Level	Diffraction of Radio Waves
High School (AP)	
Time Required	**Lesson Summary**
3-50 min class periods (150 min.)	During this lesson, students will learn about the wave and particle nature of electromagnetic waves. Students will also learn about the diffraction of light and conduct an experiment to determine the thickness of a piece of hair. Students will also observe the diffraction pattern of burning gas when viewed with a diffraction grating, thus understanding how astrophysicists know the composition of stars. Students will also learn about how diffraction of electromagnetic waves affects telescope resolution and what can be done to mitigate the effects as well as learn about how radio signals diffract when hitting the edge of an obstacle, dispersing the signal and causing weakened signals.

Standards

NGSS

HS-PS4-5 Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy

College Board: AP Physics 2 Standards

6.C.1 When two waves cross, they travel through each other; they do not bounce off each other. Where the waves overlap, the resulting displacement can be determined by adding the displacements of the two waves. This is called superposition. Examples include interference resulting from diffraction through slits as well as thin-film interference.

6.C.1.1 Make claims and predictions about the net disturbance that occurs when two waves overlap. Examples include standing waves. [SP 6.4, 7.2]

6.C.1.2 Construct representations to graphically analyze situations in which two waves overlap over time using the principle of superposition. [SP 1.4]

6.C.2 When waves pass through an opening whose dimensions are comparable to the wavelength, a diffraction pattern can be observed. Relevant Equations: $\Delta L = m\lambda$, $d\sin\theta = m\lambda$

6.C.2.1 Make claims about the diffraction pattern produced when a wave passes through a small opening, and qualitatively apply the wave model to quantities that describe the generation of a diffraction pattern when a wave passes through an opening whose dimensions are comparable to the wavelength of the wave. [SP 1.4, 6.4, 7.2]
6.C.3 When waves pass through a set of openings whose spacing is comparable to the wavelength, an interference pattern can be observed. Examples include monochromatic double-slit interference.

6.C.3.1 Qualitatively apply the wave model to quantities that describe the generation of interference patterns to make predictions about interference patterns that form when waves pass through a set of openings whose spacing and widths are small compared with the wavelength of the waves. [SP 1.4, 6.4]

6.C.4 When waves pass by an edge, they can diffract into the "shadow region" behind the edge. Examples include hearing around corners but not seeing around them, and water waves bending around obstacles.

6.C.4.1 Predict and explain, using representations and models, the ability or inability of waves to transfer energy around corners and behind obstacles in terms of the diffraction property of waves in situations involving various kinds of wave phenomena, including sound and light. [SP 6.4, 7.2]

Vocabulary	**Objectives**
Diffraction Diffraction Grating Spectroscope Constructive interference Destructive interference	• Students will identify the wave and particle nature of light. • Students will observe the diffraction of light in a spectrum tube, relating this to how astrophysicists use this information to determine the composition of a star. • Students will determine the thickness of a piece of hair using diffraction of light. • Students will identify how the diffraction of electromagnetic waves affects telescope resolution and radio signals from towers.

Materials

Articles that can be shared with students:

- https://www.electronics-notes.com/articles/antennas-propagation/propagation-overview/radio-emwave-diffraction.php

• https://gizmodo.com/a-mexican-physicist-solved-a-2-000-year-old-problem-tha-1837031984 Lab equipment for demonstration: • Diffraction grating or spectroscope • Spectrum tubes • Power source for spectrum tube Lab equipment needed for the experiment: • Scotch tape • Laser common to physics lab stock or a low cost hand held laser pointer (Amazon sells 3 packs for around $20) • Mounting slides (may be a common stock item in a physics lab or Amazon sells 35 mm film mounting slides at $20 for 100) • Meterstick • Computer paper • Preferably a classroom without windows
Pre-Requisites
Students need to know about the electromagnetic spectrum.
Safety Considerations
During the experiment, students will be using lasers. Students should use caution to not point the laser into their eyes or the eyes of other students.
Pacing Notes
Day 1 – diffraction notes, demonstration with diffraction gratings Day 2 – Diffraction lab
Before the Lesson
Read over the presentation to become familiar with the content. Print copies of the Diffraction lab Prepare lab and demonstration materials

Assessments	**Classroom Instructions**

<table>
<tr><th>Pre-Activity Assessments</th><th>Introduction</th></tr>
<tr><td>Do not grade this activity but use it to guide the rest of your instruction.</td><td>As you are taking care of administrative duties students should be answering the following questions on a sheet of paper.

What have you learned about light?

Is light a wave or a particle? (students should provide evidence from their everyday lives to back up their position)</td></tr>
<tr><th>Activity Embedded Assessments</th><th>Activities</th></tr>
<tr><td></td><td>Day 1

1. Presentation on Diffraction
a. After page 3 stop and divide students into five groups. Have each group quickly research one the discoveries mentioned on pages 2 and 3.
b. Go around the room and discuss one discovery at a time. Allow the individuals in the group to share what they found with the class.
c. After page 8 stop and ask: What stands out to you about Young's experiment?
If no one points it out mention how simplistic his methods were considering the impact of his results

2. Spectroscopy in Astronomy reading.
a. Hand out printed copies or make the following article available to your students digitally, https://gizmodo.com/a-mexican-physicist-solved-a-2-000-year-old-problem-tha-1837031984
b. Give students enough time to read the article.
c. Class discussion
Consider asking some of the following questions in addition to your own.
What are your first impressions after reading the article?
How do you think this will change your life or the products you buy?
How will this change science research?
3. Diffraction demonstration
a. Instruct students that this is how astronomers determine what elements are present in stars
b. If your classroom has windows, close the blinds or otherwise block the light.</td></tr>
</table>

	c. Hand diffraction gratings out to students. d. Insert spectrum tube into the accompanying power source. e. Turn off the lights and turn on the spectrum tube power supply f. Have students view the spectrum, noting how many lines they see and the colors they see. g. Repeat the demonstration with different spectrum tubes. h. Explain that what students just experienced was the splitting of visible light but that it works with different types of electromagnetic energy. Ask: What are the other types of EM energy? Make sure that students are able to identify the different categories of EM energy 4. Day 1 Conclusions a. Hand out the diffraction problem sheet. b. Instruct students that they are expected to complete this as homework Day 2 1. Introduction 2. Diffraction lab a. Hand out lab paper and go over directions b. Create groups. This can be done by selecting students at random or by allowing students to select their own group. c. Ask if anyone has any questions. d. Students should get started on the lab e. Discussion What observations did you make? How was your diffraction value different for thick hair vs. thin hair?
Post Activity Assessments	**Closure**
	Have students submit an exit ticket that compares using diffraction for radio astronomy and using diffraction for finding the thickness of a hair.

Culturally Inclusive/Responsive Components
Rafael G. González-Acuña, a doctoral student at Mexico's Tecnológico de Monterrey, was able to write an equation to solve the issue of spherical aberration in lenses. This equation can be used to precisely determine the specification for a lens in order to provide clearer images. His work will result in not only more precise image formation by cameras, telescopes, and microscopes; it will also offer a more cost effective solution. https://gizmodo.com/a-mexican-physicist-solved-a-2-000-year-old-problem-tha-1837031984
Educator Resources
For background information, teachers can access the Radio Astronomy Manual. Of use for this lesson, teachers can review topic 2.4 and activities 6 (Angular resolution and the diffraction limit) and 7 (Using interferometry in radio telescopes). https://almaobservatory.org/wp-content/uploads/2016/11/edu_0072.pdf
Acknowledgment
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How Radio Waves Changed the World
Simple Wireless Communication
Seeing and Hearing the Invisible
Local Wireless Radio Frequency Communication
Investigating the Internet Connection
The Geometry of Radio Astronomy

Informal

Modeling Radio Astronomy