Spectroscopic Measurement of Burning Toy Fireworks

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Abstract: *The spectroscopic measurement of sparklers, torches and senko hanabi (Japanese sparklers) was carried out. The three dimensional spectra of sparklers and torches showed that the peak intensities of the spectra fluctuate with time. In the burning of sparklers, white, titanium, senko and iron sparklers showed mainly the K peak suggesting that the incandescent emission is principally in the visible light area. The white and titanium sparklers showed high K peak intensities compared to other sparklers suggesting the high temperature burning of Al and Ti. Among the tested sparklers the excitation purities of titanium and blue sparklers were relatively low. Regarding torches, the flame, sparks and falls were compared. The K peak intensity of falls was largest compared to other kinds of torches, presumably because the falls contain the energetic aluminum. The purity of the blue torch was exceptionally small. The spectra and photographs of burning sparklers and torches were compared. The fireball and the branching sparks of senko hanabi were recorded using the profiles of K peak intensity of the senko hanabi at two burning locations.*

Keywords: *toy fireworks, spectroscopic measurement, emission spectra, torch, sparkler, glitter, senko hanabi*

Introduction

Light emission, beautiful colors and glittering sparks are important effects in toy fireworks. Sparklers, torches and senko hanabi are typical toy fireworks in Japan.

In the present work, spectroscopic measurements were carried out in order to study the spectra and burning characteristics of sparklers, torches and a senko hanabi toy firework.

Experimental

Materials

The toy fireworks used in this work were supplied by Inoue Toy Fireworks Co. Ltd. The Color Change Five Mix 5P is a set of five torches, in which the flame colors each change twice. The Color Change Torch Pro 10 Colors has flame and spark colors that change ten times. The Eight Spark 8P are eight sparklers containing red, green, yellow and blue flames, senko, titanium, iron and aluminum glitters. The senko hanabi is a Japanese traditional toy firework and produces glitter. The toy fireworks used are shown in Figure 1.

Apparatus

The spectrometer PMA-11C7473-36 is a product of Hamamatu Photonics Co. Ltd. The spectrometer is composed of an optical fiber for light intake, photo detector, spectroscope, basic software and data analyzer. The analyzer automatically calculates and records the spectrum, the respective peak wavelength and intensity, the excitation

Figure 1. Toy fireworks used in this work.

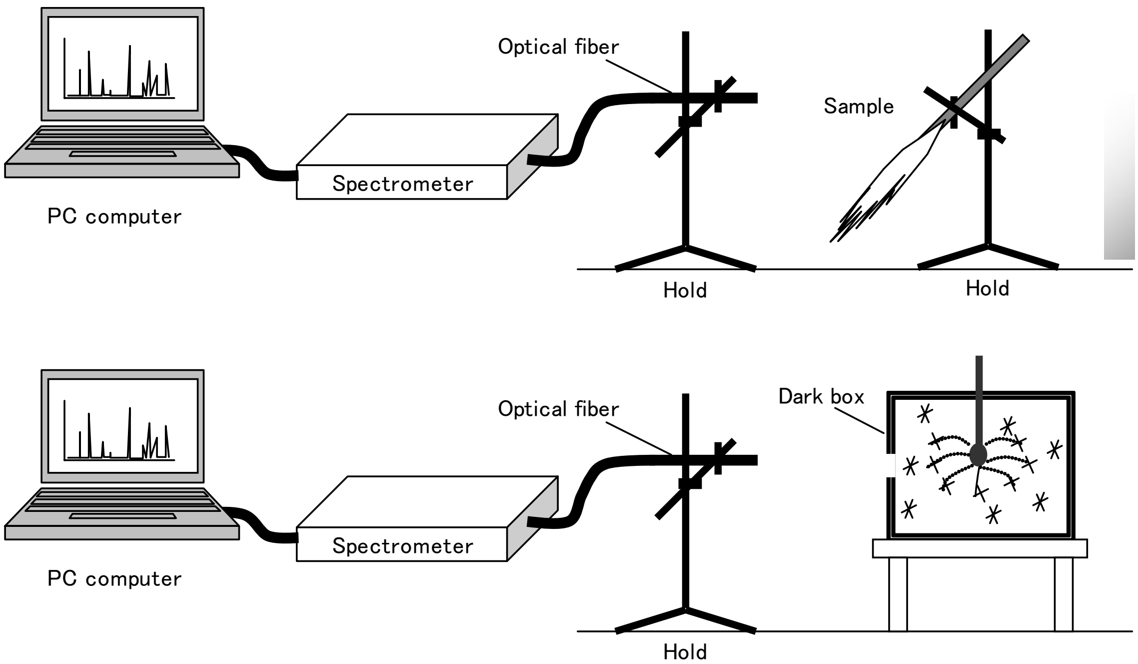


Figure 2. *Setup of the spectroscopic measurement of burning toy fireworks: sparkler and torch (upper) and senko hanabi (lower).*

purity, and so on.

The spectrometer is equipped with following functions: exposure time from 20 ms to 32 767 ms, averaging repetition from 1 to 32 767, exposure repetition from 1 to 32 767, and sensitivity low or high. The background noise can be compensated by adjusting the bias current to establish a zero baseline.

The analyzers can print out the emission spectrum at a specified time, the peak intensity profile at a specified wavelength and the three dimensional picture of the spectrum with time.

Procedure

The setup of the samples is shown in Figure 2. A torch or sparkler is supported by a clamp stand in a draft chamber and ignited by a torch burner. A senko hanabi is suspended vertically from the lid of a dark box, and ignited by a torch burner. The tip of the optical fiber of the spectrometer is placed at 4 m from the torches and sparklers and at 0.18 m from the senko hanabi.

The power sources of the spectrometer and the PC are switched on successively. The measurement conditions such as instrument sensitivity, exposure time, averaging repetition numbers, and observation repetition are set and the dark electric current is compensated. The spectrometer measurement is started at the point of ignition of the firework.

Results and Discussion

Fluctuation of the emission intensity of the sparklers and torches

The flames of firework sparklers and torches look rather uniform against time to the eye. However, the three dimensional spectra shown in Figure 3 indicate that the intensities of the spectral peaks fluctuate with time. The firework compositions are mixtures of solid particles and the combustion of the mixtures may be not uniform.

Spectra of burning sparklers

Figure 4 shows the spectra of burning sparklers. The following assignment of each peak was done according to Meyerriecks and Kosanke.[1] The yellow sparkler has three main peaks: the highest peak is assigned to K (766 nm), the second to Na (589 nm) and the third to CaCl (618 nm). The excitation purity was 72%. The green sparkler has five main peaks: the highest is assigned to K

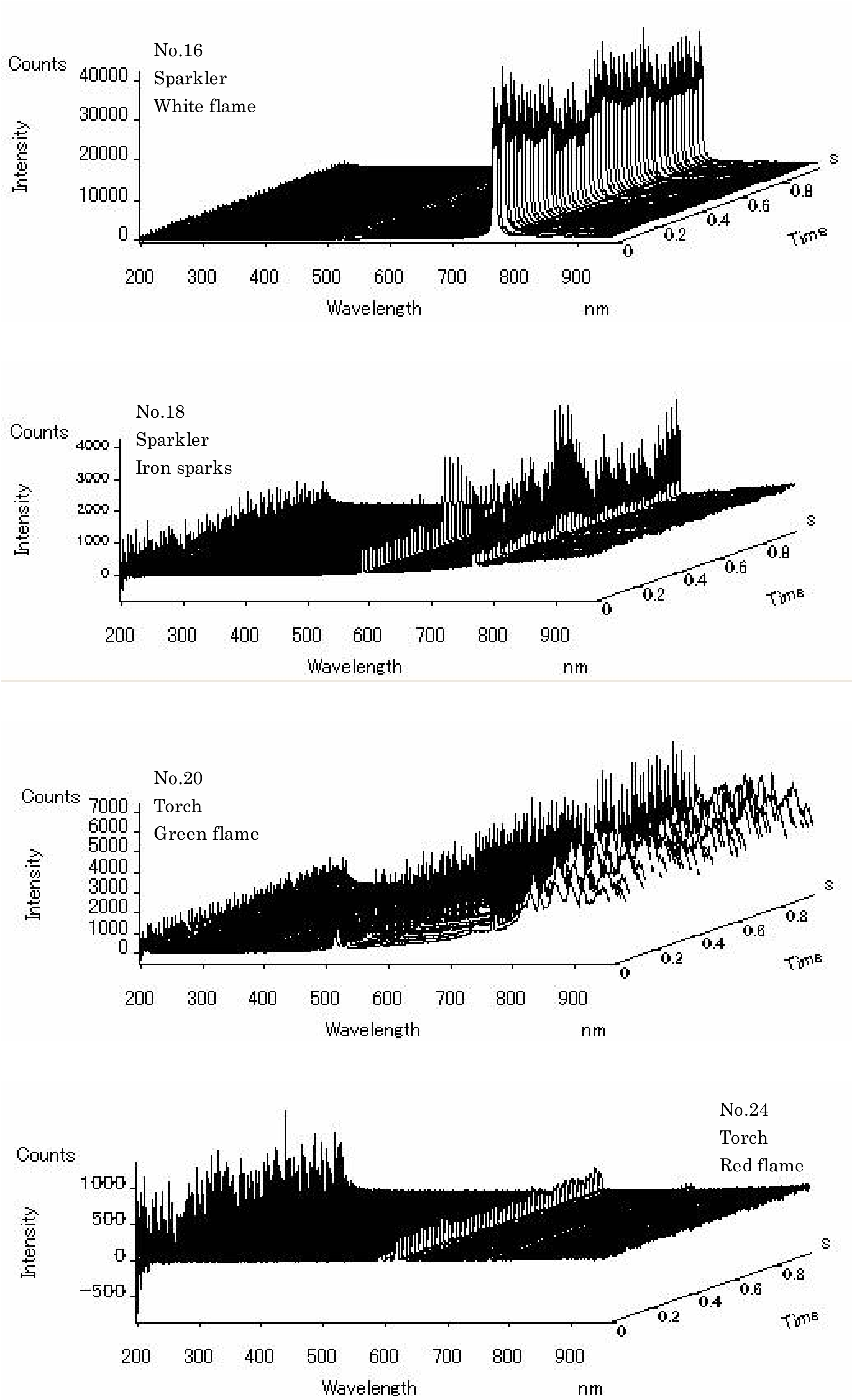


Figure 3. *Three dimensional spectra of burning sparklers and torches.*

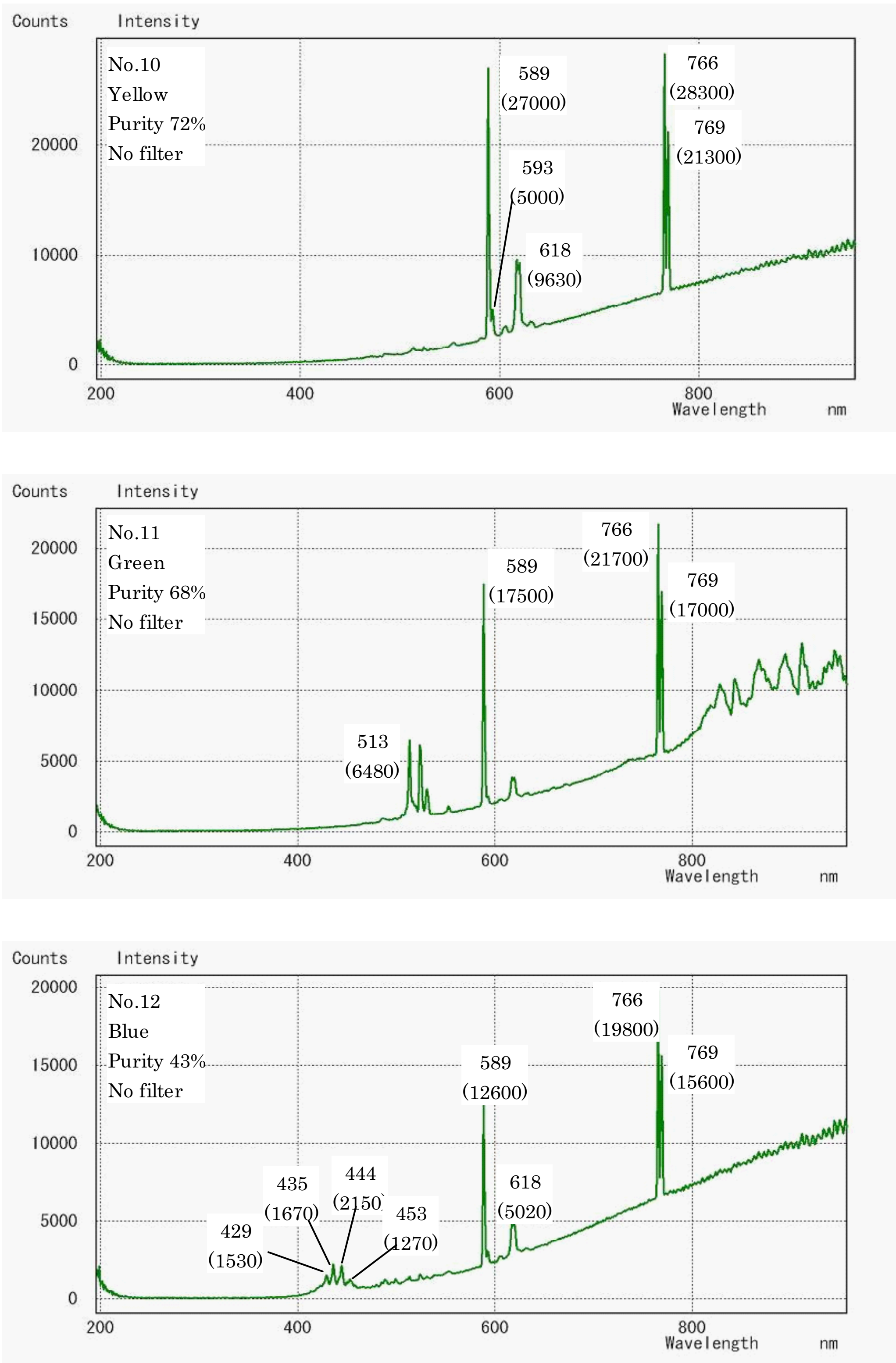


Figure 4. *Spectra of burning firework sparklers.*

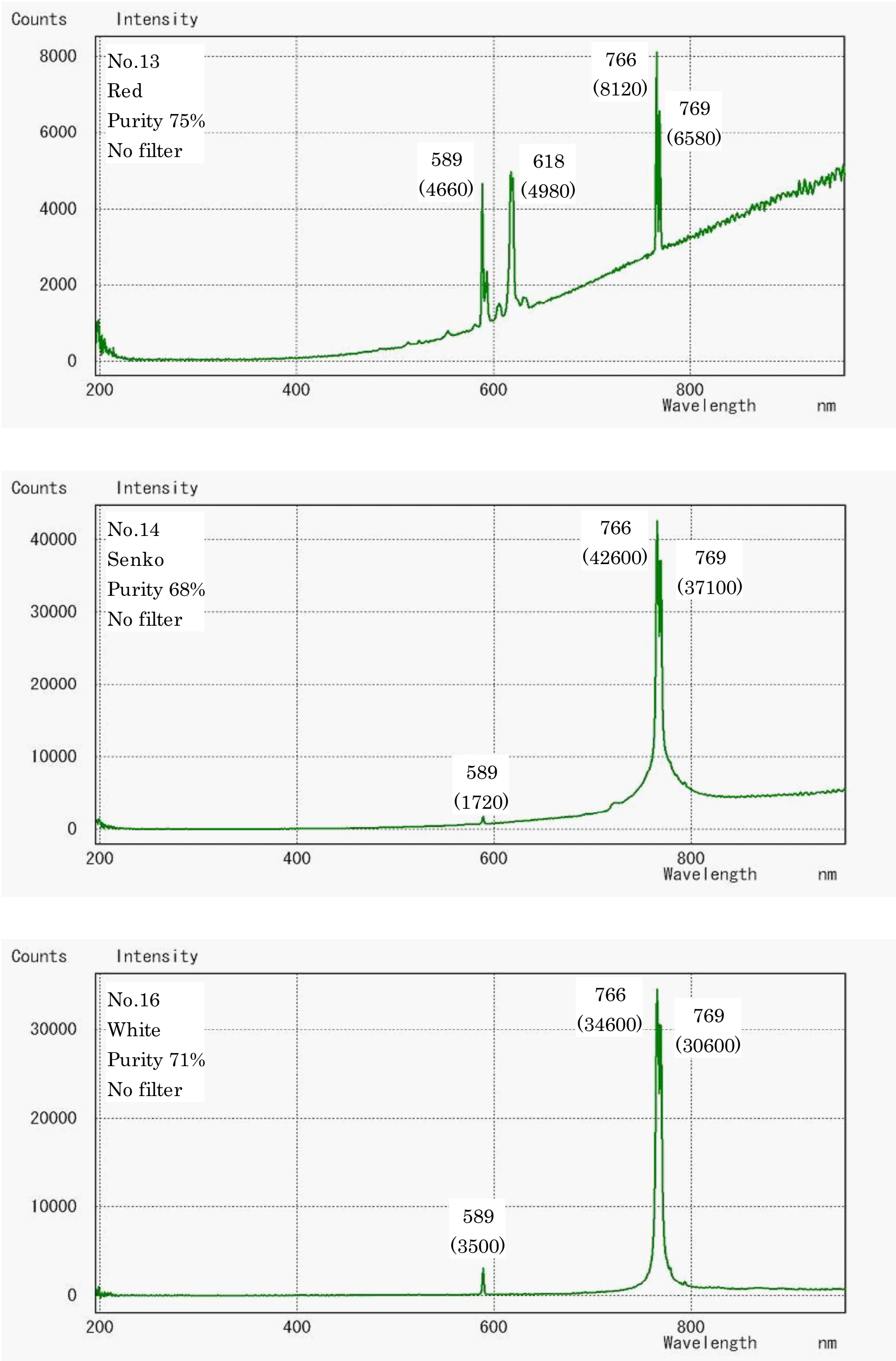
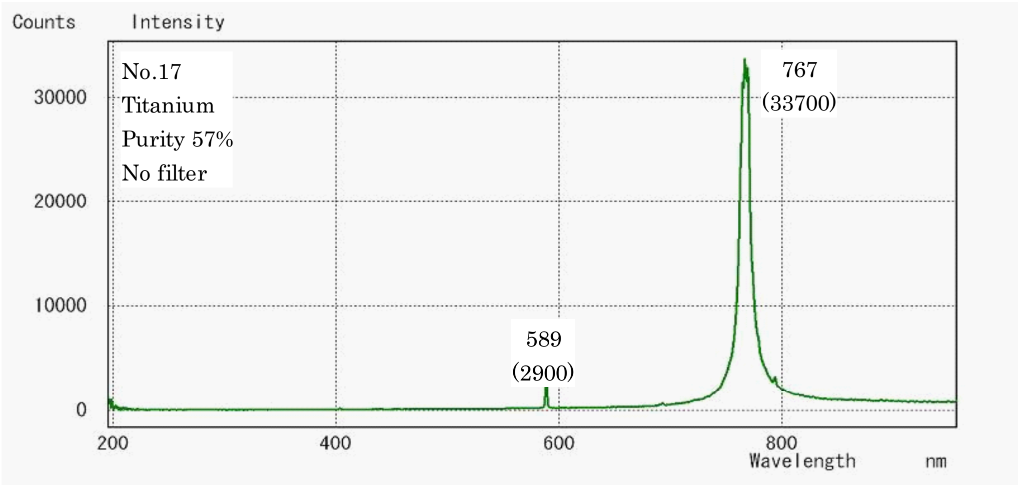


Figure 4 (contd). *Spectra of burning firework sparklers.*



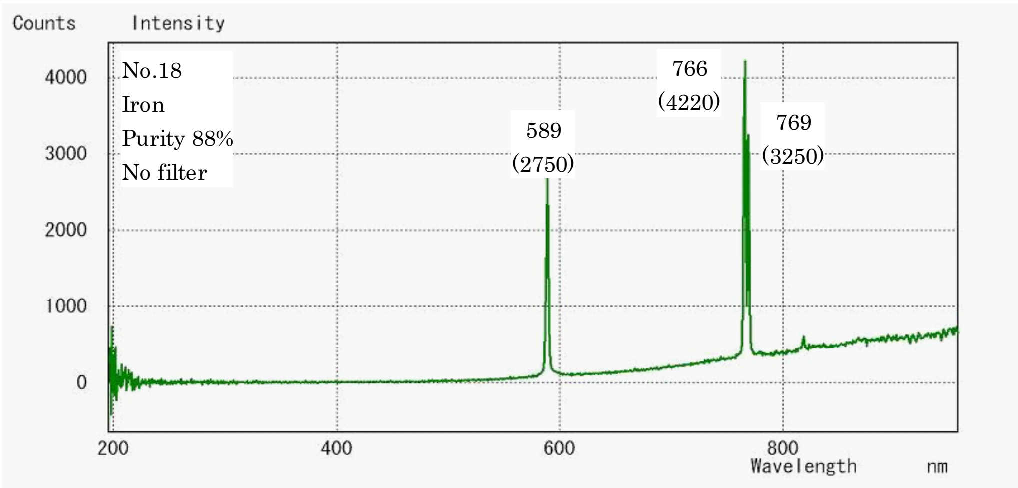


Figure 4 (contd). *Spectra of burning firework sparklers.*

(766 nm), the second to Na (589 nm), the third to an unidentified band spectrum (800–900 nm), the fourth to BaCl (513 nm) and the fifth to CaCl (618 nm). The blue sparkler has four main peaks assigned to K (766 nm), Na (589 nm), CaCl (618 nm) and CuCl (444 nm). The red sparkler has three main peak groups assigned to K (766 nm), CaCl (618 nm) and Na (589 nm). The senko, white and titanium sparklers have only one main peak assigned to K (766 nm) and the iron sparkler has two main peaks assigned to K (766 nm) and Na (589 nm). All spectra may contain incandescent emissions in the rising base lines.

The highest K peaks in the infrared emitters and the species in visible color emitters, and the exciting purities of sparklers are listed in Table 1.

Spectra of burning torches

The spectra of the burning torches are shown in Figure 5. The spectra of the green flame (No. 20), sparks (No. 38) and falls (No. 37) were recorded. All green spectra are composed of K, Na, BaCl and unidentified peaks which may be assigned to a Ba compound. The peak intensities and the excitation purities of three green torches, and the ratios of peak intensities in the three torches were different. Regarding the intensities of the BaCl green peak the order corrected to no filter was as follows: falls (120 000 counts) > sparks (5900 counts) > flame (3600 counts). The ratio of peak intensities of BaCl and Na was as follows: falls (2.19) > sparks (1.11) > flame (0.81). The excitation purity was: sparks (68%) > flame (64%) > falls (56%).

Table 1. *Important peaks in the spectra of burning sparklers.*

Sparklers	Species	Intensity (counts)	Excitation purity (%)
Yellow	K	2.83×10^4	72
	Na	2.70×10^4	
Green	K	2.17×10^4	68
	BaCl	6.47×10^3	
Blue	K	1.98×10^4	43
	CuCl	2.15×10^3	
Red	K	8.12×10^3	75
	CaCl	4.98×10^3	
Senko	K	4.26×10^4	68
	Na	1.72×10^3	
White	K	3.46×10^4	71
	Na	3.50×10^3	
Titanium	K	3.37×10^4	57
	Na	2.90×10^3	
Iron	K	4.22×10^3	88
	Na	2.75×10^3	

The reason for the differences are not clear at the moment, but the highest intensity of the green falls may be ascribed to the high content of aluminum in the fall composition and the highest combustion temperature.

The spectra of the red flame (No. 24) and sparks (No. 29) were composed of peaks of CaCl (618 nm), K (766 nm) and a little Na (589 nm). The peak intensity (750 counts) of CaCl in the sparks was larger than that (420 counts) in the flame, and the ratio (3.20) of the peak intensities of CaCl to K was higher in the flame than that (0.92) in the sparks presumably because the amount of potassium perchlorate was smaller in the red flame (No. 24) than in the red sparks (No. 29). The excitation purity (87%) of the flame was higher than that (75%) of the sparks.

No. 36 and No. 39 are the spectra of red sparks and fall torches using SrCl (672 nm) as a red emitter. The peak intensity (4200 counts) of SrCl in the falls was larger than that (860 counts) in the sparks. The excitation purities of the sparks and falls were 58% and 60%, respectively, and lower than those using CaCl as red color emitter.

No. 34 and No. 26 are the spectra of the yellow sparks and fall torches. The main peaks were Na (589 nm) and K (766 nm). The intensity (14 000 counts) of the Na peak in the falls was much larger than that (1400 counts) in the sparks. The ratio (3.68) of the Na to K peaks in the sparks was much higher than that (0.34) in the falls. On the other hand, the excitation purity (86%) of the falls was greater that (68%) in the sparks. This is the opposite of the case of the green torch.

No. 35 is the spectrum of the blue torch falls composed of CuCl (444 nm), BaCl (513 nm), Na (766 nm), K (766 nm) and an unidentified infrared emitter. An extremely low excitation purity was observed.

No. 23 and No. 30 are the purple flame and fall torches. The spectra of both fireworks were composed of those of CuCl, BaCl, Na, CaCl and K. The peak intensity (1200 counts) of CaCl in the falls was higher than that (290 counts) in the flame. The ratio (0.74) of CuCl to CaCl peak intensities in the flame was greater than that (0.18) in the falls. The excitation purities were 38% and 23% in the flame and falls, respectively.

A summary of the results is listed in Table 2. Generally, the peak intensities of falls, sparks and flame were in following order:

falls > sparks > flame

The reason for the order may be the higher Al or Ti content in the falls than in the sparks, and the absence of such metals in the flames.

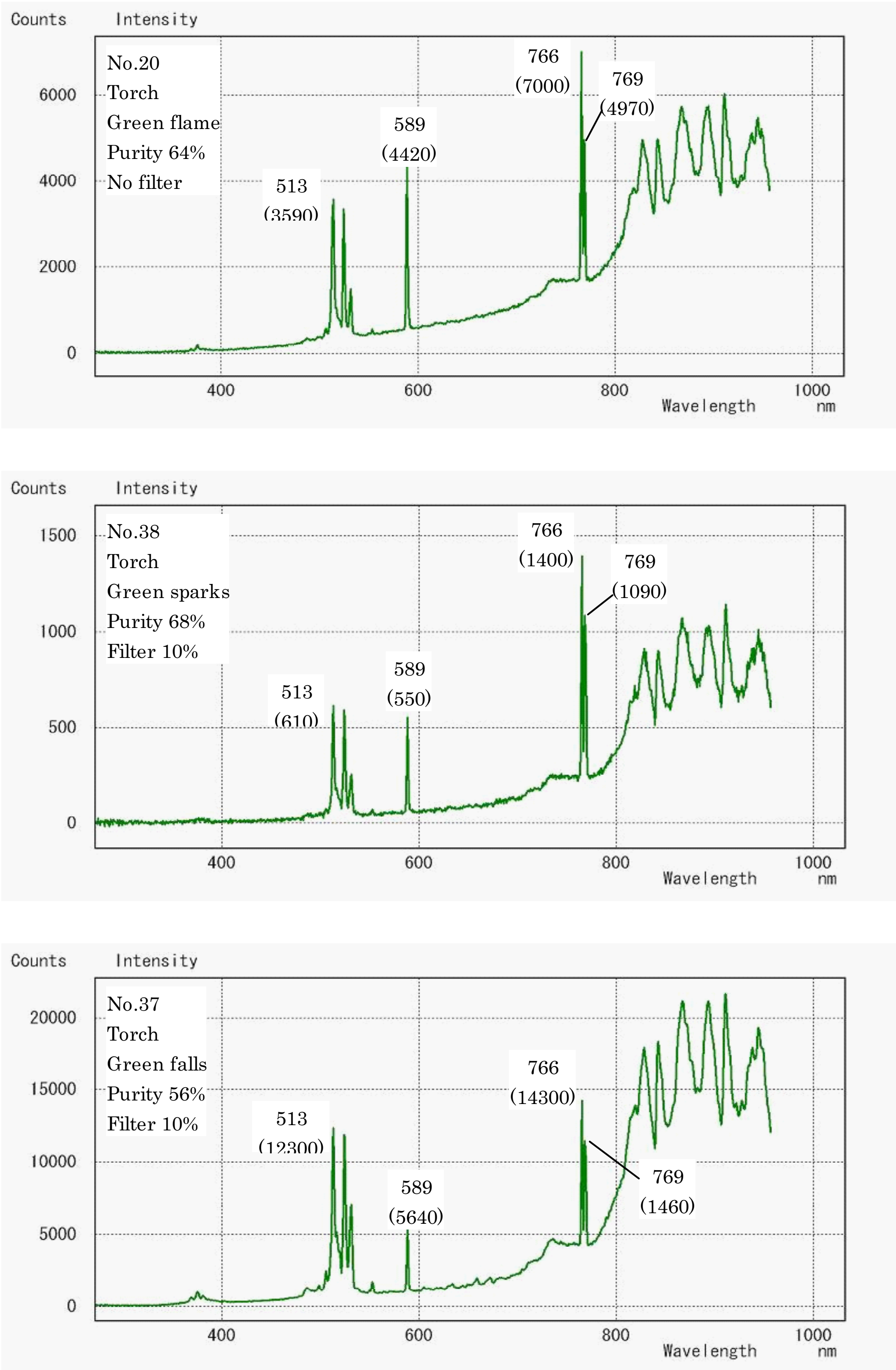


Figure 5. *Spectra of burning torches.*

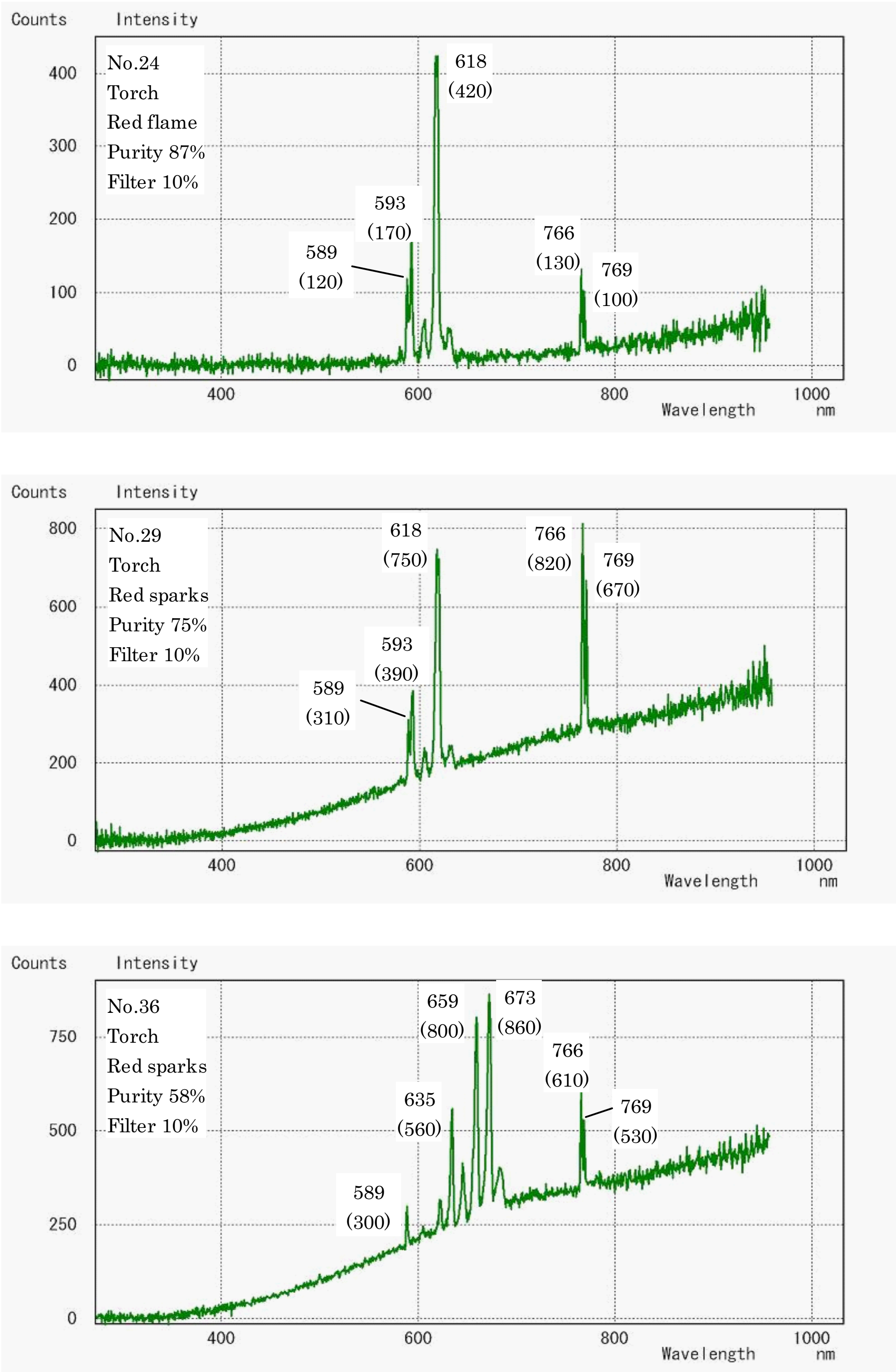


Figure 5 (contd). *Spectra of burning torches.*

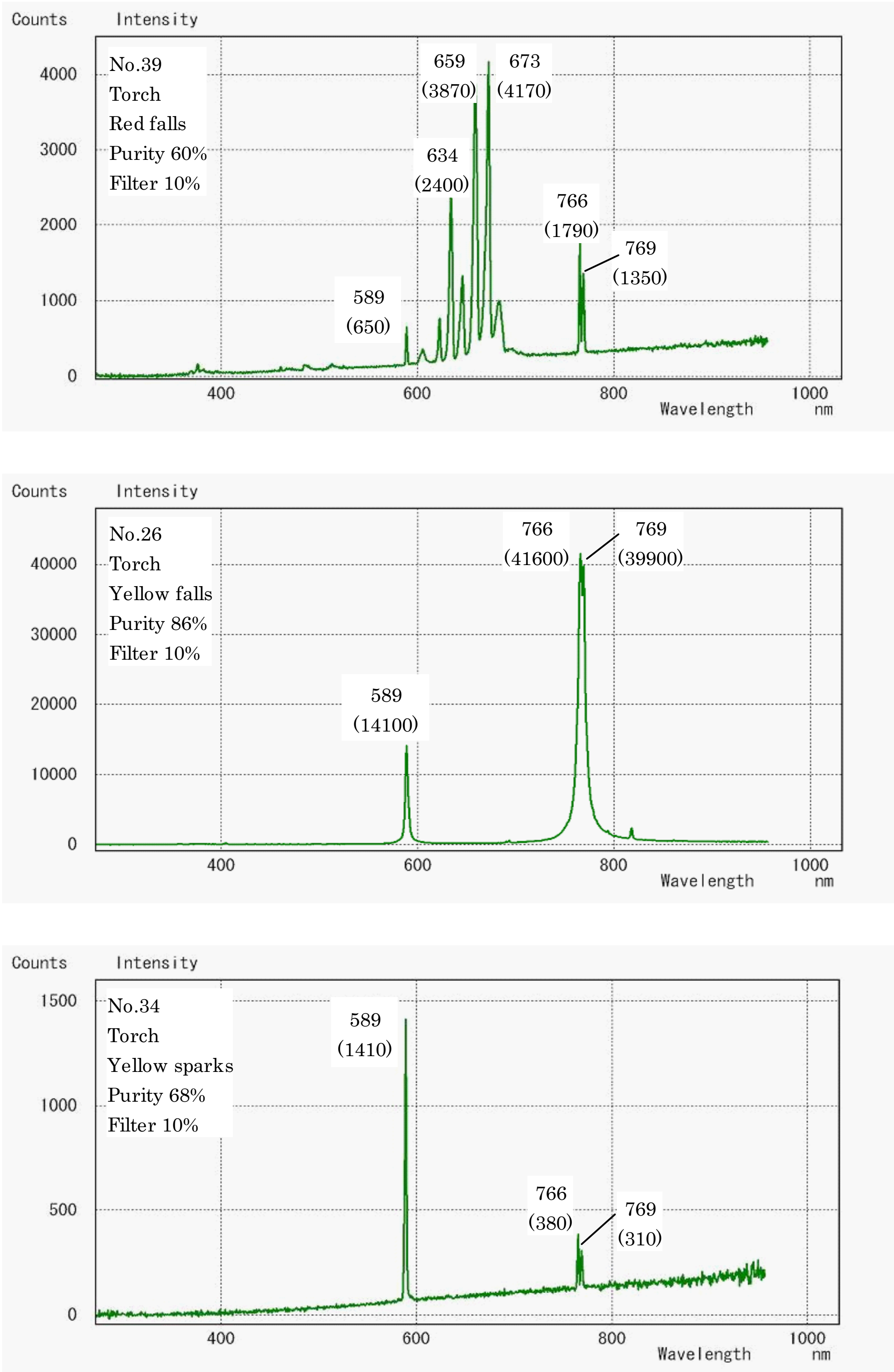
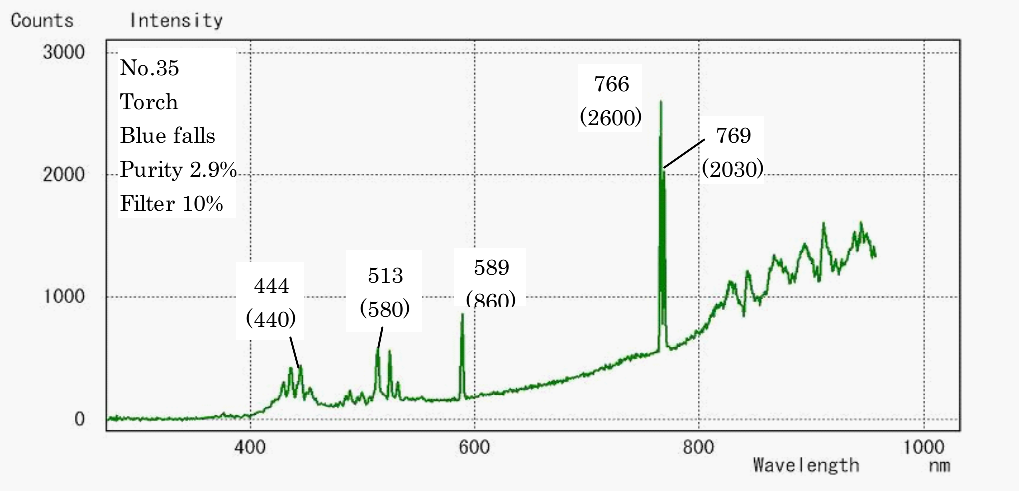
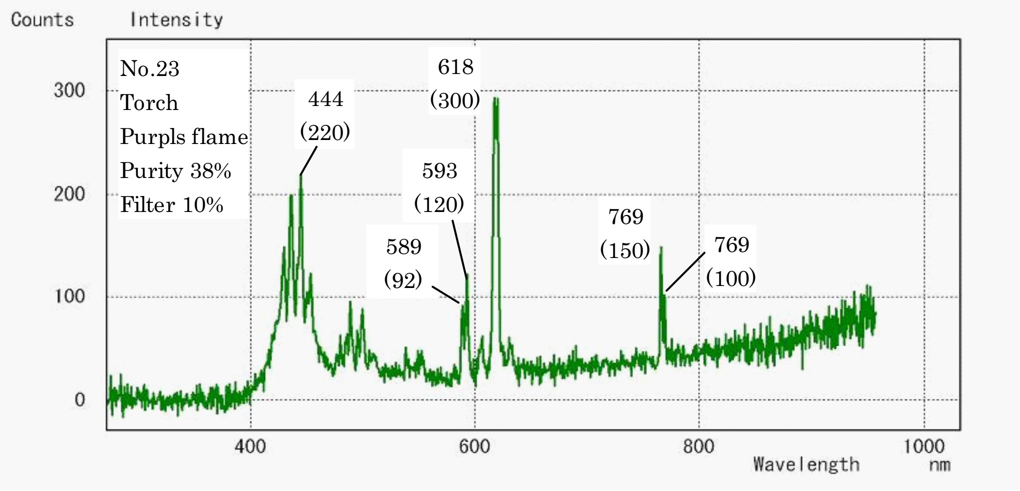


Figure 5 (contd). *Spectra of burning torches.*





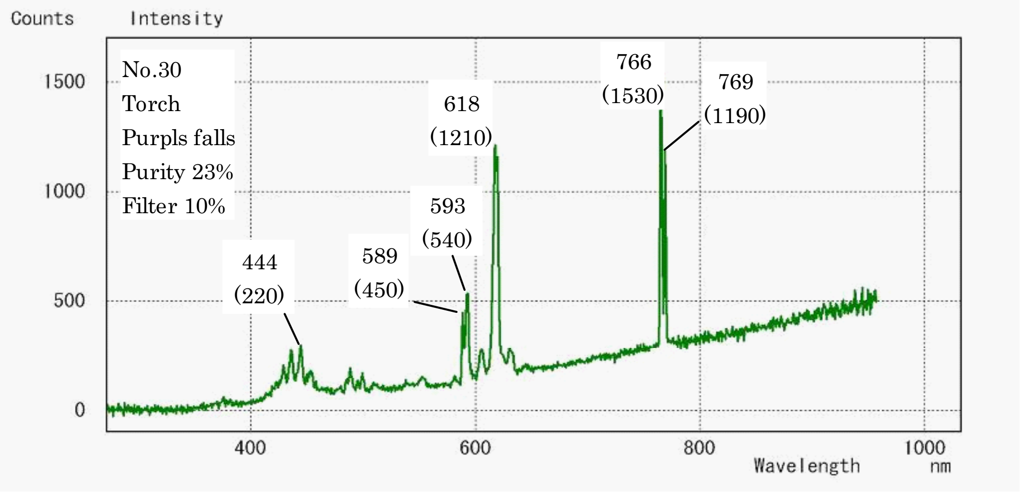


Figure 5 (contd). *Spectra of burning torches.*

Table 2. *Summary of the spectroscopic measurement of the burning sparklers and torches.*

No.	Color	Kind	Emitter (counts)				Purity (%)
13	Red	Sparkler	Na (4700),	CaCl (5000),	K (8100)		75
24	Red	Torch flame	Na (1700),	CaCl (4200),	K (1300)		87
29	Red	Torch sparks	Na (3100),	CaCl (7500),	K (8200)		75
36	Red	Torch sparks	Na (3000),	SrCl (8600),	K (6100)		58
39	Red	Torch falls	Na(6500),	SrCl (42000),	K (18000)		60
10	Yellow	Sparkler	Na (27000),	CaCl (9600),	K (28000)		72
34	Yellow	Torch sparks	Na (14000),		K (3800)		68
26	Yellow	Torch falls	Na (140000),		K (420000)		86
11	Green	Sparkler	BaCl (6500),	Na (17000),	K (22000)		68
20	Green	Torch sparks	BaCl (44000),	Na (44000),	K (70000)		64
38	Green	Torch sparks	BaCl (5900),	Na (5520),	K (14000)		68
37	Green	Torch falls	BaCl (120000),	Na(5600),	K(140000)		56
12	Blue	Sparkler	CuCl (2200),	Na (13000),	K (20000)		43
35	Blue	Torch falls	CuCl (4400),	BaCl (5800),	Na (8600),	K (2600)	2.9
23	Purple	Torch flame	CuCl (2200),	Na (920),	CaCl (2900),	K (1500)	38
30	Purple	Torch falls	CuCl (2200),	Na (4500),	CaCl (12000),	K (15000)	23

The senko hanabi gives the so called “fire-branching sparks”. The phenomenon of senko hanabi was described by Shimizu as follows:[2] When it is ignited, it burns violently with a flame at first, then the remaining ash keeping its red-hot state, contracts itself to a small red-hot ball, which is the so-called “fireball”. After a few seconds, the temperature of the fireball gradually rises and fine particles begin to fly out of the ball. The particles become more brilliant at a short distance from the ball and explosively branch into fine needle-like sparks.

Figure 6 shows a spectrum of the center of a burning senko hanabi. The spectrum has a single K peak in the infrared region. The visible light of senko hanabi comes from the incandescent emission of the condensed phase products. Figure 7 shows the change of the K peak intensity with time in the same experiment. When the senko hanabi was ignited, a strong peak intensity

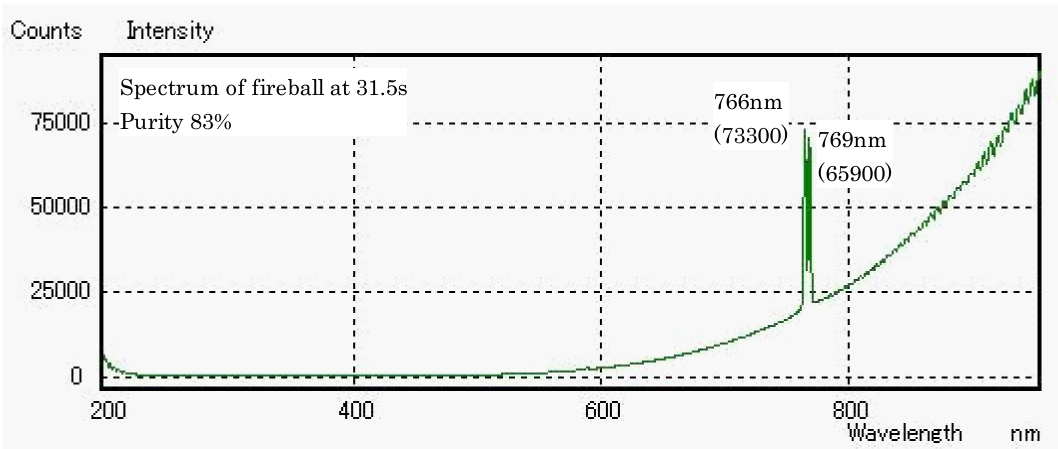


Figure 6. *Spectrum at the center of burning senko hanabi.*

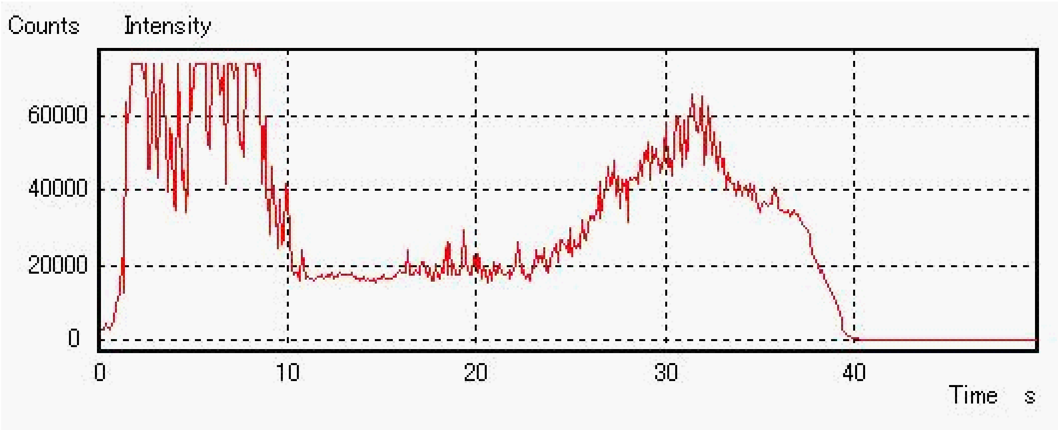


Figure 7. *766 nm peak intensity profile at the center of burning senko hanabi.*

continued corresponding to the initial violent burning of the senko hanabi. Then the intensity of the peak decreased to a lower level, and after few seconds, the intensity increased corresponding to the formation of a growing fireball. The emission from the fireball increased and peaks appeared intermittently, corresponding to the fire-branching sparks.

Figure 8 shows a spectrum of the center of the fireball with fire-branching sparks at 30.7 s. Figure 9 shows the K peak intensity change with time during the burning of a senko hanabi. In this case, the direction of the optical fiber of the spectrometer was aimed at the area around the fireball, in order to catch only the branching sparks avoiding the fireball. At first, the peak from the initial flame appeared, then after few seconds intermittent fine peaks appeared without the broad peaks of the fireball. The fine peaks might come from the emission of the sparks only. The intensity of the emission of the senko hanabi was lower than that of other toy fireworks such as sparklers and torches. Therefore the senko hanabi is enjoyed from a short distance by children.

The spectra of the fireball and sparks of a senko hanabi are very similar as shown in Figure 6 and Figure 8. In the spectra of the fireball and sparks of a senko hanabi only two K peaks appear, and the excitation purities were 83% and 85%, respectively.

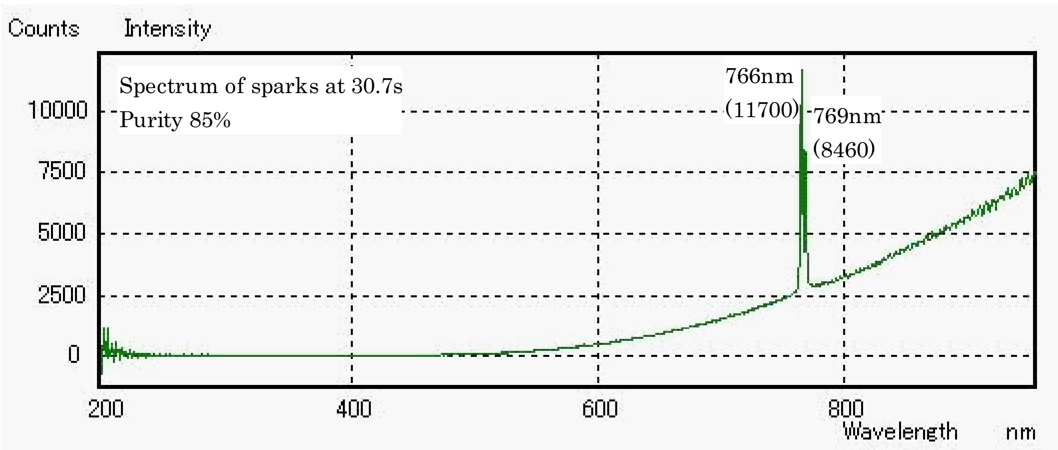


Figure 8. *Spectrum of the sparks in the neighborhood of a senko hanabi fireball.*

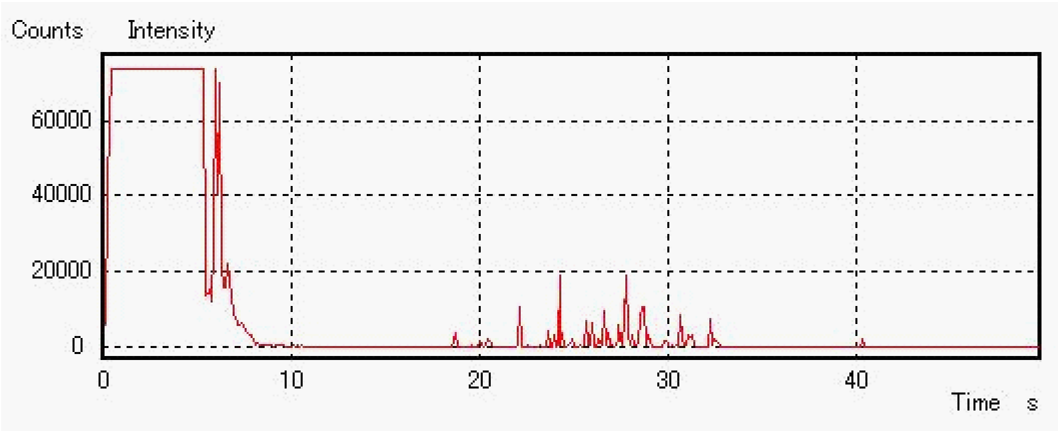


Figure 9. *766 nm peak intensity profile at neighborhood of fireball of senko hanabi.*

The orange color of the fireball and sparks of the senko hanabi comes from the incandescent emission of the condensed phase of the fireball and the sparks. The rising base lines of the spectra from 600 nm may be attributable to the incandescent emissions.

Conclusions

Spectroscopic measurement of the burning toy fireworks including sparklers, torches and senko hanabi gave the following information. The emission intensity of burning sparklers and torches fluctuated owing to the non-homogeneous mixture of the firework compositions. In burning sparklers, color sparklers have characteristic visible spectral peaks, and spark sparklers have large K peaks and a small Na peak. The intense white-yellow light of spark sparklers comes from incandescent emissions of condensed phase sparks. The excitation purities of the sparklers were from 43% (blue) to 88% (iron). In burning torches, the emission intensities were in the following order:

falls > sparks > flame

The excitation purities of torches were from 2.9% (blue falls) to 87% (red flame). In burning senko hanabi, there are three burning steps: that is, the initial burning of senko hanabi composition, the fireball burning, and the developed fireball and branched sparks burning. The spectra of the fireball and the sparks were very similar suggesting that both emissions are incandescence from the condensed phase intermediate of the senko hanabi reaction.

References

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