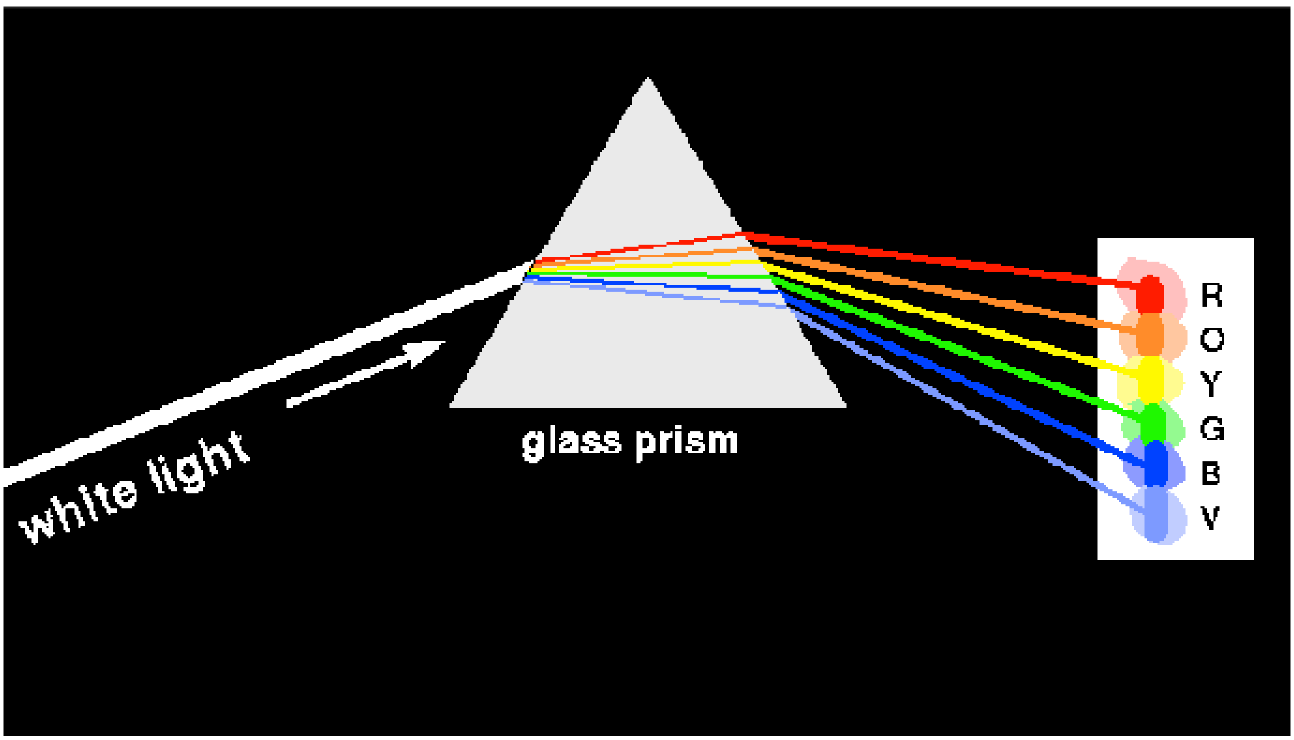
LESSON 3

Dispersion of White Light by Glass Prism



EXPLORING SPECTRA

Purpose: Students will understand that elements emit light in a distinct spectrum that can be used to identify the elements and that this information can be used to identify the composition of complex light sources like stars. Students will expand on their understanding of the visible light spectrum.

Benchmarks for Science Literacy:

- **Technology is essential to science for such purposes as access to outer space and other remote locations**, sample collection and treatment, measurement, data collection and storage, computation, and communication of information. 3A/2 (6-8)
- The stars differ from each other in size, temperature, and age, **but they appear to be made up of the same elements that are found on the earth and to behave according to the same physical principles.** Unlike the sun, most stars are in systems of two or more stars orbiting around one another. 4A/1 (9-12)
- **Increasingly sophisticated technology is used to learn about the universe**. Visual, radio, and x-ray telescopes collect information from across the entire spectrum of electromagnetic waves; computers handle an avalanche of data and increasingly complicated computations to interpret them; space probes send back data and materials from the remote parts of the solar system; and accelerators give subatomic particles energies that simulate conditions in the stars and in the early history of the universe before stars formed. 4A/3(9-12)
- When energy of an isolated atom or molecule changes, it does so in a definite jump from one value to another, with no possible values in between. The change in energy occurs when radiation is absorbed or emitted, so the radiation also has distinct energy values. As a result, **the light emitted or absorbed by separate atoms or molecules (as in a gas) can be used to identify what the substance is**. 4E/5 (9-12)

National Science Education Standards:

Physical Science- Interactions of Energy and Matter

- **Each kind of atom or molecule can gain or lose energy only in particular discrete amounts and thus can absorb and emit light only at wavelengths corresponding to these amounts. These wavelengths can be used to identify the substance.** Grades 9-12

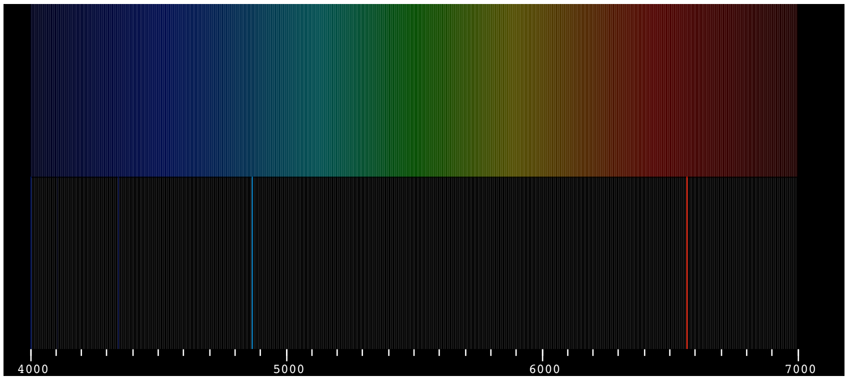
Science and Technology

- Science and technology are reciprocal. Science helps drive technology, as it addresses questions that demand more sophisticated instruments and provides principles for better instrumentation and technique. **Technology is essential to science, because it provides instruments and techniques that enable observations of objects and phenomena that are otherwise unobservable due to factors such as quantity, distance, location, size, and speed. Technology also provides tools for investigations, inquiry, and analysis.** Grades 5-8
- **Science often advances with the introduction of new technologies. Solving technological problems often results in new scientific knowledge. New technologies often extend the current levels of scientific understanding and introduce new areas of research.** Grades 9-12

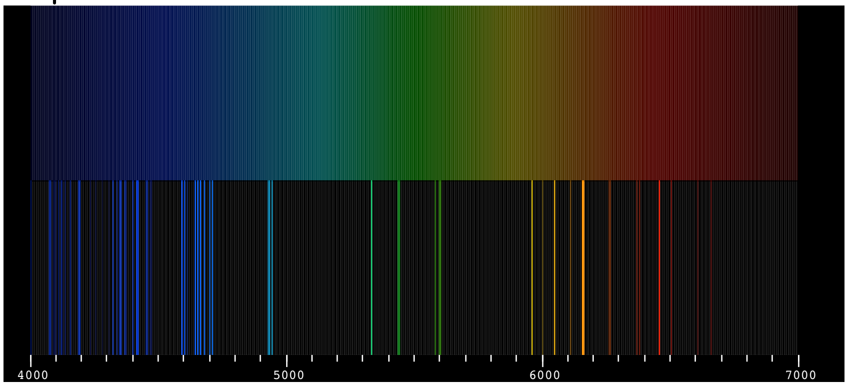
Background:

Whenever an electric charge is accelerated, an electromagnetic field (light) is generated. When electrons oscillate in an antenna, low energy, long wavelength, electromagnetic waves (radio waves) are generated. Visible light is generated when an electron "falls back" from a higher energy level in an atom to a lower energy level. The electron got to the higher energy level by some input of energy. In the spectrum tubes used in this investigation, a large voltage supplies the energy. In the Sun nuclear and magnetic processes supply the energy. This is a very simplified explanation. More detail can be found on the *Electromagnetic Spectrum* page http://imagine.gsfc.nasa.gov/docs/science/know_l1/emspectrum.html of the *Imagine the Universe* website. The Physics 2000 web page on *Electromagnetic Waves* http://www.colorado.edu/physics/PhysicsInitiative/Physics2000/waves_particles/index.html is another excellent source of background information.

Each element has characteristic energy levels, so that only certain changes in energy level are allowed for each element. Each change in energy level corresponds to one wavelength of light emitted. Each wavelength is characterized by a different color of light (although our eyes may not distinguish between colors that are very similar). Hydrogen has very few possible changes of energy in the visible range. So the spectrum for hydrogen that has been excited by a high electrical voltage is very simple. (see below)



The full spectrum on top is for reference only. Hydrogen only emits red, blue, and a faint violet light in the visible region. The spectrum of oxygen (below) is more complex.



Spectra were obtained from AtomicMac™. See Supplies and Vendors, Appendix

The Sun produces the entire visible spectrum (as well as all non-visible wavelengths) because the composition and energetics of the Sun are complex. Only students in chemistry or upper level physics need to understand the mechanism of electromagnetism. However, the mechanism of electromagnetism is not taught in this unit. Younger students who do this lesson need only to be introduced to the notion that each element has its own characteristic spectrum.

It is preferable that students construct their own spectroscope to help them understand its simple structure. Learning Technologies (see **Supplies and Vendors**, Appendix) offers kits that are simple, durable, and inexpensive. These kits are preferred if you wish to introduce numerical values for the spectral lines. However, **Constructing a Spectroscope** (see Appendix) offers a procedure for students to construct a spectroscope without numerical analysis from a shoebox or paper tube. Pre-made student spectroscopes are also available (see **Supplies and Vendors**). If you choose to use pre-made spectroscopes, make certain that you have diffraction gratings and CDs available for students to examine as part of the investigation.

Overview of Student Assignments for Exploring Spectra

1. **Student Lab Investigation** provides students with the opportunity to investigate the properties of spectroscopes and uses spectroscopes to investigate a variety of light sources. Students will need the **Spectra Data Sheet** to record data.
2. **Making Conclusions – Spectra** asks students to interpret the data obtained in the investigation.
3. **Analysis of Stars** is an application and extension of the knowledge gained in the investigation.

Materials:

- Spectroscopes for each group or spectroscope kits or materials for the shoebox spectroscope (see **Exploring Spectra – Constructing a Spectroscope:** Appendix)
- 1 CD per group- use old CDs such as promotional CDs
- Red, green, and blue filters from Lesson 1
- 1 or 2 Spectrum tube power supplies
- Spectrum tubes – at least hydrogen, helium, and nitrogen
- Incandescent light bulb and lamp (60W)
- Fluorescent (mercury) light source
- Periodic Table of the Elements (individual or large display)
- 1 or 2 microscopes – low power or dissecting
- Crayons or colored pencils- full set per group
- A fairly dark room
- Spectrum glasses - optional

Note: Spectrum tubes and power supplies are available for this activity. See **Supplies and Vendors** in the Appendix for sources. It is best to have several different elements as light sources, such as hydrogen, helium, nitrogen, oxygen and neon spectrum tubes. Fluorescent lights have mercury that will give 4-5 clear spectral lines. If you cannot purchase the spectrum tubes and power supplies, you may be able to borrow them from high schools, colleges, or science centers. Alternate light sources might be red or green LEDs, the yellowish outdoor security lights or streetlights (sodium vapor lamps), and the bluish mercury vapor streetlights.

Preparation and Procedures:

1. Before class prepare each diffraction grating. Be careful not to touch the grating with your fingers. One orientation of the diffraction grating

will diffract up and down, but rotating the grating 90° causes it to diffract to the side. You want the students to construct the spectroscope so that the grating diffracts to the side. In a dark room with one small light source, hold the grating near your eye and look to the side. If you don't see a spectrum, rotate the grating 90°. You should now see a spectrum to the side. Write 'up' on the top of the grating. This will help students to assemble their spectroscopes correctly.

2. At the beginning of class hand out **Student Lab Investigation** and **Spectra Data Sheet**. Have materials available and instruct students to read activity and get materials for the group. One person from each group should be responsible for materials.
3. Instruct the students to begin the activity. It is helpful for students to know that thin, closely spaced grooves on the grating and the CDs separate light. Older students (grades 11 and 12) may explore the physics and math of diffraction.
4. Students should now make their own spectroscopes.

Note: Read the **Student Lab Investigation** carefully. Timing and organization are important. For some of the activities students will need room lights on and sometimes they will need only the single light source. Give them clear time limits to perform activities. They should be able to complete steps 1-3 of the student procedure in 10 minutes. Constructing a spectroscope will take 15-20 minutes.

5. After the students have made their spectroscopes, turn off room lights and begin the 5th step of the procedure of the **Student Lab Investigation**. Red filters generally transmit light only in the red end of the spectrum, but the band of red wavelengths is fairly broad. Depending on the quality of the green filter, more or less red is also transmitted and yellow is often present. It is very difficult to obtain blue filters that transmit only blue. Usually, the blue filter also transmits green and red. This is a wonderful opportunity for students to think about Lesson 1 and test what happens when green light and blue light are used to illuminate the various colors of paper. This could be a topic for the Independent Investigation.

6. Examine the gas spectrum tubes. Ask the students to record the color of the glowing gas to their unaided eye before using the spectroscopes. Start with the hydrogen gas tube in the power supply. The room should be dark. If you are using spectroscopes that show numerical values for wavelengths, you may find it helpful to have the single incandescent light bulb on near the spectrum tube to illuminate the numbers. Students may have to get close to the spectrum tube to see the spectrum clearly. Give each group time for every member to see the spectrum for hydrogen and to record the lines on the **Spectra Data Sheet**. Switch to the helium gas tube. The hydrogen tube may very hot! Continue the process for every gas. If you do not have a mercury tube, you can use the fluorescent lights in your classroom – they contain mercury.
7. Identifying unknowns: This is an important step and, hopefully, you were able to obtain helium and nitrogen spectrum tubes. The colors of these two glowing gases appear very similar to the naked eye. Both appear bluish with pink tones. Tell your students that you are going to energize one of the gases and they have to tell you which gas it is. The color of the glowing gas to the naked eye will not help them. They will need to use the spectrum. The spectra of helium and nitrogen are very different. Choose one tube and energize the gas.

Note: Students need to be reminded to point the slit directly at the light source and look to one side to see the spectrum.

It is assumed that your students have heard of elements and had some exposure to the Periodic Table of the Elements. It would be helpful to have the Periodic Table available for the students to refer to as you tell them what elements are being used as a light source.

8. Assign **Making Conclusion- Spectra**
9. It is recommended that you assign **Analysis of Stars** to be completed in class by each student after the completion of the investigation. Students will need **Worksheet 1: The Spectra of Seven Elements** and **Worksheet 2: The Absorption Spectra of Five Stars**. This assignment is an application and an assessment of what they have learned in this lesson; therefore it is important that each student work independently to allow you to assess how she/he is working with the new information.

Note: You can extend this exploration of spectroscopy with a unit offered by The Stanford Solar Center on the Sun and the use of spectroscopy to study the Sun and other stars. The unit is titled *Sun and Stars* at http://solar-center.stanford.edu/webcast/wcpdf/sun&stars5-8.pdf.

Results for Analysis of Stars:

1. What elements are in each star?
    a. Star 1: **helium, hydrogen, lithium**

    b. Star 2: **helium, hydrogen, iron, lithium, magnesium, neon, sodium**

    c. Star3: **helium, hydrogen, iron, lithium, magnesium, sodium**

    d. Star4: **helium, hydrogen**

    e. Star5: **helium, hydrogen, iron, lithium, magnesium, sodium**

2. What stars, if any, contain all seven elements? **Star 2**

3. What elements, if any, are in every star? **Helium and hydrogen**

4. Hypothesize an explanation for #3.

Look for thoughtful hypotheses. Depending upon the age and background of your students, their knowledge base will vary. Hydrogen and helium are the most abundant atoms in the universe and in stars. In our Sun approximately 92.1% of the atoms are hydrogen and approximately 7.8% are helium. Stars convert hydrogen to helium by fusion. Further conversions are made by fusion of helium and eventually fusion of heavier elements. (See *We Are All Star Stuff* http://stp.gsfc.nasa.gov/whats_hot/kids/All_Star_Stuff.htm) The remaining .1% is made of oxygen, carbon, nitrogen, neon, iron, silicon, magnesium, sulfur, and a few trace elements. Other stars will have slightly different compositions as this activity shows, but hydrogen and helium will be common to all.