Hypersonics STEM Curriculum

Hypersonics on the Light Spectrum

Grade	Time	Subject Area	Key Concepts
High School	35 min	Physics	Light Electromagnetic spectrum

Lesson Overview

In this lesson, students will explore resources to help them label a diagram with the different categories of waves within the electromagnetic spectrum. Students will apply their knowledge of the electromagnetic spectrum to explain how different humans and animals perceive light as well as how the different types of electromagnetic waves are used on hypersonic vehicles.

This lesson is part of a series of high school physics lessons using hypersonics as a context to apply optics content.

NGSS Standards

HS-PS4-1 Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.

HS-PS4-3 Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other.

HS-PS4-4 Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter.

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.

Learning Objectives

By the end of this lesson, students will be able to:

- Label the different regions of the electromagnetic spectrum.
- Explain wavelength, frequency, and energy trends across the electromagnetic spectrum.
- Compare and contrast different types of electromagnetic waves.
- Explain how humans and animals perceive light differently.

Essential/Overarching Question

Light – is there more than meets the eye?

Key Vocabulary

Speed – the rate at which an object is moving. Speed is calculated by dividing the distance travelled by the time it took to travel that distance.

Speed of Sound – the rate at which sound moves through a medium. The speed of sound depends on both the density and the temperature of the medium. The speed of sound through air at 20° C (68° F) at sea level is 343 m/s (767 mph).

Mach – the ratio of the speed of an object to the speed of sound or how many times the speed of sound an object is moving. It is often followed by a number indicating the ratio; for example: Mach 1 is the speed of sound, Mach 2 is twice the speed of sound, Mach 5 is five times the speed of sound.

Sonic – speeds equal to the speed of sound (Mach 1).

Subsonic – speeds smaller than the speed of sound (less than Mach 1).

Transonic – speeds near (Mach 0.8-1.2) the speed of sound where drag is highest (e.g. sound barrier).

Supersonic – speeds greater than the speed of sound (Mach 1 and greater).

Hypersonic – speeds greater than five times the speed of sound (Mach 5 and greater).

Fluid – a substance with no fixed shape; a liquid, gas, or plasma. A substance that flows when an external force is applied to it.

Flow – the motion of a fluid (liquid, gas, or plasma) when it experiences unbalanced forces.

Speed of Light – the maximum speed at which electromagnetic (EM) radiation (which includes visible light) can travel, when it propagates through a vacuum. This number is slower when EM travels through materials. The speed of light in a vacuum is c = 299,792,458 meters per second ≈ 3×10^8 m/s.

Electromagnetic Wave – waves that are created as a result of vibrations between an electric field and a magnetic field, These include radio waves, microwaves, infrared, visible light, ultraviolet, X-rays, and gamma rays.

Electromagnetic Spectrum – the range of all types of electromagnetic radiation, organized by wavelength or frequency.

Wave – the propagation of a disturbance from one location to another that carries energy in an organized manner.

Wavelength – the distance between identical points (crest to crest, trough to trough) of two consecutive waves.

Frequency – the number of occurrences of a repeating event per unit time.

Gamma Rays – electromagnetic waves with the smallest wavelengths ($< 10^{-11}$ m) and highest energy. They are produced in the radioactive decay of atomic nuclei.

X-Rays – electromagnetic waves of high energy and very short wavelengths (10^{-11} m – 10^{-9} m), which is able to pass through many materials opaque to light.

Ultraviolet Light – electromagnetic waves with wavelengths shorter than that of visible light, but longer than x-ray (10^{-9} m – 4 x 10^{-7} m). UV light makes up about 10% of the electromagnetic radiation that come from the Sun.

Visible Light – electromagnetic waves between the infrared and ultraviolet wavelengths (4 x 10^{-7} m – 7 x 10^{-7} m) that can be detected by the human eye.

Infrared Light – electromagnetic waves with wavelengths between microwaves and visible (7 x 10^{-7} m – 10^{-4} m) light. Infrared includes thermal radiation and black body radiation.

Microwaves – electromagnetic waves with wavelengths shorter than a radio wave but longer than infrared waves (10^{-4} m – 10^{-1} m). They are used in radar, communications, and microwave ovens.

Radio Waves – electromagnetic waves with the longest wavelengths ($> 10^{-1}$ m). They are used for long-range communication.

Short Radio Waves – radio waves with wavelengths shorter than 200 m (10 m – 2 X 10^{2} m).

Television and FM Radio Waves – frequency modulated radio waves with shorter wavelengths (2.8 m – 3.4 m).

AM Radio Waves – amplitude modulated radio waves with longer wavelengths (176 m – 561 m).

Long Radio Waves – radio waves with wavelengths greater than a kilometer (< 10^3 m).

Refraction – the redirection, or bending, of a wave as it passes from one medium to another caused by a change in speed.

Diffraction – the bending of a wave around the corners of an obstacle or the spreading of a wave through an aperture.

Reflection –the change in direction of a wave as it strikes the boundary between two different media so that the wave returns into the medium from which it originated.

Index of Refraction – a dimensionless number (n) that measures how much light is bent, or refracted, when entering a material – a measure of how much the material slows down the light wave as it passes through it.

Snell's Law – a formula used to describe the relationship between the angles of incidence and refraction of a wave passing between two mediums → $n_1 \sin\theta_1 = n_2 \sin\theta_2$.

Angle of Incidence – the angle between a ray incident on a surface and the line perpendicular (at a 90-degree angle) to the surface.

Angle of Reflection – the angle between a ray reflected from a surface and the line perpendicular (at a 90-degree angle) to the surface.

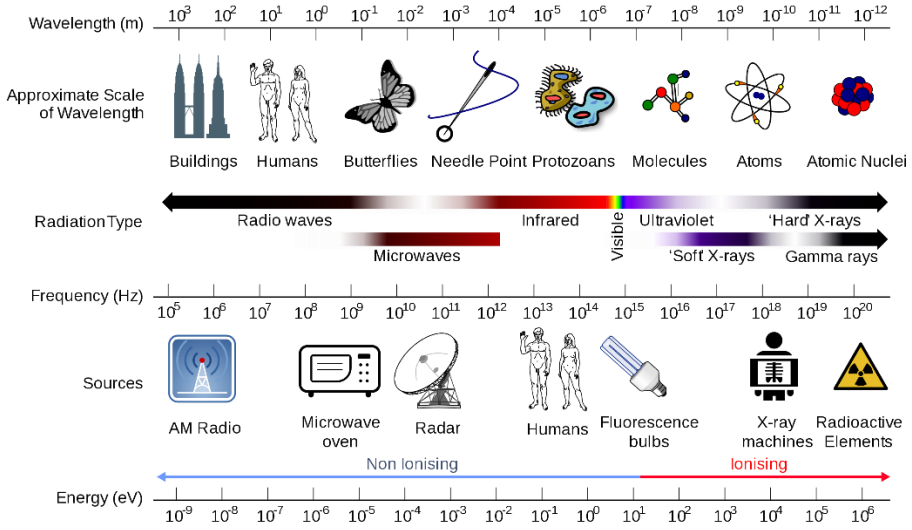
Angle of Refraction – the angle between a ray refracted in a medium and the line perpendicular (at a 90-degree angle) to the surface.

Normal – the perpendicular line drawn to the reflecting surface.

Science Concepts Overview

The electromagnetic spectrum refers to all types of electromagnetic radiation – or light. The electromagnetic spectrum is categorized by ranges of wavelengths and frequencies. The categories include gamma rays, x-rays, ultraviolet, visible, infrared, microwaves, and radio waves. X-rays have the shortest wavelengths, highest frequencies, and highest energy. Radio waves have the largest wavelengths, smallest frequencies, and lowest energy. Within some categories of electromagnetic waves, there are sub-categories. For example, radio waves include short radio waves, long radio waves, AM radio waves, and television and FM radio waves.

Each type of electromagnetic wave serves a different purpose in our everyday lives from using x-rays to diagnose injuries to using microwaves to reheat your lunch. The only electromagnetic waves that the human eye can see are within the visible spectrum. Within the visible spectrum, red light has the longest wavelength, shortest frequency, and lowest energy, while blue is at the opposite end of the rainbow with the shortest wavelength, longest frequency, and highest energy. Some animals, such as dogs, can see ultraviolet light. Others, such as mosquitos, can see infrared light.



Materials List

- ☐ Prisms (optional)
- ☐ Colored pencils, pens, or markers (assortment)
- ☐ Devices with access to the internet (one per student)
- ☐ Hypersonics on the Light Spectrum handout (one per student)
- ☐ Hypersonics on the Light Spectrum Exit Ticket handout (one per student – 2 per page)
- ☐ Optional – an assortment of books on the electromagnetic spectrum

Lesson Preparation

Prior to the lesson, the instructor should gather material, make copies of the Hypersonics on the Light Spectrum handout and the Hypersonics on the Light Spectrum Exit Ticket handout, and ensure that the devices that the students will be using to do the activity are charged and connected to the internet.

If possible, the instructor should provide students with either an electronic copy of the Hypersonics on the Light Spectrum handout and/or links to the websites through whatever learning platform is used at their school. This will help students more easily and quickly get to the correct resources.

Safety

There are no additional safety concerns beyond normal classroom procedures for this lesson.

Procedure

Engage (10 minutes)

1. As a class, watch the video on the colors of the rainbow https://www.youtube.com/watch?v=Gf33ueRXMzQ
2. Pose the following series of questions to your students:
    - In the song, they state "And inside every rainbow, Is the spectrum of light" What do they mean by the spectrum of light? Is it just what we see? Is there more to a rainbow than what we see?
3. Instructors could have prisms available for students to look through and see a rainbow.
4. Have students share their answers using either a think-pair-share format, or as an entire class discussion.
5. Individually, or as a class, read the Introduction of the Hypersonic on the Light Spectrum handout.

Explore (15 minutes)

6. Students will use a variety of resources to learn more about the different categories of electromagnetic waves along the spectrum.
7. As students explore the online resources, they are asked to label an electromagnetic spectrum diagram:
    - Label the ranges for the nine different types of electromagnetic waves: AM radio, gamma rays, infrared, microwaves, radio waves, television and FM radio, ultraviolet, visible, and x-rays.
    - Label/color the visible spectrum call out box with the ranges for the different colors.
    - Draw and label arrows that show increasing frequency, increasing wavelength, and increasing energy.

Explain & Elaborate (5 minutes)

8. Students will be asked to explain and elaborate on their understanding of the electromagnetic spectrum by answering the Analysis Questions:
    - FM radio waves tend to sound better, but AM radio waves travel farther. Based on the information you gathered, why do you think that is so?
    - When traveling at hypersonic (greater than five times the speed of sound) speeds, aircraft are exposed to extreme altitudes, temperatures, pressure, and friction. Based on the information you gathered, what are things that should be considered when designing internal and external facing electromagnetic sensors on the aircraft?
    - Many of the sensors on hypersonic vehicles used for navigation are heat (infrared) sensors. Based on the information you gathered, what are things that need to be considered when designing those sensors?
    - Some animals are able to see beyond the visible spectrum. For example, mosquitos can see into the infrared and dogs can see some ultraviolet waves. How do you think this changes their perspective on light?

- There is a good chance that you or someone you know is color blind, whether it is red-green color blind, blue-yellow color blind, or completely color blind. How do you think this changes your/their perspective on light?

Evaluate (5 minutes)

9. Students will complete the Hypersonic on the Light Spectrum Exit ticket which asks them to:
    - Rank gamma rays, infrared, ultraviolet, visible, and x-rays from largest wavelength to smallest wavelength. If there are any ties, indicate that by circling the two wave types. *(infrared > visible > ultraviolet > x-rays > gamma rays)*
    - Rank AM radio, microwaves, television, FM radio, and visible from largest frequency to smallest frequency. If there are any ties, indicate that by circling the two wave types. *(visible > microwaves > FM radio = television > AM radio)*
    - Rank microwaves, radio waves, ultraviolet, visible, and x-rays from largest energy to smallest energy. If there are any ties, indicate that by circling the two wave types. *(x-rays > ultraviolet > visible > microwaves > radio waves)*

STEM Career Connections

- Hypersonics engineering
- Aerospace engineering
- Aeronautical engineering
- Test engineering
- Systems engineering
- Physics
- Optics
- Machinists
- Manufacturing
- Metrology

Extensions

Students can further *explore* the electromagnetic spectrum by picking one of the types of electromagnetic waves and doing research into the multiple ways we use those types of waves in our everyday lives. Students could watch the video below to jumpstart their research.

Fuse School – Global Education. (2021, September 14). *Electromagnetic waves | electricity | physics | FuseSchool* [Video]. YouTube. https://www.youtube.com/watch?v=508ZsmsIlno

References & Resources

E. G. Blackman. (n.d.). *The electromagnetic spectrum*. University of Rochester Astronomy 104 – The Solar System. https://www.pas.rochester.edu/~blackman/ast104/spectrum.html

Fuse School – Global Education. (2021, September 14). *Electromagnetic waves | electricity | physics | FuseSchool* [Video]. YouTube. https://www.youtube.com/watch?v=508ZsmsIlno

MooMoo Math and Science. (2020, June 23). *What is the electromagnetic spectrum* [Video]. YouTube. https://www.youtube.com/watch?v=7F6fT5p5oFk

National Aeronautics and Space Administration Goddard Space Flight Center. (2013, March). *The electromagnetic spectrum*. Imagine the Universe! https://imagine.gsfc.nasa.gov/science/toolbox/emspectrum1.html

National Aeronautics and Space Administration Goddard Space Flight Center. (n.d.). *Regions of the electromagnetic spectrum*. Imagine the Universe! https://imagine.gsfc.nasa.gov/science/toolbox/spectrum_chart.html

SciShow. (2019, July 8). *A surprisingly simple secret to supersonic flight* [Video]. YouTube. https://www.youtube.com/watch?v=kGefMLHJBKA

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TED-Ed. (2013, September 19). *Light waves, visible and invisible - Lucianne Walkowicz* [Video]. YouTube. https://www.youtube.com/watch?v=O0PawPSdk28

TestTube 101. (2015, November 11). *Flying at hypersonic speeds* [Video]. YouTube https://www.youtube.com/watch?v=vL1qAfS0gic

TMBGkids. (2009, September 15). *They Might Be Giants - Roy G Biv (official TMBG video)* [Video]. YouTube. https://www.youtube.com/watch?v=Gf33ueRXMzQ

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Hypersonics on the Light Spectrum

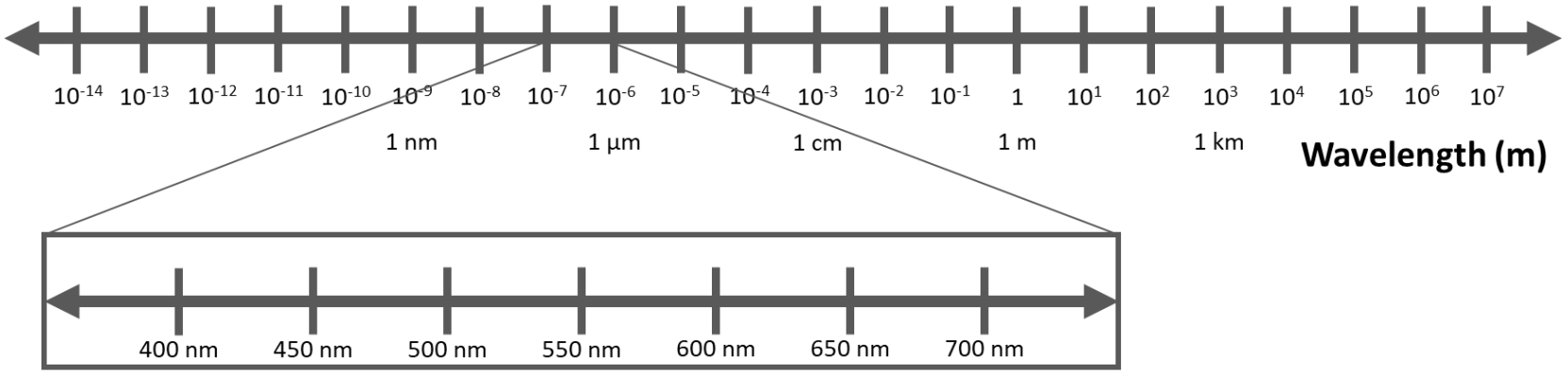
Introduction

When we talk about light in science, we mean much more than what meets the eye – literally. Light refers to any type of ***electromagnetic wave***. The ***visible light***, or the segment of the electromagnetic spectrum that the human eye can view, is a very small portion of the full ***electromagnetic spectrum***. Electromagnetic waves are categorized based on ***wavelength***, ***frequency***, and ***energy***. Moreover, each category of electromagnetic waves serves a different purpose. *We are going to use a variety of resources to learn more about the different categories of electromagnetic waves along the spectrum.*

The Electromagnetic Spectrum

Using your textbook and/or the online resources provided on the next page, fill in the diagram below:

- ☐ Label the ranges for the nine different types of electromagnetic waves: AM radio, gamma rays, infrared, microwaves, radio waves, television and FM radio, ultraviolet, visible, and x-rays.
- ☐ Label/color the visible spectrum call out box with the ranges for the different colors.
- ☐ Draw and label arrows that show increasing frequency, increasing wavelength, and increasing energy.



✈ Resources

MooMoo Math and Science. (2020, June 23). *What is the electromagnetic spectrum* [Video]. YouTube. https://www.youtube.com/watch?v=7F6fT5p5oFk

TED-Ed. (2013, September 19). *Light waves, visible and invisible - Lucianne Walkowicz* [Video]. YouTube. https://www.youtube.com/watch?v=O0PawPSdk28

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E. G. Blackman. (n.d.). *The electromagnetic spectrum*. University of Rochester Astronomy 104 – The Solar System. https://www.pas.rochester.edu/~blackman/ast104/spectrum.html

✈ Analysis Questions

1. FM radio waves tend to sound better, but AM radio waves travel farther. Based on the information you gathered, why do you think that is so?

2. When traveling at hypersonic (greater than five times the speed of sound) speeds, aircraft are exposed to extreme altitudes, temperatures, pressure, and friction. Based on the information you gathered, what are things that should be considered when designing internal and external facing electromagnetic wave sensors on the aircraft?

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4. Some animals are able to see beyond the visible spectrum. For example, mosquitos can see into the infrared and dogs can see some ultraviolet waves. How do you think this changes their perspective on light?

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Name: _____ Date: _____

Hypersonics on the Light Spectrum Exit Ticket

1. Rank gamma rays, infrared, ultraviolet, visible, and x-rays from largest wavelength to smallest wavelength. If there are any ties, indicate that by circling the two wave types.

Largest _____, _____, _____, _____, _____ Smallest

2. Rank AM radio, microwaves, television, FM radio, and visible from largest frequency to smallest frequency. If there are any ties, indicate that by circling the two wave types.

Largest _____, _____, _____, _____, _____ Smallest

3. Rank microwaves, radio waves, ultraviolet, visible, and x-rays from largest energy to smallest energy. If there are any ties, indicate that by circling the two wave types.

Largest _____, _____, _____, _____, _____ Smallest

Name: _____ Date: _____

Hypersonics on the Light Spectrum Exit Ticket

1. Rank gamma rays, infrared, ultraviolet, visible, and x-rays from largest wavelength to smallest wavelength. If there are any ties, indicate that by circling the two wave types.

Largest _____, _____, _____, _____, _____ Smallest

2. Rank AM radio, microwaves, television, FM radio, and visible from largest frequency to smallest frequency. If there are any ties, indicate that by circling the two wave types.

Largest _____, _____, _____, _____, _____ Smallest

3. Rank microwaves, radio waves, ultraviolet, visible, and x-rays from largest energy to smallest energy. If there are any ties, indicate that by circling the two wave types.

Largest _____, _____, _____, _____, _____ Smallest