SPECTRA

COLLECTION OF TASKS - ACTIVITIES FOR MIDDLE SCHOOL AND HIGH SCHOOL

KVANT®

CONTENTS

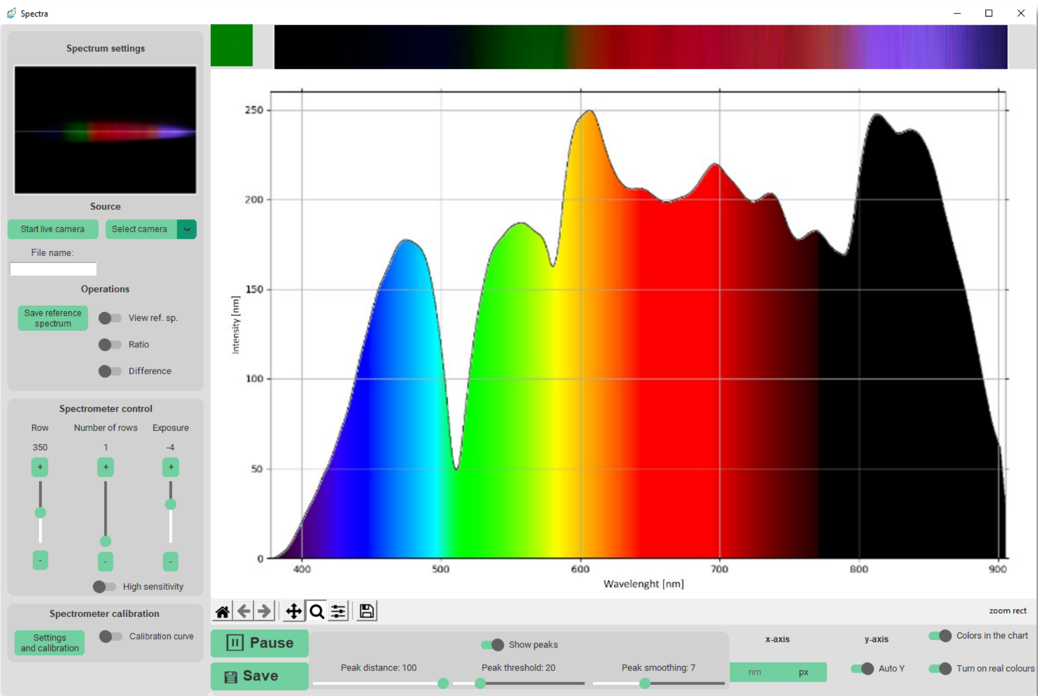
HOW TO USE THE SPECTROMETER?

The collection of tasks provides several topics for school experiments in the fields of light, electromagnetic radiation, and particles of the micro world, which can be realized using the school spectrometer SPECTRA. Instructions are created for individual activities, supplemented by connections between the investigated physical phenomena and situations from everyday life.

EMISSION SPECTRUM

How to display the emission spectrum of a light source?

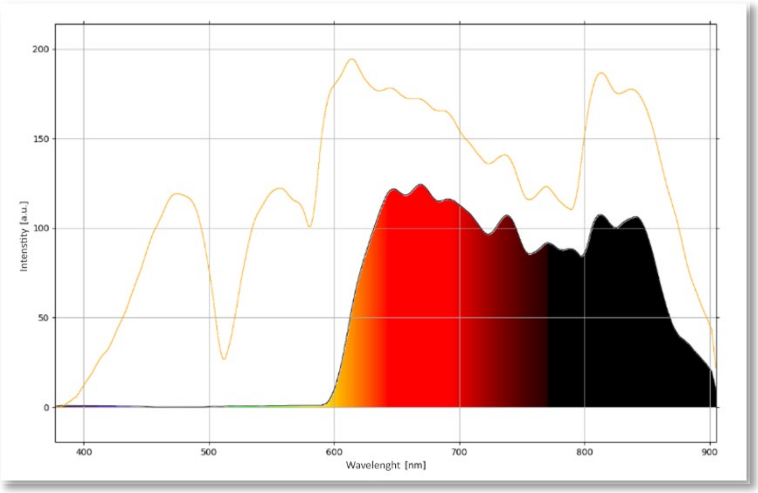
1. We connect the spectrometer to the computer via a USB cable.
2. If the live image from the camera does not appear in the window, click on "Select camera" and select the camera of the connected spectrometer. If the spectrometer is connected correctly, a live image should be displayed in the window. If the image is still not displayed, we check the connection or restart the program.
3. We aim the spectrometer at the light source or connect it to the light source using an optical fiber.
   If the light is too weak, bringing the spectrometer closer and rotating it appropriately is necessary. If it is too strong and some parts of the spectrum already exceed the maximum possible values on the y-axis, the spectrometer needs to be tilted slightly obliquely concerning the light source so that the required light intensity is reached.
4. The graph shows **how much light falls on individual colors of the spectrum.**
5. If the light is too weak, we increase the **exposure** or turn on the "**High sensitivity**" function of the camera.
6. If we are satisfied with the result, we can start the spectrum analysis.
7. We can pause the recording of the camera or leave it running and watch how the spectrum will change over time.
8. A practical function is the **Display of peaks**. This option finds the peaks of the spectrum and assigns wavelength values to them.
9. We save our results using the "**Save**" button. (More information about the software in the manual)



Graph of the continuous spectrum of a halogen lamp

REFERENCE SPECTRUM

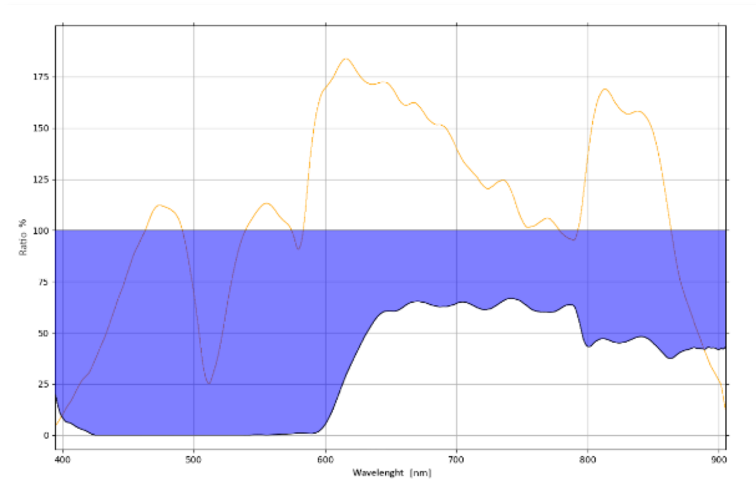
The reference spectrum is the currently displayed spectrum in the graph. The set of coordinates of the currently displayed graph is stored in the internal memory. The reference spectrum can be used for comparison with the currently displayed spectrum or for working with the ratio and difference operations. The ratio and difference are possible between the spectrum currently displayed in the graph and the reference spectrum stored in the memory.



Comparison of the current spectrum of the light bulb transmitted through the red filter (filled with color) and the reference spectrum of the light bulb (without fill, shown by the orange line)

RATIO (%)

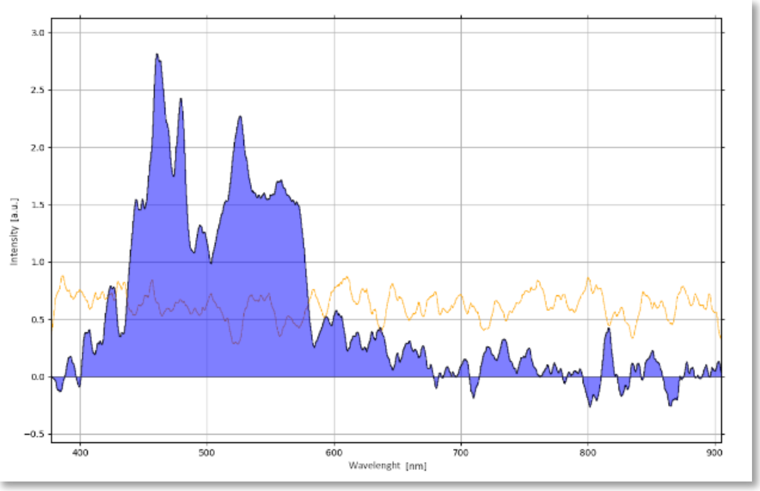
1. We will display the spectrum of the source, which will be a reference. We save by clicking "Save reference spectrum".
2. Insert a filter between the light source and the spectrometer, the transmittance of which you want to determine.
3. We will display the spectrum of transmitted light.
4. We turn on the "Share" function to display the share of the current and reference spectrum.



Graph of the proportion of the actual (light bulb light spectrum passed through the red filter) and the reference spectrum (light bulb spectrum)

DIFFERENCE

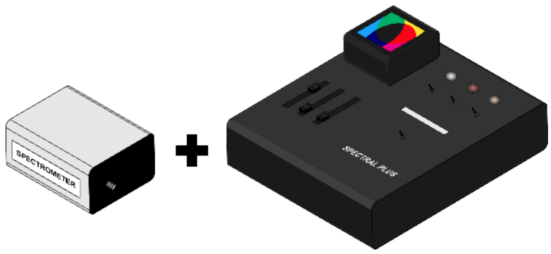
1. We will display the source spectrum, which will be considered a reference. (in this example the background spectrum)
2. We save the reference spectrum by clicking "**Save reference spectrum**".
3. We will display the current spectrum from which you want to read the reference spectrum. (in this case the small signal spectrum)
4. We turn on the "**Difference**" function to display the difference between the current and the reference spectrum.



Small signal spectrum graph (color graph) after subtraction of background reference spectrum (graph without color)

1 ARTIFICIAL LIGHT SOURCE - EMISSION SPECTRA OF LIGHT SOURCES - WHICH BEST MEET YOUR NEEDS?

Middle school *- <u>Physics</u>: Topic: Light - Source of light, Sun and light bulb as sources of light*
High school *- <u>Physics</u>: Topic: Electromagnetic radiation and particles of light - Emission spectrum, line spectrum, continuous spectrum*



SPECTRA + SPECTRAL PLUS

In this topic, we will familiarize ourselves with the parameters of light sources so that we can choose a light source that will suit our requirements and needs. We will find out what the emission spectra of individual light sources look like and what the difference is between them.

What is an emission spectrum? It is the spectrum of light emitted by matter. The emission spectrum can be linear or continuous.

Indoor measurement using a school spectrometer allows you to compare the spectra of different artificial light sources.

1.1 What are the emission spectra of light bulbs, fluorescent lamps, and LEDs?

OTÁZKY:

1. Which spectrum is continuous and which contains lines, and bands?
2. Which light source will be the most suitable for the correct display of colors?
3. What does the dark area behind the red part of the light bulb spectrum mean? Does it also occur in the fluorescent and LED spectrum??

Utilities:

Spectrometer, **SPECTRAL Plus** (or different light sources - light bulb (tungsten or halogen), LED, fluorescent), optical cable, lens, computer with SW Spectra

Procedure:

1. Using the USB cable, we connect the spectrometer to the computer and turn on SW Spectra, select the camera of the spectrometer, and start the measurement.
2. We connect the optical cable and lens to the spectrometer.

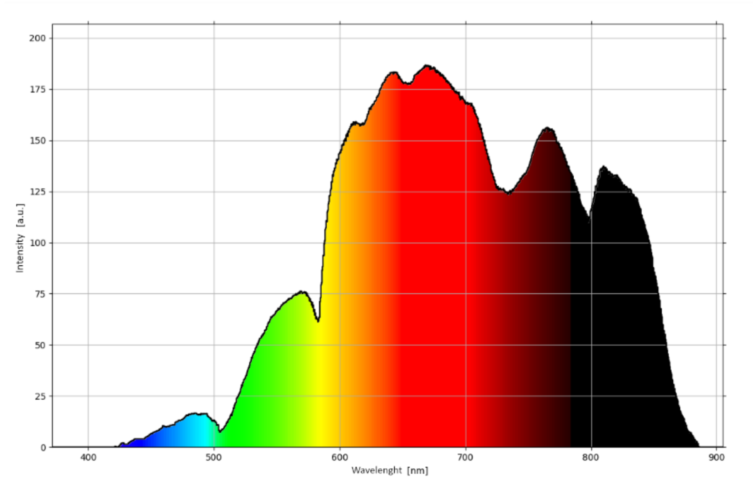
Recommended setup of the experiment

3. We turn on SPECTRAL Plus and gradually measure the spectra of various light sources – LED, neon, halogen bulb, and fluorescent tube (fluorescent tube).
4. We save each spectrum and compare.

Results, answers to questions, and measurement analysis:

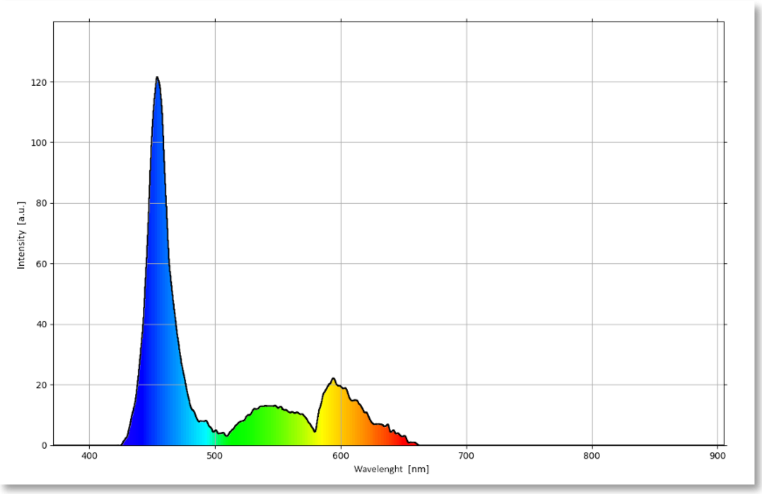
1. A classic light bulb and an LED have a **continuous spectrum**.

   Light bulb - emits more in the infrared region than in the visible part, but the spectrometer is not sensitive to this radiation and displays values only after about 870 nm.



The spectrum of a (halogen) light bulb

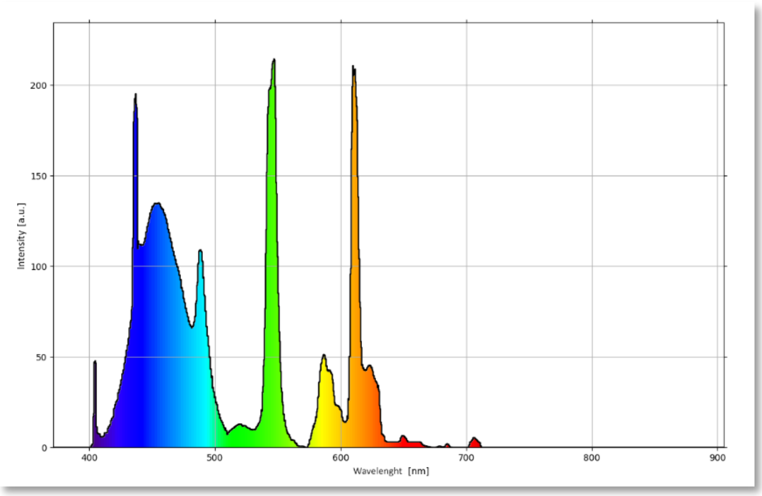
   LED - emits monochromatic blue light. This light creates a bright blue region in the spectrum. To produce white light, a luminophore is placed on the inside of the LED. When the phosphor is illuminated with blue light, it absorbs some of the light and emits light with a wide range of wavelengths. These wavelengths together create white light.



LED spectrum

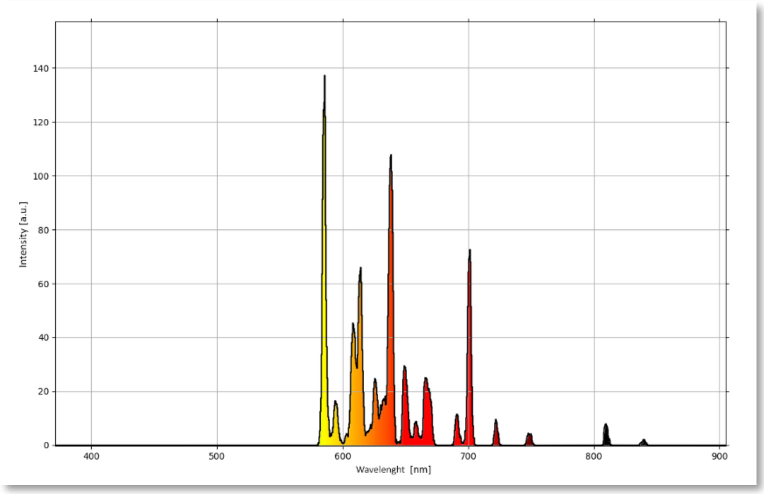
A fluorescent lamp and a neon lamp have a **line spectrum**.

The spectrum of the fluorescent lamp used contains both lines of mercury, the ionization of which produces primarily ultraviolet light (similar to the tubes used in solariums), as well as bands of visible light, which are created after the impact of UV radiation on the luminophore.



Fluorescent lamp spectrum

A neon tube is a gas discharge lamp containing mainly neon at low pressure.



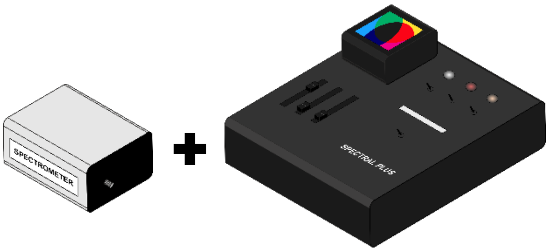
Neon tube spectrum

2. From the point of view of the correct display of the colors of objects (CRI value (Color Rendering Score) - it is a percentage representation of the share of sunlight wavelengths in artificial lighting. The sun emits light that has a CRI of 100) fluorescent lamps can be considered as the worst source (low CRI value). This is also confirmed by its light spectrum, which is significantly interrupted and contains only some colored bands. The light reflected from objects does not contain all the color components that would be reflected when using full-spectrum light, light close to natural sunlight (CRI > 91), which greatly distorts the perception of colors by the human eye. Incandescent and LED display colors more faithfully, but for correct color display, it is necessary to use a source with a continuous spectrum (high CRI value) and a color temperature close to 6000 K, which is closest to white sunlight.

3. This is a part of infrared radiation close to visible light that the spectrometer can still capture. Since this area is no longer visible to the human eye, we cannot even assign a suitable color to it. In the spectrum of fluorescent lamps and LEDs, infrared light practically does not occur - that is why their light efficiency is higher than that of a light bulb.

2 TRANSMITTED LIGHT - WHY DO OBJECTS LOOK SO STRANGE IN DIFFERENT COLORS OF LIGHT??

Middle school *-* *<u>Physics</u>: Topic: Light Reflected, transmitted, and absorbed light, decomposition of light, colors of the spectrum*
High school *-* *<u>Physics</u>: Topic: Electromagnetic radiation and light particles - Visible radiation*



SPECTRA + SPECTRAL PLUS

White light can be broken down into individual colors. Thus we obtain its spectrum. The light that strikes an interface can be reflected, transmitted, or absorbed by the material. In this topic, we will examine the spectrum of transmitted light through different color filters.

2.1 Observing the spectrum of the white light of an LED bulb passed through a red, blue, and green filter.

QUESTIONS:

1. What part of the spectrum is absorbed and transmitted by the red filter?
2. What part of the spectrum is absorbed and transmitted by the green filter?
3. What part of the spectrum is absorbed and transmitted by the blue filter?

Utilities:

Spectrometer SPECTRA, SPECTRAL PLUS (or LED, red, blue, green filter (e.g. euro packs, plastic mineral water bottle, colored glasses,...)), holder, optical cable, lens, computer with SW Spectra

Procedure:

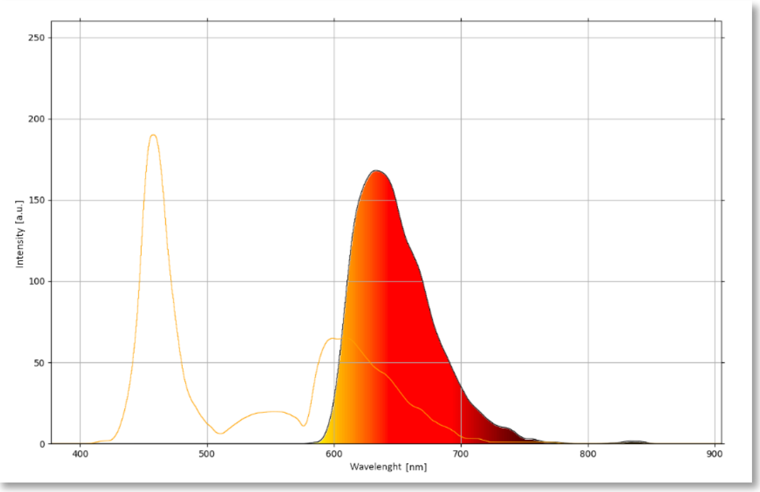
1. Using the USB cable, connect the spectrometer to the computer and turn on SW Spectra, select the camera of the spectrometer, and start the measurement.
2. We connect the optical cable and lens to the spectrometer.

Recommended experimental setup.

3. First, we record the light spectrum of the LED without filters for comparison and save it as a reference spectrum.
4. Subsequently, we place individual filters between the light source - in this case the LED and the lens.
5. With the help of a school spectrometer, we will record the spectrum of transmitted light through various filters.
6. We save and compare the results.

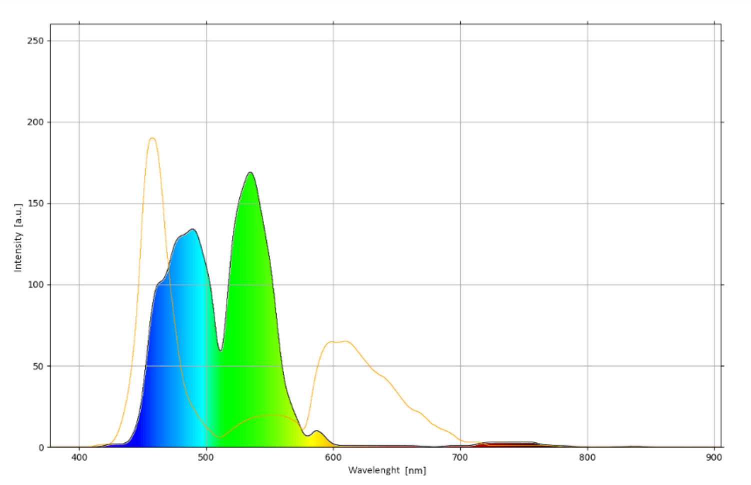
Results, answers to questions, and measurement analysis:

1. As can be seen from the spectrum, the red filter absorbed a significant part of the visible spectrum of the LED and let the red part of the spectrum pass, which is what we expected.



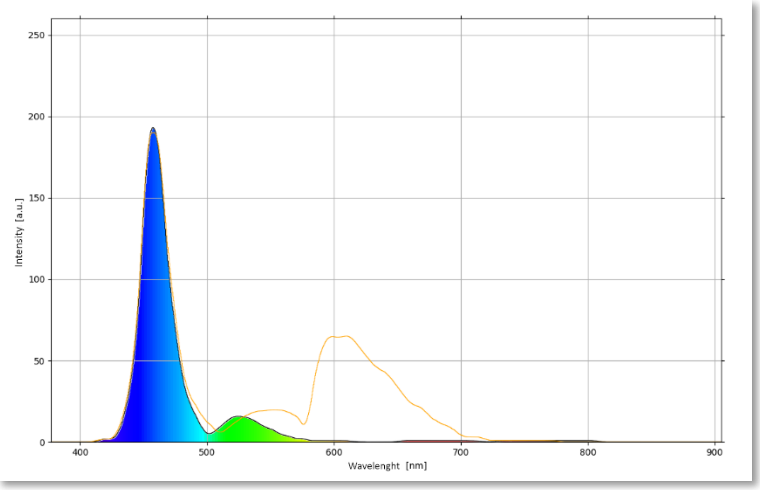
The amplified spectrum of LED light transmitted through a red filter, the spectrum of LED light in the background (graph without color)

2. Our green filter let through the green part of the spectrum, but also let through a large part of the blue spectrum. The red part of the spectrum was absorbed almost completely.



The amplified spectrum of LED light transmitted through a green filter, the spectrum of LED light in the background (graph without color)

3. The blue filter completely absorbed the red part of the spectrum and partially let through the green. There was minimal attenuation of blue light.



The amplified spectrum of LED light transmitted through a blue filter, the spectrum of LED light in the background (graph without color)

2.2 Observing the spectrum of light from a light bulb passed through a red, blue, and green filter. How it differs from the spectra of LEDs?

Utilities:

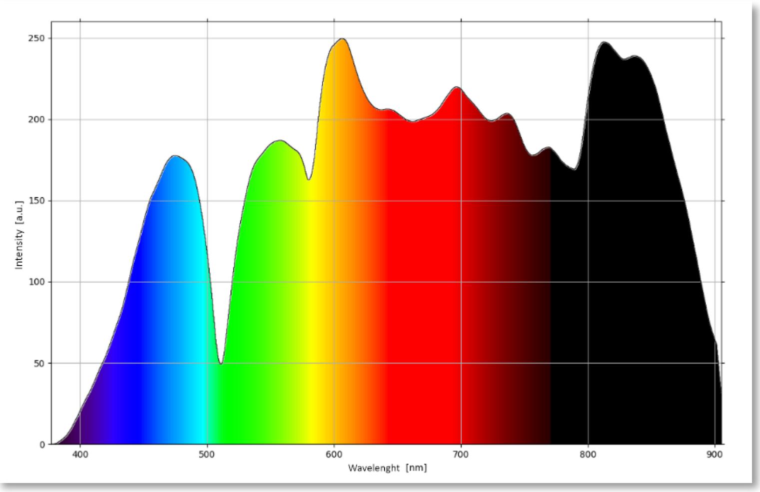
Spectrometer SPECTRA, SPECTRAL PLUS (or light bulb (tungsten or halogen) or, red, blue, green filter (e.g. euro packs, plastic mineral water bottle, colored cups,...)), holder, computer with SW Spectra

Procedure:

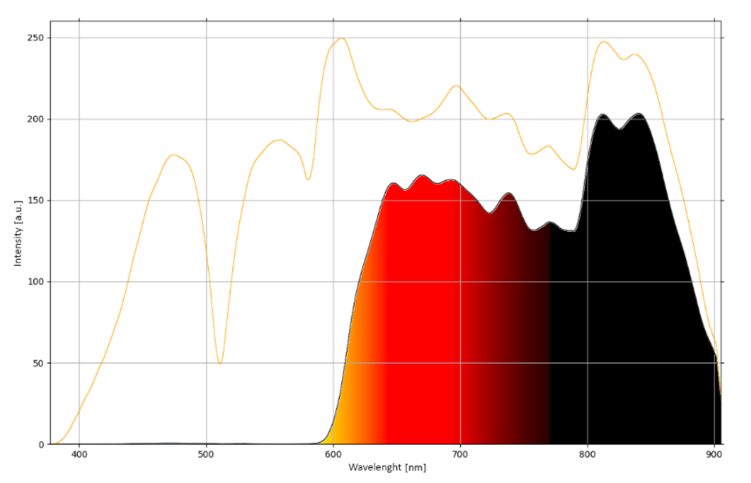
1. Using the USB cable, connect the spectrometer to the computer and turn on SW Spectra, select the camera of the spectrometer, and start the measurement.
2. We connect the optical cable and lens to the spectrometer.
3. First, we record the light spectrum of a halogen bulb without filters for comparison and save it as a reference spectrum.
4. Subsequently, we place individual filters between the light source - in this case, the halogen bulb and the lens.
5. With the help of a school spectrometer, we will record the spectrum of transmitted light through various filters.
6. We measure the spectrum of transmitted light through all three filters at once.
7. We save the results and compare them with each other and with the measurements with the LED.

Measurement results and analysis:

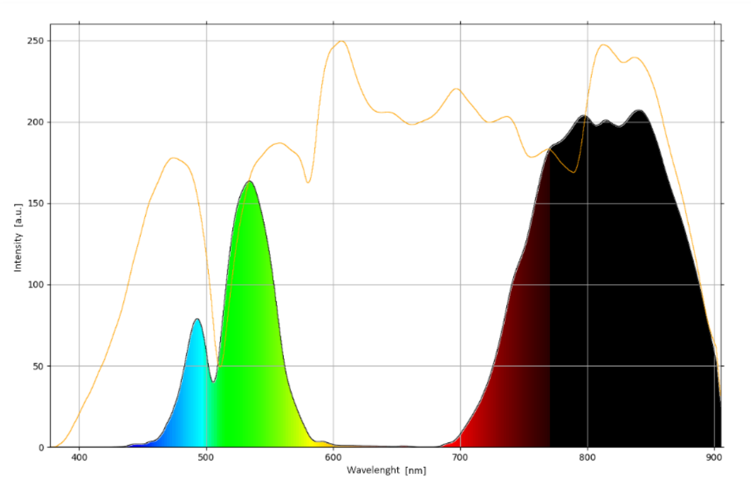
As can be seen from the recorded spectrum, in addition to visible light, the bulb also emits a lot of infrared radiation, which we can perceive as heat. With the help of a halogen bulb, we can also monitor the permeability of these filters in the infrared region. Infrared radiation is transmitted by all three filters.



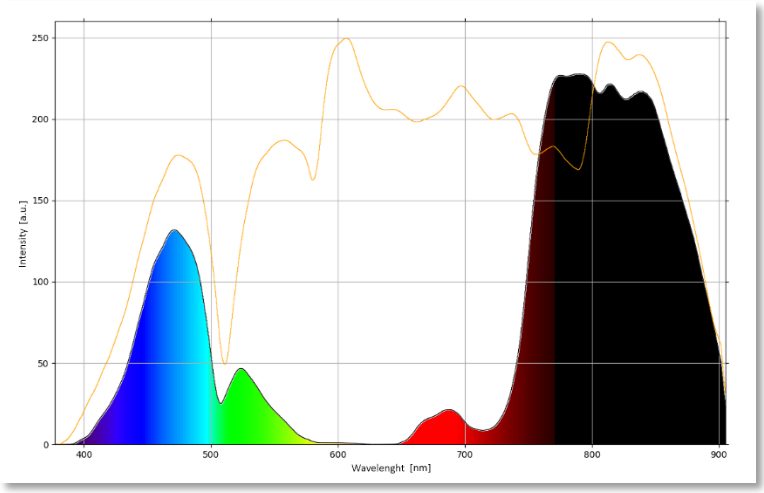
The light spectrum of a light bulb



The spectrum of light from a light bulb transmitted through a red filter, the spectrum of a light bulb in the background (graph without color)



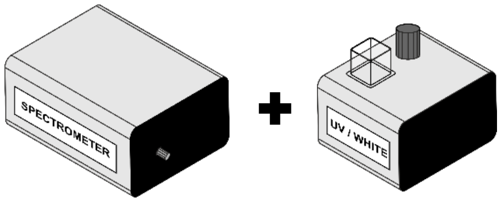
The amplified spectrum of light from a light bulb transmitted through a green filter, the spectrum of a light bulb in the background (graph without color)



The amplified spectrum of light from a light bulb transmitted through a blue filter, the spectrum of the light bulb in the background (graph without color)

3 LIGHT ABSORPTION - WHY PLANTS ARE GREEN?

Middle school *– Physics: Topic: Light - Light and photosynthesis*
Biology: Thematic unit: Basic life processes of organisms - Plant nutrition, photosynthesis
High school *- Physics: Topic: Electromagnetic radiation and particles of light - Emission spectrum, line spectrum, continuous spectrum*



SPECTRA + SPM-UV-W-LS/SPM-W-LS

The goal is to apply knowledge from biology and physics and create links between them. We will observe what happens to the white light spectrum after it passes through the green chlorophyll solution and what happens when it passes through the yellow leaf solution.

Chlorophyll is a green synthetically active dye in plants that commonly grow around us. It is found in the chloroplasts of plant cells. We made a solution from this dye that represents the chlorophyll in green leaves. It will be important to find out which part of the solar spectrum plants need for their life.

3.1 Comparison of the color of the spectrum of sunlight and the spectrum of light that passed through a solution of chlorophyll a) from green leaves, b) from yellow leaves.

QUESTIONS:

1. Which part of the light spectrum will plants use?
2. Which part of the spectrum do plants need for photosynthesis??
3. Which part of the light spectrum do they not need? What will the plant do with the light it doesn't need?
4. Why the yellow pigment of the leaves transmits almost the entire spectrum of sunlight?

Utilities:

Spectrometer SPECTRA, White light source SPM-UV-W-LS or SPM-W-LS with cuvette (can be replaced, for example, with a flashlight and a beaker), chlorophyll solution from green leaves and yellow leaves, computer with SW Spectra

Preparation of the chlorophyll solution the day before: We cut fresh green leaves and cover them with alcohol. We mix and let it stand until the next day. If the solution is too dark, add a little alcohol. Using the same procedure, we prepare a solution from yellow leaves.

Procedure:

1. Using the USB cable, connect the spectrometer to the computer and turn on SW Spectra, select the camera of the spectrometer, and start the measurement.
2. Using an optical fiber, we connect the white light source to the spectrometer.

Recommended setup of the experiment

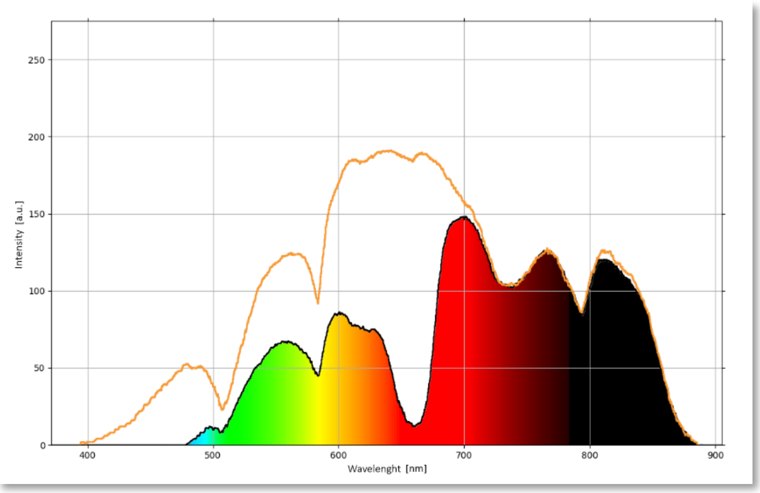
3. We turn on the light source in white light mode, insert the empty cuvette into the source, and set the light intensity so that the output is not oversaturated.
4. We save this spectrum as a reference and display it in the graph.

   a)
5. Pour the chlorophyll solution into the cuvette and insert it into the source. Care must be taken to ensure that the cuvette is dry!
6. The graph displays the current spectrum that corresponds to the absorption spectrum of chlorophyll. By comparing it with the reference spectrum of white light, we can find out which components of light the plant uses.
7. We save the measurement.

   b)
8. Wash and dry the cuvette.
9. Pour the solution from the yellow leaves into the cuvette and repeat the procedure.
10. We save the measurement.
11. Let's compare the results.

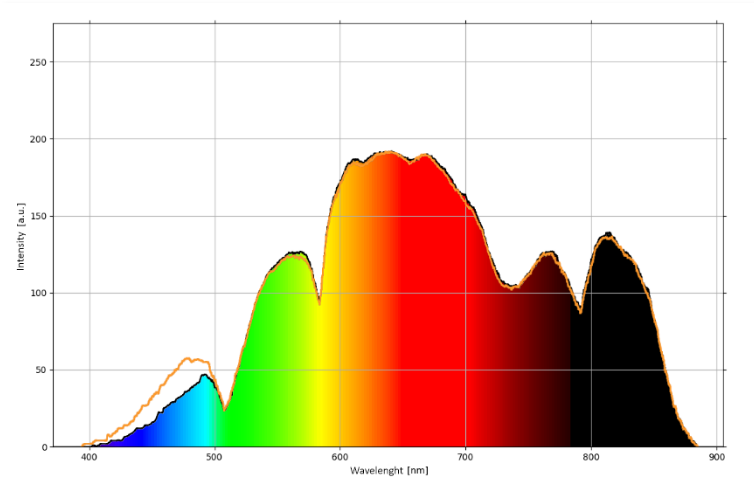
Results, answers to questions, and measurement analysis:

1. After analyzing the absorption spectrum of chlorophyll, we see that the plant absorbs and thus uses the red part of the spectrum and the blue-violet part of the spectrum.



a) Absorption spectrum (color graph) of chlorophyll from green leaves compared with white light spectrum (graph without fill)

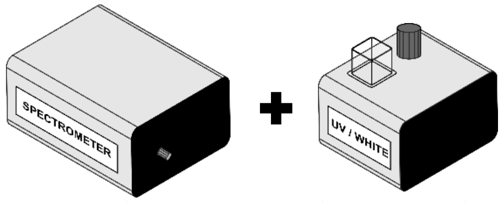
2. The plant uses the red part of the spectrum for photosynthesis. It is the most energetically advantageous for her. The blue-violet part is photosynthetically less efficient, it converts energy into heat or otherwise.
3. The green and yellow component of light is unnecessary for the plant, therefore the leaves do not capture it and therefore either let it through or reflect it. This reflected light is perceived by our eyes as green. The same plant allows the red part of the spectrum above 700 nm because it cannot use it.
4. When the leaves die, they turn yellow because chlorophyll loses its ability to photosynthesize. A yellow leaf does not use the incident light and therefore transmits it entirely, which we can see on the graph of the absorption spectrum of yellow leaves.



b) Absorption spectrum (color graph) of chlorophyll from orange leaves compared with white light spectrum (graph without fill)

4 LUMINESCENCE - WHY DO SOME OBJECTS OR SUBSTANCES GLOW?

High school *- <u>Physics</u>: Topic: Electromagnetic radiation and light particles - Infrared and ultraviolet radiation, their properties and use*



SPECTRA + SPM-UV-W-LS

***Luminescence,* or *luminescence,* is the emission of visible electromagnetic radiation that occurs during physical, chemical, or biological events. This phenomenon only works if energy is supplied to a substance called a luminophore. This energy causes the transition of the luminophore to the excited state. The luminophore reaches its original energy state by emitting light. The principle of luminescence is simple:**

luminophore + energy → luminophore⋆ → luminophore + light

Luminescent light is emitted without heat and is therefore also known as "cold light". Luminescence is of great importance in practice, for example, today everyone is familiar with fluorescent lamps, which are a typical example of the use of luminescence - UV radiation produced by a mercury discharge lamp is visible on the luminophore layer on the inner surface of the fluorescent lamp.

There are several types of luminescence. We can divide it, for example:

In terms of luminescence duration:

- **fluorescence (luminescence that disappears almost immediately after the end of the energy supply)**
- **phosphorescence (luminescence with a long decay that lasts even after the end of the energy supply)**

Z hľadiska spôsobu excitácie:

- **chemiluminiscencia - luminiscencia energiou chemickej reakcie**
- **elektroluminiscencia – luminiscencia vplyvom elektrického poľa alebo prechodom elektrického prúdu**
- **fotoluminiscencia - luminiscencia spôsobená ultrafialovým alebo viditeľným svetlom**

Fotoluminiscenčné spektrá umožňujú overiť platnosť tzv. Stokesovho pravidla – <u>vlnová dĺžka vyžiareného svetla je väčšia ako vlnová dĺžka svetla, ktoré budí fotoluminiscenciu.</u> To znamená, že vyžiarené svetlo má menšiu energiu ako UV svetlo dopadajúce na vzorku.

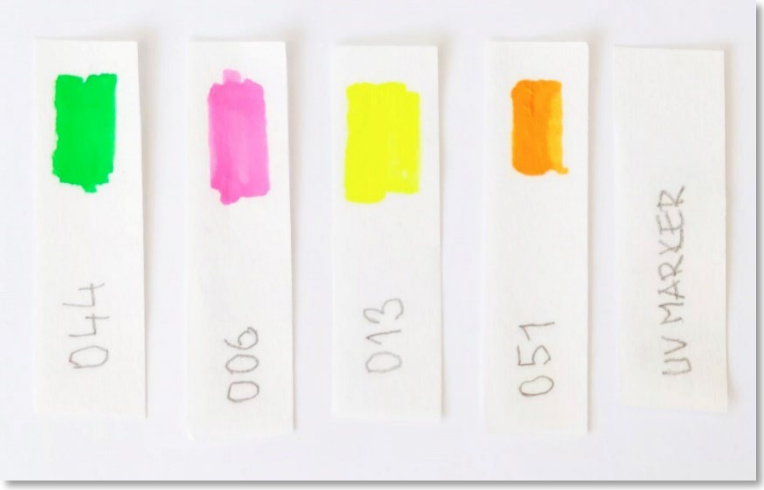
4.1 Observation of the luminescence spectrum of colored papers or highlighters.

QUESTIONS:

1. What kind of luminescence is it in terms of the method of excitation?
2. What species is it in terms of the duration of luminescence?
3. The measured spectrum confirms the validity of Stokes' rule?
4. We will compare the colors of the luminescence spectra with the colors of papers or highlighters as they are in white light.

Utilities:

spectrometer SPECTRA, White light source SPM-UV-W-LS with cuvette (can be replaced, for example, with a pocket UV lamp and a beaker), office paper, recycled paper, highlighters, color notepads of bright colors,..., computer with SW Spectra



Preparation for the experiment - dyeing recycled or filter paper with highlighters

Procedure:

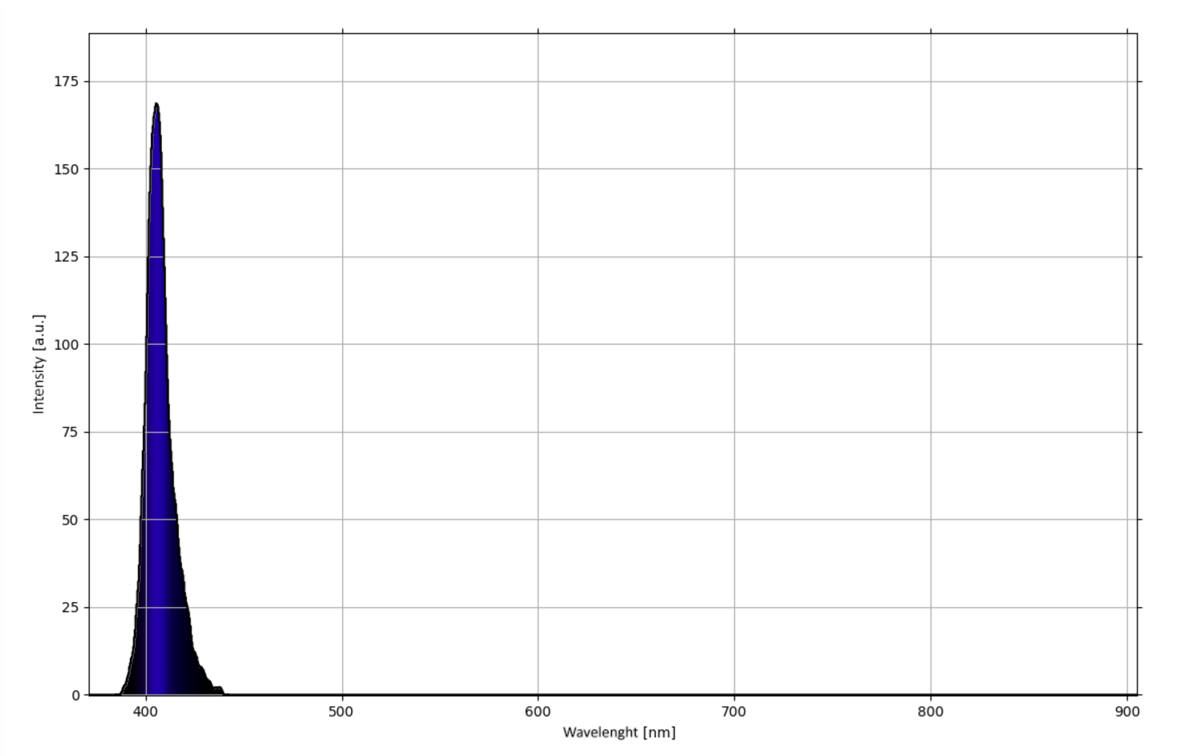
1. Using the USB cable, connect the spectrometer to the computer and turn on SW Spectra, select the camera of the spectrometer, and start the measurement.
2. Using an optical fiber, we connect the UV light source to the spectrometer.
3. We turn on the light source in UV mode.
4. With the UV light switched on without a cuvette, we insert colored papers into the space for the cuvette so that the UV light falls on the paper at an angle of 45° and is reflected into the detector.

Paper in a cuvette at an angle of 45°

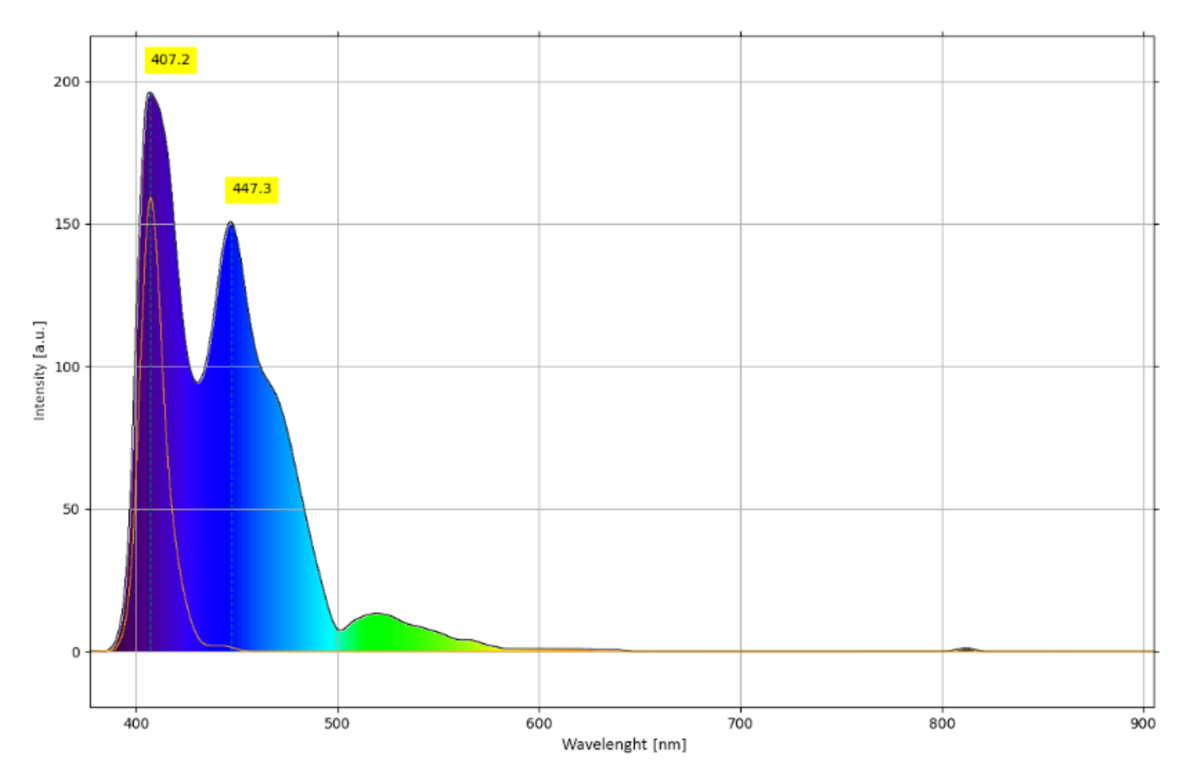
5. We gradually insert filter paper without treatment or colored with highlighters (or colored notepads of bright colors) into the space for the cuvette,....)
6. We save each luminescence spectrum and then compare it.

Results, answers to questions, and measurement analysis:

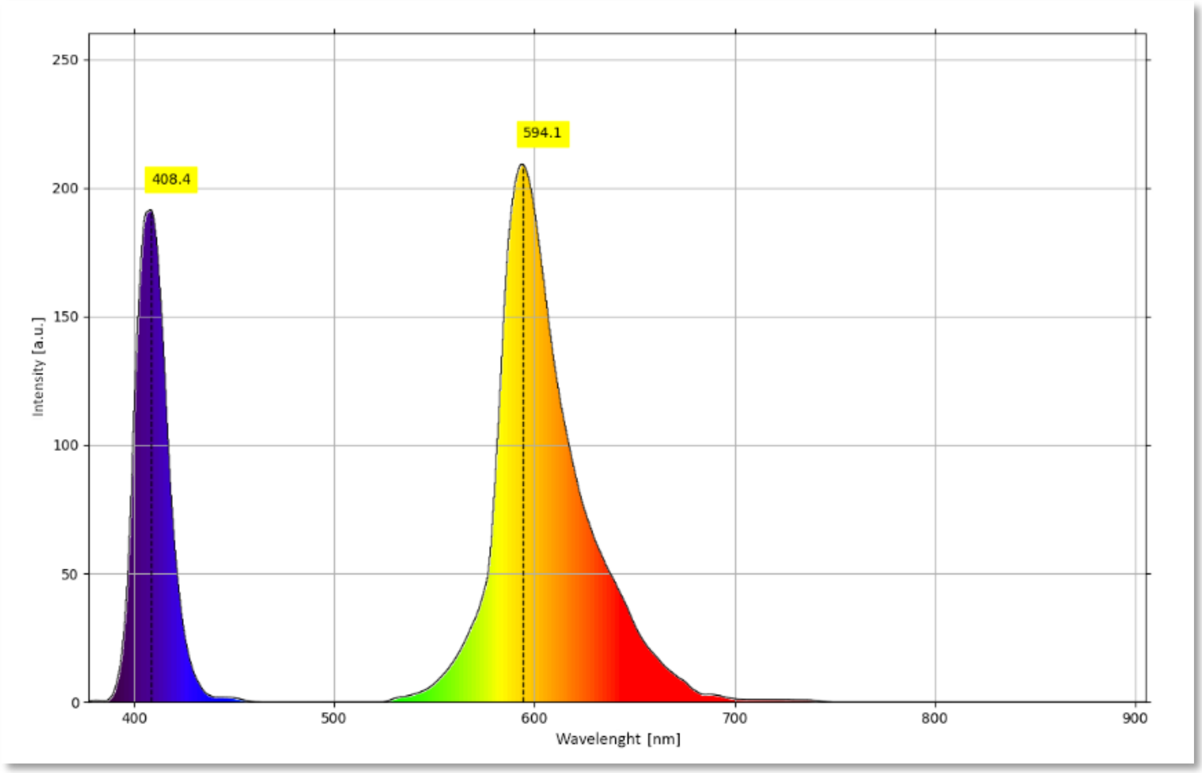
1. This is photoluminescence, as the luminophore is excited by light.
2. This is fluorescence, as the luminescence spectrum disappears immediately after the removal of UV light.
3. Stokes' rule applies. The emitted fluorescence spectrum has a longer wavelength than the excitation UV light. The verification of the rule is shown in the individual graphs of the luminescence spectra when we compare the spectrum of UV light and the luminescence spectrum.
4. Recycled paper - no luminescence spectrum
   Green highlighter - green luminescent spectrum
   Yellow highlighter - green-orange luminescent spectrum
   Orange highlighter - orange-yellow luminescent spectrum
   Pink highlighter - orange-yellow luminescent spectrum
   UV marker - blue luminescent spectrum



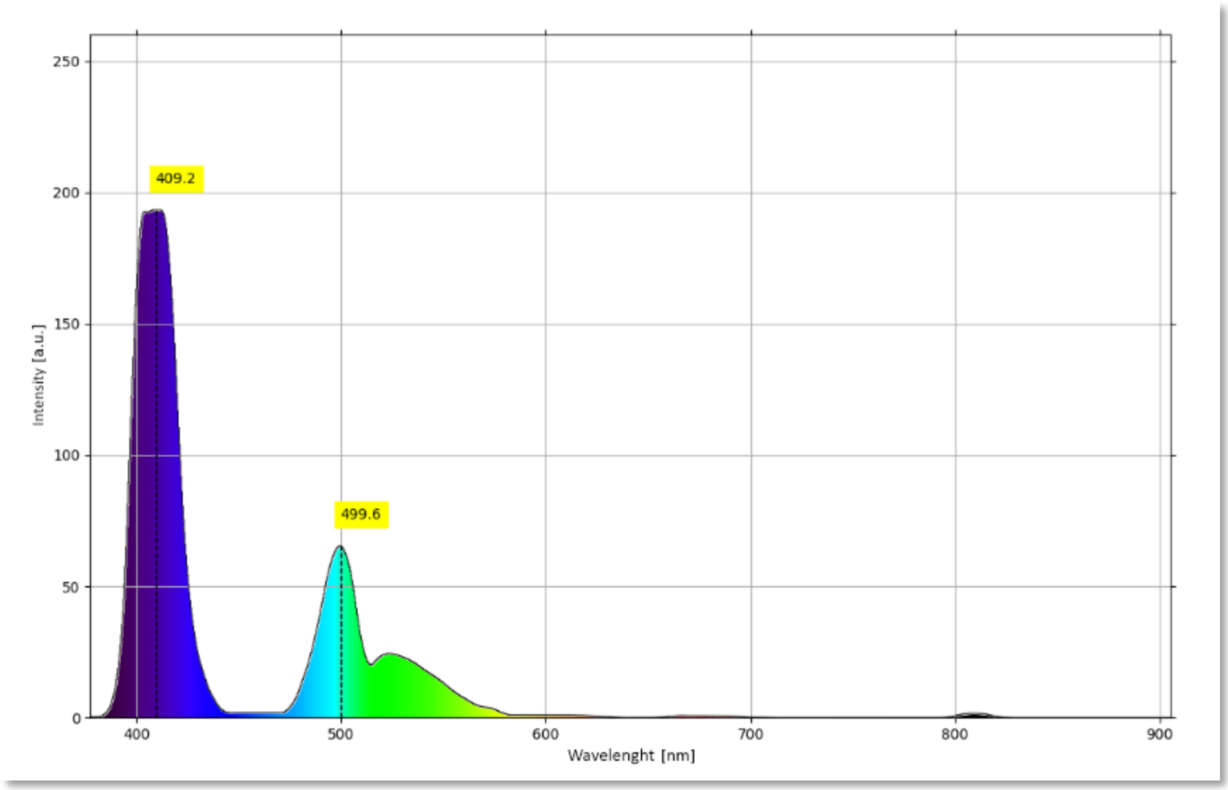
Reflection of the UV source from recycled paper (without luminescence)

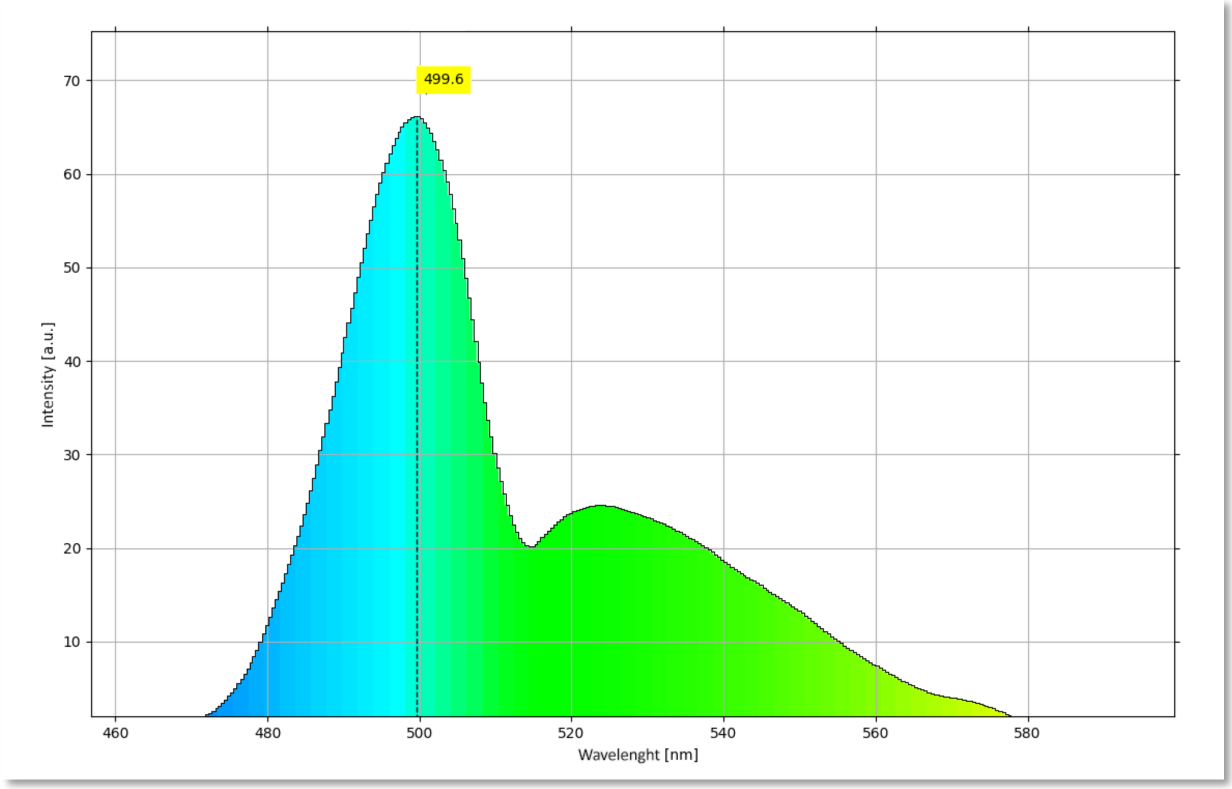


Amplified luminescence spectrum of the UV marker (amplification of the current spectrum causes oversaturation of the UV part corresponding to the emergence of luminescence). The spectrum of the UV source is shown as a reference (graph with an orange line)

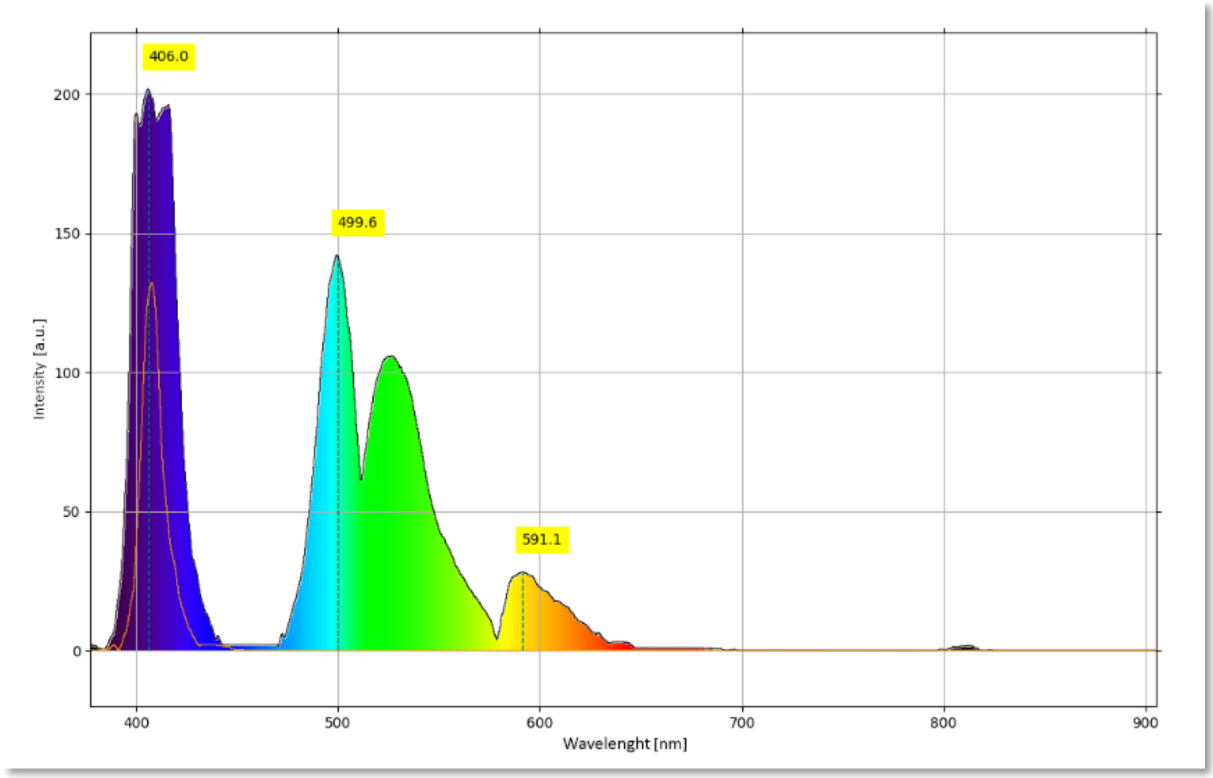


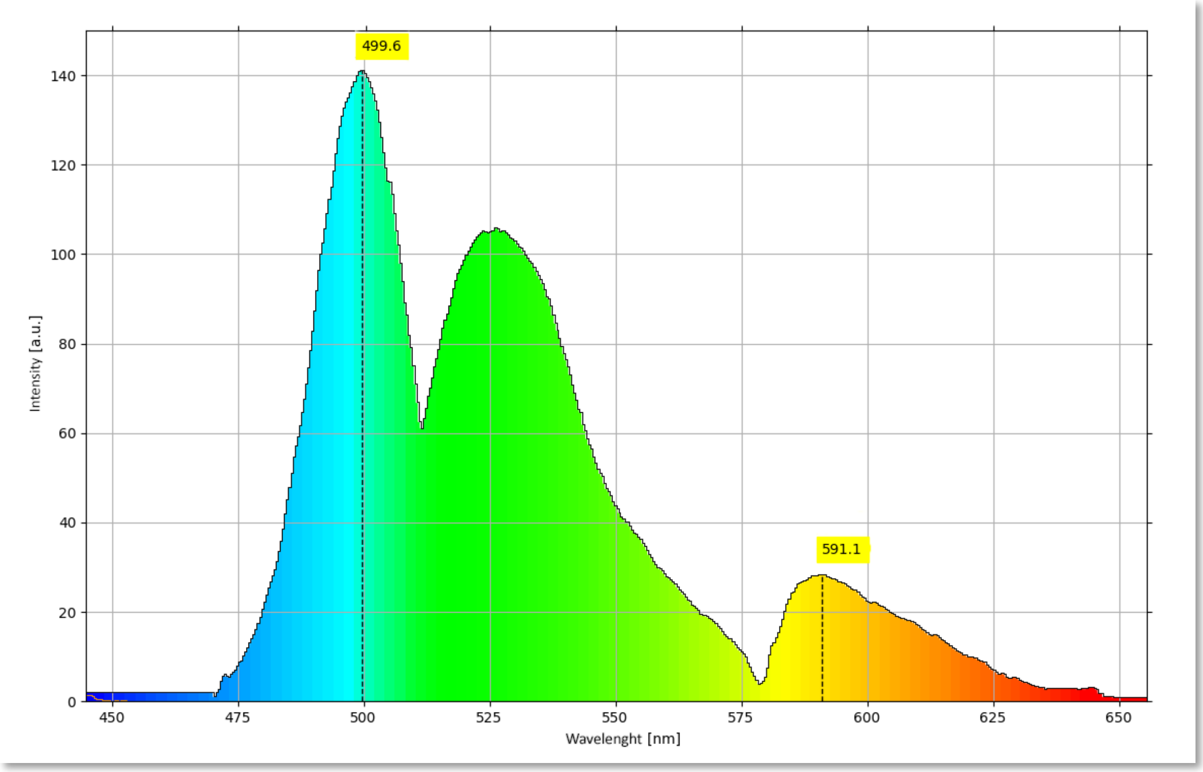
The luminescence spectrum of the orange highlighter - the wavelength of the UV source is smaller than the wavelength of the luminescence spectrum (verification of Stokes' rule)



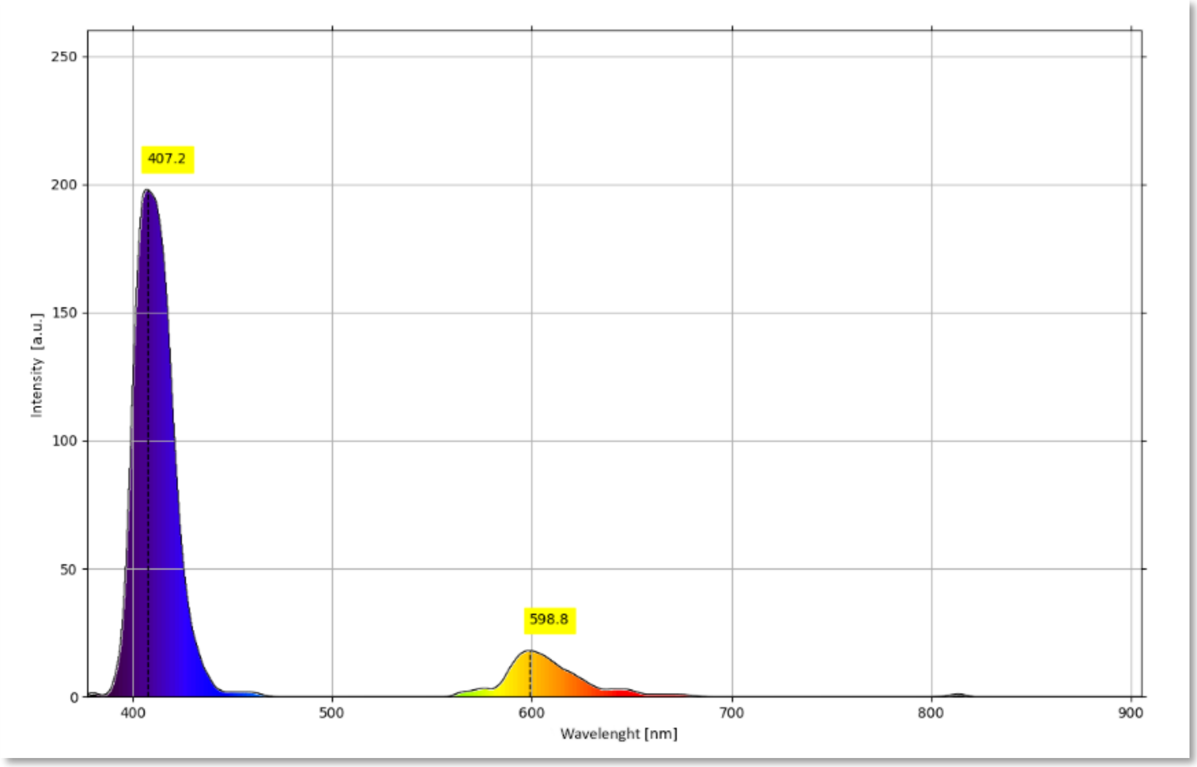


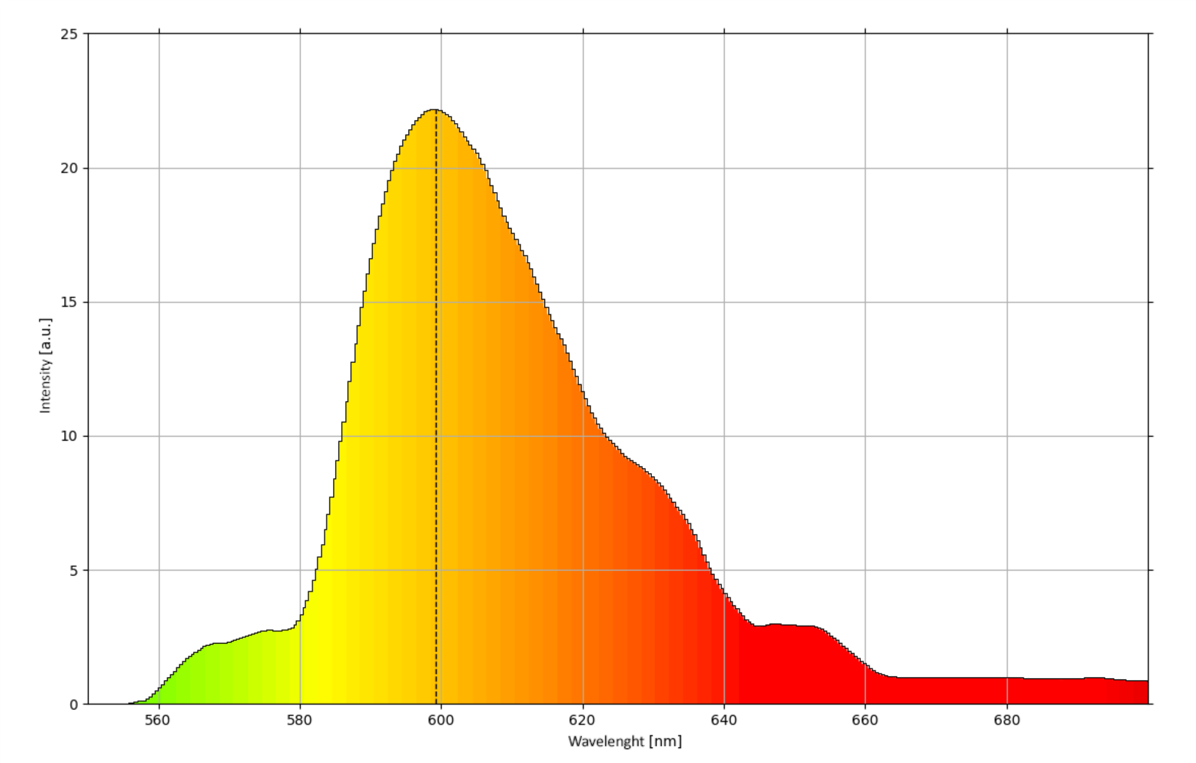
Amplified and zoomed in on the luminescence spectrum of the green highlighter





Amplified and zoomed in on the luminescence spectrum of the yellow highlighter

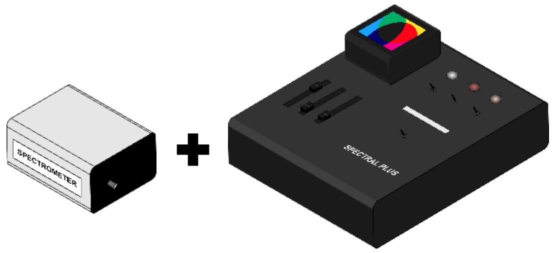




Amplified and zoomed in on the luminescent spectrum of the pink highlighter

5 EMISSION SPECTRUM OF THE LAMP - WHY DOES THE LAMP LIGHT?

High school *– Physics: Topic: Electromagnetic radiation and particles of light - Emission spectrum, line spectrum, continuous spectrum*



SPECTRA + SPECTRAL PLUS

Fluorescent lamps are low-pressure light tubes filled with mercury vapor. The inner walls of the tubes are covered with luminophore (a substance capable of luminescence – it changes ultraviolet radiation into light). The main charge is mercury, argon is added to facilitate ignition.

How does it work

A fluorescent lamp is a type of electric light source that uses the radiation of a glowing electric discharge in mercury vapor to convert electrical energy into light. The discharge emits invisible ultraviolet radiation, which irradiates a thin layer of a suitable luminophore applied on the inside of the fluorescent lamp tube. The radiation excites the luminophore molecules, which subsequently emit photons of visible light when they return to their original state.

The colors (wavelengths) of the light produced by the glow discharge are specific to each gas – they are like the 'fingerprints' of the gas. Therefore, we can tell what kind of gas is inside the tube by analyzing the spectral lines. Green and blue lines are typical for mercury vapor. Mercury atoms also emit light in the ultraviolet wavelength range.

5.1 How to show that argon and mercury are part of an energy-saving fluorescent lamp?

QUESTIONS:

1. As we will show that argon is present in the emission spectrum.
2. Why is the resulting light white?

Utilities:

Spectrometer, **SPECTRAL Plus**

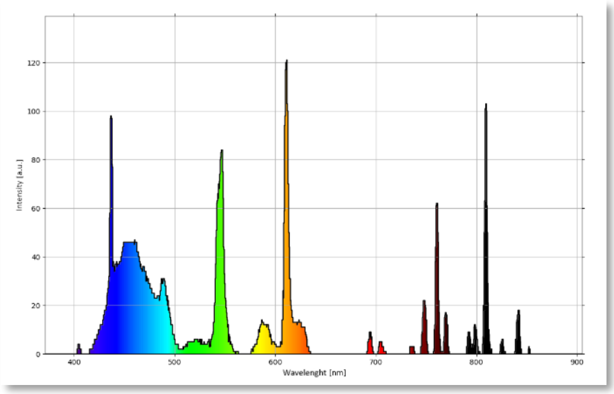
Procedure:

1. Using a USB cable, connect the spectrometer to the computer and turn on SW Spectra, select the camera of the spectrometer, and start the measurement.
2. We connect the optical cable and lens to the spectrometer.

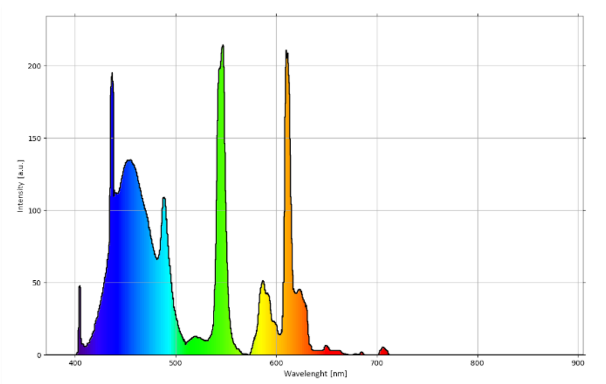
Recommended experimental setup

3. We turn on SPECTRAL Plus and aim the optical cable with the lens over the fluorescent tube.
4. We turn on the fluorescent lamp and immediately save the recorded spectrum.
5. After 15 seconds, we save the spectrum again.
6. We compare.

Results, answers to questions, and analysis of the measurement:

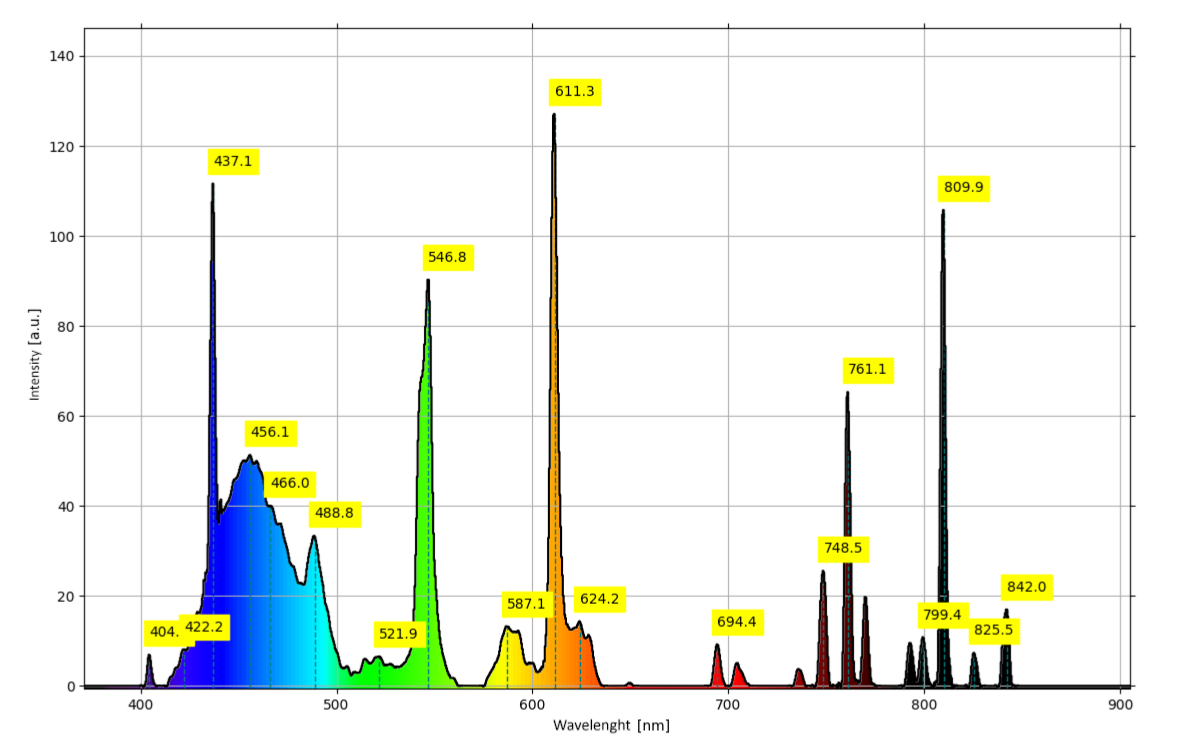


Spectrum immediately after switching on



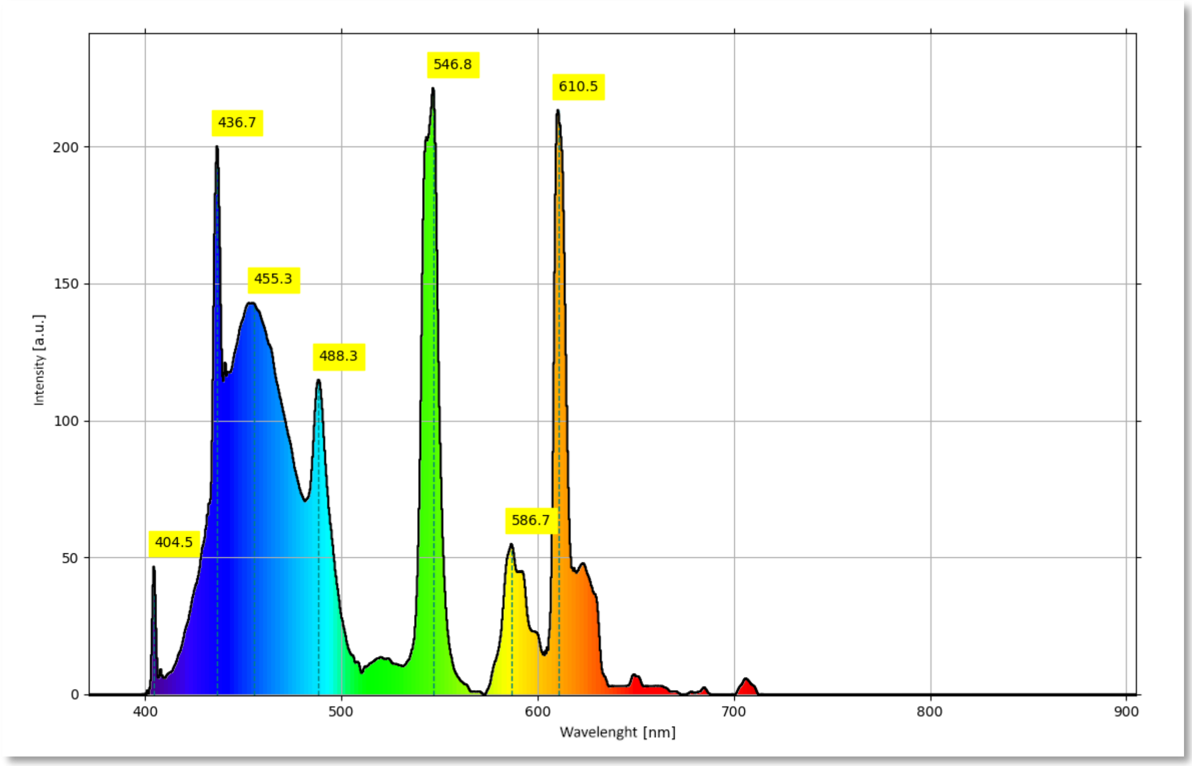
Spectrum 15 s after switching on

1. To create mercury vapors in a fluorescent lamp, it is necessary to supply them with sufficient energy. This is what argon is used for in a fluorescent lamp. We can prove the presence of argon by looking at the spectrum immediately after switching on the fluorescent lamp. Then we can observe the spectral lines in longer wavelengths and after comparing them with those in the table, we can confirm that it is argon.
   However, after transferring its energy to mercury, the argon goes out, so after 15 seconds we no longer observe the argon spectral lines.



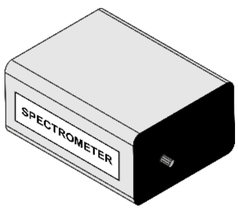
The spectrum of the fluorescent lamp immediately after switching on, in the right part of the graph we can see the spectral lines of argon

2. In the spectrum of the fluorescent bulb, we can see a few main bright lines and a part of the continuous spectrum with a dominant blue color. Green and blue lines are typical for mercury vapor. Mercury atoms also emit light in the ultraviolet wavelength range. It is the ultraviolet components that are responsible for the luminescence of the luminophore, which is applied on the inside of the tube. The excited phosphor is responsible for the light's continuous blue spectrum and red components. The phosphor emits a wide range of wavelengths. It also contains impurities such as europium, which is responsible for the red line. So the resulting spectrum is a combination of the mercury spectrum and the phosphor spectrum.



6 PROPERTIES OF SOLAR RADIATION - OBSERVATION

__Middle school__ – Physics: Topic: Light - Source of light, Sun and light bulb as sources of light
__High school__ - Physics: Topic: Electromagnetic radiation and particles of light
Emission spectrum, line spectrum, continuous spectrum



SPECTRA

With the help of the SPECTRA school spectrometer, we can examine the solar spectrum, as well as the spectrum of sunlight reflected from various objects, or passing through various objects. We obtain the light spectrum by dividing it into individual colors. The light that shines at the interface of the medium can be reflected, transmitted, or absorbed by the material.

Measurement with a school spectrometer in the outdoor environment allows, in the first step, to measure the spectrum of the Sun, and the sky and point out the differences between them.

Recommended setup of the experiment

6.1 Observation of the spectrum of clear sky, clouds, and Sun.

Utilities:

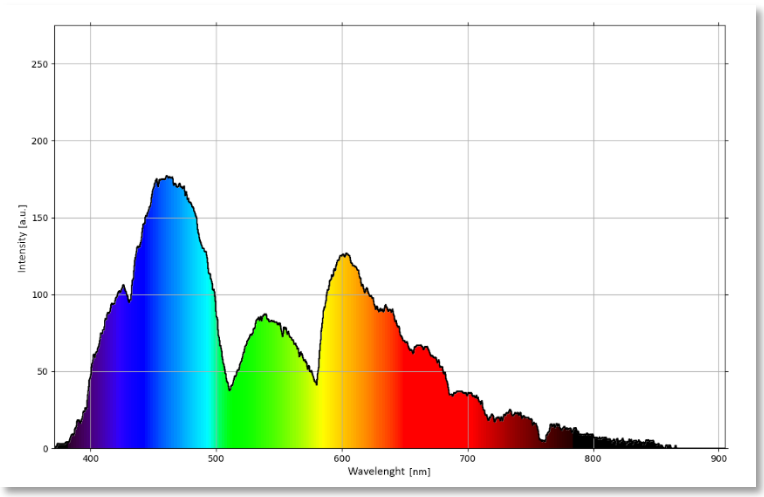
Spectrometer SPECTRA, optical fiber, lens, stand, computer with SW Spectra

Procedure:

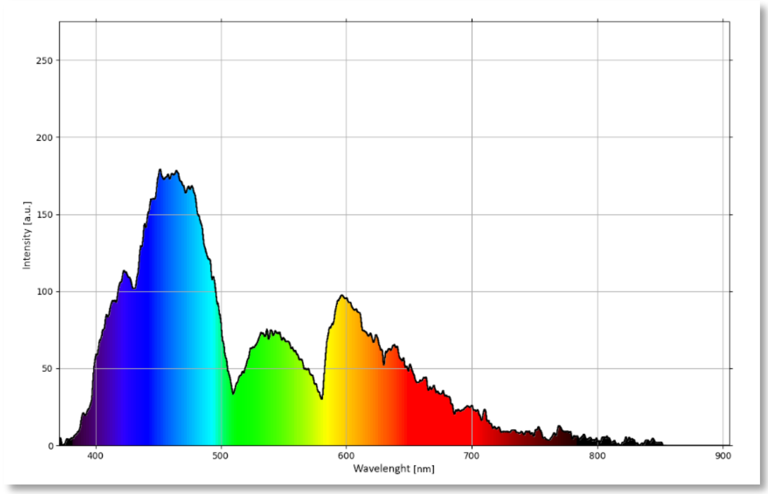
1. Using the USB cable, connect the spectrometer to the computer and turn on SW Spectra, select the camera of the spectrometer, and start the measurement.
2. We will connect an optical cable and a lens to the spectrometer, if necessary we will also use a stand.
3. We aim the spectrometer successively at clouds, a clear sky, and the Sun and watch how the displayed spectrum changes.
4. We save the individual spectra and then compare them. The "Difference" function can also be used for „comparison“.

Measurement results and analysis:

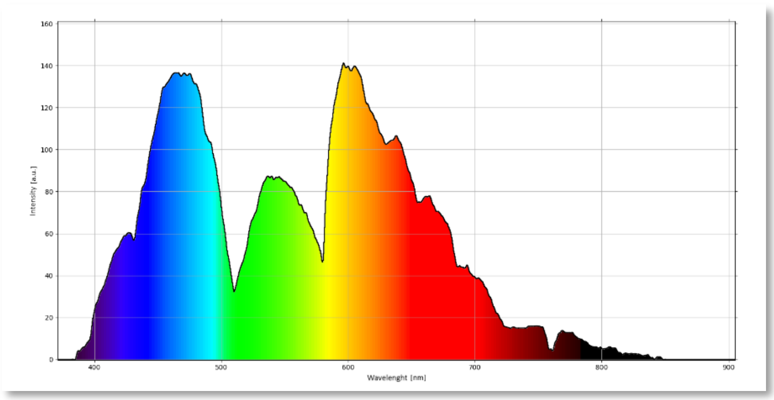
In the continuous spectrum of solar radiation, in addition to visible light, we can also observe **ultraviolet (below 400 nm) and infrared radiation (above 780 nm)**.



The spectrum of white clouds

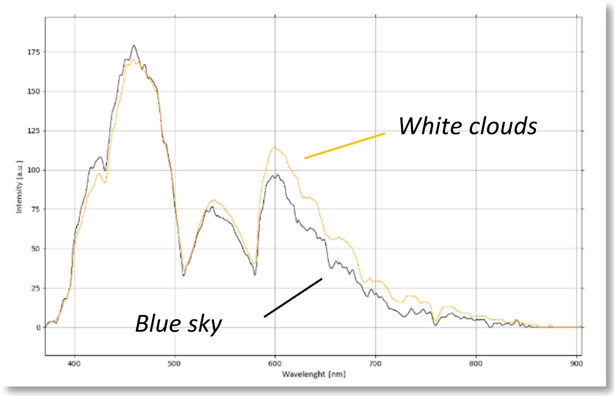


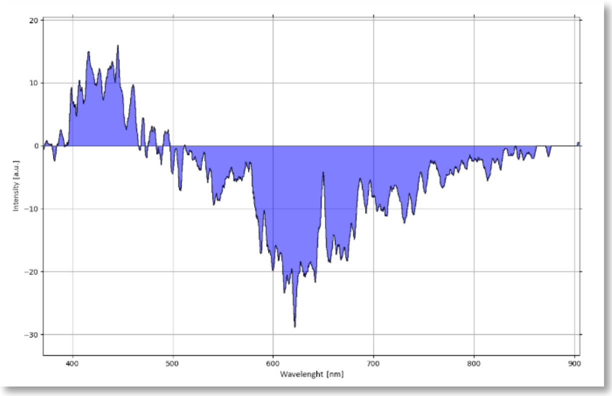
Blue sky spectrum



The spectrum of solar radiation around 11:00 AM near the solar disk.

<u>Comparison of the spectrum of white clouds and blue sky:</u>

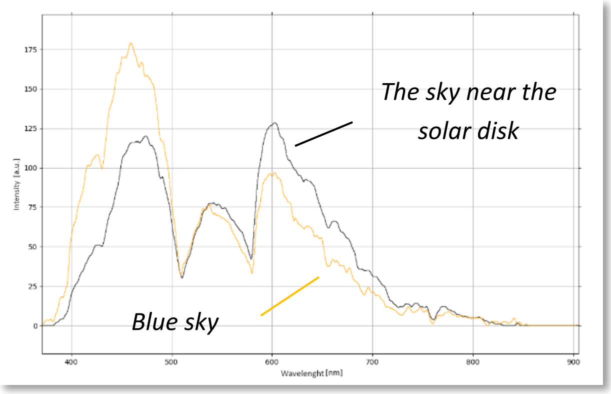


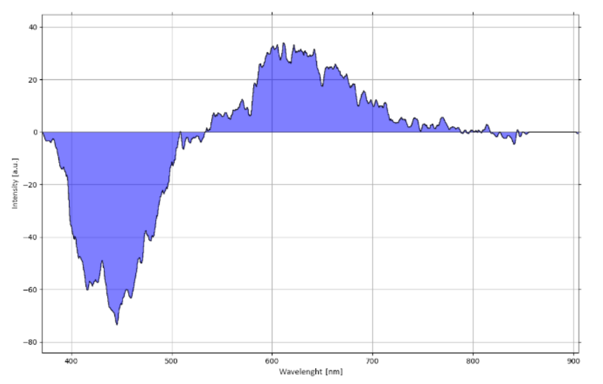


The difference between the spectra of blue sky and white clouds

From the graphs, we can see that the blue sky contains more of the blue component of light and less of the red. In the case of clouds, since they are denser, there is a more uniform molecular scattering and thus we can observe a greater intensity of light components with a longer wavelength.

<u>Comparison of the blue sky spectrum and the sky near the solar disk:</u>





The difference between the spectra of the sky near the solar disk and the blue sky

The blue sky spectrum mainly contains shorter wavelengths (blue), which is related to the molecular scattering of solar radiation in the atmosphere. Short wavelengths are scattered the most intensively. Therefore, the sky shines primarily with blue diffused light. The other components remain in direct solar radiation and in its immediate vicinity, which we can observe in the spectrum of solar radiation near the solar disk (the sky near the solar disk already contains several longer wavelengths).

Other subjects to observe:

Comparison of the solar spectrum in the morning and the evening:

If we compare the solar spectrum in the lunch hours and the evening hours, we find that the course is similar, but not the same. In the case of the spectrum of evening solar radiation, we can notice that the spectrum is shifted to longer wavelengths, while the intensity in the region of shorter wavelengths is lower.

6.2 HOW ARE THE COLORS OF OBJECTS FORMED? Observing the spectrum of reflected light from various objects outside - grass, flowers, snow, colored papers, ...

Utilities:

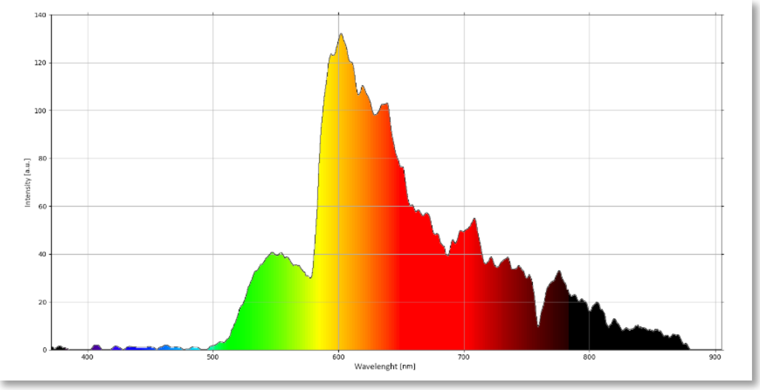
Spectrometer SPECTRA, optical fiber, lens, computer with SW Spectra

Procedure:

1. Using the USB cable, connect the spectrometer to the computer and turn on SW Spectra, select the camera of the spectrometer, and start the measurement.
2. We connect the optical cable and lens to the spectrometer.
3. We aim the spectrometer at objects illuminated by sunlight.
4. Using a school spectrometer, we will record the spectrum of reflected light from various objects.
5. The measurement is best carried out as a student activity during a sunny day outside in nature, while it is possible to measure the reflected spectrum of grass, flowers, or clothes, car paint, house walls, etc.
6. We will compare the results.

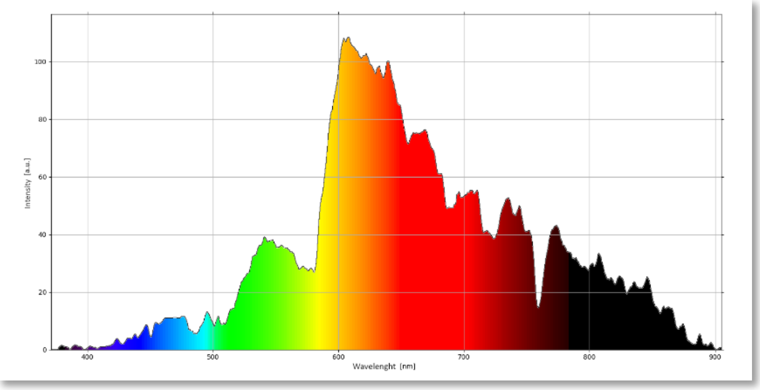
Measurement results and analysis:

The yellow flower mainly reflected the yellow-orange part of the spectrum, but in the reflected light the green color is partly present. The resulting color perception is thus composed of several colors of the spectrum. So it is not a pure spectral color, but a mixture of different colors.



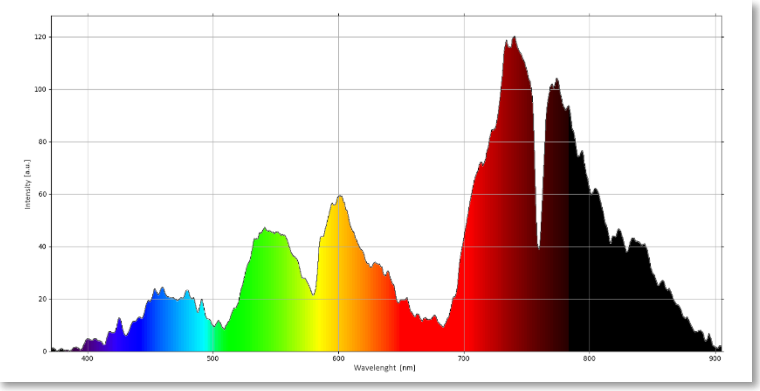
Reflected spectrum of sunlight from a yellow flower

The orange flower reflected the yellow-orange part of the spectrum shifted more towards red wavelengths, but in the reflected light there is also a green color present.



The reflected spectrum of sunlight from an orange flower

We can see on the spectrum reflected from a green leaf that it is similar to the absorption spectrum of chlorophyll from problem 3. Chlorophyll absorbs in the UV and the red region of the spectrum, therefore the light reflected from the leaves has a green color and we perceive the leaves as green. Since the spectrometer can also display the near-infrared spectrum, we can see that even these wavelengths are not absorbed by the chlorophyll, and are reflected from the plant leaves.



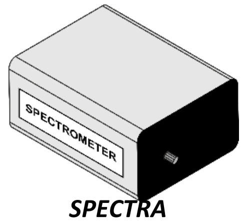
The reflected spectrum of sunlight from a green leaf

Other subjects to observe:

Observation of the spectrum of transmitted light through various objects - colored vases, glasses, films, sunglasses.

7 FRAUENHOFER LINES - WHICH WAVELENGTHS ARE ABSORBED BY THE ATMOSPHERE?

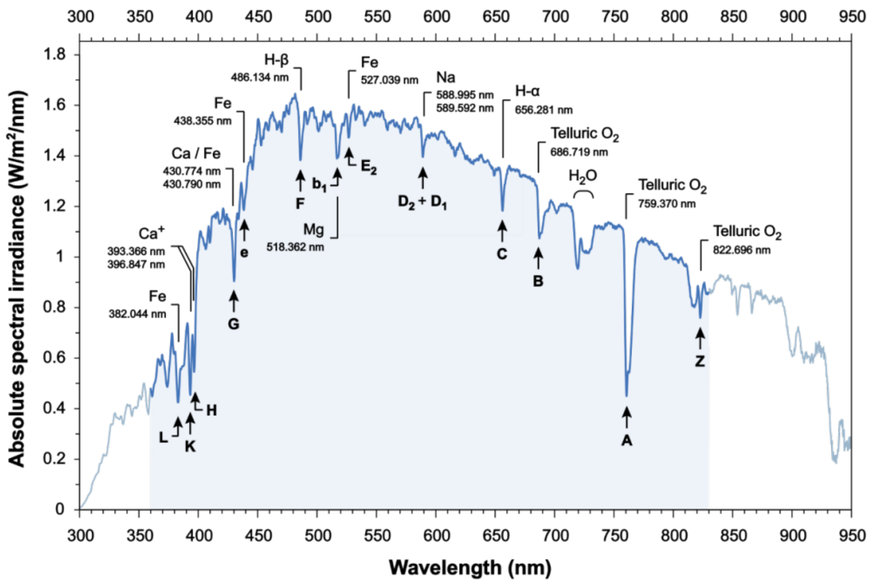
High school – Physics: Topic: Electromagnetic radiation and particles of light
Emission spectrum, line spectrum, continuous spectrum



SPECTRA

The brightest star in our sky is the Sun. Absorption lines in the solar spectrum were first noticed by an English astronomer in 1802, but it was the German physicist Joseph von Fraunhofer who first measured and cataloged more than 600 of them about 10 years later. These lines are now collectively known as "Fraunhofer lines". In the 1800s, scientists did not know that these lines were of chemical origin. Thus, the letters used by Fraunhofer to identify the lines are not related to chemical symbols or to the symbols used to indicate the spectral types of stars. Astronomers today use some designations simply for convenience and ease of line identification.

We now know that each absorption line is caused by the transition of an electron between energy levels in an atom. Each element has a different pattern of absorption lines. After observing the line pattern of a particular element in the laboratory, it is possible to determine whether those elements exist elsewhere in the universe simply by looking at the pattern matching the absorption lines.



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In this exercise, we work with the solar spectrum between about 380 and 900 nm and identify some of the strongest Fraunhofer lines.

Frauenhoferove čiary - absorpčné sp Frauenhofer lines - absorption spectral lines that arise in the solar photosphere Frauenhofer lines - absorption spectral lines that arise in the solar photosphere and the Earth's atmosphere.

7.1 Identification of Fraunhofer lines and absorption lines of water in the emission spectrum of sunlight.

Utilities:

Spectrometer, optical cable, and lens, table with wavelengths of Fraunhofer lines

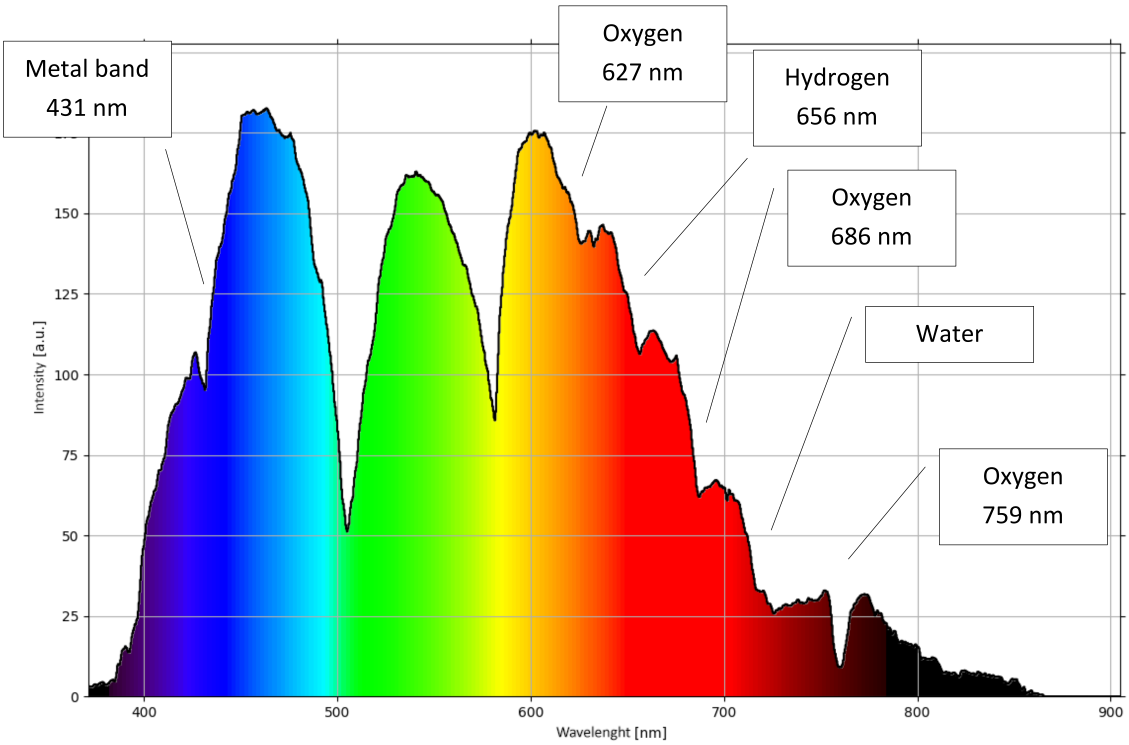
Procedure:

1. Using the USB cable, connect the spectrometer to the computer and turn on SW Spectra, select the camera of the spectrometer, and start the measurement.
2. We connect the optical cable and lens to the spectrometer.

Recommended experimental setup

3. We aim the spectrometer at the sky and set the scanning parameters so that the spectrum is not oversaturated.
4. We save and analyze the measurement.

Measurement results and analysis:

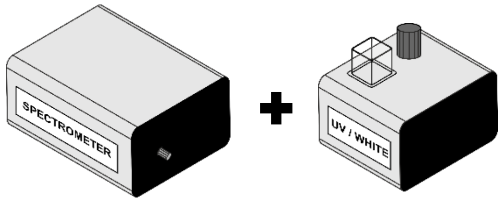


Identification of absorption lines in the spectrum of sunlight.

Note: The division into RGB components is caused by filters that are part of the camera.

8 BULB TEMPERATURE CHANGE - BLACKBODY THEORY

High school - Topic: Electromagnetic radiation and light particles - Emission spectrum, line spectrum, continuous spectrum



SPECTRA + SPM-UV-W-LS

All bodies at any temperature emit electromagnetic radiation. The higher the body temperature, the more intense the radiation. Black body theory deals with radiation from bodies. At low temperatures, mainly low-energy waves, such as infrared radiation, are emitted. If a body exceeds a certain temperature limit, it emits mainly red light (light with a long wavelength in the visible light region) - for example, a hot iron. If we further increase the temperature, the color changes from orange to green to blue. After a further increase in temperature, it is ultraviolet, X-ray, and gamma radiation. So, the higher the temperature, the shorter wavelengths are represented, which correspond to radiation with greater energy.

With this experiment, we can show that the brighter the bulb shines (i.e. connected to a higher voltage), the spectrum changes so that the peak of the curve shifts to the left (to lower wavelengths) because a warmer object emits more blue light. This is a qualitative verification of Planck's law of black-body radiation.

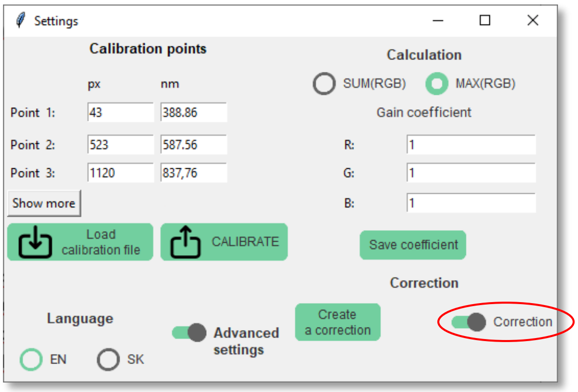
Procedure:

1. Using the USB cable, connect the spectrometer to the computer and turn on SW Spectra, select the camera of the spectrometer, and start the measurement.
2. Using an optical fiber, we connect the white light source to the spectrometer.

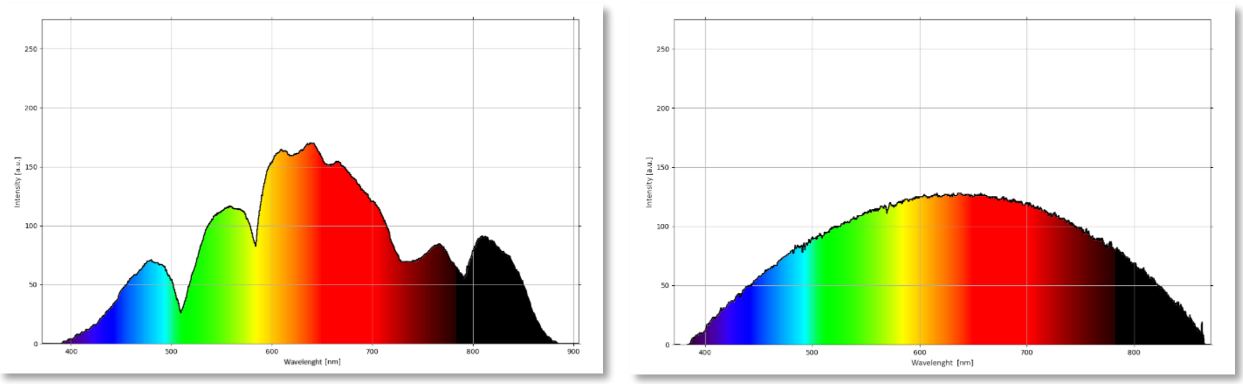
Recommended setup of the experiment

3. We turn on the light source in white light mode, do not insert the cuvette into the source, and turn the potentiometer to the maximum position.
4. Using the SW, we set the exposure so that the signal is not oversaturated (-3).

5. *We pause* the spectrum.
6. We set the curve correction as follows:
   a) Click on Settings and calibration → *Advanced settings* → *Create correction*
   b) A dialog box will confirm that the correction has been created.
   c) Click on ok and turn on *Correction* in the settings.

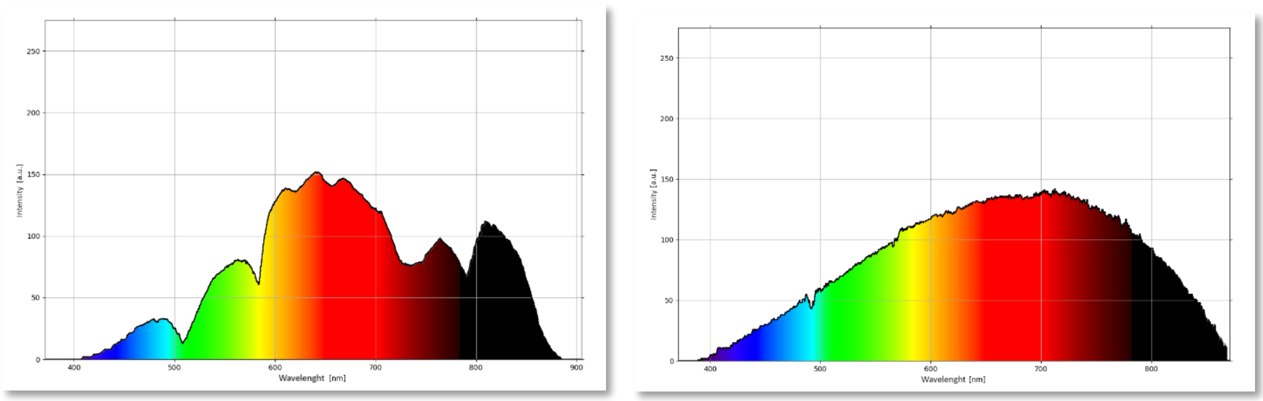


   d) We start the measurement and save.
7. We save the corrected curve as a reference spectrum.



The spectrum of the lamp at the maximum input power P_1 without correction (left) and with correction (right)

8. We change the power of the source by turning the potentiometer, we increase the intensity by changing the exposure (0 or -1).
9. We adjust the spectrometer's scan parameters so that your new corrected spectrum has approximately the same peak intensity as the reference spectrum. We save the result.
10. We look at the uncorrected spectrum by turning off *Correction* in the *Settings and calibration* window.

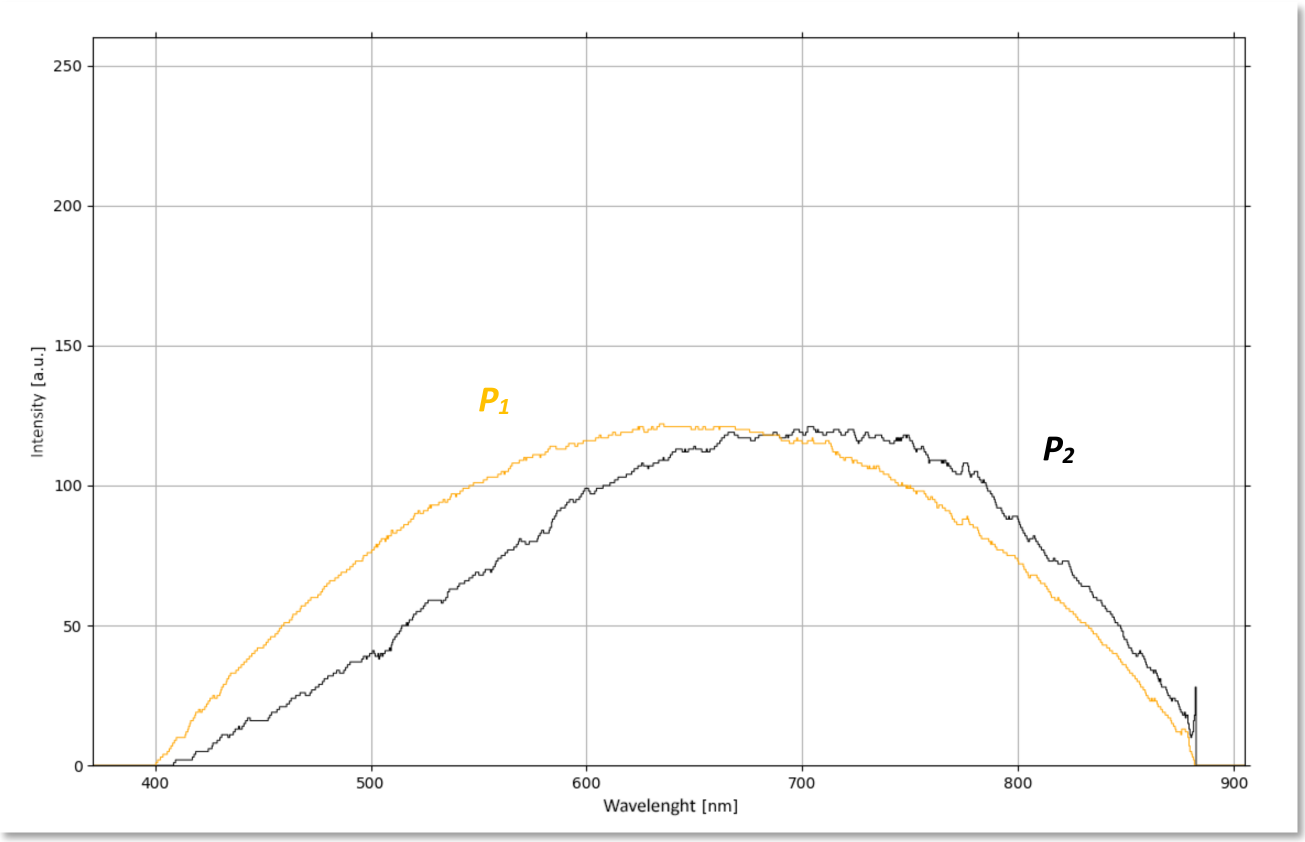


The spectrum of the light bulb at the input power P_2 (where $P_2 < P_1$) without correction (left) and with correction (right)

11. We will compare both spectra so that the corrected spectrum at reduced power will be displayed as the current spectrum and the reference spectrum at maximum power will be displayed in the background.

Measurement results and analysis:

When we compare both curves, we see that the source with lower temperature, i.e. lower power and voltage, has maximum intensities at higher wavelengths than the source with higher temperature and thus also higher power and voltage. The peak is shifted to the right part of the spectrum on a light bulb with a lower voltage by Planck's law of blackbody radiation.



Comparison of corrected spectra at source power P_1 and $P_2 < P_1$

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