SPECTRA OF THE MONTH

ANALYSIS OF SPARKLER EMISSION PEAKS THROUGH SPECTROSCOPY

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INTRO

BACKGROUND OF APPLICATION

Fireworks have long been tied to both spiritual and secular celebrations. Their origins are often attributed to China around 200 B.C.E., though "modern" fireworks utilizing gunpowder (a mixture of potassium nitrate, sulfur, and charcoal) came later sometime between 600-900 C.E. They did not appear in Europe until around the 13th century, though by the 15th century they were heavily featured in religious festivals and other important occasions. The fascination with fireworks traveled with European settlers to the New World. Fireworks were a significant part of the first Independence Day celebration, a role that has only increased since then.

Fireworks today come in a wide variety of intensity, duration, volume, and color. While the first two can be controlled by the amount of gunpowder contained in fireworks, the second two are altered through the inclusion of additional elements or molecules. Flashes and bangs can be added though inclusion of aluminum powder, while sparks can be added with iron fillings. The color of a firework is also dependent on elemental inclusions. For example, adding copper produces a blue shade of firework, strontium a deep red hue, and barium a very bright green. Elements can also be mixed to give mixed colors, with strontium and sodium, which would produce red and yellow independently, giving an orange color to fireworks. Some colors can be achieved with multiple elements. For example, white fireworks can be created with the addition of titanium, zirconium, or magnesium.

In all cases, the included elements can be identified by the light they produce, and not just based on the general color. Similar to the previously studied laser-induced breakdown spectroscopy (LIBS) technique, lit fireworks will produce specific wavelength peaks that can be attributed to specific elements, which can be used to identify elemental composition. This experiment aims to measure different colored sparkler samples and detect the specific elements that give each sample their respective color. Three different colored sparkler samples (red, green, and blue) were used, as the elements that correspond to these colors (strontium, barium, and copper, respectively) have distinct peaks from one another.

DESCRIPTION OF SPECTROSCOPY SETUP

The setup for this experiment (Figure 1) was based around the AvaSpec-ULS4096CL-EVO. Utilizing the same electronics and design as our AvaSpec-ULS2048CL-EVO, this unit doubles the detector pixel number with a 4k CMOS detector. This allows for a significant increase in resolution, with this specific unit (200-1100 nm wavelength range, 10 µm slit) offering a resolution of 0.5 nm compared to a resolution of 1.0 nm for a comparable ULS2048CL configuration. As with the ULS2048CL, this device offers USB3.0 communication, which has ten times the speed of USB2, a fast AS-7010 microprocessor, and 50 times more memory capacity, meaning more spectra can be stored onboard and more overall functionality can be realized. Furthermore, this spectrometer can be customized with a wide range of slit sizes, gratings, and fiber optic entrance connectors for a variety of application needs.

FIGURE #1 Spectroscopy Setup for sparkler measurement

The light source used for this experiment was the light generated from the sparkler samples. As stated previously, each sparkler sample had a distinct color, which was produced through a specific elemental composition, with the red sample containing strontium, the green sample containing barium, and the blue sample containing copper. All samples will have large concentrations of potassium nitrate, sulfur, and charcoal. Other accessories used for this experiment included a 2-meter long 600-micron core fiber optic cable to ensure a safe distance between the spectrometer and the sparkler, a 25 mm diameter collimating lens to capture the most amount of light from the sparkler sample, and individual stands to mount the sparkler samples and collimating lens respectively.

DESCRIPTION OF METHODOLOGY

Each sample was placed a safe distance from the spectrometer and collimating lens to ensure neither was damaged from the sparkler samples. The samples were continuously measured after they were ignited, leading to approximately 500 measurements per sample.

For data collection, we used the Scope-Minus-Dark mode in AvaSoft. Because the samples were measured outside for safety, substantial ambient light was present in the form of sunlight. In Scope-Minus-Dark mode, the dark spectrum (the ambient light the spectrometer measures with no light source) is subtracted from the raw counts (i.e., scope mode) for each wavelength. This is essential to isolate and identify the peaks of the sparkler samples. We used an integration time of 5 milliseconds, which can be adjusted to increase or decrease the amount of light being measured at one time and affects the overall magnitude of the reported spectrum. We set averaging to 1 so that each measurement of the sparkler peaks was independent and the best data set for demonstrating unique peaks could be selected.

Because such a large number of measurements were taken, the data was saved via the Live Output function to both Microsoft Excel and ASCII file types, the first of which was used for analysis. This Excel data was processed through the open-source software Octave. Each sample data set was examined, and the most ideal measurements for each sample were selected and plotted via Octave. Additional code was utilized to display the spectra in a manner similar to what would be shown in our AvaSoft software.

IMAGE OF MEASUREMENT TECHNIQUE IN ACTION

TEST DATA AND RESULTS

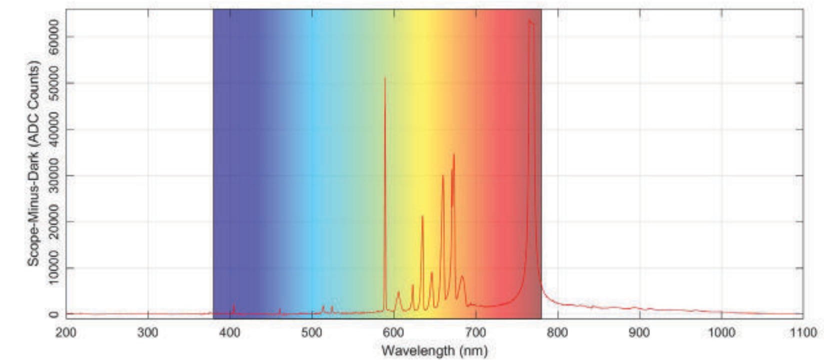

FIGURE #2: Spectra of red sparkler sample.

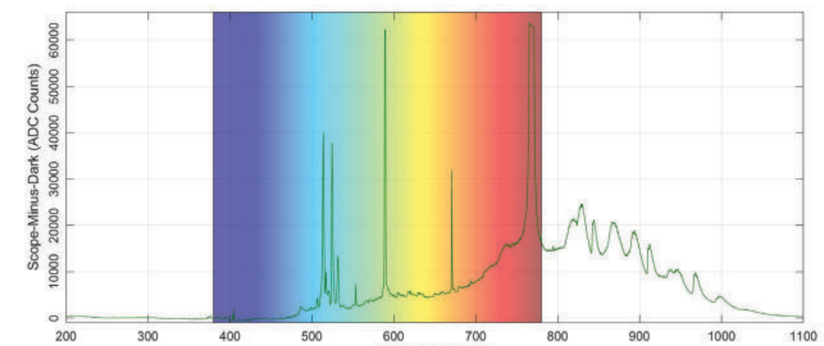

FIGURE #3: Spectra of green sparkler sample.

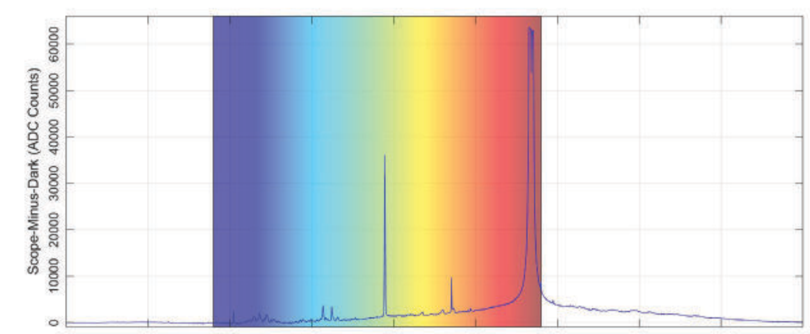

FIGURE #4: Spectra of blue sparkler sample.

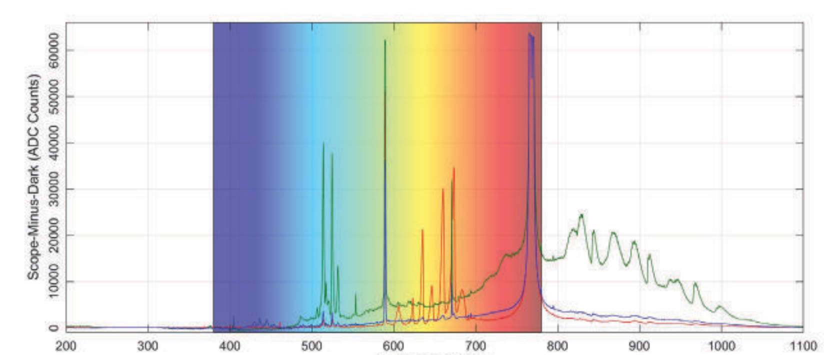

FIGURE #5: Spectra of red sparkler (red), green sparkler (green), and blue sparkler (blue) samples, shown together for comparison.

ANALYSIS

All three samples showed significant peaks around 590 nm, 660 nm, and 770 nm (Figures 2-5). The peak at 590 nm can be attributed to sodium. While each sparkler sample had specified distinct colors, they all shared a yellow hue that increased their overall brilliance. The 660 nm and 770 nm peaks can be linked to hydrogen and oxygen, respectively, both of which are present in charcoal. The 770 nm peak can also be traced to the potassium in potassium nitrate. The red sparkler sample showed many additional peaks, including a peak around 405 nm, 460 nm, 610 nm, and 670 nm (Figure 2). The first two peaks are indicative of strontium, a common element added to fireworks for red coloring. The 610 nm and 670 nm peaks could be indicative of lithium, another element used for red coloring. Other peaks between 600 nm and 700 nm were present but did not correspond to any elements specifically used to add color to fireworks. The green sparkler sample showed many peaks from about 500 nm to 550 nm, as well as 800 nm to 1000 nm (Figure 3). The peak at 553 nm is highly indicative of barium, the most used element to add green color to fireworks. The peaks around 865 nm and 965 nm may also be identified as barium peaks, but this is less conclusive due to the noise present in this area. The blue sparkler sample showed additional peaks around 405 nm, 435 nm, 445 nm, 515 nm, and 525 nm (Figure 4). The 405 nm peak may correspond to iron, which can be added to fireworks for added sparks. The 435 and 445 nm peaks could be indicative of calcium, which can be used to deepen the color of fireworks. The 515 and 525 nm peaks are close to minor peaks of copper, which is the main element for adding blue color to fireworks. Surprisingly, these two peaks were also seen in the green sparkler sample at significantly higher counts than the blue sparkler sample.

While this magnitude difference cannot be directly compared without more complex analysis, it makes sense that the green sparkler sample could combine elements that produce blue and yellow to create a green color. Indeed, the corresponding copper and sodium peaks were measured to be the highest in the green sparkler sample, which could give a green color when combined. A graph of all the spectra together is included for comparison of all samples (Figure 5).

CONCLUSION

In conclusion, the present experiment highlights the use of spectroscopy in correlating elemental composition to specific colors of firework samples, with peak wavelengths indicating the presence of specific elements. Further analysis could fully characterize the composition of each sample, such as the concentrations of individual elements and molecules but this would require the use of a chemometric calibration of the system and is beyond the scope of this experiment. The AvaSpec-ULS4096CL is an ideal candidate instrument for high-resolution applications with the capability of achieving resolution as low as 0.05 nm (FWHM) in the ultra violet. Typical broadband configurations of the instrument cover the range from 200-1100 nm or 200-800 nm and can achieve resolution of 0.4-0.5 nm (FWHM). While AvaSoft is an excellent tool for data collection and analysis, the Live Output save function allows for data analysis through other means and third-party software such as Octave. Please contact an Avantes Application Engineer for more information on the configuration that is best suited for your data collection.

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