Spectra Analysis in Sunset Color Demonstrations with White-Color LED as a Light Source

Makoto Hasegawa, Seika Tokumitsu

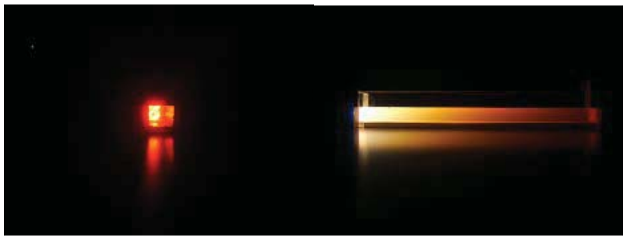
***Abstract*—**Spectra of light beams emitted from white-color LED torches are different from those of conventional electric torches. In order to confirm if white-color LED torches can be used as light sources for popular sunset color demonstrations in spite of such differences, spectra of travelled light beams and scattered light beams with each of a white-color LED torch (composed of a blue LED and yellow-color fluorescent material) and a conventional electric torch as a light source were measured and compared with each other in a 50 cm-long water tank for sunset color demonstration experiments. Suspension liquid was prepared from acryl-emulsion and tap-water in the water tank, and light beams from the white-color LED torch or the conventional electric torch were allowed to travel in this suspension liquid. Sunset-like color was actually observed when the white-color LED torch was used as the light source in sunset color demonstrations. However, the observed colors when viewed with naked eye look slightly different from those obtainable with the conventional electric torch. At the same time, with the white-color LED, changes in colors in short to middle wavelength regions were recognized with careful observations. From those results, white-color LED torches are confirmed to be applicable as light sources in sunset color demonstrations, although certain attentions have to be paid. Further advanced classes will be successfully performed with white-color LED torches as light sources.

***Keywords*—**Blue sky demonstration, sunset color demonstration, white LED torch.

I. Introduction

FASCINATING demonstration experiments are effective to stimulate interests of children and/or students in elementary and secondary school ages towards sciences and technologies. The authors and the student project team "Rika-Kobo" have had several those experiences of performing various science demonstration experiments as well as various science classes including experiments at schools in the local community [1]-[3]. For example, at two elementary schools, science classes have been periodically performed for 5th-grade and 6th-grade classes at almost every four months over the past 10 years. One of the established scenarios for such science classes is related to sunset color and blue sky demonstrations. Although detailed physics principles for the phenomena are difficult [4], [5]; this science class is performed once a year for the 6th-grade classes. More specifically, a hand-made 50 cm-long water tank is provided for each group of 4 to 6 children, and suspension liquid is prepared from acryl-emulsion and tap-water in the tank. A conventional electric torch is placed at one end of the water tank as a light source, and light beams emitted therefrom are allowed to travel in the suspension liquid, as can be seen in Fig. 1. Children are encouraged to observe colors from the opposite end and/or the side of the water tank. When viewed from the opposite end of the water tank, the so-called "sunset color" can be observed as shown in Fig. 2 (a). In addition, children can also recognize that different colors are visible in accordance with distances from the light source (the electric torch), as shown in Fig. 2 (b), when viewed from the side of the tank. After such observations, reasons of appearing sunset color as well as blue sky are explained.

Fig. 1 A photo of the sunset color demonstration



(a) When viewed from the end (b) When viewed from the side

Fig. 2 Typical observed colors with a conventional electric torch

Although the conventional electric torches are usually used as light sources in sunset color demonstrations, white-color LED torches (composed of a blue-color LED element and yellow-color fluorescent material) become popular and easily available recently. Light beams emitted from the white-color LED torches look more "white", as compared with light beams emitted from the conventional electric torches (typically looked somewhat yellow). This is a beneficial aspect for allowing children to have a concept that "white light" means light beams with no specific colors. However, there are certain differences in spectra of emitted light beams between the white-color LED torches and the conventional electric torches.

In view of the above, spectra of travelled light beams and scattered light beams obtainable with a white-color LED torch

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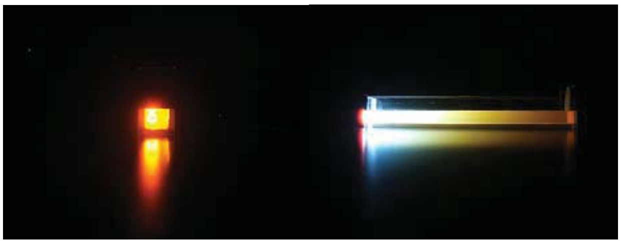
and a conventional electric torch as a light source in sunset color demonstrations were measured and compared with each other [6]-[8].

II. Experimental Setup and Sunset-Color Observation with the White-Color LED Torch

A hand-made water tank was employed, made of acrylic plates of 2 mm in thickness. The overall size of the water tank was: about 50 cm in length; about 6 cm in width; and, about 7 cm in height. 1000 mL water was put in the tank. Tap-water instead of distilled-water was used in this time, as in actual demonstration scenes at local schools where distilled-water is hardly available. Then, about 5 mL water was removed from the tank and about the same amount of acryl-emulsion was added, so that suspension liquid with concentration of about 0.4 to 0.5% was prepared. This is a typical value of suspension liquid concentration in usual demonstrations to be performed at the local schools.

As light sources, a white-color LED torch (composed of a blue-color LED element and yellow-color fluorescent material) and a conventional electric torch were employed, both of which were commercial products. Typical observed colors with the conventional electric torch as the light source were previously shown in Fig. 2. As the counterpart examples, typical observed colors with the white-color LED torch as the light source are shown in Fig. 3.



(a) When viewed from the end (b) When viewed from the side

Fig. 3 Typical observed colors with a white-color LED torch

When viewed from the side of the water tank in the case where the white-color LED torch was used as the light source, the so-called "sunset-like color" was observed at positions far from the torch as the light source, as can be seen in Fig. 3 (b). It should be noted, however, the observed color was looked like orange, rather than red typically observed in the case with the conventional electric torch as previously shown in Fig. 2 (b).

Such differences in the observed colors were more clearly recognized when the light source was viewed from the opposite end of the water tank through the suspension liquid therein. More specifically, with the conventional electric torch as the light source, the torch looked in red just like the sun at actual sunset scenes, as shown in Fig. 2 (a). On the other hand, with the white-color LED torch as the light source, the torch looked in yellow to orange, rather than in red, as shown in Fig. 3 (a).

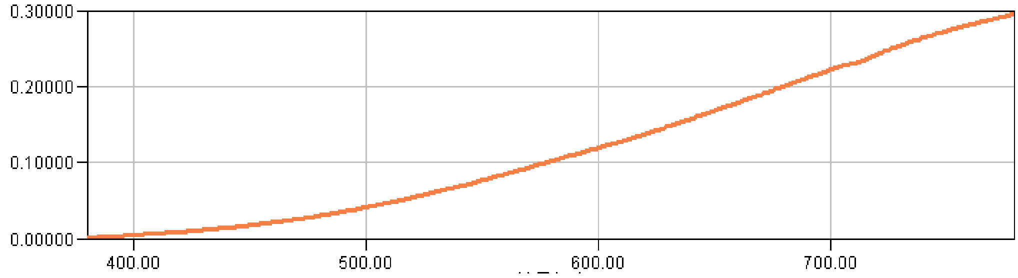
Accordingly, although white-color LEDs can be used as light sources in sunset color demonstrations, some attentions have to be paid to such differences.

III. Spectroscopic Measurements of Travelled and Scattered Light Beams

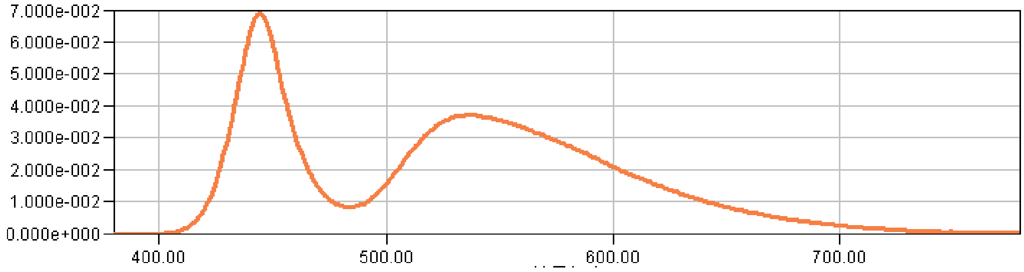
For the purpose of further studying the aforementioned differences in the observed colors due to different light sources, spectroscopic measurements were conducted with respect to light beams travelled through the suspension liquid in the water tank as well as the scattered light beams in the side of the tank. As measuring apparatus, a spectroradiometer, CS-1000A, Konika Minolta, Inc., was used. This apparatus enables us to conduct spectroscopic measurements of light beams at desired positions including within water or liquid, by employing an optical fiber guide. Specifically, the optical fiber guide can be attached to a light intake port of the apparatus so that light beams can be input into the apparatus as input light beams for measurements. The input light beams are spectrally diffracted by means of planar diffraction gratings, and then received with a photodiode array with 512 elements. In accordance with its specifications, measurement wavelength range is from 380 nm to 780 nm, and wavelength resolution is 0.9 nm/pixel.

As examples of measured results with this apparatus, Fig. 4 shows measured spectra of light beams emitted from the conventional electric torch and the white-color LED torch, both employed in this study. In these cases, the optical fiber guide was disposed at the position apart from the torch by about 2 cm, and the emitted light beams were guided into the apparatus without travelling through the suspension liquid. Sufficient S/N levels were not realized with a single data acquisition, and thus, data acquisitions in the wavelength range from 380 nm to 780 nm were repeated five times, and the respective results were accumulated as a single result. These procedures were further repeated five time. An average of the thus-obtained five accumulated results was then calculated, and shown in Fig. 4. In each of the spectra traces in Fig. 4, the horizontal and vertical axes respectively indicate wavelengths (nm) and absolute spectral radiance levels ($W \cdot sr^{-1} \cdot m^{-2} \cdot nm^{-1}$). These results clearly indicate that the light beams emitted from the conventional electric torch exhibit monotonically increasing spectrum towards longer wavelength regions as shown in Fig. 4 (a), while the white-color light beams emitted from the white-color LED torch are actually realized by combination of blue and yellow colors as found in Fig. 4 (b).

For the purpose of comparison, the water tank was filled with tap-water and the light beams emitted from the respective torches were allowed to travel in the tap-water. In such a condition, spectra measurements were conducted by disposing the optical fiber guide in the tap-water in the water tank at positions corresponding to 10 cm, 20 cm, 30 cm, and 40 cm from the torch so as to guide the travelled light beams into the apparatus. The results (not shown here) indicated that the obtained absolute spectral radiance levels simply decreased with increased distances from the torch as the light source without any significant changes in spectra shapes.

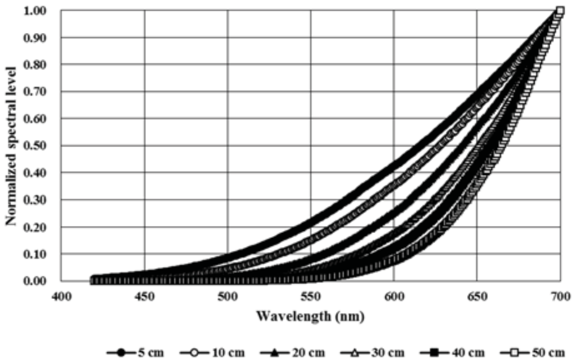


(a) From the conventional electric torch

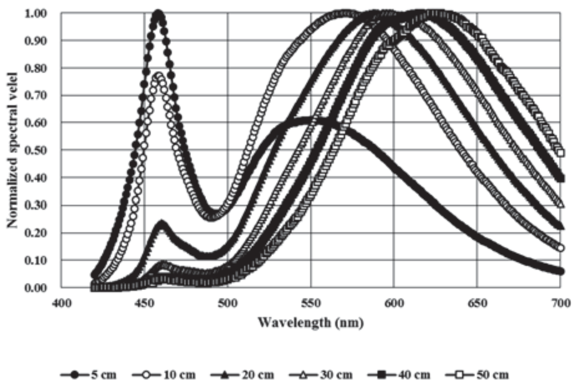


(b) From the white-color LED torch

Fig. 4 Spectra data of light beams from the respective torches



(a) With the conventional electric torch as the light source



(b) With the white-color LED torch as the light source

Fig. 5 Spectra data of the light beams travelled in the suspension liquid over the respective distance (normalized data)

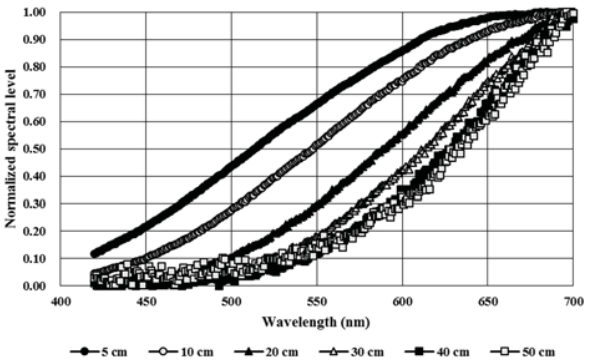
As the next step, in the condition where the water tank was filled with the suspension liquid prepared in the manner as described before and the light beams emitted from the respective torches were allowed to travel in the liquid, spectra measurements were conducted in the similar manner. Specifically, the optical fiber guide was disposed in the suspension liquid in the water tank at positions corresponding to 5 cm, 10 cm, 20 cm, 30 cm, and 40 cm from the torch so as to guide the light beams, travelled in the suspension liquid over the corresponding distance, into the apparatus. The optical fiber guide was also disposed at the outside of the opposite end of the water tank, in other words, where the light beams were allowed to travel in the suspension liquid over the full length of the tank (50 cm). The results are indicated in Fig. 5, as the travelled distances as parameters [7].

It should be noted that the respective spectral data shown in Fig. 5 were normalized with respect to each maximum level.

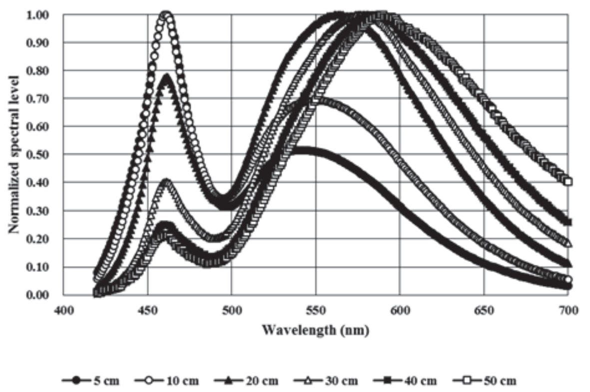
Fig. 5 (a) shows that the spectral data of the light beams emitted from the conventional electric torch and travelled in the suspension liquid over the respective distance; the mid-wavelength components disappeared with increased travel distance within the suspension liquid. Thus, after travelled the longer distance, only longer-wavelength components remained.

In Fig. 5 (b), the spectral data of the light beams emitted from the white-color LED torch and travelled in the suspension liquid over the respective distance exhibit more complicated changes. Specifically, at the travelled distance of 5 cm, the blue-color region peak has the highest level over the entire wavelength range. The level at around 550 nm corresponds to about 60% of the blue-color region peak. However, with increased travel distances, the peak level in the blue-color region is reduced, and in contrast, the levels in the mid- to longer wavelength regions increase to show the highest level.

For example, at the travelled distance of 10 cm, the highest peak exists at around 570 nm. This peak position gradually shifts toward the longer-wavelength region, and finally the peak exists at around 630 nm in the spectral data obtained at the opposite end of the water tank, in other words, for the light beams travelled over the entire length of the water tank (i.e., 50 cm).



(a) With the conventional electric torch as the light source



(b) With the white-color LED torch as the light source

Fig. 6 Spectra data of the light beams scattered from the suspension liquid at the respective distance (normalized data)

Fig. 6 shows the spectral data of the light beams scattered from the suspension liquid toward the outside of the water tank at the respective position [7]. The data were obtained by disposing the optical fiber guide in the outside of the water tank and in the direction perpendicular to the side wall of the water tank so as to catch the scattered components of the light beams after travelled through the suspension liquid over the corresponding distance from the light source (the conventional electric torch or the white-color LED torch). As in Fig. 5, the respective spectral data shown in Fig. 6 were normalized with respect to each maximum level.

In Fig. 6 (a) showing the spectral data of the light beams emitted from the conventional electric torch and scattered after travelled in the suspension liquid over the respective distance, the mid-wavelength components still remain in the case of travelled distances of 5 cm to 20 cm. When viewed from the side of the water tank in these regions, yellow to orange colors are significantly recognized and the above-mentioned spectral data are coincident with such observation results. After travelled over 30 cm or longer, only longer-wavelength components are contained in the scattered light beams. Such results also show reasonable coincidence with the observation fact that red color can be significantly observed.

In Fig. 6 (b), the spectral data of the light beams emitted from the white-color LED torch and scattered after travelled in the suspension liquid over the respective distance exhibit more complicated changes.

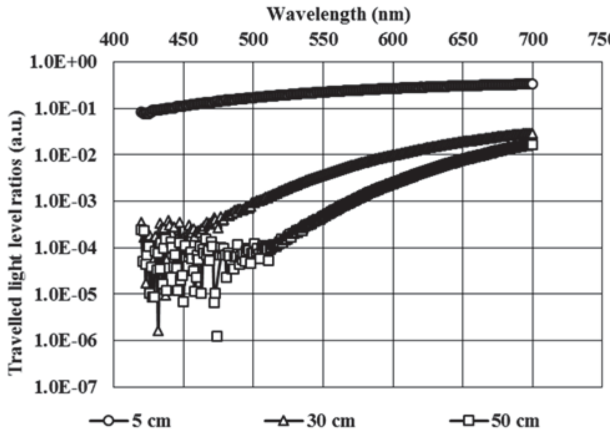
At the travelled distances of 5 cm and 10 cm, the highest level exists in the blue-color region. Specifically, the intensity level at around 550 nm corresponds to about 50% of the peak level in the blue-color region at the travelled distance of 5 cm, and about 70% at the travelled distance of 10 cm. In the spectra data of the scattered light beams after travelled over 20 cm, the maximum level shifts in the mid-wavelength region (at around 560 to 570 nm). Although a certain amount of the blue-color components still remains in this case, its intensity level is reduced to about 80% in the mid-wavelength components. With further increased travel distance, the intensity level in the blue-color region is further reduced, while the peak showing the maximum level further shifts from the mid-wavelength region toward the longer-wavelength region.

IV. Discussions

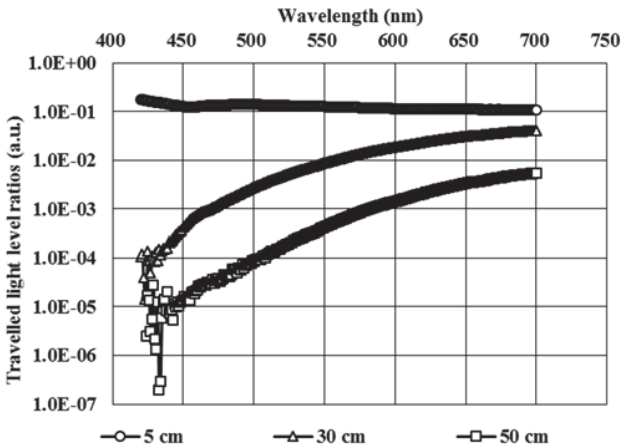
In each case where either the conventional electric torch or the white-color LED torch was used as the light source in the sunset color demonstrations, the short-wavelength components gradually disappeared as the light beams were allow to travel through the suspension liquid over longer distances. As a result, only longer-wavelength components finally remained.

Fig. 7 shows relationships between wavelengths and ratios of the travelled light levels over the original light levels at several travelled distances [8]. Specifically, the vertical axis indicates the relative values obtained by dividing the spectral levels of the travelled light beams by the spectral levels of the light beams immediately after emitted from the respective light sources (as shown in Fig. 4). Reductions in the shorter wavelength regions can be clearly recognized in both cases.

In spite of a certain similar tendency, certain differences also exist. Due to the original differences in the wavelength components contained in the light beams emitted from the respective torches, a larger amount of longer-wavelength components is likely to remain when the conventional electric torch was used, as compared to the case where the white-color LED torch was used. Such tendencies can provide reasonable explanations for differences in the observed sunset colors with the respective torches. On the other hand, it should also be noted that the light beams from the conventional electric torch contain less amount of shorter-wavelength components (such as in a blue-color region). This leads to the fact that a blue-sky-like color becomes less visible in demonstrations. In contrast, the light beams from the white-color LED torch (composed of a blue-color LED element and yellow-color fluorescent material, as used in this study) are likely to contain a larger amount of shorter and mid-wavelength components in the spectral data at the shorter travelled distances, which significantly disappear later with increases in the travelled distances. As a result, when white-color LED torches are used as light sources in sunset color demonstrations, changes in colors in shorter- to mid-wavelength regions can be observed more significantly. However, the light beams from the white-color LED torch composed of a blue-color LED element and yellow-color fluorescent material, as used in this study, contain less amount of longer-wavelength components (such as in a red-color region). Thus, reproduction of red sunset color becomes less visible in demonstrations.



(a) With the conventional electric torch as the light source



(b) With the white-color LED torch as the light source

Fig. 7 Relative ratios of travelled light levels with respect to original levels of light beams immediately after emitted from the respective light sources (torches)

V. Actual Use of White-Color LED Torches in Sunset Color Demonstrations in Elementary Schools

When white-color LED torches were actually used as light sources in sunset color demonstrations performed at elementary schools, children were able to realize that the white-color light beams emitted from the LED torches were viewed as “sunset-like color” after travelled in the suspension liquid in the water tank. At the same time, several children reported that scattered light beams at a position apart from the LED torch by about 10 cm looked in green to yellow-green colors. This kind of reactions were not obtained when the conventional electric torches were used as light sources. Differences in spectra data as described in the above can be reasonable explanations.

VI. Conclusions

In order to confirm availability of white-color LED torches as light sources for sunset color demonstrations, spectra of travelled light beams and scattered light beams in sunset color demonstrations with each of a white-color LED torch (composed of a blue-color LED element and yellow-color fluorescent material) and a conventional electric torch as a light source were measured and compared to each other. The light beams from the white-color LED torch contain a larger amount of shorter- to mid-wavelength components and a less amount of longer-wavelength components, as compared to those from the conventional electric torch. As a result, more significant changes in colors of scattered light beams can be recognized. However, reproduction of red sunset color is less visible. Thus, white-color LED torches can be used as light sources in sunset color demonstrations, although some attentions have to be paid to such differences.

When audiences of demonstrations have higher levels of knowledges and/or interests in the related phenomena, advanced observations and explanations can become possible. For example, both the white-color LED torches and the conventional electric torches can be simultaneously employed as the light sources in sunset color demonstrations so as to compare the results obtainable with them to each other. Such scenario will allow the audiences to think of the observation results in much advanced levels, for example, about differences in spectra of emitted light beams from these two types of torches, certain differences in scattering of light beams due to differences in their wavelengths, and actual understandings of principles of sunset color and blue sky.

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