

## Capturing the Rainbow

(What is a spectroscope and how does it work?)

**Terms to understand:** visible spectrum, refraction, absorption spectra, prism, Fraunhofer lines, spectrophotometer, energy states, conjugated  $\pi$ -electrons, molecular orbitals, photon.

### Learning Objectives

#### Content

- To review the visible spectrum and the refraction of light.
- To relate the visible spectrum to energy.
- To understand the relationship between the visible spectrum and absorbance spectra.
- To understand how a spectroscope works.

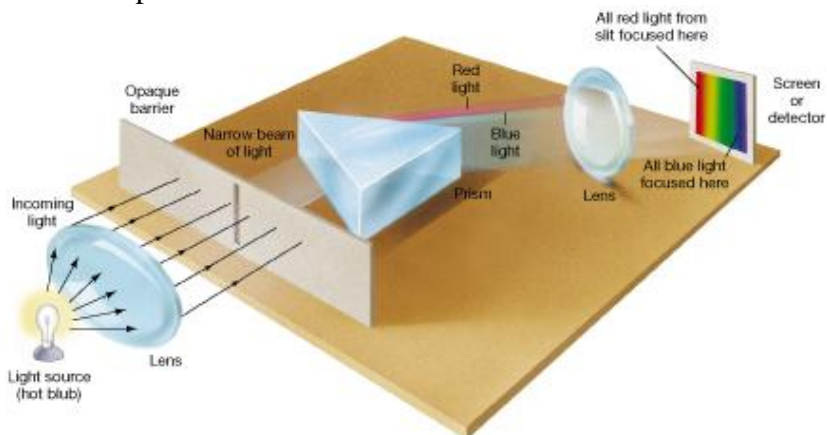
#### Process

- To be able to interpret spectra.
- To be able to apply concepts to new situations

#### Prior Knowledge

- General Chemistry Course
- Organic Chemistry Course

Virtually everyone has seen a rainbow caused by sunlight hitting raindrops and being dispersed into its component colors as the *visible spectrum*. The same phenomenon occurs when a beam of light is *refracted* as it passes through a *prism* and produces a colored spectrum as depicted below.



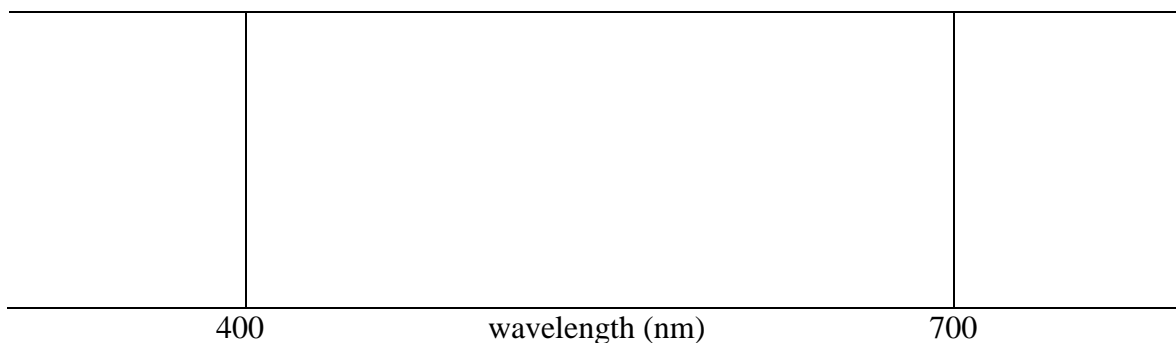
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Fraunhofer in the early 19<sup>th</sup> century observed that the color spectrum produced by sunlight contained some sharp dark lines in it. These were due to the *absorption* of specific wavelengths of light by atoms and diatomic molecules in the atmospheres of the earth and sun. Before the origin of these bands was known and before specific

wavelengths and energies could be assigned to them, these *Fraunhofer lines* were used as points of reference in spectral studies. We now know the origin and wavelengths of these bands as presented below.

Line Designation	Wavelength (nm)	Color	Source	Photon Energy (J)
A	759.4 - 762.1	Extreme Red	O <sub>2</sub>	
B	686.7 - 688.4	Red	O <sub>2</sub>	
C	656.3	Red	H	
D	589.6 & 589.0	Yellow	Na	
E	527.0	Green	Fe	
b	518.4 & 517.3	Dark Green	Mg	
F	486.1	Blue	H	
G	430.8	Violet	Fe & Ca	

1. The visible spectrum (400 nm – 700 nm) is a small part of the entire electromagnetic spectrum. On the figure below, draw dark vertical lines that correspond to the Fraunhofer lines used as reference points by early researchers.



2. Using colored pencils provided, color in what the spectrum of sunlight might look like. Go online and compare what you have drawn to what is actually observed.
3. What are the names of the spectral regions below 400 nm and above 700 nm? Label these regions on the diagram.
4. The energy of a *photon* of light in joules is related to its wavelength by the equation

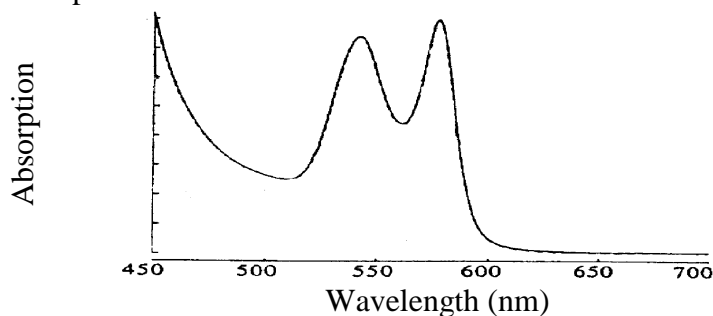
$$E = h\nu = \frac{hc}{\lambda}$$

where  $h$  is Planck's constant ( $6.626 \times 10^{-34}$  J s),  $c$  is the speed of

light ( $3.00 \times 10^8$  m/s), and  $\lambda$  is the wavelength in m. The sodium D line (actually two lines very close together) is the result of gaseous sodium atoms in the sun's atmosphere absorbing a photon with the energy necessary to excite an electron to a higher *energy state*. This energy can be calculated precisely. Each person in the group take two Fraunhofer lines, calculate and fill in the energy values in the introductory table. Compare your answers to make sure they make sense and are

consistent. Is the energy of the sodium D transition greater or less than the transition that corresponds to the oxygen B line?

- Absorption transitions in the visible spectrum for molecules tend to be broader rather than the sharp lines seen in atoms. Broad absorption bands of biological molecules are typically due to transitions between *molecular orbitals* associated with *conjugated  $\pi$ -electron* systems. If a molecule is colored, it means that there are transitions between energy states in the molecule that correspond to the energy of photons in the visible range. If a molecule is red, what part of the visible spectrum is being absorbed? Explain.
- If a substance has broad absorption bands around 450 nm and 650 nm but not in the middle of the visible spectrum, what color(s) might it be?
- In order to see the actual absorption spectrum of a substance, it needs to be viewed through a spectroscope. The diagram with the prism on the preceding page could represent a spectroscope except there is no place indicated for a sample. Indicate where on the diagram a solution of a colored compound should be placed in order to observe its absorption spectrum.
- Today, spectrophotometers are used instead of spectroscopes. Instead of the human eye, electronic detectors are used to measure the amount of light absorbed and produce a plot of absorbance vs. wavelength, i.e. an absorbance spectrum. An example is shown below.



What color would this substance be? Could it be chlorophyll? Why or why not?

- On the diagram, sketch in the absorbance spectrum you would expect if the concentration of the substance were halved. How would differences in concentration affect the observed color?