Spectral Tubes Activity

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Description

Spectral lines are seen as bright bands when we look at light from a hot, tenuous gas with high-quality color filtering. Just as each musical instrument has a set of overtones that give it a unique sound, each element has a set of spectral lines that give a unique identification. The discovery of spectral lines led to the development of quantum mechanics. When observed correctly, the solar spectrum is covered with dark lines, each corresponding to an element.

Spectral lines from every naturally occurring element have been observed in both a laboratory and in some star in the universe. These observations show the universe is similar in all directions and distances.

Spectra can be seen with prisms or gratings. Both spread the colors in space (or disperse the light) so that you see a rainbow when looking at an incandescent source. When present, this rainbow indicates that you are looking at a hot object. It is also possible to use filters to allow only selected wavelengths into your eye or other detector.

Spectral lines contain a great deal of information about their source. By their very presence spectral lines tell you the composition and temperature of the gas or star. Measuring more accurately the change of brightness across the line tells you the rotation and velocity (through the Doppler shift). If the polarization properties are measured (using really good sunglasses) you can measure the magnetic field of the object.

When you watch the weather forecast and see the 3-D movies of clouds you are watching spectroscopy at work. Spectral lines of water vapor are observed by satellites and interpreted to give the temperature and altitude of the clouds. An example of using the rainbow is the ear thermometer, which works by sensing the infrared radiation coming from the eardrum and converting it to a temperature. HMI, an instrument on SDO, will use an Fe I line at 6173 Å to map the surface velocity and magnetic field of the Sun.

Required Information and Equipment

This activity works best with a small group of people (< 15). A dark room works better than a lit room. Standing allows people to move around and see changes with viewing angle. Sitting keeps younger people under control.
Assemble this equipment:

1. Spectral slides or glasses

2. Spectrometer assemblies built from posters (for quantitative work)

3. Spectral tubes and spectral tube power supply, other light sources include incandescent bulbs (especially clear with visible filaments), black lights, small fluorescent lights, mercury lamps in a gym or streetlight, sodium lamps in a streetlight. If you use a small fluorescent fixture, painting the reflector behind the bulb black will make the spectrum more visible.

4. Slits of various shapes and sizes, these can be cut from cardboard. In general, the narrower the source of light the better the spectrum will look. Spectra from wide sources will overlap some of the colors from the opposite sides, dimming the spectrum. Slits can be held in front of the slide or glasses to make a wide source skinny. Experiment with the distance from the slide to the slit to see what works best.
5. Digital camera or telephone with camera to record the spectra. We have had success using these cameras to record the spectra, even putting two sources in a frame to allow a comparison.

Instructions

1. Arrange room so that people are < 10 ft from sources; set up sources
2. Outline activity, name parts of sources, demonstrate sources
3. Distribute slides or glasses (if using glasses fire a camera flash behind people for a good effect), demonstrate the use of the slides or glasses
4. Turn off lights in room, dark adaptation is useful
5. Run through sources; comments for each source are listed in the first table.
6. Look at the incandescent and fluorescent sources through slits; the spectral tubes are narrow enough to act as their own slit. Compare various lamps by looking at them at the same time.
7. Do quantitative work if spectrometers are available

Questions

1. Why do you see fluorescent light as white?
2. What does your television look like through a spectral slide? Does looking through a slit help?
3. What does your computer screen look like through a spectral slide? Does looking through a slit help?

Possible Extensions

1. Visit a better spectrometer. How can you make a better spectrometer? One idea is to spread the light over a larger area. What are other ways?
2. Whether you see dark or bright lines is summarized by Kirchoff's Laws. Pictures of the Sun at different wavelengths can be used to illustrate these laws.
3. If you can make measurements of the wavelengths of the hydrogen source you can fit them to the Balmer series. Wavelengths of the Balmer lines of hydrogen are given by this formula

$$\lambda = 3645.6 \left(\frac{n^2}{n^2 - 4} \right) \text{ Å}, \tag{1}$$

Table 1: Light Sources

Source	Comments
Incandescent	Shows the rainbow; shape of source determines shape of spectrum; illustrates Planck's law
Black light	Rainbow, shape of source; rotate dual source power supply to allow viewers to compare with spectrum of incandescent bulb to see red cutoff
Fluorescent	Discrete images of bulb; compare different types of fluorescent bulbs to see the different mixes of colors; mention RGB colors used in computer screens
Neon	Discrete lines with a recognizable color
Hydrogen	Hα (red), Hβ (teal), and Hγ (blue); some continuum from molecular H_2; you may also see Hδ at 4101 Å
Helium	Discovered as a yellow line at 5875 Å in a spectrum of a solar prominence in 1868, chemically isolated in 1895; visible lines are 6678, 5875, 5412 (He II), 5047, 4921, 4713, 4686 (He II), 4471, and 4384 Å (He II means the first ion of He, which is produced by the high temperature in the tube.)
Mercury (Hg)	Wavelength standards with bright lines. One of the yellow lines may be seen as a doublet (two closely-spaced lines.)
Sodium (Na)	Bright line (actually two) at 5896 & 5890 Å. Used as a wavelength standard and to study the atmosphere 60 miles above the Earth
Nitrogen (N_2)	Banded structure, dim source that can be difficult to see if people are too far from tube
Oxygen (O_2)	Banded structure, dim source that can be difficult to see if people are too far from tube
Carbon dioxide (CO_2)	Banded structure, bright source with bands at wavelengths from red to purple
Air	Dominated by nitrogen bands
Unknown	Use to test comprehension

where $n = 3, 4, ..., \infty$. How do the measured wavelengths agree? Quantum mechanics was developed to explain this and other patterns in atomic spectra.

4. The overtones of a trombone or guitar string are almost evenly spaced in frequency. How would the Balmer series compare?

5. The Sun is bright enough that we can take pictures of the Sun in quite unusual ways. Can you find some? The Internet has many sites with images of the Sun in narrow-band filters, labeled as Hα and Ca II K & K.

6. Spectra are used to classify stars into spectral types. How does this work? This is an astronomy project that uses the physics of spectra. See §7.17 of Tattersfield (1979) for an introduction to spectra of stars. For more details on classifying stellar spectra you can look at Jaschek and Jaschek (1987) and Kaler (1989).

Table 2: Kirchoff's Laws

Lines	Background	Comments
Bright	Dark	Hot material in front of cooler material or reflection
Dark	Bright	Cooler material in front of hotter material
Bright	Bright	Denser, hot material in front of hot material

Further Information and Resources

Balmer, J. J. 1885, Note on the spectral lines of hydrogen, *Ann. Phys. Chem.*, **25**, 80–85 (translation posted at http://web.lemoyne.edu/~giunta/balmer.html).

Jaschek, C. and M. Jaschek 1987, *The Classification of Stars* (New York: Cambridge Univ. Press).

Kaler, J. B. 1989, *Stars and Their Spectra: An Introduction to the Spectral Sequence* (New York: Cambridge Univ. Press).

Kurucz, R. L., I. Furenlid, J. Brault, and L. Testerman 1984, *Solar Flux Atlas from 296 to 1300 nm, National Solar Observatory Atlas No. 1*, June 1984.

Mills, H. R. 1994, *Practical Astronomy: A User-friendly Handbook for Sky Watchers* (Chichester, England: Albion Publishing Ltd.) Section 4.18 describes using a camera to observe the spectrum of a star.

Tattersfield, D. 1979, *Projects and Demonstrations in Astronomy* (New York: Wiley), look at pp. 156–164.

Taylor, P. O. 1991, *Observing the Sun* (Cambridge, England: Cambridge Univ. Press).

Wollaston, W. H. 1802, A method of examining refractive and dispersive powers, by prismatic reflection, *Phil. Trans. Roy. Soc. London*, **92**, 365–380. There is a figure of his prismatic arrangement and line identification on the last page.

Websites that discuss spectra:

http://solar-center.stanford.edu/activities/cots.html (includes the cut-out spectrometer)

http://www.lmsal.com (examples of narrow-band images of the Sun)

http://imagine.gsfc.nasa.gov/docs/teachers/lessons/supernova/supernova_student.html

http://nemesis.lonestar.org/reference/electricity/fluorescent/index.html A discussion about fluorescent lighting and how the colors are made (section 3). The 35 mm gratings can be used to do comparisons of the various types of fluorescent tubes.

http://www.tomatosphere.org/EngManual/light.html An interesting page showing some concepts of light and plant growth. The spectra are reversed from normal convention.

The spectral tubes and power supply are available as "Spectrum Analysis Power Supply and Tubes" from http://www.scientificsonline.com. The same site sells the 35 mm slide transmission gratings and a variety of other simple spectrometers. Local colleges and universities may allow you to borrow the power supply and tubes.

Worksheet to Calculate Wavelengths

In 1802 Wollaston noticed dark lines in the solar spectrum. Fraunhofer (1817) published lists of the lines as a wavelength calibration, and noted some were not present in stars — but other stars had more. Brewster (1836) noted that the lines altered with the elevation of the sun.

Similar absorption lines can be observed in other regions of the electromagnetic spectrum. Each absorption line in a star corresponds to the wavelength of an emission line of a chemical element in the laboratory. Spectral lines of every naturally occurring element have been observed in at least one star somewhere in the Milky Way.

The Hα, Hβ, Hγ, and Hδ lines are part of the Balmer series of the hydrogen atom. Quantum mechanics was invented, in part, to explain the wavelengths of these lines.

Because the Fraunhofer lines are well-known, they are used as standard wavelengths when discussing the optical properties of optical materials. This was just what Fraunhofer wanted!

Table 3: Fraunhofer Line Identification

Line	Caused by	λ (Å, 10^{-10} m)
A - (band)	O_2 (Atm.)	7594 – 7621
B - (band)	O_2 (Atm.)	6867 – 6884
C	H (Hα)	6563
a - (band)	O_2 (Atm.)	6276 – 6287
D (2 lines)	Na	5896 & 5890
E	Fe	5270
b (2 lines)	Mg	5184 & 5173
c	Fe	4958
F	H (Hβ)	4861
d	Fe	4668
e	Fe	4384
f	H (Hγ)	4340
G	Fe, Ca, & OH	4308
g	Ca	4227
h	H (Hδ)	4102
H	Ca II	3968
K	Ca II	3934

Lines with uppercase letters are broad and seen in low-resolution spectra. Lines with lowercase letters require higher-resolution spectra to be seen.

The lines of Mercury (Hg) are often used as wavelength standards due to the ease of building mercury lamps and the many lines in the visible spectrum.

Solar Spectrum

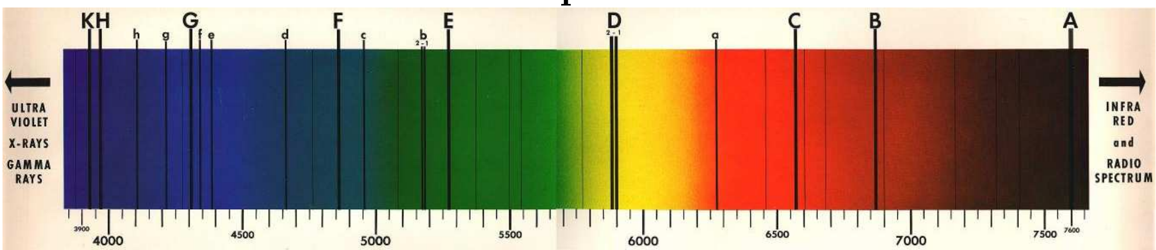

Figure 1: A classic view of the solar spectrum and Fraunhofer lines. Letters correspond to the table.

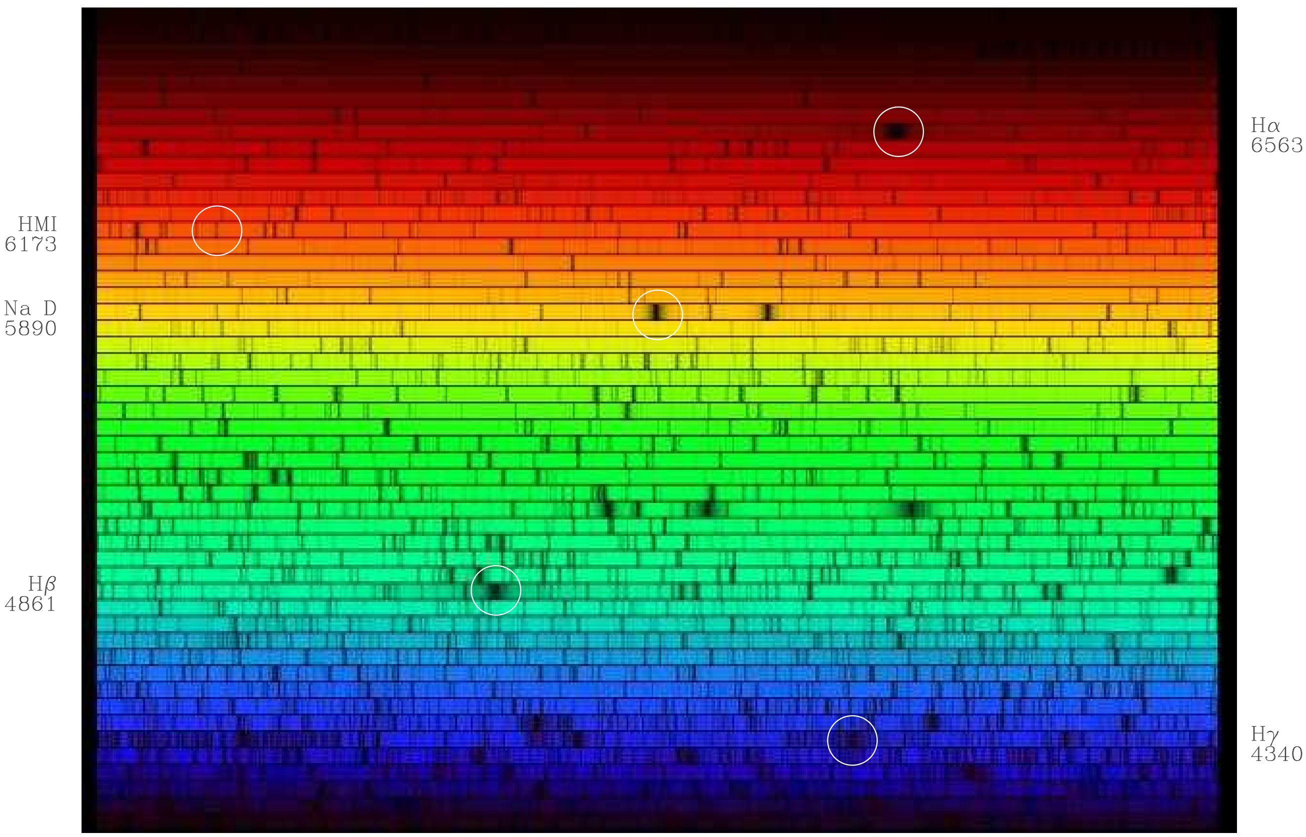

Figure 2: A high resolution version of the spectrum of our Sun, this image was created from a digital atlas observed with the Fourier Transform Spectrometer at the McMath-Pierce Solar Facility at Kitt Peak National Observatory, near Tucson, Arizona. This image mimics an echelle spectrum, with wavelength increasing from left to right along each strip, and from bottom to top. Each of the 50 slices covers 60 Å, for a complete spectrum across the visual range from 4000 to 7000 Å. Several lines are identified. (Courtesy of N. A. Sharp, NOAO/NSO/Kitt Peak FTS/AURA/NSF.)