Spectral Plus Demonstration Set

User Guide

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1 Introduction

Using Demonstration Set

Spectral Plus Demonstration Set is designed for easy visualization of the basic light and color behavior. Physical phenomena that can be demonstrated using the set are:

- Additive color mixing
- Subtractive color mixing
- Light diffusion
- Light absorption
- Light dispersion
- Different ways of white light creation
- Bright-line spectrum
- Continuous spectrum

1.1 Contents of the Demonstration Set

The Set consists of:

- RGB display (square of 36 LEDs containing 12 red, 12 green, 12 blue LEDs)
- Neon tube
- white LED diode with phosphor wavelength converter
- incandescent bulb
- cold cathode fluorescent lamp
- selector of manual and automatic mode for color mixing
- power supply 12V

Accessories:

- Set of color and diffusion filters (red, green, blue, diffusion, 2 white diffusion filters, CMYK filter)
- Spectroscope (5 pieces)

Figure 1 – Spectral Plus Demonstration Set

1.2 Technical Specification

Technical Specification parameters are listed in Table 1:

Dimensions: (L x W x H)	250mm x 250mm x 80mm
Weight	1300 g
Input voltage	12 V DC
Input current consumption	700 mA
LED wavelengths	Green: 525 nm, Red: 630 nm, Blue: 470 nm
Filters	1 - red 2 – green 3 – blue 4 – CMYK 5 – diffusion 6 – white diffusion 6 – white diffusion

Table 1 – Technical Specification

Demonstration experiments

Light Transmission and Absorption

Absorption is a material tendency to capture individual colors (wavelengths) of incoming light by the material. **Transmission** is a material tendency to release individual colors (wavelengths). Each material is described by its spectral **transmission diagram** that shows which wavelengths are absorbed and which are transmitted.

With Spectral Plus Demonstration Set you can easily demonstrate the color absorption and transmission by using the set of color filters. View the uncovered RGB display using a color filter. The filter transmits only a specific range of wavelengths and the rest is absorbed. The transmission and absorption of the filters is represented by their transmission diagrams. Transmission diagrams for individual filters are displayed in Figures 2, 3, 4.

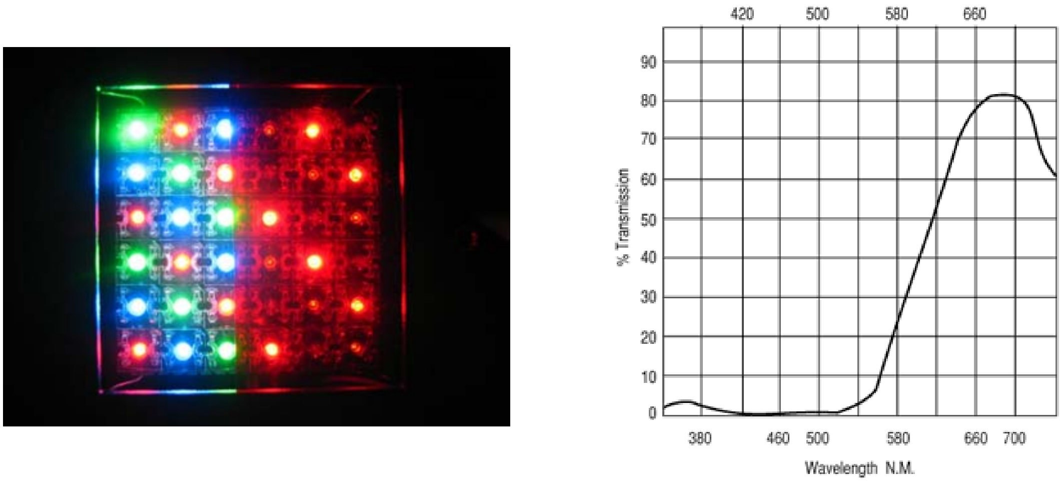


Figure 2 – Red filter absorption and transmission, red filter transmission diagram.

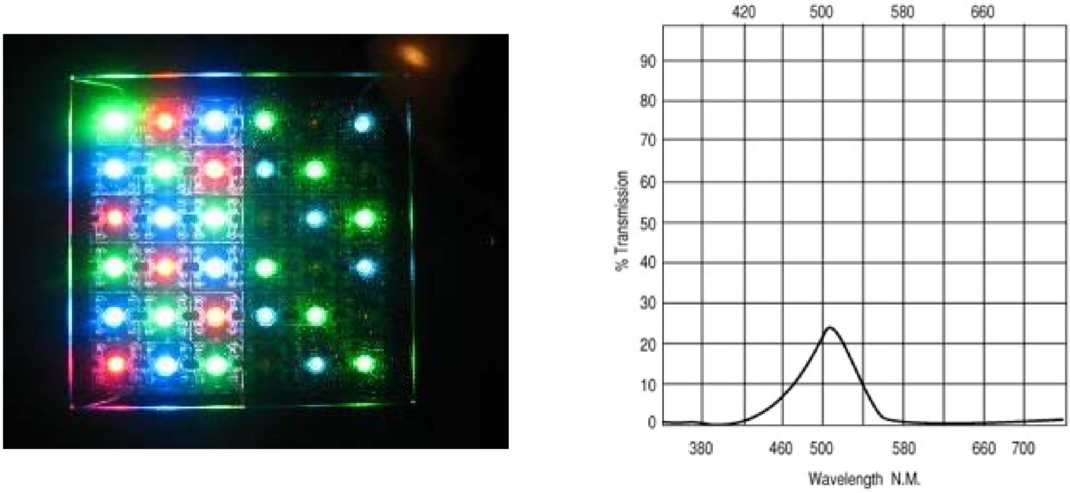


Figure 3 – Green filter absorption and transmission, green filter transmission diagram.

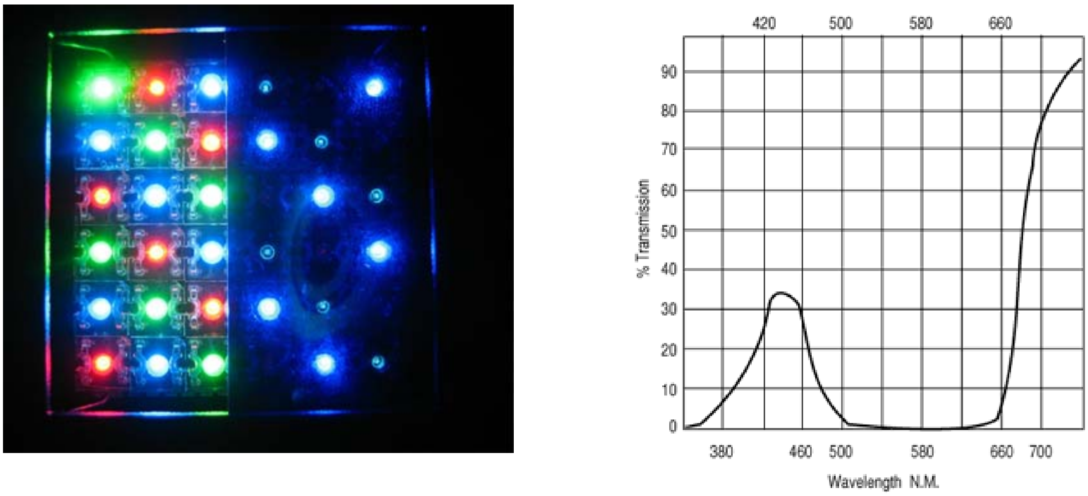


Figure 4 – Blue filter absorption and transmission, blue filter transmission diagram.

Filters transmit only a narrow range of wavelengths, while other wavelengths are significantly suppressed. The red filter is a best example (Figure 2). The green filter transmits also a small part of blue light and the blue filter transmits also a small part of green light. The explanation is in the transmission diagram of green and blue filter and in the emission spectrum of individual LEDs – Figure 5.

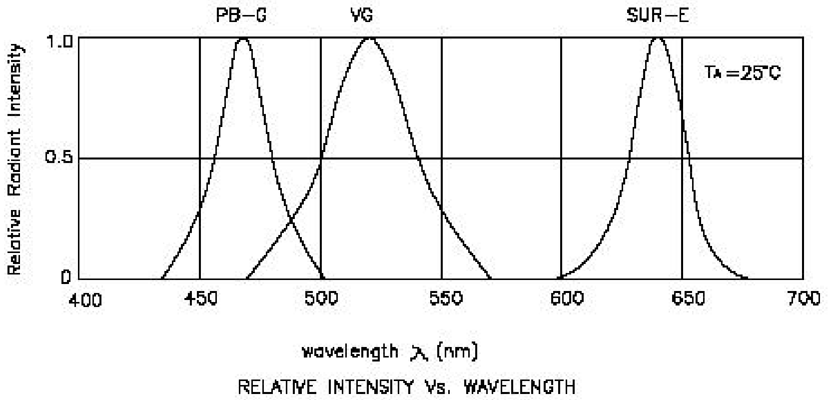


Figure 5 – Emission spectrum of individual LEDs (from left): blue, green, red.

In the emission spectrum of LEDs you can see that wavelength for green and blue colors are close to each other. In the transmission diagrams you can see that blue filter partially transmits also wavelengths belonging to green and vice versa. Therefore these filters cannot suppress other colors completely.

If you put all three filters across each other, almost all light is absorbed. This experiment can be done as an individual student activity – students can draw all three diagrams into one picture. Then they will see that three filters together suppress almost whole visible spectrum.

Caution:

You can damage your eyes if you look directly to uncovered LED display at high intensity level. Therefore it is not recommended to turn the LED intensity to levels higher than 5.

1.3 Light Diffusion

Light diffusion can be demonstrated using a diffusion filter. If you watch uncovered LED display through the diffusion filter you can see that the light sources (dots) are scattered into wider beams – they are diffused (Figure 6). If you change the distance between the filter and the light source, at certain distance the light is perceived as if it was emitted from a homogeneous planar light source.

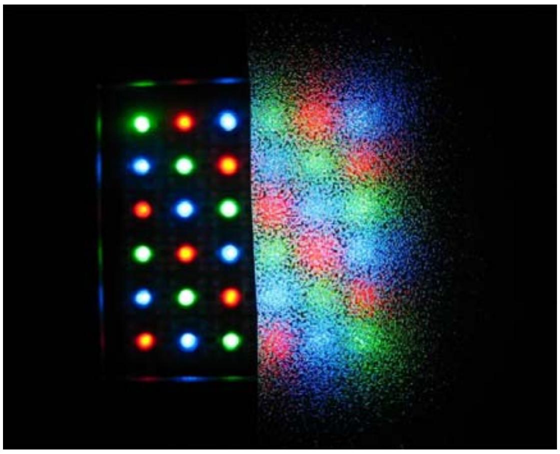


Figure 6 – Light diffusion on a clear diffusion filter.

Some examples of diffusion filters applications are: traffic lights, lights in cars and other large light sources where the light is generated by many small light sources, but using diffusion filter it appears as homogeneous.

You can create color diffusion filter easily by putting clear diffusion filter and color filter together. Using this combined filter you can demonstrate for example red traffic light.

By changing the distance of the filter and the display the colors mix together (Figure 7).

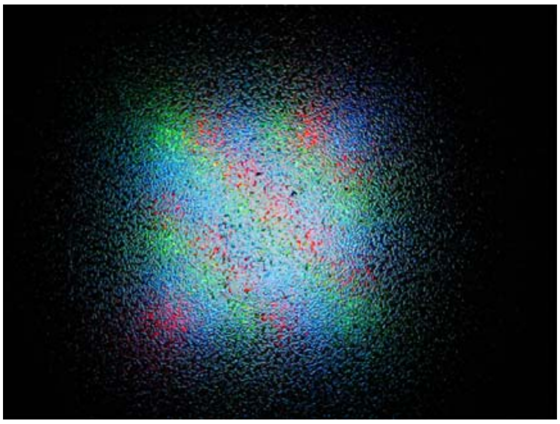


Figure 7 – Mixing of colors from the RGB display caused by diffusion filter.

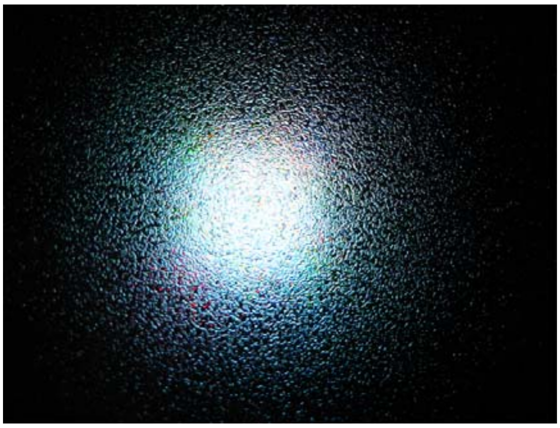


Figure 8 – Mixing of colors into white at certain distance of diffusion filter.

At certain distance the color dots disappear and you can see white light (Figure 8). You can see even better diffusion effect on the white diffusion filter – the colors mix into white at very small distance of the filter and display.

Mixing of three color components (R, G, B) into while light is a demonstration of an additive color mixing, which is the main focus of next chapter.

1.4 Color mixing

To demonstrate color mixing with Spectral Plus Demonstration Set, put two white filters on the RGB display – one on the bottom and one on the top of the filter holder. By changing intensity of individual colors you can demonstrate two types of color mixing – **additive** (light sources mixing) and **subtractive** (color filters mixing).

1.4.1 Additive color mixing

Additive color mixing is mixing of different light sources. There are three primary colors for this type of mixing: red, green and blue. With this three colors the RGB color model is defined. Any color can be mixed using these three colors (Figure 9). If you turn all three color components to maximum intensity level, the final color is white.

Figure 9 – Additive color mixing: orange created by combination of red and green.

Color mixing can be done as a demonstration or as an individual student's activity: students get a table with RGB codes (proportions or intensities in %) and their task is to name the colors they get. Inverse task is more complicated: find RGB codes for a specific color. Here you can demonstrate subjective perception of color.

In Table 2 you can see 16 named colors in standard HTML 3.2 used in computer graphics.

(R,G,B)	**Name**
(100%,0%,100%)	Fuchsia (Magenta)
(50%,50%,50%)	Grey
(0%,50%,0%)	Green
(0%,100%,0%)	Lime
(50%,0%,0%)	Maroon
(0%,0%,50%)	Navy
(50%,50%,0%)	Olive
(50%,0%,50%)	Purple
(100%,0%,0%)	Red
(75%,75%,75%)	Silver
(0%,0%,0%)	Black
(100%,100%,0)	Yellow
(100%,100%,100%)	White
(0%,100%,100%)	Aqua (Cyan)
(0%,0%,100%)	Blue
(0%,50%,50%)	Teal

Table 2 – The Sixteen Named Colors with their RGB percentage.

An example of the additive color mixing application is a TV set display or a computer's monitor. Each pixel on the screen can be represented in the computer's memory as independent values for red, green and blue. These values are converted into intensities and sent to the display. Typical display hardware used for computer monitors uses a total of24 bits of information for each pixel (commonly known as bits per pixel – bpp). This corresponds to 8 bits each for red, green, and blue, giving a range of 256 possible values or intensities, for each color. With this system, approximately 16.7 million discrete colors can be reproduced, although the human eye can distinguish between only around 10 million discrete colors (this number varies from person to person depending upon the condition of the eye and the age of the person).

1.4.2 Subtractive color mixing

The principle of subtractive color mixing is light absorption (for details see Chapter 2.1). If white light comes through a color filter, some color components are absorbed by the filter. The resulting color of the light coming from the filter is specified by the transmission curve of the filter.

The primary colors for subtractive color mixing are cyan, magenta and yellow. If you use filters of these three colors, the final color is black. This is the principle of CMY(K) color model ("K" refers to the black color). Any color can be mixed using these three colors.

To demonstrate subtractive color mixing, turn all three RGB components to full intensity, put two white filters on the filter holder (to produce homogeneous white light), and put the CMYK filter on the top of the filter holder (Figure 10). We will place both lacteal filters on the bottom of the holder, so that the effect of colour matching will be more visible.

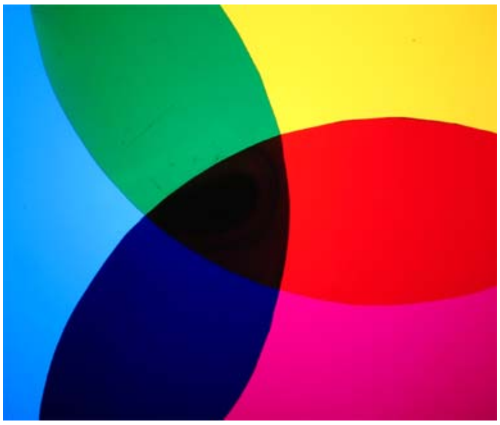
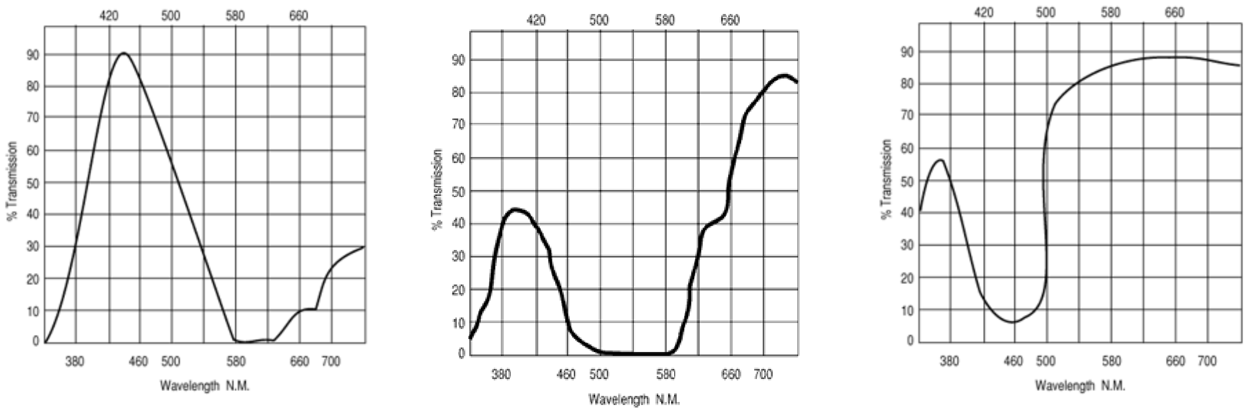


Figure 10 – Subtractive color mixing.

CMYK filter consists of three filters – cyan, magenta and yellow, primary colors of subtractive color mixing. Transmission diagrams for the three filters are drawn in Figure 11.



Cyan filter **Magenta filter** **Yellow filter**

Figure 11 – Transmission diagrams of filters in CMYK filter.

You can see that colors in the filter that are next to each other produce together the primary colors of additive color mixing – red (yellow + magenta), green (cyan + yellow) and blue (cyan + magenta).

If you draw all three transmission diagrams into one picture, you can see that small amount of light is still transmitted. This explains why the color in the middle of CMYK filter (all three filters together) is not completely black.

Subtractive color mixing causes the color appearance of objects, because object in nature are able to absorb light components. The perception of green color of object does not mean that the object is a source of a green light, but when illuminated by white light (consisting of RGB components), it absorbs the red and blue components and reflects only the green component, which makes the object appear green.

Subtractive color mixing is also used for example in color printers. Colored ink is applied to paper using CMYK color model. On the other hand, computer monitor uses additive color mixing based on RGB color model. This sometimes causes situations when color on the monitor is slightly different from the color on the paper.

1.4.3 Automatic mode (Auto)

Spectral Plus Demonstration set contains also automatic mode – you can turn it on with the “Auto” switch. If you turn on the automatic mode, the color will change automatically. Manual regulation is not possible in this case, but you can change the speed of color transition. This feature can be turned on as a background decoration.

1.5 Light and spectra of different light sources

Light of different light sources is produced differently. It can be produced for example by hot wire, electric discharge, fluorescence, emission of light in semiconductor diodes. For light from each of the sources there is a characteristic **emission spectrum**. There are two types of spectra – continuous and discrete. Spectrum can tell you information about the character of light, because the way how the light is produced is directly linked to its spectrum. Therefore we can see different spectral pictures of different light sources.

Continuous spectrum contains all colors of visible spectrum and the color changes continuously. This type of spectrum is typical for thermal radiation, e.g. light from incandescent bulbs, from the Sun, or from arc discharge.

Discrete spectrum contains bright lines. This type of spectrum is typical for those light sources, in which the light is produced by “jumping” of electrone from one energy level to another. At this jump – transition from higher energy level to lower level – a light with specific wavelength is emitted. This wavelength represents one bright line in the spectrum. Light with more specific wavelengths is produced in a light source; therefore you can see more lines in the spectrum. The specific layout of the lines in the spectrum is typical for a specific light source. The discrete spectrum is typical for discharge tubes, fluorescent lamps or LEDs.

You can see a spectrum if you watch a light source through **spectroscope**. In spectroscope there is a grid, where the light is diffracted. Light with different wavelengths is diffracted differently. If the light coming to the grid is mixed of different wavelengths, after it comes from the grid, it is divided into original wavelengths. As we can identify the wavelengths from which the light is mixed, we can also identify what kind of light is coming from the light source.

1.5.1 Spectrum of the RGB Display

If we produce white light on the RGB display (all three colors at full intensity) and watch the display through spectroscope, we can see three colors – red, green and blue. Even if the light is white, we can identify that it is composed from these three colors.

The emission spectrum of the LEDs used in RGB display is displayed in Figure 5. LEDs emit a monochromatic light, i.e. the color of the light emitted by the diode has only one wavelength. In fact, it is not only one wavelength, but a narrow range of wavelengths with the peak at the dominant wavelength.

Caution:

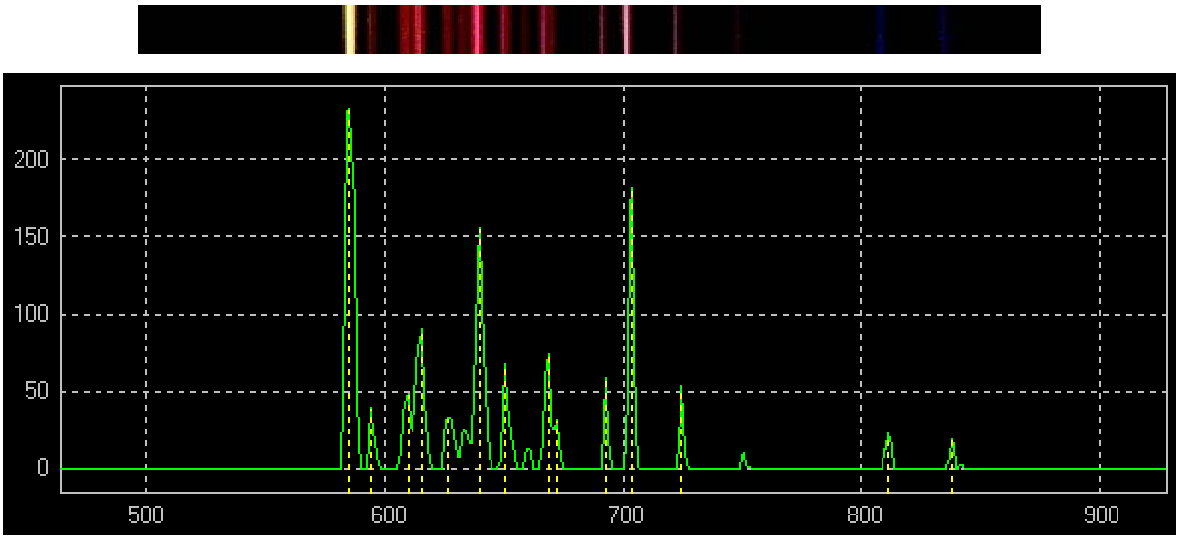
RGB display must be covered with two white filters when watching through spectroscope. We will place one of them closely above RGB display and the second one on the top of the filter holder.

1.5.2 Spectrum of the incandescent bulb

If you watch the incandescent bulb through the spectroscope, you can see a continuous spectrum. The light of the bulb is produced by a tungsten filament that is heated to high temperature and emits light. The color of the light emitted from the bulb depends on the temperature of the tungsten filament. The light from the bulb is yellowish, because at this temperature of the filament the dominant wavelength is approximately 600nm, which is typical for yellow.

1.5.3 Spectrum of the Neon Tube

A neon tube is a gas discharge lamp containing primarily neon gas at low pressure. The term is sometimes used for similar devices filled with other noble gases, usually to produce different colors.



1.5.4 Spectrum of the LED with phosphor

White LED containing phosphor produces also white light. If you watch the light through a spectroscope, it is similar to continuous spectrum, but there is one dominant blue line in the spectrum. The emission spectrum of the diode is displayed in Figure 12.

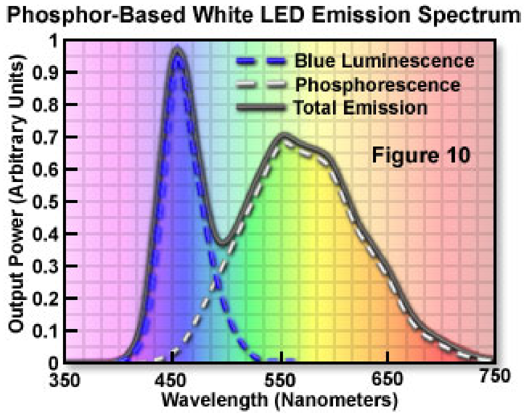


Figure 12 – Spectrum of white LED with phosphor

The diode emits a monochromatic blue light. This light makes the bright blue line in the spectrum. To produce white light, there is a wavelength converter – **phosphor** – put on the inner side of the LED lens. When the phosphor is illuminated by the blue light, it absorbs part of the light and emits light with wide range of wavelengths. These wavelengths mixed together produce white light. In other words, the phosphor converts the blue light into white light. The resulting spectrum then contains one (Figure 11).

1.5.5 Spectrum of the fluorescent tube

If you watch the spectrum of the discharge tube, you can see several main bright lines and a part of continuous spectrum with dominant blue color.

Figure 13 – Spectrum of the fluorescent discharge tube.

The fluorescent tube is filled with mercury vapors and on the inner surface of the lamp there is a phosphor powder. After applying high voltage on the electrodes in the tube a glow discharge is produced. The light is produced during the collisions of the electrons and molecules. During the collisions the electronsand molecules exchange energy – this energy is released in the form of a light. The colors (wavelengths) of the light produced in the glow discharge are specific for each gas – they are like the “fingerprints” of the gas. Therefore we can say what kind of gas is inside the tube by analyzing the spectral lines. The orange, green and blue lines are typical for mercury vapors. Mercury atoms release light also in the ultraviolet wavelength range. The spectral diagram of the discharge tube is displayed in Figure 14.

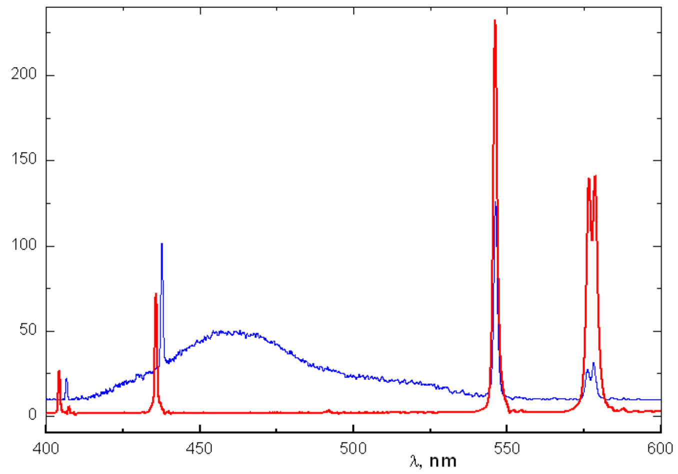


Figure 14 – Spectrum of the fluorescent tube.

You can see that there is also a part of a continuous spectrum in the spectrum of the tube. This is caused by the phosphor powder on the inner surface of the lamp. It converts the invisible ultraviolet light into a visible blue light, which is dominant in the spectrum. The phosphor (similarly as in the case of white LED with phosphor) emits wide range of wavelengths. This is why you can see the continuous part in the spectrum. The resulting spectrum is the combination of mercury spectrum and spectrum of the phosphor.

If we used phosphor with different spectral diagram, the resulting color of the lamp would be different – the blue light in Figure 14 and its maximum would shift towards different wavelengths. But the mercury lines in the spectrum would remain unchanged.

2 Advantages of Spectral Plus Demonstration Set

Main advantages of Spectral Plus Demonstration set:

- **Interesting light effects** – experiments with light and color effects have strong motivation potential and can make physics more interesting and closer to more students; the automatic mode enables to use the set not only during the teacher's explanation.
- **Ease of use** – easy manipulation with the colored lights intensity, easy turning on and off the light sources, simple spectroscope construction and manipulation.
- **Demonstrative explanation** – good visibility of spectra through the spectroscope, visual demonstration of color creation
- Multifunctional use – the set can be used for explanation of optics, waves and parts of atom physics
- **Safe use** – neither students nor teacher are in contact with high voltage during manipulation with discharge tube (which is necessary when using traditional discharge tube demonstration sets)