

Spectroscope

ELECTROMAGNETIC SPECTRUM

Scientists learn much about the world by splitting things apart. A geologist can split rocks, a botanist can split seeds, and a physicist can split atoms. About the only thing an astronomer can split is a beam of light, but even that reveals a great deal — from the temperature of a star to the final moments of matter falling into a black hole.

Our eyes perceive the light from a star as a single color. But instruments split the light into its individual wavelengths or colors. The intensity of each wavelength tells astronomers how hot the star is, what it's made of, how it's moving, and whether it has companions, like other stars or even planets.

Visible light is just one of the forms of energy that make up the electromagnetic spectrum. Other forms include infrared and radio waves, which have a longer wavelength than visible light, and ultraviolet, X-rays, and gamma rays, which are *shorter* than light.

Telescopes on the ground or in space detect these forms of energy and split them into *their* component wavelengths, too. Each type of energy tells us about the environment in which it was created. Infrared, for example, comes from relatively cool objects like gas clouds and planets. And X-rays come from some of the most violent objects in the universe, like disks of hot gas spiraling into black holes.

By splitting each form of energy, astronomers build a more complete understanding of the universe — one wavelength at a time.

This is the transcript of a StarDate radio episode that aired in July 2004. Script by Damond Benningfield, ©2001, 2004.



Just as a geologist collects rocks or minerals and a botanist collects plants, an astronomer collects light. Astronomers usually cannot touch the objects they study, like stars or galaxies. But they can analyze the light these celestial objects radiate using a spectroscope. When an astronomer looks at a star through a spectroscope, he or she sees a colorful spectrum that is full of information.

Students will construct their own spectroscope as they explore and observe spectra of familiar light sources. Extension activities expand their understanding of different kinds of spectra and sharpen their observing skills. You may challenge more advanced students to make technological improvements to their instruments.

MATERIALS

For class:

- Incandescent light bulb (60-100-watt frosted) and base
- String of clear holiday lights (optional)
- Fluorescent light (single bulb)
- Transmission grating sheet (available from science supply store)
- 2 transparency sheets
- Glo-Doodler (available from Colorforms)

For each spectroscope:

- Half of a manila folder
- Sheet of black paper
- 3 index cards (3x5-inch size)
- Tape or rubber bands
- Scissors
- A small paper clip
- Hole puncher

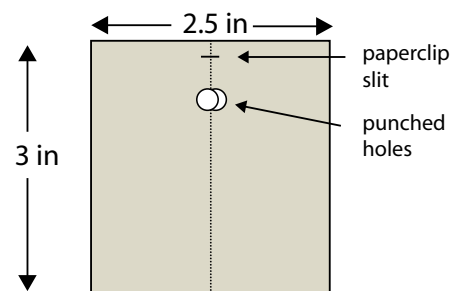
PREPARATION

Making the transmission grating cards

1. Cut a 3x5-inch index card in half, resulting in two 3x2.5-inch cards. Then cut a narrow strip off the three inch side of one of the halves. This will help fasten the card onto the spectroscope tube.
2. Fold each 3x2.5-inch card in half along the short side, then snip a slit perpendicular to the fold about half a centimeter from either corner of the fold. Punch a hole about two centimeters down in the fold. The opening should be about a centimeter wide.

Preparing the grating

1. Sandwich the transmission grating material between two sheets of transparency material. Try not to touch the very sensitive grating with your fingers.
2. Cut the “sandwich” into 1x2-cm pieces.
3. Tape it into place over the viewing hole on the index card along the edges. Do not put tape OVER the hole or small slit.





ACTIVITY

ENGAGE

Distribute individual grating cards to the students. Let them look around the room. You may wish to have a light bulb (e.g. 60- 100-watt frosted bulb) or string of holiday lights available.

EXPLORE

With gratings in hand, ask students to look at an incandescent light source (light bulb with a filament) through the grating while holding it close to their eye.

ASK STUDENTS

- Where does the spectrum appear?
Spectra appear to the right and left of the light source.
- What is the color order?
Violet is closest to the light source and red is most distant.
- What could be done to improve the appearance or view of the spectrum?
Darken the room.

The grating is part of a spectroscope. As the students noticed, spectra are best viewed against a dark background. Ask for alternatives to darkening the room. If necessary, hint at something hand-held, since this instrument should be portable. If no one mentions it, suggest that a tube, with the grating fixed at one end, will block stray light from the view of the spectrum and provide the structural support for the spectroscope components.

What could you use to block out the stray light to make a dark background for viewing spectra?

Attach the grating to one end of a tube. Cut a manila folder in half along the fold. Place a black sheet of construction paper on top of the manila folder half. Roll them together along the long side so that the black paper lines the inside of the tube. Secure with rubber bands or tape.

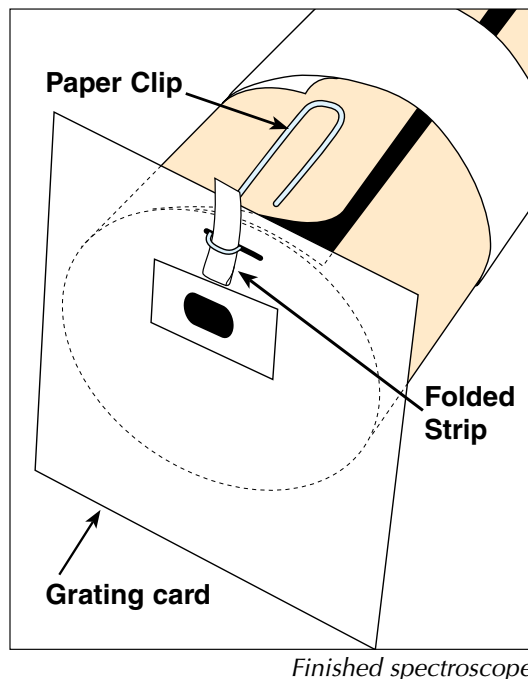
Attach the grating card to the tube (see figure, right). Fasten a paper clip to one end of the tube, leaving a bit of the clip end over the tube edge. Fasten the grating card to the paper clip and secure with a folded card strip.

Have the students look at the incandescent bulb through the tube (with the grating end next to the eye). The tube should aim directly at the bulb; the students may need to move their heads to one side to see the spectrum.

Turn off the incandescent bulb and turn on a single fluorescent bulb. Does the spectrum of the fluorescent bulb look like that of the incandescent bulb? What is the same or different? (Students should see a continuous spread of color in both bulbs' spectra. They also may see separate bands of color only in the fluorescent bulb spectrum.)

NATIONAL SCIENCE EDUCATION STANDARDS

- Content Standard in 9-12 Physical Science (Interactions of energy and matter)
- Content Standard in 9-12 Earth and Space Science (Origin and evolution of the universe)
- Content Standard in 9-12 Science and Technology (Abilities of technical design)



Cover up part of the fluorescent light bulb so that a narrow slit of light is seen. Try making a slit in a double-thick manila folder and holding it in front of the fluorescent source. Compare the incandescent light and the fluorescent light. Do you see color bands now in one of the lights? Which one?

Color bands appear dimmer and thinner with the slit in place for the fluorescent bulb. The incandescent bulb has no bands.

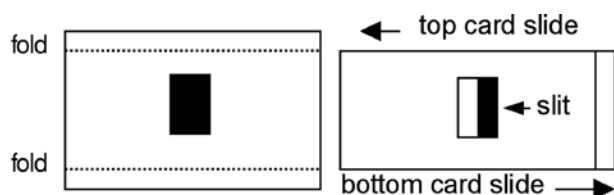
Which observing method renders the best detail view of the spectrum feature — with or without the slit?

With the slit. There is a limit — if the slit is too narrow, the spectrum appears too faint.

Where is a better place to put the slit, so that an observer can view other light sources?

At the opposite end of the tube.

Make an adjustable slit from two index cards. Cut identical rectangular slots, about 1x3 cm, into the center of two index cards. Stack the cards then fold both cards together along both long sides. The cards should now slide across each other. Adjust the size of the slit by sliding one slot over the other.



Hold the adjustable slit at the opposite end of the tube from the grating and open and close it until you find a position that shows detail and still allows enough light through to see the spectrum clearly. Rotate it if necessary so that the spectrum

has its largest height. This insures the parallel grooves in the grating run in the same direction as the slit.

Congratulations! You have constructed a working spectroscope.

EXPLAIN

This is a transmission grating. Its surface is scored or etched with thousands of parallel grooves per centimeter. As light travels through the narrow grooves, diffraction effectively turns each groove into a new source of light. As the light spreads out, it interacts or interferes with light of the same wavelength from other grooves. Sometimes the light waves reinforce each other (constructive interference), other times they cancel out and become invisible (destructive interference). Collectively, the constructive interference pattern directs a particular color along a unique angle from the grating. The result is a color spectrum. That's why blue light appears closest to the image of the source, while red is farthest away. Along those angles, the constructive interference for that color lines up.

The tube blocks stray light that washes out details in the spectrum. Against the dark background, subtle details of the spectrum are easily seen. It also acts as a structure to attach the grating. The slit allows the wavelengths (colors) of light to be resolved. The diffraction grating is allowing you to see images of the slit side by side. The narrower the slit, the more detail you can see. For instance, a narrow slit may resolve a pair of lines in what appeared as a single emission feature viewed through a

wide slit. But as the slit narrows, less light passes through. So an observer must strike a balance between the spectrum's resolution and brightness.

The incandescent light has a hot filament which produces a continuous spectrum (hot liquids also produce continuous spectra). The fluorescent light is made of a tube of hot gas which produces an emission spectrum — more energy is released at certain wavelengths than at others so those colors are more distinct. Which wavelengths are produced depends upon the nature of the gas within a tube. Each gas has its own “fingerprint” or pattern of wavelengths. In a fluorescent light, the gas is mercury.

[For some grade levels, the above explanation is too technical; the teacher may wish to demonstrate constructive and destructive interference with water waves.]

EXTEND

Turn on the incandescent light and hold up the Glo-Doodler in front of it. Ask students to describe how this spectrum is different from that of the bulb by itself or from the fluorescent bulb. (The Glo-Doodler absorbs certain wavelengths, which show as black bands in the spectrum.)

Think of a safe way to view the spectrum of the Sun — **DON'T LOOK AT THE SUN DIRECTLY!!** For instance, point the spectroscope at brightly lit clouds or the full Moon (which shines by reflected sunlight). What type of spectrum does the Sun produce? (The Sun produces an absorption spectrum. The Sun's photosphere, the solar layer where the Sun radiates most of its light, is cooler than deeper solar layers. The hotter, deeper layers of the Sun act like the light bulb filament while the photosphere acts like the Glo-Doodler. Atomic elements in the photosphere selectively absorb certain wavelengths of light. The resulting spectrum shows the absorbed wavelengths as diminished bands, or lines, as astronomers call them.)

Scientists use spectroscopes to safely explore any heated object, from the surface of the Sun to a chemical heated by a flame. How could a scientist determine what elements may exist in the Sun's photosphere? What process would you suggest?

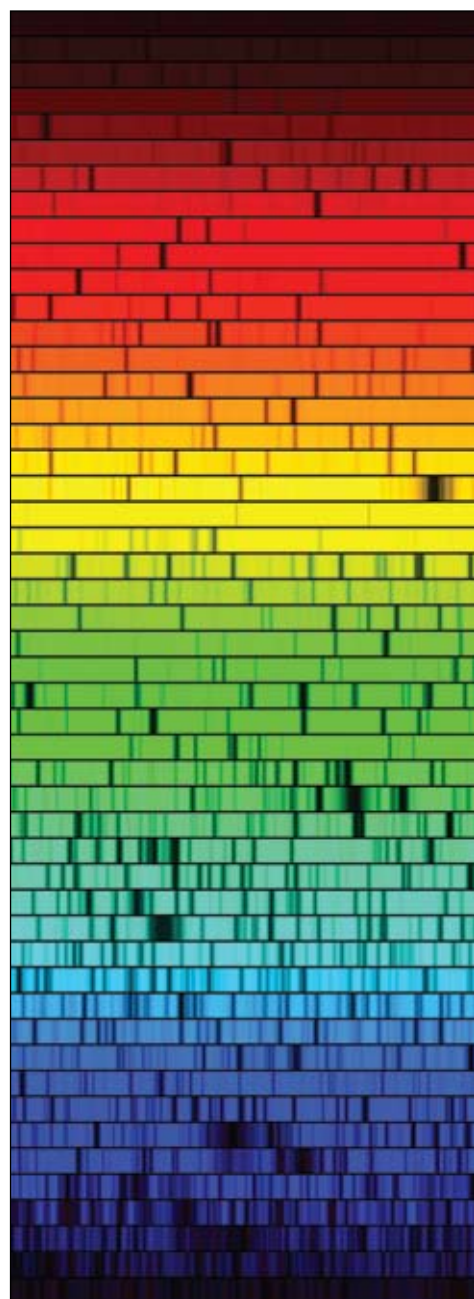
The spectroscope that the students construct in this activity does not allow for direct measurement of wavelengths. Based on their knowledge of spectroscope construction and their observations of spectra, ask students how they would improve their spectroscope. Could it allow an observer to measure the wavelength as they view a spectrum through the spectroscope? They should include a procedure for calibrating the wavelength scale.

EVALUATE

Given a diagram of a scientific spectrograph or spectroscope, identify the main parts: slit, tube, and grating or prism. Early spectroscopes used a prism instead of a grating.

TECHNICAL NOTES FOR CHEMISTRY/PHYSICS TEACHERS

- This activity fits well with your exploration of atomic structure, spectra of various elements, how spectra vary for isotopes, and Kirchhoff's laws.



A portion of our Sun's spectrum reveals dark lines representing specific elements present in the Sun's atmosphere.