# Quantitative Spectroscope

**P2-7061**

## INSTRUCTIONAL GUIDE

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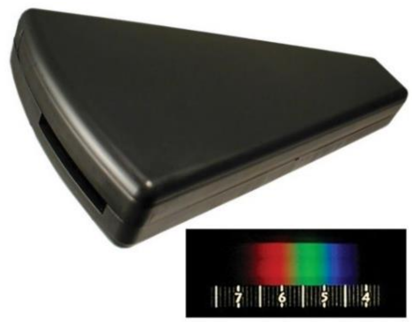
- Quantitative Spectroscope

**Recommended for Activities:**

- **Spectrum Tube Carousel Classroom Bundle (P2-9901)**

  OR

- **Spectrum Analysis Classroom Bundle (P2-9502)**



## Background

At some point, you may have noticed a rainbow projected onto a table or wall from the rim of a glass or crystal that was placed in the sun. Where did these colors come from? Why were they always in the same order with red on one side and blue on the other? At a time when it was commonly believed that light was made up of tiny particles called corpuscles, Christian Huygens (1629-1695) made a conceptual leap and described the behavior of the reflection and refraction of light with the same models that described the behavior of waves in water. As years passed, other great scientists such as Augustin Fresnel (the Fresnel lens) and Thomas Young (1773-1829) contributed experimental evidence to support the wave theory of light. Young's experiments, particularly those dealing with the diffraction of light conclusively demonstrated that light must travel in waves.

This conceptual model of light worked well until scientists tried to explain spectra made by burning chemical salts in a flame. These spectra did not stretch continuously from red to blue as the spectra of ordinary daylight does, but had several bright lines and many large dark spaces in between. Light would again be viewed as a particle when, in 1921, A.H. Compton demonstrated that light possessed *momentum*, a very particle-like quality.

Today, our current theory of light embraces both wave and particle aspects. Light is an electromagnetic wave that travels in small particle-like packets called photons. Each photon travels at the same speed: $3 \times 10^8$ m/sec, the speed of light. The energy of a photon is directly proportional to its frequency. The higher the frequency, the more energy it contains. We are all familiar with ROY G. BIV. The letters stand for the colors in the rainbow with Red, Orange, Yellow, Green, Blue, Indigo, and Violet. These colors are listed in order of increasing energy (decreasing wavelength) and comprise our visible spectrum. But the electromagnetic spectrum doesn't stop at visible light! It continues beyond the visible into higher energies with ultra violet, x-rays, and gamma rays. It also extends below red into lower energies with infra-red, and radio waves.

Electromagnetic radiation (in our specific case, light) is created when an electron moves from a higher energy level (electron orbit) to a lower energy level. The photon of light that is emitted has an energy that corresponds exactly to the difference in energy between the two orbits.

## Introduction

The heart of the spectroscope is the diffraction grating. This thin plastic film has thousands of very closely spaced lines etched in its surface—in our particular case, 500 lines per cm. This grating bends light as it passes through the lines etched on its surface according to the principles of diffraction. Additive and destructive interference between the light waves diffracted by the grating develop the spectrum seen with the spectroscope. Since the amount of diffraction is dependent on wavelength, we can quantify the wavelengths being emitted from a light source by the amount the light is diffracted. The numbered scale should be to the left of the slit as you look through the eyepiece. Each number on the scale indicates the wavelength of light in nanometer (nm) when multiplied by 100 (1 nm equals 1 x $10^{-9}$ meters).

Several types of spectra can be viewed with the Quantitative Spectroscope:

**Continuous Spectra** are usually produced by a luminous liquid or solid, such as the glowing filament of a lamp. The intensity of different wavelengths may vary so some colors may appear brighter than others.

**Emission Spectra** are produced by photons emitted from an excited element or compound (such as a gas spectrum tube) as it moves from a high energy level to a low energy level. The spectrum produced by this method is unique to each element and can be used to identify unknown matter.

**Absorption Spectra** are generated by passing a continuous spectrum (white light) through a cooler gas located between the light source and the observer. The cooler gas absorbs the wavelengths it would normally *emit* if it were the energized source, so dark lines will appear in the continuous spectrum. This can be thought of as the inverse of an emission spectrum.

## Activities

Hold the spectroscope so the small end with the square hole is toward you. The wider, curved end has a narrow slit (which lets light into the spectroscope) and a wide window with a numbered scale. While holding the spectroscope a few inches in front of your eye, look through the eyepiece of your spectroscope and point the slit end at an incandescent light bulb.

The Quantitative Spectroscope is a great tool to use for open-ended light and color activities. First try looking at a fluorescent light bulb with your spectroscope. Now, instead of a smooth continuous spectrum you see several bright lines. One is violet, one is cyan (light blue-green), one is green, one is yellow, one is orange, and a couple of red lines. This spectrum is primarily produced by mercury vapor. Try looking at other types of lamps, such as neon, or sodium vapor lamps. How do these compare? Can you identify the gases inside each light source? Compare other light sources if you can, such as halogen lamps, gas lanterns, headlights, LEDs, neon signs, etc. Great sources for interesting spectra are the halide lamps commonly found in gymnasiums. Can you tell which lamps use solid filaments by looking at their spectra?

**Wavelengths for "brighter" spectral lines for some elements are given:**

| Element | Wavelength (nm) |
|---|---|
| Hydrogen (H) | 434, 486, 656 |
| Mercury (Hg) | 436, 546, 577, 579 |
| Helium (He) | 447, 471, 492, 502, 588, 668 |
| Sodium (Na) | 589, 590 |

Note that in many cases closely-spaced spectral lines may not be resolvable with this spectroscope and wavelength data is given for reference only.

Sodium is very common and very bright and may be present in many flame spectra as a trace of contamination. A classic light and color activity is identifying unknown white salts by observing their color when ignited in a flame. These salts can be introduced into a flame by dipping a moist wire into the chemical salt then bringing the salt-coated wire to the base of the Bunsen burner flame. The flame will begin to burn with a color characteristic of the salt used.

**Other bright line spectra can be produced by burning salts of various chemicals in a gas (Bunsen burner) flame. Some common elements are:**

| Element | Wavelength (nm) | Color |
|---|---|---|
| Copper (Cu) | 530 | Green/Blue |
| Sodium (Na) | 589 | Yellow |
| Strontium (Sr) | 606 | Orange |
| Lithium (Li) | 670 | Red |

Spectrum tubes contain a range of gases and are a great resource to observe the emission spectra of many different gases. When they are energized, the gases glow and emit photons of unique wavelengths making for another great unknown identification activity with the Quantitative Spectroscope. For example, helium and hydrogen are both light gases at the top of the periodic table, but helium has one more electron than hydrogen. Helium will have a more complex emission spectrum compared to hydrogen due to its extra electron.

## Resources

**Project Star Spectrometer (P2-7055)** Explore flame spectra, streetlights and solar spectra with this dependable device. Since it is labeled in electron volts and nanometers, you can use it in both your physics and chemistry labs.

**RSpec Explorer (P2-9505)** Digitally capture an individual spectrum, and then compare it to a series of known spectra! The included camera and software make this an easy and inexpensive solution to studying quantitative spectral data in the classroom.

**Spectrum Tube Carousel Classroom Bundle (P2-9901)** A classic atomic theory demonstration! Energize the gas and view the characteristic atomic spectral lines with any spectroscope. This complete set comes with 8 different gas Spectrum tubes. Spectroscopy Tube length is approx. 26 cm.