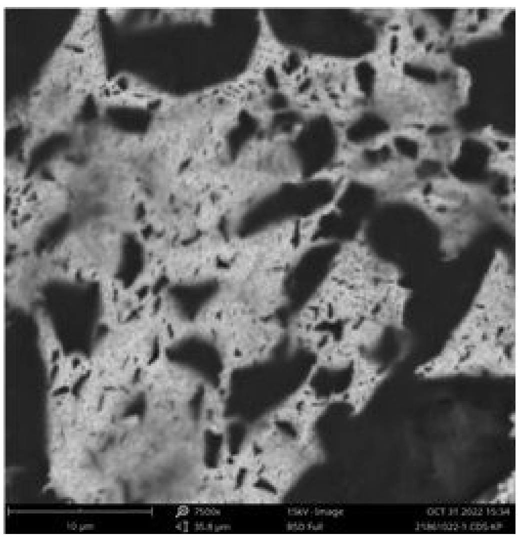

FIGURE 3. Result of the SEM analysis.

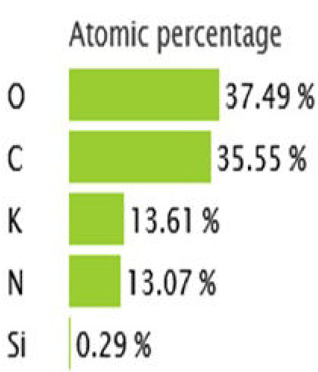

FIGURE 4. Result of the EDX analysis.

second diffraction peak preceded by a narrower first diffraction peak. These similarities indicate that the material produced in this study is Carbon Dots.

The results of SEM and EDX analysis can be seen in Figs. 3 and 4. SEM shows that the Carbon Dots produced in this study tend to form layers interspersed with pores. This result is different from the research by Sabet and Mahdavi, which shows that Carbon Dots aggregate and form chunks [21]. The atomic percentage analyzed based on EDX shows that oxygen and carbon occupy the most significant proportion. This percentage shows that the samples made are in the form of carbon particles. The results of EDX analysis in line with previous studies, indicating carbon atoms' dominance in Carbon Dots [22]. A large number of K and N atoms is present because the two atoms do not evaporate completely during heating process. The presence of K, N, and O atoms can also indicate that these three atoms are surface state functionalization of Carbon Dots with carbon atoms as the core of the Carbon Dots material formed.

Particle size analysis results are presented in Fig. 5. This analysis shows the presence of carbon nanoparticles with diameters of 108.4 nm and 1.12 nm. The observation of particles with a size of 1.12 nm proves that there are Carbon Dots particles in the samples where the size of the Carbon Dots is in the range of < 10 nm [23]. However, several studies have also reported the presence of Carbon Dots with larger sizes,

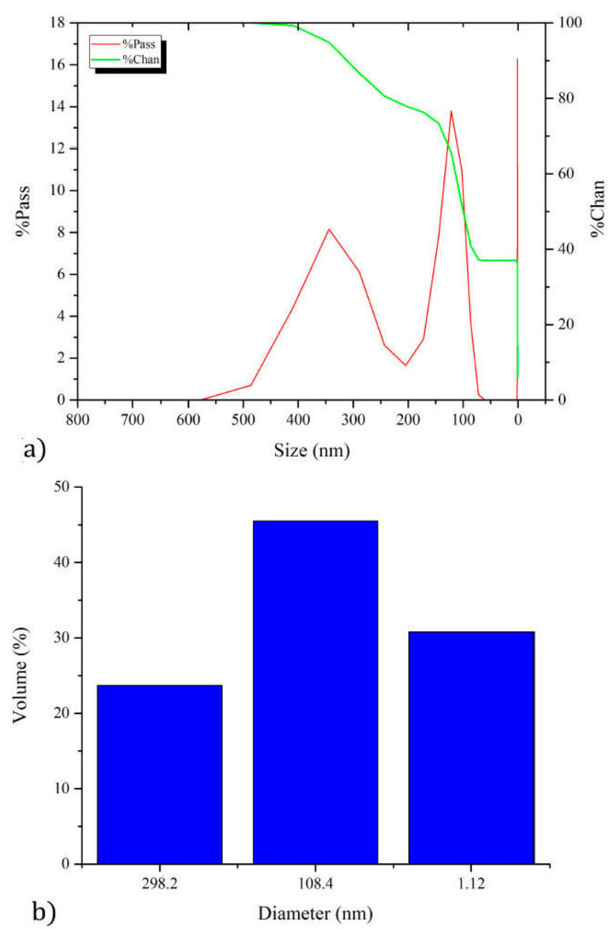

FIGURE 5. Results of PSA analysis a) graph of the particle size distribution and b) bar chart of the peak summary.

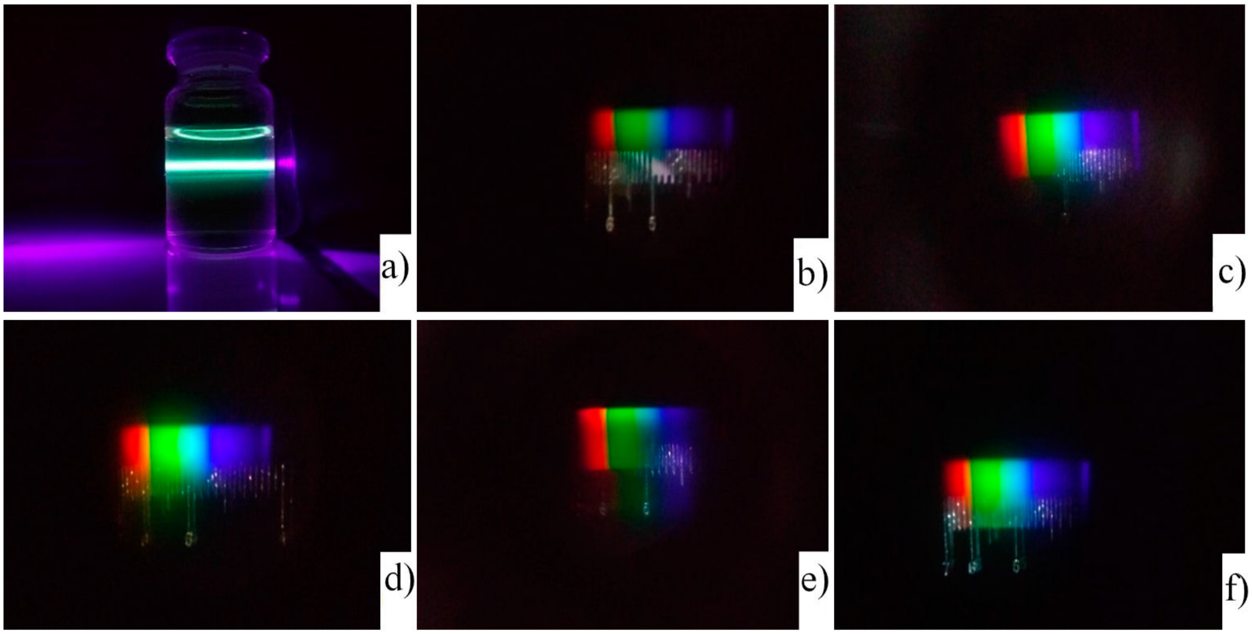

FIGURE 6. a) The luminescence of the Carbon Dots after being irradiated by a laser with a wavelength of 405 nm and the spectrum viewed with the Kirchoff-Bunsen spectroscope for concentrations of b) 0.05 g/L, c) 0.14 g/L, d) 0.28 g/L, e) 0.36 g/L, and f) 0.53 g/L.

for example, 15 nm to 20 nm [24]. Each of these particles occupies the proportion of 45.5% and 30.8%. This indicates that Carbon Dots are present in the sample. As measured by PSA, the carbon nanoparticles with a size > 100 nm may be clusters of carbon dots that form layers, as seen in the SEM results.

3.2. The effect of carbon dots concentration on luminance spectral bandwidth

In this subsection we discuss the observation results of the luminescence of Carbon Dots when illuminated by violet laser. The luminescence of the Carbon Dots with violet laser irradiation produces cyan light when viewed with the naked eye. A previous study has been reported about the appearance of Carbon Dots fluorescence when exposed to light with a wavelength of 405 nm [25, 26]. The luminescence of the Carbon Dots after being irradiated by a laser with a wavelength of 405 nm can be seen in Fig. 6a). The light spectroscopy results of Carbon Dots with various concentrations can be seen in Figs. 6b) to f).

Even though when using the naked eye, the Carbon Dots glow a cyan color, the spectroscopic results show that the Carbon Dots glow a spectrum of light from red to violet. This might happen because the Carbon Dots particles produced in this study are not homogeneous, so particles of different sizes emit light waves with colors other than green-blue or cyan. The appearance of the cyan color when the Carbon Dots are irradiated with a laser may occur because the Carbon Dots particles, which emit light waves with a green-blue color, are more dominant than particles that emit light waves with other colors.

The spectrum of light emitted by Carbon Dots is then analyzed for the bandwidth of each color spectrum. The reading of the spectroscopic results shows five primary colors: red, orange, yellow, green, blue, and violet. The results of fitting the linear model for the influence of the concentration of Carbon Dots on the luminescence spectrum for these colors can be seen in Fig. 7.

Figure 7 shows that the addition of Carbon Dots has a different effect on the width of the visible light spectrum band emitted by Carbon Dots. The addition of the concentration of Carbon Dots causes a tendency to increase the spectral bandwidth for red, orange, green, and blue light. This increase is indicated by the slope value > 0 on the graph of the luminescent colors. However, the slope of the graph in the red color spectrum is so small (close to zero) that it can be said that there is almost no effect of the addition of Carbon Dots on the widening of the red color spectrum band. Furthermore, the addition of Carbon Dots causes a narrowing of the yellow and violet spectrum bands. This narrowing is indicated by the slope of the graph in the violet and yellow luminescence spectrum, which is < 0. In addition, the plot shows that the linear model has a less high model fit. In future research, it will be better if the research is carried out with more data variations. Figure 7 also provides information that the broadest spectral bandwidth is in green, followed by violet, red, blue, yellow, and orange. The green spectrum shows the widest bandwidth and the increase in bandwidth of the green and blue spectra when Carbon Dots are added support the fact that Carbon Dots tend to emit cyan luminescence. The predominance of green-blue color and the band widening of this color spectrum also indicates that as the concentration of

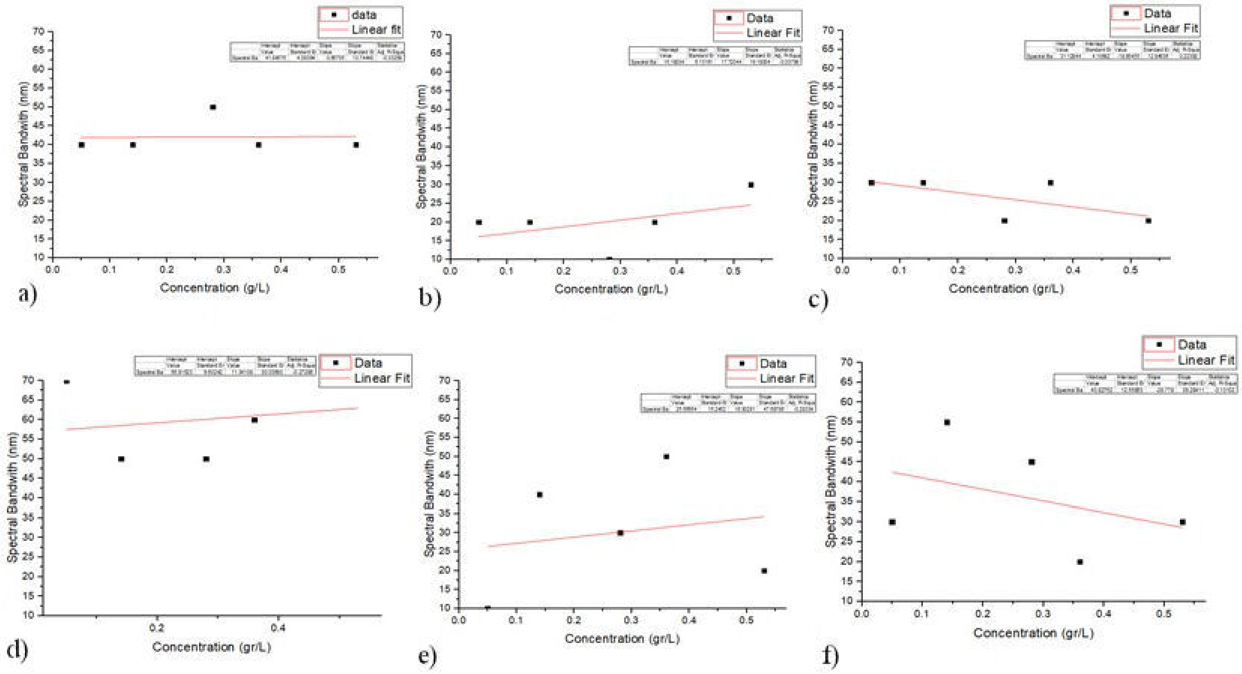

FIGURE 7. The linear fit plot of the effect of Carbon Dots concentration on the width of the luminescence spectrum using the Kirchoff-Bunsen spectroscope for the color spectrum of a) red, b) orange, c) yellow, d) green, e) blue, and f) violet.

Carbon Dots increases, the added Carbon Dots particles mainly emit photons with wavelengths in the green-blue spectral range. This result is different from the results of research by Su *et al*,. [9], which shows a tendency to narrow the energy band gap and a shift to the red color spectrum when Carbon Dots are added. This difference may be due to several factors, including differences in the surface states of Carbon Dots [27], differences in pH [28], and differences in particle size of Carbon Dots [4]. The narrowing of the violet color spectrum indicates that these Carbon Dots have the potential to be used as LED lamps because they can shift the UV light spectrum toward the violet spectrum. This shift causes a reduction in the possibility of UV rays being emitted by LED lamps so that they can have a better health effect on humans.

4. Conclusion

Based on the description in the results and discussion section, there is an effect of adding the concentration of Carbon Dots to the bandwidth of the luminescence spectrum. The addition of Carbon Dots concentration is observed to increase the bandwidth of the red, orange, green, and blue light spectra of the Carbon Dots luminescence. However, the increase in bandwidth is not significant in the red color spectrum. Furthermore, the narrowing of the spectral band is observed in the yellow and violet spectra when the concentration of Carbon Dots is increased.

This research is certainly not without limitations. For better research in the future, research can be done by adding more concentration variations, using a more accurate spectroscope or spectrometer, or using Carbon Dots with different materials or production methods.

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