Lesson Plan
Dr. Elmer Imes and Spectroscopy

*Portrait of Dr. Elmer Samuel Imes,
Image from Fisk University, courtesy AIP Emilio Segré Visual Archives.*

*Dr. Imes working in a laboratory,
Image from Fisk University, Nashville, courtesy AIP Emilio Segré Visual Archives.*
Grade Level(s): 9-12  Subject(s): History, Physics

In-Class Time: 90 min  Prep Time: 10-15 min

Materials

- AIP Handout on Elmer Imes (see supplemental material)
- Access to equipment necessary to stream video Elmer Imes in his Laboratory in the classroom (see AIP Center for History of Physics website)

Build Your Own Spectrometer (students will be put in groups of 2-3):

- Fluorescent light source
- Incandescent light source (flashlight)
- Red LED
- Other light sources
- 1 CD or DVD
- 1 cereal box
- 1 pair of scissors
- Aluminum foil
- Business cards (enough for each student to have at least 2)
- 1 roll of tape
- Colored pencils
- Ruler
- Protractor triangle or printable 60° angle template (see Cool Cosmos for a printable template)

Objective

In this lesson plan, students will learn about the life of Dr. Elmer Imes, the second African-American to receive a Ph.D. in physics in 1918 and a physics professor at Fisk University. Students will learn about Imes’ experimental work on spectroscopy and how it was a turning point in modern scientific thinking that demonstrated the general applications of applied physics. Finally, students will learn about the principles of spectroscopy and build their own spectrometer.

Introduction

Elmer Samuel Imes (1883 – 1941)
Elmer Samuel Imes was the second black Ph.D. physicist in the United States. He completed his PhD at the University of Michigan in 1918, more than 40 years after Edward Bouchet, the first black Ph.D., received his degree from Yale. Imes worked under the direction of Professor Harrison Randall, a renowned physicist who was an expert in infrared spectroscopy. His research has been heavily cited and his findings incorporated into physics textbooks. He is among the first African American scientists to make important contributions to the development of modern physics.
Born in Memphis, Tennessee, Imes went to grammar school in Oberlin, Ohio where his father had graduated from college. From about 1895 to 1895, Imes attended Agricultural and Mechanical College High School in Normal, Alabama and earned his Bachelor’s degree from Fisk University in 1903. Upon graduating from Fisk, Imes taught mathematics and physics at Georgia Normal and Agricultural Institute in Albany, Georgia and at the Emerson Institute in Mobile, Alabama. In 1913, Imes returned to Fisk to pursue a master’s degree and work as an instructor of science and mathematics. Imes’ education at Fisk furthered his ambition to do research in physics. Having reached the limit of what he could do at Fisk, Imes decided to enroll as a graduate student in physics at the University of Michigan. As a black student, Imes could not attend the predominantly white institutions in the South, so he had to look elsewhere.

Michigan had established itself as a center for infrared spectroscopy by 1914. Imes’ doctoral dissertation was a measurement and analysis of the near-infrared spectrum of the hydrogen halides (HF, HCl and HBr). Imes published his first paper on this research, “Measurements on the Near Infra-red Absorption of some Diatomic Gases,” in the Astrophysical Journal in 1919.1 His paper provided the first accurate determination of the distances between atoms in molecules, provided evidence for the existence of two isotopes of chlorine, expanded the range of applicability of quantum theory.2 Soon after, Imes co-authored a paper with Randall which they presented at an American Physical Society meeting that same year and published in Physical Review. Imes finished his Ph.D. in only four years, graduating in 1919.

Infrared Spectroscopy
At the University of Michigan, Imes worked in Randall’s laboratory designing and building high-resolution infrared spectrometers and detectors. Infrared spectroscopy is the study of how molecules absorb infrared radiation and ultimately convert it to heat. By examining how this occurs, we will not only learn about how infrared radiation is absorbed, but we will also learn about molecular structure and how the study of infrared spectroscopy can provide information about the structure of organic molecules. An infrared spectrum of a chemical substance is very much like a photograph of a molecule. However, unlike a normal photograph which would reveal the position of nuclei, the infrared spectrum will only reveal a partial structure. It is the purpose of this narrative to provide you with the tools necessary to interpret infrared spectra, successfully.

The term "spectroscopy" refers to the study of spectra. A **spectrum** is the range of wavelengths, or radiating energy, given off by an energy source. For example, a typical light bulb emits white light. The **white light** you see is actually a combination of different colors of light, each with its own energy level (or frequency) and color. When white light is split into individual wavelengths, the full spectrum of colors becomes visible: violet, blue, green, yellow, orange and red.

In addition to the colors of light in the visible spectrum, there is radiation that is not visible. Those beyond the violet end of the spectrum are known as ultraviolet, while those beyond the red end of the spectrum are known as infrared. Although they cannot see them, scientists can detect the energy transmitted by these radiations, often in the form of heat.

There are three devices used to study spectra: the **spectroscope**, **spectrograph**, and **spectrometer**. A spectroscope magnifies spectra for visual observation, a spectrograph produces photographic images, and a spectrometer measures the brightness of the various colors of light within a spectrum. Imes used a **spectroscope** that could detect infrared radiations as well as the visible spectrum to analyze molecules. An infrared spectroscope allowed Imes to study the smallest building blocks of life: **subatomic particles**.

All molecules are composed of at least two atoms, and all atoms contain subatomic particles called protons, neutrons and electrons. The center of an atom, the nucleus, contains protons and possibly neutrons. Electrons orbit, or move in defined patterns, around the nucleus. With **infrared spectroscopy**, Imes could determine the position and movements of **electrons** within a **molecule**.

When the individual wavelengths of light pass through a molecule in a spectroscope, some of the colors are absorbed, or taken in, and others are emitted, or given off. The wavelengths contain individual particles of light called photons. When photons collide with electrons, they "bump" the electrons, changing their motion. Some photons are absorbed by the electrons, while others "bounce off." Each molecule's structure, specifically the motions of its orbiting electrons, determines which colors of light are absorbed and which are emitted.

By analyzing the spectrum produced by a particular molecule, Imes could understand the position and movements of the electrons within its atoms. Imes could also calculate interatomic distance, or the distance between atoms and molecules. Imes' research enabled scientists to identify unknown substances and to better understand the known chemical elements. His innovative methods for examining molecules had a significant impact on the advancement of quantum theory.

When Imes began his work on infrared spectroscopy in 1918, **quantum theory** was regarded with skepticism by many scientists, as it was still fairly new. Imes' research proved to scientists around the world that quantum theory could be used to gather information about phenomena that physics could not explain. His work also helped show that quantum theory could be used to study and solve a wide range of scientific problems.

Imes was correct in thinking that quantum theory had general use in scientific research. Since his lifetime, quantum theorists have answered questions about the creation of the universe, harnessed nuclear energy, and developed the circuits for the first computer.
**Instructions/Activities**

Begin by reviewing the principles behind spectroscopy and spectrometry with the class and Dr. Elmer Imes in a historical context.

1. Introduce the class to Dr. Elmer Imes using the information in the introduction and the AIP handout on Elmer Imes. Students can be given copies of the handout to read in class or take home. Explain Dr. Imes’ work and show students a video of Dr. Imes in his laboratory at Fisk University (stream the video from the AIP Center for History of Physics website).
2. Explain the principles behind spectroscopy and spectrometry.

**Addressing Prior Knowledge**

1. Write ROY G BIV on board. Ask the students what they know about what this means. This stands for the colors of the rainbow in order – red, orange, yellow, green, blue, indigo, violet.
2. Direct students to draw in their notebooks how a rainbow is produced. Light is being refracted by small water droplets in the atmosphere.
3. Tell students that you can create a rainbow without water and the sun’s light in the classroom.
4. Turn the lights off and shine a white light through a prism. Be sure the light exiting the prism shines on a screen or board.
5. Ask the students to share what they observe. Students will observe that the light exits at a different angle than it entered.
6. Lead students to understand that the light is being refracted by the prism as it travels through the prism and white light is composed of all of the colors of the rainbow and that each color represents a specific wavelength of light. As the white light passes through a prism, the different wavelengths of light are refracted at different angles so the individual colors can be observed.
7. Ask students to predict what will happen if a blue light is used instead of a white light. Shine a blue light through a prism and ask the students to compare their predictions to observations. Students should observe that blue light exits as a different angle than the white light.
8. Pick a student to use markers to draw on the poster sheets where the red light begins and ends. Ask other students to do the same for the other colors of light.
9. **Schematic of what student should be seeing:**

![Image from Wikimedia Commons](https://commons.wikimedia.org/wiki/File:Spectrum.png)

10. **Questions to consider with your students**
    a. Are the marks in the “right” place? In not, why not?
    b. Do all of your students see colors exactly the same way?
Build Your Own Spectrometer
Adapted from NASA: Cool Cosmos; Build Your Own Spectrometer, http://coolcosmos.ipac.caltech.edu/cosmic_games/spectra/makeGrating.htm. See the website for illustrations.
Note: While students are working, you can play music from the Harlem Renaissance in the background. For suggestions, see the Further Reading and Additional Resources section.

Instructions for building your own spectrometer:
1. Divide the class into groups of 2-3 students. Each group will construct one spectrometer.
2. Measure 1.5 inches on the top of the box and make a mark with a marker.
3. Using the 90 degree edge of the triangle, draw a guideline across the width of the box.
4. Cut along the guideline, then unfold the flaps you just made. Cut off the flaps leaving a square hole on the top of the cereal box.
5. Lay the cereal box flat on the table. Place the short edge of the triangle along the top edge of the box with the 90 degree edge at the center of the cereal box. Draw a 3 inch diagonal line towards the center of the box. Flip the box over and do the same on the other side of the cereal box (make sure the slits are on the same edge of the box but on opposite sides.
6. Slide the CD into the slit as far as it can go with the reflective side facing inside the box.
7. On the opposite short edge of the box from the CD, draw a line at half an inch from the top of the box and 1.5” from the top of the box. Cut along those lines and cut a rectangle that is one inch high out from the side of the box. To cut it, first poke a hole towards the top of the box with a pen. Then, cut a rectangle using the hole as a starting point.
8. Take the two business cards and place over the rectangle leaving a horizontal slit between the cards. The gap should be between 0.4 and 1 mm wide.
9. Tape the business cards in place.
10. Point the slit at a bright light bulb, and look into the square hole. The spectra will show up on the CD edge that is inside the box.
11. Now the students can point the spectrometer toward different light sources (fluorescent, incandescent, etc.) and compare what they see. If they want, students can take pictures of the spectra with digital cameras in order to record their observations.

Required/Recommended Reading and Resources
- Handout on Fisk University and Dr. Elmer Imes
- Critical Past video of Dr. Imes in a laboratory (see AIP Center for History of Physics website for video).
Discussion Questions

On Elmer Imes:
1. What was life like for Dr. Imes when he was your age? What was life like for African Americans at that time in history?
2. Why did Dr. Imes study infrared spectroscopy?
3. What was significant about Dr. Imes research? What was going on in the history of physics?

On Spectroscopy:
1. What is a spectrum? How did your class create one?
2. How did the filters affect the spectrum of light you observed?
3. Are there parts of the spectrum that humans can’t see? Which parts can our eye detect?
4. In what way could looking at objects in different colors or frequencies give us useful information?

Further Reading and Additional Resources

Other resources on Elmer Imes:

Resources on the Harlem Renaissance:

Audio and Video Materials:

Scholarships:
- University of Michigan Imes-Moore Fellows Program is a Master’s degree bridge program. For more information, see http://www-applied.physics.lsa.umich.edu/imes_moore.html.

Extensions

Related Resources from the AIP African Americans in Physics, Astronomy, and Related Disciplines Teacher’s Guide:
- Lesson Plans:
  - Physicist Activist: Dr. Elmer Imes and the Civil Rights Case of Juliette Derricotte

### History/Social Studies

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<th>Description</th>
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<td>CCSS.ELA-LITERACY.RH.9-10.2</td>
<td>Determine the central ideas or information of a primary or secondary source; provide an accurate summary of how key events or ideas develop over the course of the text.</td>
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<tr>
<td>CCSS.ELA-LITERACY.RH.9-10.3</td>
<td>Analyze in detail a series of events described in a text; determine whether earlier events caused later ones or simply preceded them.</td>
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<tr>
<td>CCSS.ELA-Literacy.RH.11-12.7</td>
<td>Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., visually, quantitatively, as well as in words) in order to address a question or solve a problem.</td>
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### Science & Technical Subjects

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<td>CCSS.ELA-Literacy.RST.11-12.4</td>
<td>Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics.</td>
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### Dimension One: Practices

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Constructing explanations (for science) and designing solutions (for engineering)
4. Obtaining, evaluating, and communicating information

### Dimension Two: Crosscutting Concepts

1. Cause and effect
2. Structure and function

### Dimension Three: Disciplinary Core Ideas

Core Idea PS1: Matter and Its Interactions
Core Idea PS4: Waves and Their Applications in Technologies for Information Transfer
Core Idea ETS1: Engineering Design