SPECTROCLICK KIT

EXPLORE THE INTERACTION OF LIGHT AND MATTER
THE SCIENCE OF SPECTROSCOPY

SPECTROCLICK
60 HAZELWOOD Dr., Room 213
Champaign, IL 61820

WARNING: NOT INTENDED FOR CHILDREN UNDER THE AGE OF 6
ADULT SUPERVISION REQUIRED
FOR CLASSROOM USE ONLY

SPECTROCLICK KIT
INSTRUCTIONS

SpectroClick, Inc.
60 Hazelwood Dr., Room 213
Champaign, IL 61820
spectroclick.com

SPECTROCLICK KIT parts are made in China and the U.S.A.
SPECTROCLICK KIT is assembled in the U.S.A.

DISCLAIMER
SpectroClick Kit and spectroclick.com materials should never be used for any medical, regulatory, industrial, or commercial measurement. It is explicitly unsuitable for any purpose other than education.

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HANDLE BATTERIES WITH CARE:
WHEN ACTIVITY IS COMPLETED, STORE BATTERIES APART FROM LED BULBS. PLACE EACH BATTERY IN A SEPARATE PACKAGE SO THAT SIDES ARE NOT TOUCHING.

SPECTROCLICK KIT PRIMARY

Note: In addition to the SpectroClick Kit components, students require plain water.

Observe for yourself that light is made up of all the colors of the rainbow! Have you seen the color spectrum from a rainbow outside, from light that passes through a prism, or from light shining on a DVD?

People see white light when all the colors are present at once. As the white lights in your home or school shine on various objects, why doesn't everything look white? Materials interact with the light that shines on them. Some light is reflected (as with a mirror) and some is absorbed, just like a sponge absorbs water. The light you see is reflected light or, if looking through a window, transmitted light.

One way to see the differences among various materials is by measuring their colors using spectroscopy, the study of the interaction of light with matter. The **SpectroClick Kit** allows you to see light and a spectrum through a diffraction grating, and see how to measure the colors. First take out the materials in your kit and match them to the parts drawing.

First steps

Before you assemble the parts on the cardboard base, hold the white cardboard diffraction grating and look through it at the lights around you:

- lights overhead
- desk lamp lights
- computer screen lights

Look at all the lights you can, except DON'T look directly at the sun and DON'T look at a laser light! All other lights are safe to look at with the diffraction grating.

Did you see different combinations of colors with each kind of light source? This is because each kind of white light, even if it looks about the same to us, is actually made up of different combinations of colors of light.

Assemble your kit

Open up the SpectroClick Kit cardboard base so that it is flat. Fold one end to make a rectangle with a slot to hold the LED bulb and battery.

Insert the battery between the LED prongs. To turn on the light, place the long prong on the side of the battery with numbers. If the prongs slip, they can be secured to the battery with a piece of tape.

Once the LED is shining, place the battery and LED in the slot so that the bulb faces the SpectroClick cardboard base rays. Slide your diffraction grating into the stand and place it on the cardboard base. Look straight through the diffraction grating at the light. No rainbows appear when you look straight at the light. But now, look from side to side through the diffraction grating – you should see rainbow colors! Each set of little rainbow colors is a spectrum (the plural is spectra).

View the colors

The colors you see in each spectrum on both sides of the LED are in the same order as the rainbow: Red, Orange, Yellow, Green, Blue, Indigo, Violet. Many people remember this from the first letters of the name ROY G BIV. The diffraction grating allows you to see three sets of the color spectrum.

See if you can match up the colors by looking along the lines on the cardboard base. Scientists discovered that every substance has its own signature set of colors, and by measuring the amounts of each color, the substance can be identified. Looking at the angles just like you are is the first step!

Compare samples

Take the stopper out of the cuvette and open up the sample cup. Put plain water into your sample cup and use the pipette to transfer water to the cuvette. Fill it around ¾ full and put the stopper back on the cuvette.

Now place the cuvette on the cardboard base in front of the LED. Do you see the same spectrum through the diffraction grating when light passes through the water in the cuvette? How is it different from viewing the LED without the sample?

Open up the cuvette, put the plain water back into the sample cup and add the red dye tablet. Close the sample cup and shake gently to dissolve the dye, then transfer the red color water to your cuvette and close it. Again place the cuvette between the light and the diffraction grating. How is the spectrum with a red color sample different from the clear sample?

Can you answer these questions? See page 14 for the answers!

- Which changed the most when you compare the red sample to the clear sample: the amount of red, orange, yellow, green, or blue in the spectrum?
- When something is red, does it absorb red light or blue light? If you want your sample to absorb red light, what color solution would you use?
- When you look around the room, is everything that is the same color made of the same material?

Making measurements with spectroscopy

The parts in your SpectroClick Kit are similar to those in scientific instruments used to make precise measurements. This informs us about the makeup of everything from nearby objects to distant stars in the universe. You have seen for yourself the difference in spectra produced by different color samples. Light does not just illuminate everything, allowing us to see it -- light is full of information about the world around us!

SPECTROCLICK KIT SECONDARY/MIDDLE SCHOOL

Note: In addition to the SpectroClick Kit components, students should have two small cups (around 4 to 6 oz. each) and access to plain water.

By viewing a rainbow, or manipulating a prism, or even observing light reflecting from a DVD, you are observing the separation of white light into its component colors. Even when not deliberately manipulating white light, not everything looks white because light interacts with whatever material it shines on. Some light is reflected (as with a mirror) and some is absorbed, just like a sponge absorbs water. Almost all the light you see is reflected light or, if looking through a window, transmitted light.

Spectroscopy is the study of how light and matter interact, which includes measuring the differences in color of different materials. By assembling and using components of a rudimentary spectrometer, you will see changes in light intensity as light passes through samples, observing a simple spectrum for each sample. Your observations are similar to those recorded in spectrometers used for analysis of different materials.

Topics included are:

- Essential components of a spectrometer and the order in which light traverses through the components.
- Use of a diffraction grating, including the concepts of dispersion and diffraction order.
- Relationship between sample concentration and transmitted light intensity.

First steps

Before you assemble the parts on the cardboard base, hold the white cardboard diffraction grating and look through it at the lights around you, such as overhead lights, a desk lamp, and computer screen lights. Look at a variety of lights, except DON'T look directly at the sun and DON'T look at a laser light. All other lights are safe to look at with the diffraction grating. Did you see different combinations of colors with each kind of light source? This is because each kind of white light, even if it looks about the same to us, is actually made up of different combinations of colors of light.

Assemble the kit and view spectra

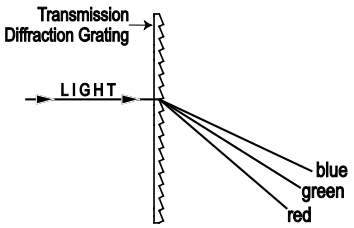
Open up the SpectroClick Kit cardboard base so that it is flat, then fold up the end to make a rectangle with a slot. Insert the battery between the LED prongs and place the lighted LED in the slot so that the bulb faces the cardboard base rays. If the prongs slip, they can be secured to the battery with a piece of tape.

Slide your diffraction grating into the stand and place it on the cardboard base. When you look straight through the diffraction grating, you will see just the LED light with no spectrum; this is a zero order spectrum because none is visible. First, second, and third order spectra are visible to each side. Here, the white light was separated by the

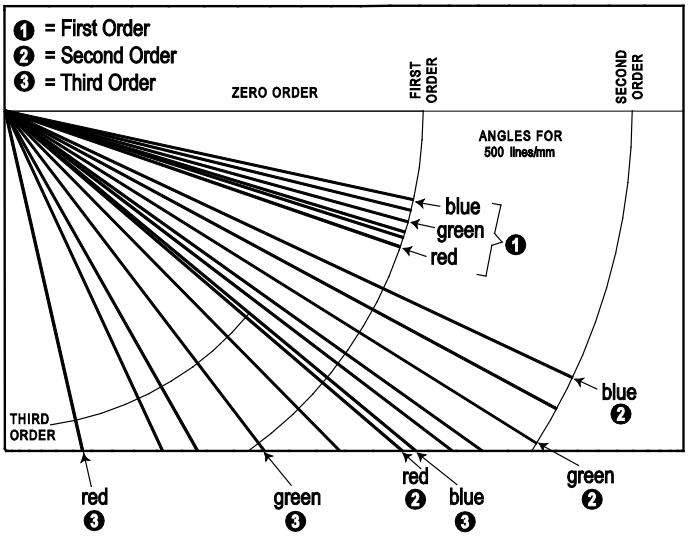
diffraction grating into its component wavelengths, similar to what is seen with a rainbow or a prism.

Scientific Background and Experiments

A transmission diffraction grating is made of a transparent material with regularly spaced groves cut into one side. Light passing through the material is diffracted, or separated into light with wavelengths visible at different angles that we see as different colors, always in the order of Red, Orange, Yellow, Green, Blue, Indigo, and Violet. Many people remember this from the first letters of the name ROY G BIV.



Zero order (looking straight at the light) follows a path that does not change angle when passing through the grating. You can view the first, second and possibly the third, order angles for each spectrum by looking along the lines on the base plate. Negative first, second and third order are on the other side of zero order (a mirror image of the positive orders).



Observations

Open the cuvette and the sample cup, and place plain water into the sample cup. Using the pipette, fill the cuvette around ¾ full with plain water and replace the cap. Place the cuvette on the cardboard base on the square in front of the LED and look at the light through the diffraction grating. Are all colors equally present in the spectrum?

Add the red dye tablet to the sample cup, close it and shake gently to dissolve the dye. Remove the plain water from the cuvette, then transfer the red color water to your cuvette and close it. Again place the cuvette between the light and the diffraction grating. How is the spectrum with a red color sample different from the clear sample?

Remove half of the red color sample from the cuvette, placing it in an empty cup. Now dilute your sample with additional plain water to the earlier level in the cuvette. Are you seeing a difference in the spectrum as you dilute the sample? Continue to dilute the sample by half several times, observing the sample color (to your eye) and the spectrum (through the instrument) each time. Which happens first: dilution so that the sample looks perfectly clear or dilution so that the spectrum looks identical to the spectrum through pure water?

Follow up questions -- See page 14 for the answers!

- Which changed the most when you compare the red sample to the clear sample: the amount of red, orange, yellow, green, or blue in the spectrum?
- When something is red, does it absorb red light or blue light? If you want your sample to absorb red light, what color solution would you use?
- You have a friend who is red-green color blind. Suggest how the friend could use a diffraction grating to determine whether a colored soda straw is red or green.

Making measurements with spectroscopy

The parts in your SpectroClick Kit are similar to those in scientific instruments used to make precise measurements, informing us about the makeup of everything from nearby objects to distant stars in the universe. You have seen for yourself the difference in spectra produced by different color samples. While you can only observe visible light, bees can see light in the near infrared spectrum. Various materials can respond to light all the way from gamma rays (wavelengths less than 0.01 nm) to radio waves (wavelengths from 1 mm to many kilometers).

Not only can we learn about materials by looking at their absorption, but also at their reflection or emission. For example, the light from a lightning bolt has ultraviolet emission from nitrogen molecules, and the blue inner flame of a candle is due to carbon molecules (the yellow outer flame is emission from small soot particles). Our eyes can discern a limited range of light, but we can learn about a myriad of substances and their interactions through spectroscopic analysis.

SPECTROCLICK KIT ADVANCED

Note: In addition to the SpectroClick Kit components, students should have two small cups (around 4 to 6 oz. each) and access to plain water.

By assembling and using components of a rudimentary spectrometer, you will observe changes in light intensity as light passes through samples, and be able to analyze a simple spectrum. While not producing high quality data, manipulating the components fosters understanding of the relationships among light intensity, concentration, and instrument parameters.

Topics included are:

- Essential components of a spectrometer and the order in which light traverses through the components.
- Use of a diffraction grating, including the concepts of dispersion and diffraction order.
- Relationship between sample concentration and transmitted light intensity.
- Limitations of the rudimentary spectrometer, and how a quality instrument overcomes the limitations to produce useful data, using the example of stray light and its relationship to measurement quality.

Assemble the kit and view spectra

Open up the SpectroClick Kit cardboard base so that it is flat, then fold up the end to make a rectangle with a slot. Insert the battery between the LED prongs and place the lighted LED in the slot so that the bulb faces the cardboard base rays. If the prongs slip, they can be secured to the battery with a piece of tape.

Slide your diffraction grating into the stand and place it on the cardboard base. Zero order is obtained by looking straight through the diffraction grating; first, second, and third order spectra are visible to each side. A spectrum is produced by a beam of light passing through material with certain properties, separating light into its component wavelengths, similar to what is seen with a rainbow or a prism.

Conducting Quantitative Analysis with a Camera and Software

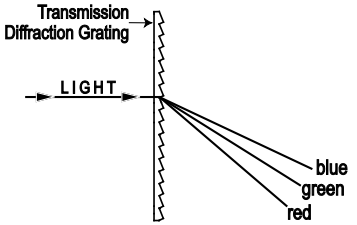
You can use a digital camera along with supporting software to make this experiment semi-quantitative. Free software is available at www.asdlib.org/onlineArticles/elabware/Scheeline_Kelly_SpectrophotomerV2/index.html

The software runs under Microsoft *Windows*, and was written for Windows *XP*. Revised software to run on other systems will be posted at SpectroClick's website when available.

Scientific Background and Experiments

Diffraction gratings

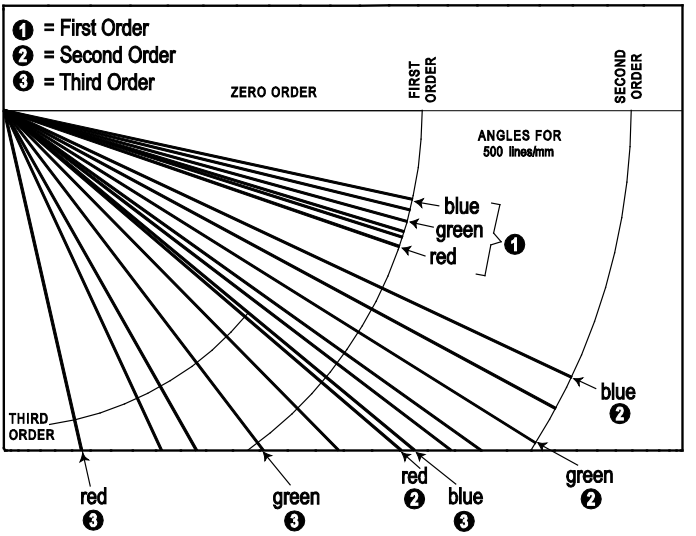
A transmission diffraction grating is made of a transparent material with regularly spaced groves cut into one side. Light passing through the material is diffracted, or separated into light with wavelengths visible at different angles that we see as different colors, always in the order of red, orange, yellow, green, blue, indigo, and violet.



The separation of light is governed by the equation:

$$n\lambda = d\cos\theta\sin\beta$$

where n is the diffraction order, λ is the wavelength, d is the spacing between the diffraction grating grooves (usually calculated in nanometers/groove), θ and β are the angles of grating rotation and diffraction, respectively.



Zero order (looking straight at the light) follows a path that does not change angle when passing through the grating. You can view the first, second and possibly the third, order angles for each spectrum by looking along the lines on the cardboard

base. Negative first, second and third order are on the other side of zero order (a mirror image of the positive orders).

Measuring light intensity

Spectrometers are instruments that measure light intensity. This includes measuring the absorbance of light at various wavelengths in solution samples. The absorbance, A, of a solution is a measure of how much light passes through a solution versus how much is absorbed by the solution. Absorbance is defined using Beer's Law

$$A = -\log_{10} \frac{I}{I_0}$$

where I_0 is the amount of the experimental wavelength of light present before it passes through the solution, and I is the amount of light present after the light has passed through the solution. In general, the darker the solution, the less light passes through it and the higher the absorbance.

What makes this rudimentary spectrometer different than a spectrometer that functions as a precise scientific instrument? Both have similar components: a light source, cuvette, grating, and detector (for your spectrometer, your eyes!). But a spectrometer is a system, not just a collection of parts. Components are the individual parts, while a system is the combination of components, arranged according to the component characteristics to produce results.

From rudimentary to precise instruments

A component missing from your kit is a box to shield the parts from room light. You can see why this is necessary: with the room lights on, look at the first order spectrum. Now turn off the lights and look again. If it is very dark, is anything different? Of course – with the lights off, you may not see the walls or anything else in the background. When the room lights are on, you see not only light from the LED shining through the cuvette to the grating and then on to your eye, but also stray light from around the room.

Your eye only distinguishes the spectrum from the stray light because you know a rainbow when you see one. A camera you would use as a detector is not as discerning – it just records all light. So instead of measuring I and I_0, it includes the sum of those values plus any stray light I_{stray}. This is a measurement error – even if your sample absorbs all the blue light, the detector still registers the stray light at the position where only blue light is expected. The Beer's Law equation then looks like this:

$$A = -\log_{10} \frac{I + I_{stray}}{I_0 + I_{stray}}$$

How can you get rid of stray light? Putting everything in a box to keep out room light is a good start. Having a clean, unscratched, unfogged diffraction grating is another. Keeping fingerprints off the cuvette is still another. Compensating for stray light is an example of how complex systems are built to enhance instrument function.

Observations

Open the cuvette and the sample cup, and place plain water into the sample cup. Using the pipette, fill the cuvette around ¾ full with plain water and replace the cap. Place the cuvette on the cardboard base on the square in front of the LED and look at the light through the diffraction grating. Are all colors equally present in the spectrum?

Add the red dye tablet to the sample cup, close it and shake gently to dissolve the dye. Remove the plain water from the cuvette, then transfer the red color water to your cuvette and close it. Again place the cuvette between the light and the diffraction grating. How is the spectrum with a red color sample different from the clear sample?

Remove half of the red color sample from the cuvette, placing it in an empty cup. Now dilute your sample with additional plain water to the earlier level in the cuvette. Are you seeing a difference in the spectrum as you dilute the sample? Continue to dilute the sample by half several times, observing the sample color (to your eye) and the spectrum (through the instrument) each time. Which happens first: dilution so that the sample looks perfectly clear or dilution so that the spectrum looks identical to the spectrum through pure water?

Follow up questions -- See page 14 for the answers!

- Which changed the most when you compare the red sample to the clear sample: the amount of red, orange, yellow, green, or blue in the spectrum?
- When something is red, does it absorb red light or blue light? If you want your sample to absorb red light, what color solution would you use?
- If a sample is so intensely colored that only 10% of the original light penetrates the sample at a particular wavelength, to what absorbance does this correspond?
- If you dilute the sample in the previous question by a factor of 2, what absorbance would you expect to see?
- If a high quality spectrometer can reliably record an aborbance of 0.01, how many times would you have to dilute the original sample (that transmitted only 10% of the light) to reach an aborbance of 0.01?
- The grating in your kit has 500 grooves per millimeter, or d = 1/500 mm = 0.002 mm = 2 micrometers = 2000 nm. Fluorescent lights put out a lot of light at 546 nm. At what angle would such green light be visible with this grating? (There is more than one correct answer.)
- You have a friend who is red-green color blind. Suggest how the friend could use a diffraction grating to determine whether a colored soda straw is red or green.

Making measurements with spectroscopy

The parts in your SpectroClick Kit are similar to those in scientific instruments used to make precise measurements, informing us about the makeup of everything from nearby objects to distant stars in the universe. You have seen for yourself the difference in spectra produced by different color samples. While you can only observe visible light (between 400 and 700 nm), bees can see light in the near infrared spectrum all the way to 900 nm. Various materials can respond to light all the way from gamma rays (wavelengths less than 0.01 nm) to radio waves (wavelengths from 1 mm to many kilometers). Not only can we learn about materials by looking at their absorption, but also at their reflection or emission. For example, the light from a lightning bolt has ultraviolet emission from nitrogen molecules, and the blue inner flame of a candle is due to carbon molecules (the yellow outer flame is emission from small soot particles). Our eyes can discern a limited range of light, but we can learn about a myriad of substances and their interactions through spectroscopic analysis.

Notes

Answers to Questions

PRIMARY

• In the red sample, the green and blue parts of the spectrum change the most in comparison with the clear sample.
• The red sample does not absorb red light, it does absorb blue light. For a sample to absorb red light, you would use a blue or green solution.
• Everything that is the same color is not made of the same material. Strawberries, a stop sign, and a superhero cape may all be red, but they are made of different materials.

SECONDARY/MIDDLE SCHOOL

- In the red sample, the green and blue parts of the spectrum change the most in comparison with the clear sample.
- The red sample does not absorb red light, it does absorb blue light. For a sample to absorb red light, you would use a blue or green solution.
- Place the straw so it is standing vertically at the sample location on the cardboard base. Illuminate the straw with white light from the front or the side instead of from the back, using the LED, flashlight, or light bulb. You will see the straw in zero, first, second, and third order. If the image of the straw comes out at the same angle as green light, then it's green. If it comes out at the same angle as red, then it's red.

ADVANCED

- In the red sample, the green and blue parts of the spectrum change the most in comparison with the clear sample.
- The red sample does not absorb red light, it does absorb blue light. For a sample to absorb red light, you would use a blue or green solution.
- If 10% of the light gets through the sample, then I/I_0 = 0.1 and $A = -\log_{10}(0.1) = 1$.
- From the grating equation, with θ=0 ($\cos\theta = 1$), $n\lambda = d\sin\beta$. In first order, $\sin\beta$ = 1*546 nm/2000 nm = 0.273. This corresponds to β = arcsin(0.273) or 15.8°. For n=2, $\sin\beta$ = 2*546 nm/2000 nm = 0.546. This corresponds to β = arcsin(0.546) or 33.1°. For n=3, $\sin\beta$ = 3*546 nm/2000 nm = 0.819. This corresponds to β = arcsin(0.819) or 55.0°. The negative orders have the same angular magnitude, but the opposite sign.

- Place the straw so it is standing vertically at the sample location on the cardboard base. Illuminate the straw with white light from the front or the side instead of from the back, using the LED, flashlight, or light bulb. You will see the straw in zero, first, second, and third order. Measure the angle at which the image of the straw is centered and put that into the grating equation. If the apparent wavelength is shorter than 580 nm, the straw is green. If the wavelength is 600 nm or longer, it's red!

Additional Resources

Analytical Sciences Digital Library articles:
http://www.asdlib.org/onlineArticles/elabware/Scheeline_Kelly_Spectrophotometer/

Focal Point article:
https://www.osapublishing.org/as/abstract.cfm?uri=as-64-9-256A

Optical Society of America online educational materials:
http://www.osa.org/en-us/membership_education/youth_education/

Notes

SPECTROCLICK KIT

PARTS INCLUDED: