Fingerprints of Light Part 1

Instructional Objectives

After viewing the program and participating in the accompanying activities, the student will be able to:

1. describe the role of electrons in the emission of light,

2. explain why each atom or element has a unique pattern of diffraction, and

3. give an example of how spectroscopy can assist scientists in their study of the universe.

Synopsis

Program 24 begins with "HST Data Stream." Eric Chaisson shares some of the latest information received from the Hubble Space Telescope.

In "Science Links," students are introduced to the three types of spectra: continuous, bright line or emission spectra, and dark line or absorption spectra. Just as each person has a unique fingerprint which can be used as identification, so does each star and object in the sky. Students are shown diffraction gratings and a spectroscope as tools to view spectra of light.

The work of Kirchoff and Bunsen is highlighted as viewers first see actual examples of the three types of spectra.These two scientists discovered that the light emitted by hot, dense objects gives off a continuous spectrum—a spectrum in which all of the colors are visible. The program goes on to explain and demonstrate bright line or emission spectra, and dark line or absorption spectra.

The explanation of these phenomena is presented through graphics of atoms that display varying energy levels. Electrons can only exist on specific energy levels, and usually rest at the lowest level possible. Absorption of energy will boost an electron to higher levels, but the same amount of energy is quickly released as light, and the electron returns to its low level. Viewers are reminded that different amounts of energy produce different colors of light. The color of the light emitted corresponds to the amount of energy absorbed and released.

Because each element has a unique pattern of energy levels on which the electrons can exist, each has a unique pattern to its spectrum, providing a means of identification that serves as a fingerprint of its light.

In "People Behind the HST," students meet John Brandt. John, a Senior Research Associate and Professor at the University of Colorado, is the Principal Investigator of the Goddard High Resolution Spectrograph aboard the Hubble Space Telescope.

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Vocabulary

Absorption Line Spectrum – A spectrum produced by light that has passed through a gas. Because the gas absorbs certain wavelengths of the light's continuous spectrum, these specific wavelengths will be missing when the light is re-emitted. Blueish absorption spectra are also referred to as dark line spectra.

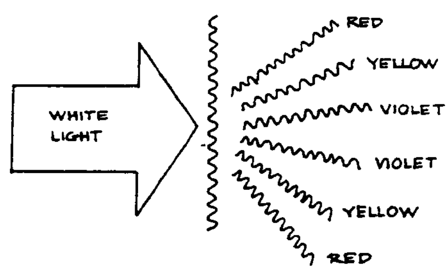
Bright Line Spectrum – Another name for emission spectrum.

Bunsen, Robert (1811–1899) – Inventor of the bunsen burner and the spectroscope.

Continuous Spectrum – The spectrum produced by a hot, dense matter. These spectra appear as a continuous blend of the colors of the spectrum, with no lines of emission or absorption.

Dark Line Spectrum – Another name for absorption spectrum.

Diffraction Grating – A piece of glass ruled with up to 5,000 parallel grooves per centimeter. The grooves cause reflected radiation to spread into its component



wavelengths and frequencies. As light hits these grooves, it bends the different wavelengths to varying degrees. Red is bent the most, violet is bent the least.

Emission Spectrum – A spectrum produced by a glowing gas. In an emission spectrum, a series of bright lines are produced against a black background. Each element produces light at certain wavelengths. Emission spectra are also referred to as bright line spectra.

Kirchoff, Gustav (1824–1887) – Proposed the idea that any source could emit and absorb radiation as the explanation of spectral lines and color.

Orbital - A specific level at which an electron can orbit.

Spectroscope - A device used for viewing the spectrum of a light source.

Spectrum - The array of colors seen when light, passing through a prism or grating, is broken into its component parts. The colors always appear in the exact order of red, orange, yellow, green, blue, violet.

Previewing

Have students diagram an atom on the board.

Review the electron cloud theory of atoms. Remind students that while scientists believe the cloud theory is a more accurate representation of electron movement about a nucleus, it is easier to diagram an atom by using the Bohr model. Draw a diagram of the Bohr model of an atom, indicating that as the electrons whirl about an atom, they exist at specific energy levels, or orbitals. The number of levels varies by element. The spacing between the levels is not always the same, but usually the distance between the first and second orbital is greater than the distances between the other orbitals. Stress the fact that the electrons are never found in between these levels.

Distribute diffraction gratings to the students. Let students use a magnifying glass to look at the grooves of the diffraction grating. Have them view a variety of light sources through the grating and describe what they see.

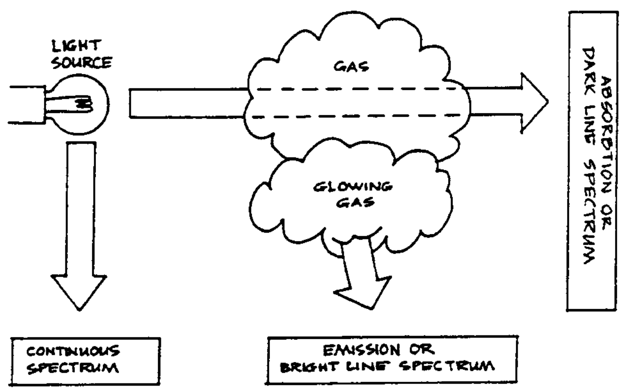
Discuss the fact that like the earth, the sun and stars are surrounded by layers of gases. The atmosphere which surrounds a star affects the light that we see. Ask students how they think the presence of such gases would affect the light.

Ask students what they remember of the differences among the wavelengths of the colors of light. Some students may have participated in an activity suggested in Program 23 in which they used a rope to demonstrate that shorter wavelengths transmit more energy than longer ones. Discuss why this explains that blue light has higher energy than red light.

Prepare students for the fact that the world of the infinitesimally small does not always mimic our world. Some things are beyond the logic of what we have come to know and experience. In this program, students will learn that electrons exist on specific levels, and even though they move from one level to another, they can never exist in between.

Postviewing

To help explain the differences of the three types of spectra, copy the diagram below for the students. A hot solid, liquid, or compressed gas produces a continuous spectrum. The light emitted by a glowing gas produces a bright line, or emission spectrum. Light that passes through a gas will produce a dark line, or absorption spectrum. Point out to students that the absorption spectrum produced by light passing through a gas is missing the exact lines of color that are seen in that gas' emission spectrum.



Explain that scientists often study the light of an element in its gaseous form. In a gas, the atoms are more fully separated. Gases glow when they are heated or when an electric current is passed through them.

Have students look at the light reflecting off a compact disc. The tiny grooves in the surface break up the light into its spectral colors.

Have students research the periodic table and look for the relationship between atomic weight and the number of electrons in an atom.

Explain and diagram the four movements possible to electrons as they orbit the nucleus. 1. Revolution around the nucleus, 2. Rotation of the electrons' orbits, 3. Orbital wobbling, and 4. direction of the electron's spin on its own axis.

Have students make a list of elements and indicate how many electrons are orbiting on each energy level or orbital.

Ask students what about this lesson seemed out of their normal sense of logic. Once again, tell students that the world of atoms does not follow the same physical rules that we understand. Electrons move from level to level, but never exist in between.

Have students take the diffraction gratings home at night to look at different street lights. Many streets, parking lots, and parks have different forms of street lights. Students

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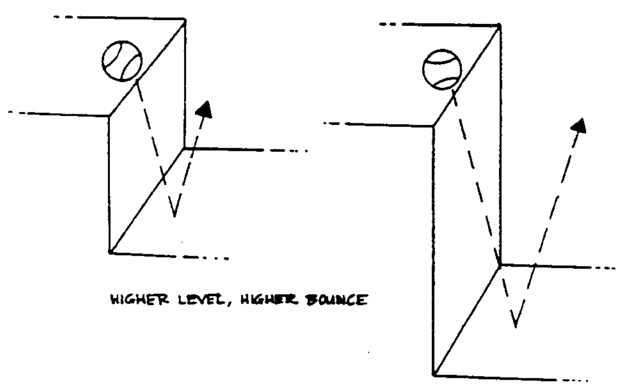
should compare the spectra produced by the lights with incandescent bulbs, mercury vapor (lights that appear bluish) and sodium vapor (lights that appear pinkish).

Have students research the contributions of the many scientists associated with the discoveries of atoms and electrons. Students may wish to report on Balmer, Bohr, Bunsen, Fraunhofer, Kirchoff, Lenard, Mendeleyev, Meyer, Pauli, Planck, Ritz, and Rutherford.

Students may be interested in learning that the element helium was first detected by the unidentifiable absorption lines in the solar spectrum. At first, scientists thought that these lines might be the product of an element unique to the sun (hence the name helium for helios, the Greek word for sun). Helium was later detected on the earth and throughout the universe.

Active Involvement

Use a superball to help explain the absorption and emission of light. Have the ball represent the energy of a photon. The height from which the ball begins its bounce is almost the same as the height to which it will rebound. The potential energy of the ball when it is raised is released as the ball bounces. Similarly, the energy that an electron absorbs is in direct proportion to the energy which it will emit. Furthermore, just as a ball cannot rest in between steps, an electron cannot be in between orbitals. Point out to students that unlike the ball falling from step to step, the electrons never even exist in between orbitals.



Pass the light of a laser through a prism so the students can see that the red light can not be broken down any further. Pass the light through a diffraction grating to see that only red light is separated by the grating.

To display a continuous spectrum in the classroom, take a piece of cardboard the size of a slide and cut a vertical slit in the middle, about 1/8 inch wide. Place the cardboard in the slide projector and shine the light through the slit.

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Hold or tape a diffraction grating over the lens of the projector. Position a piece of paper to the wall on which to project the spectrum. Have students draw a band around the spectrum and label where each color falls.

Use emission spectra tubes, such as Geisler tubes, to let students view emission spectra. In a darkened room, attach the tubes to the power source, so that the gases glow. (Caution, high voltage.) Have students hold up diffraction gratings to their eyes to see the spectra produced by the glowing gases. The best sources for this purpose are hydrogen, helium, mercury, and neon.

You can produce a spectrogram, or spectrum recorded on film, by using a camera with a manual shutter, high speed (400) film, and an emission spectra tube. This should record even more lines than were visible by the human eye. Place a camera on a tripod parallel to the gas tube. Place a diffraction grating over the camera lens. Keep the room as dark as possible. Setting the aperture at a very low setting and using the manual shutter, photograph the spectrum for increasingly long time periods, from 15 to 120 seconds. After the photographs are developed, have students compare and contrast the different photographs. Give students a chance to look at the spectra with their diffraction gratings and compare with the spectrograms they have made of the same gas.

Use a showcase bulb (a long, thin, incandescent lamp much like an aquarium lamp) for students to view a continuous spectrum. The long filament provides a better light source than a regular incandescent bulb. If you hook the light up to a variable power supply, students may be able to detect an increase in blue light as the power, and temperature, increases.

Sprinkle simple table salt over a gas flame. Have students note the change of color in the flame from blue to yellow. Use this as an example of the color produced by the element sodium.

Write the word "flavors" on the board and list underneath the words up, down, strange, charm, top, and bottom. Next to each flavor, write red, blue and green. Take suggestions as to what these words might refer. Explain to students that as tiny as atoms, and their protons, neutrons and electrons are, it is believed that there are additional components of atoms that are tinier still. These are called quarks, and come in six properties or flavors, each flavor having three colors. Challenge students to research this theory and discover the meanings to the terms antiparticle, charm, gluon, gypsi (j/psi), hadron, lepton, neutrino, and super gut.

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See for Yourself: Experiments/Projects

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Building Your Own Spectroscope

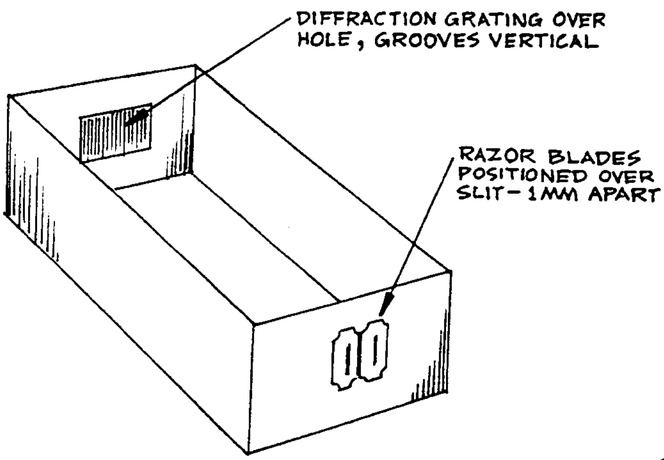
You can make your own spectroscope with materials from your home and school.

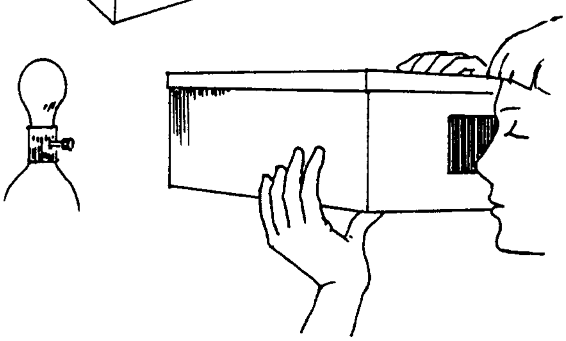
▶ MATERIALS:

- cigar or shoe box
- diffraction grating
- two razor blades
- paper clips
- tape

▶ DIRECTIONS:

Cut a hole, slightly smaller than the size of the diffraction grating, in one end of the box. Paper clip the grating over the hole, making sure the grooves of the grating are vertical.





FOR BEST RESULTS, CLOSE ONE EYE AND HOLD DIFFRACTION GRATING END CLOSE TO OPEN EYE

Use your spectroscope to look at a variety of light sources, but as with any other optical device, NEVER LOOK AT THE SUN through your spectroscope. If you want to look at the solar spectrum, you can look at a reflection of the sun's light off a piece of white paper. You may look at the sky on a cloudy day. Compare the spectra that you see when you look at fluorescent lights, neon lights, incandescent light bulbs, and gas flames. Under supervision, you may sprinkle baking soda or salt on a gas flame and note the spectra produced.

On the opposite end of the box, make a narrow vertical slit, no wider than 1/4". Tape two razor blades over the opening so that they form a slit, 1 millimeter wide.

Tightly cover the box and seal off any areas that might let in light. Test to make sure your grating is positioned correctly. Holding the diffraction grating end of the box up to your eye, point the box at a bright light other than the sun. If you do not see any spectrum at all, turn the diffraction grating 1/4 turn. If you only see colors at the ends of the slit, turn the grating 1/2 turn. When the grating is properly aligned, tape it in place.

Fingerprints of the Elements

Here is an activity that you can do with a partner, but under the supervision of a teacher or other adult. Be sure to wear your safety goggles when you do this activity.

▶ MATERIALS:

- propane flame
- liquid solutions of copper, lithium, barium, sodium and potassium
- wire

▶ PROCEDURE:

Assemble all your materials. On the chalkboard or a piece of poster board, write the names of the five elements that you are using in the experiment.

1. Have your teacher light the propane flame. What color is the flame? What does this color tell you about the flame?

2. Dip one piece of wire into the copper solution. Place the end of the wire in the flame. What color is the flame burning? Write a precise description of the color of the flame under the word copper on the board or chart.

3. Using a clean wire every time, repeat Step #2 with the lithium, barium, sodium, and potassium. Be sure to write the color of each burning element under its name on the board or chart.

4. Turn the bottles so no one can read the labels of the solutions. Dip a fresh piece of wire into one of the solutions, and then into the propane flame. Have your partner use the information on the board or chart to determine which element you are burning.

Science Career Profile

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John Brandt

Senior Research Associate at the Laboratory for Atmospheric and Space Physics

Professor, Astrophysical, Planetary and Atmospheric Sciences, University of Colorado, Boulder

Principal Investigator, Goddard High Resolution Spectrograph

Education A.B. Mathematics
Ph.D. Astronomy
M.B.A.

General Responsibilities

John Brandt's interest in astronomy, which primarily involves researching comets, has provided him with an exciting career of observation, research, and teaching in a field that he loves. Over the years, he has worked on many projects with NASA and the University of Colorado. Currently, John is located at the University of Colorado, but his work for NASA continues to be a main focus of his career.

John is the Principal Investigator of the Goddard High Resolution Spectrograph (GHRS) aboard the Hubble Space Telescope, and is responsible for all aspects of the instrument. He has been involved with the GHRS since it was first proposed, and will remain in charge of the instrument throughout its scientific operation.

The Goddard High Resolution Spectrograph is a device which, like other spectrographs, breaks light into its component colors. This allows astronomers to learn what elements make up the stars and planets and determine their temperatures. The GHRS team has a long list of objects to study with the spectrograph. John is primarily interested in analyzing comets, but other scientists want to use the spectrograph to study the planets, nearby stars, the interstellar medium, nearby galaxies and quasars. Many of the GHRS programs are designed to improve understanding of the evolution of stars.

As the Principal Investigator, John is responsible for coordinating the group of sixteen astronomers who make up the team for this instrument. Now that the Hubble Space Telescope has been launched, the team meets regularly to discuss the mission. The early problems with the HST's mirror have given the group a new challenge. While they await the necessary repairs and corrections, they are busy developing ways in which they can make the best use of how the telescope is operating at this time.

Besides his work with the HST, John has received a research grant to study comets and is responsible for coordinating a group of students studying these objects. Few people realize that comets are continually changing. For example, their tails frequently disconnect and float away and are replaced by new tails. Halley's Comet, for example, had twenty to thirty tails disconnect within five months.

Because John is highly involved in "cometary research," or studying comets, he served as the Discipline Specialist for the International Halley Watch in 1985-86. Four years later, he is still busy with these responsibilities. He is working closely with a book publisher in Boulder to complete work on an atlas of the thousand best pictures taken of this famous comet, as it swung by on its most recent orbit past earth.

A Typical Day

A typical day for John could find him working at his office in Boulder, Colorado; his office at the Goddard Space Flight Center in Greenbelt, Maryland; at the Space Telescope Science Institute in Baltimore; or working on a plane as he flies back and forth between cities. His work might involve changes to the Goddard High Resolution Spectrograph program, a remeasurement of a Halley's Comet figure, or a discussion on a research question with one of his students at the university.

When John gets to his office in the morning, he will find up to twenty messages on his electronic mail. John credits this system, called NASA SPAN (NASA Space Physics Analysis Network), for the many scientists' ability to keep in touch throughout the day. Because the sixteen members of his team are located coast to coast, and throughout the United States and Canada, it could be difficult for them to communicate quickly and efficiently, but through this system they are able to get messages and data to one another at the speed of light.

John's research and HST duties keep him so busy that he rarely teaches large group classes at the university. He works closely with students on a one to one basis though, and may occasionally substitute for another professor.

When not researching comets, or working on one of his many projects, John takes advantage of his Colorado location by hiking in the Rocky Mountains. He also relaxes on his off hours by listening to music and reading all types of literature.

Career Viewpoint

When asked what it is he would most like to be doing, John is able to answer, "I'm doing it!" He feels fortunate that he absolutely and thoroughly enjoys his work. John admits that there is a certain amount of drudgery in his job, but knows that this would be the case in any job he was doing.

Even after thirty years of an interesting scientific career, John still loves the excitement of discovery. According to John, it is marvelous to poke into a baffling question and suddenly have it make sense. As long as the excitement remains, he will continue working in his field.

John also loves the chance to work with students and members of the community. He welcomes questions from non-scientists, because they offer him a unique way to learn. People often provide a new viewpoint when they ask questions, a viewpoint that may cause even a top notch scientist to re-examine his ideas and discover something new.

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