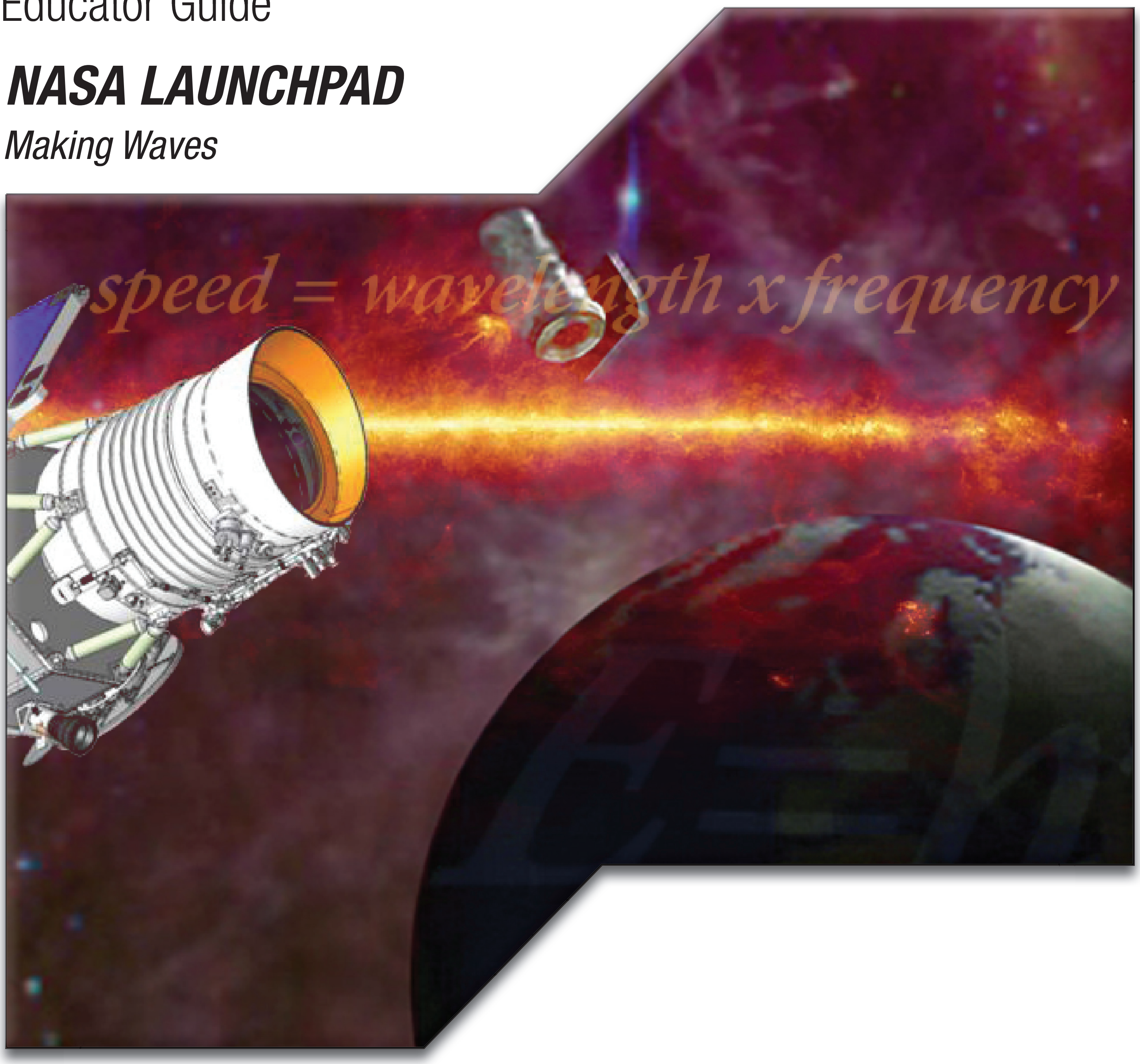
National Aeronautics and Space Administration

NASA eClips™

Educator Guide

NASA LAUNCHPAD

Making Waves



Educational Product	
Educators & Students	Grades 9-12

NP-2009-12-232-LaRC

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EDUCATOR GUIDE

NASA eClips™

Making Waves

National Standards:

National Science Education Standards (NSES)

Physical Science

Interactions of Energy and Matter

National Council of Teachers of Mathematics (NCTM)

Understand numbers, ways of representing numbers, relationships among numbers, and numbering systems

Develop a deeper understanding of very large and very small numbers and of various representations of them

Communication

Communicate mathematical thinking coherently and clearly to peers, teachers and others

Representation

Create and use representations to organize, record and communicate mathematical ideas

International Society for Technology in Education: National Educational Technology Standards (ISTE/NETS)

Research and Information Fluency

Locate, organize, analyze, evaluate, synthesize and ethically use information from a variety of sources and media.

Digital Citizenship

Advocate and practice safe, legal and responsible use of information and technology.

NASA LAUNCHPAD

Grade Level:
9-12

Subjects:
Chemistry, Physical Science, Physics

Teacher Preparation Time:
30 minutes

Lesson Duration:
Three 55-minute class meetings.

Time Management:
Class time can be reduced to one and a half 55-minute classes if students complete mathematical calculations independently as homework and students complete the EXTEND activity as optional.

Lesson Overview:

Students are asked to organize different energy images into a logical pattern. Working in teams, students investigate and research different sections of the electromagnetic spectrum and share their findings with the class. Students are challenged to apply their knowledge to determine relationships between wave frequency, wavelength and energy of electromagnetic radiation. This lesson is developed using a 5E model of learning.

Prior Knowledge:

To be successful in this activity, students need a working knowledge of scientific notation.

Icons flag five areas of interest or opportunities for teachers.

- **Technology** highlights opportunities to use technology to enhance the lesson.
- **Modification** denotes opportunities to differentiate the lesson.
- **Resources** relate this lesson to other NASA educator resources that may supplement or extend the lesson.
- **Connections** identify opportunities to relate the lesson to historical references and other topics or disciplines.
- **Check for Understanding** suggests quick, formative assessment opportunities.

Materials List:

- Electromagnetic Energy Cards (one set per group)
- Student Guide (one copy per student)
- Class set of calculators
- Computers

Essential Questions:

- What is the electromagnetic spectrum?
- How can energy be transmitted?
- What is the relationship between the energy, wavelength and frequency of a wave?
- How do advances in technology, such as the Fermi gamma ray telescope, advance our understanding of the universe?

Instructional Objectives:

Students will:

- create a visual representation of the electromagnetic spectrum;

- calculate the wavelength, frequency, and amount of energy of a wave;
- document the uses of electromagnetic radiation in everyday activities.

5E Inquiry Lesson Development

ENGAGE (20 minutes)

Teacher Prep:

Reproduce the sets of electromagnetic energy cards on page 10. Cut apart the six images and mount them on cardstock. One set will be needed for each group. Laminate the cards for durability.

Procedure:

1. Divide students into groups of three or four.

2. Give each group a set of the electromagnetic energy cards. Ask students to place the cards in a logical sequence and be prepared to share their rationale for the sequence with the class. The six images are:
   - Figure 2 – illustration of a black hole
   - Figure 3 – light bulb
   - Figure 4 – x-ray of a hand
   - Figure 5 – infrared picture of a cat
   - Figure 6 – microwave oven
   - Figure 7 – AM/FM radio

3. Have each group share the sequence and explain to the class the rationale for the order chosen.

   (**TECHNOLOGY**) Have all the images on one slide on an interactive white board and have each group move the objects in their chosen order.

4. Ask the students to find a connection between the images. *(The images are examples of items associated with different types of radiation on the electromagnetic spectrum.)*

5. (**TECHNOLOGY**) Show the NASA eClips™ video segment *Launchpad: The Fermi Gamma Ray Space Telescope* (4:32). This segment can be found on the NASA eClips™ page of the NASA web site:

   http://www.nasa.gov/audience/foreducators/nasaeclips/launchpad/index.html

The video may be streamed or downloaded from the nasa.gov web site; a captioned version is also available at the nasa.gov site. When using the nasa.gov web site, click on the program playlist and scroll through the list beneath the video player to locate the appropriate segment. To turn closed captioning on or off, click on the “CC” icon at the lower right hand corner of the video player.

(**MODIFICATION**) This video may be streamed from the NASA eClips You Tube™ channel:

http://www.youtube.com/watch?v=CPGSuCC9alM&feature=PlayList&p=D7BEC5371B22BDD9&index=10

6. After watching the video, ask students to define the term electromagnetic spectrum in their own words. Have students share their definitions with the class.

EXPLORE (30 minutes)

During this **EXPLORE** activity, students investigate the electromagnetic spectrum. They will compare and contrast different types of radiation found on the spectrum.

Lesson Background:

The electromagnetic spectrum is the name for the range of electromagnetic waves when they are placed in order of increasing frequency. As you can see in figure 1, there are many different types of waves, ranging from radio waves to gamma rays. All types of radiation on the spectrum share some characteristics, such as speed, but each type of wave has a unique wavelength and frequency. Electromagnetic waves can transfer energy without a medium. Electromagnetic waves travel as vibrations in electric and magnetic fields. An electric current is surrounded by a magnetic field. When the electric field changes, so does the magnetic field. The changing magnetic field, in turn, causes the electric field to change. The result is an electromagnetic wave. The energy that is transferred by electromagnetic waves is called electromagnetic radiation.

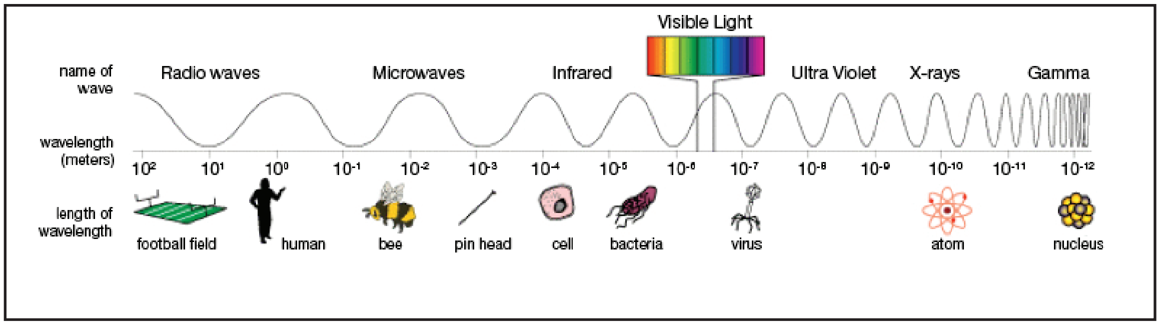

Image credit: NASA

[Figure 1. Diagram of the electromagnetic spectrum.]

Note: the unit of measurement for wavelength in the diagram is meters (m).

The wavelength, or length of a wave, can be used to compare different kinds of radiation. Wavelength is defined as the distance from one point on a wave to the corresponding point on the next wave. Because wavelength is a distance, the unit of wavelength is the meter (m).

The frequency of a wave is also used to compare waves. Frequency is defined as the number of waves per unit of time. The frequency also represents the number of waves that will pass a given point per unit of time. The unit of frequency is the hertz (Hz) which is defined in general as occurrences or counts per second. In this case it is wavelengths per second (1 Hz = 1 wavelength/s). Radio waves have the lowest frequency compared to other types of waves and gamma waves have the highest.

The speed of a wave can be measured, and what scientists have discovered is that the speed of all types of electromagnetic waves is the same. Scientists call this speed the speed of light because visible light, the light humans can see with the naked eye, is the most familiar kind of wave. The speed of light is measured to be 300,000,000 m/s, which can also be written as: 3×10^8 m/s (approximately 186,000 miles per second).

Gamma rays, the type of radiation studied by the Fermi Telescope, have the shortest wavelengths and the highest frequencies of the electromagnetic spectrum. Because these waves have the greatest amount of energy, they are the most penetrating of all electromagnetic waves, making them valuable in controlled medical situations. Some radioactive substances and certain nuclear reactions produce gamma rays. Some objects far out in space give off bursts of gamma rays. The gamma rays travel for billions of years before they reach Earth. Earth's atmosphere blocks these gamma rays, making orbiting telescopes like Fermi important to the study of these high energy waves.

Source: Radio Jove http://radiojove.gsfc.nasa.gov

Procedure:

1. (**TECHNOLOGY**) Break the class into seven groups and assign each group a section of the electromagnetic, or EM, spectrum to investigate. Using the Internet, students should find the following information on their assigned part of the EM spectrum:
   a) Frequency, wavelength, and energy associated with the particular part of the spectrum.
   b) Identify the type of radiation by name and give examples of how humans encounter this type of radiation, either directly or indirectly.
   c) Example of something that is the same relative size of one wavelength for that part of the spectrum.

2. Have students fill in their information in Table 1 on page 4 in the Student Guide.

3. While students are working, hang a large piece (approximately 2 meters in length) of bulletin board paper on the wall. Mark off a horizontal axis using a logarithmic (powers of 10) scale. Label the axis "Wavelength (m)." At the top of the paper draw the wave frequency pattern similar to Figure 1. Do not add any other labels at this time.

4. Have the students mark off the boundaries of their sections of the electromagnetic spectrum on the chart. Label the corresponding frequency and wavelength below each section. Include examples of human encounters, either direct such as sunburn, or indirect such as a black hole, and an example of something the same relative size of that type of wavelength.

5. Once all groups have posted their information, have the class fill out Table 2 on page 4 in the Student Guide.

6. (**CHECK FOR UNDERSTANDING**) Discuss what students have learned during the EXPLORE activity using the questions on page 5 of the Student Guide.

7. (**CONNECTIONS**)(**RESOURCE**) When discussing question 4 of the EXPLORE activity in class, point out to students that there are several different types of telescopes that utilize different parts of the electromagnetic spectrum. An overview of these telescopes can be found at:
   http://imagine.gsfc.nasa.gov/docs/science/know_l2/emspectrum.html

EDUCATOR GUIDE

EXPLAIN (30 minutes)

During the **EXPLORE** activity students discovered qualitative information about the electromagnetic spectrum. During the **EXPLAIN** activity, students discover that speed, wavelength and frequency are related.

speed = wavelength x frequency

The speed of all electromagnetic waves is the same and is called the speed of light (*c*). As a result, the wavelength decreases as the frequency increases. Waves with the shortest wavelengths have the highest frequencies. The amount of energy carried by an electromagnetic wave increases with frequency; therefore, the higher the frequency of the wave, the higher its energy.

Students are introduced to two equations that relate frequency, wavelength, and energy of electromagnetic radiation:

$$c = \lambda \nu$$

$$E = h\nu$$

c = speed of light = 3.0×10^8 m/s
λ = wavelength in meters
ν = frequency in wavelengths/second or hertz (Hz)
E = energy of one photon of light in joules (*J*)
h = Planck's Constant = 6.63×10^{-34} J·s

1. Have students use the chart created in class to help them answer the questions on page 6 of the Student Guide and complete the calculations on pages 7-8.
2. **(MODIFICATION)** Students can be given two completed examples of problems using the two equations if they are unable to answer the mathematical questions in the Student Guide:

   a. Question 8a – Calculate the wavelength of radiation with a frequency of 610 kHz.
   $3.0 \times 10^8 = \lambda(610000)$
   $\lambda = 490$ m

   b. Question 8e – Calculate the energy of radiation with a frequency of 6.51×10^{14} wavelengths/second.
   $E = 6.63 \times 10^{-34}(6.51 \times 10^{14})$
   $E = 4.31 \times 10^{-19}$ J

EXTEND

1. To give students an idea of how electromagnetic radiation plays a part in their lives, have them keep an "Electromagnetic Journal" for one week. In this

EDUCATOR GUIDE

journal they should record each time they come in contact with some form of electromagnetic radiation, i.e. cell phone, cordless phone, wireless network, listening to the radio, watching TV, getting an x-ray, tanning, etc. Students should also record:

1. The date and time of contact;
2. The type of electromagnetic radiation in which they came in contact;
3. A one sentence description of the interaction.

(**MODIFICATION**)(**TECHNOLOGY**) Ask students to document some of their interactions with digital images. Students may create a multimedia presentation using the images.

2. At the end of the week, ask students to share their journals. As a class, tally the number of times each type of electromagnetic radiation was encountered. Have a classroom discussion about the results of the tally. Which types of radiation were encountered the most often? What evidence did students have of the encounter?

(**TECHNOLOGY**) Using graphing software or a graphing calculator, have students construct graphic representations of their results.

EVALUATE (30 minutes)

1. Use questions, discussions, and the Student Guide to assess students' understanding.

2. **(RESOURCE) (TECHNOLOGY)** Show the NASA eClips™ video segment *Launchpad: Infrared Astronomy on Mauna Kea* (4:26). This segment can be found on the NASA eClips™ page of the NASA web site:

http://www.nasa.gov/audience/foreducators/nasaeclips/launchpad/index.html
The video may be streamed or downloaded from the nasa.gov web site; a captioned version is also available at the nasa.gov site. When using the nasa.gov web site, click on the program playlist and scroll through the list beneath the video player to locate the appropriate segment. To turn closed captioning on or off, click on the "CC" icon at the lower right hand corner of the video player.

3. (**MODIFICATION**) This video may be streamed from the NASA eClips You Tube™ channel: *http://www.youtube.com/watch?v=J4CYaDq0coQ*

a. Answer the following question: “Why do astronomers build radio telescopes and X-ray telescopes in addition to the optical telescopes with which most people are familiar?”

(Celestial objects emit many forms of electromagnetic radiation and not all celestial objects emit the same types of radiation. For example, some objects emit energy in the form of x-rays, while much of the background microwave radiation in space is believed to be a remnant of the Big Bang. Each form of energy gives us different information about the universe.)

b. Thermograms are infrared photographs that show emission of infrared radiation emitted from objects. If you lived in a cold climate, how could a thermogram taken of your home be helpful to you as a homeowner?

(Answers will vary but should include a discussion of being able to see where heat is escaping from the house.)

c. Why are the colors of light arranged in the order red, orange, yellow, green, blue, indigo, violet?

(This is the order of increasing frequency and energy of light waves. This can be modeled by placing a prism on an overhead projector screen or in front of a bright light and looking at the sequence of colors as the white light is split into individual wave components. Because different wavelengths of light energy refract, or bend, a different number of degrees when passing through a prism, the different wavelengths are separated. The shorter the wavelength, the larger the angle of refraction.)

Making Waves: EM Energy Cards

Figure 3
Image Credit: NASA

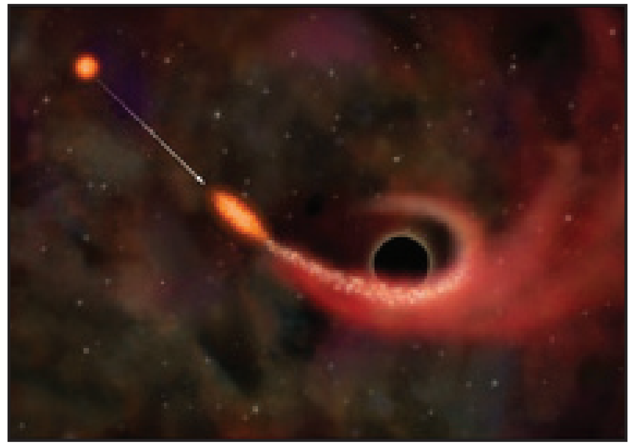

Figure 2
Image Credit: NASA/CXC/M. Weiss

Figure 4
Image Credit: NASA

Figure 6
Image Credit: NASA

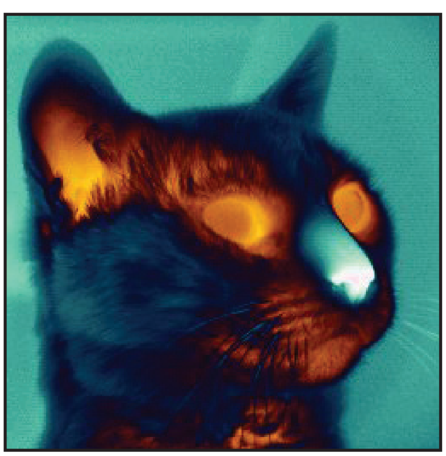

Figure 5
Image Credit: SE-IR Corporation, Goleta, CA

Figure 7
Image Credit: NASA

STUDENT GUIDE

Making Waves

Essential Questions:

- What is the electromagnetic spectrum?
- How can energy be transmitted?
- What is the relationship between the energy, wavelength and frequency of a wave?
- How do advances in technology, such as the Fermi gamma ray telescope, advance our understanding of the universe?

Background

The universe is home to many strange and beautiful phenomena. Some of these spectacles can generate huge amounts of energy. Super massive **black holes**, merging **neutron stars**, streams of hot gas moving close to the speed of light . . . these are but a few of the marvels that generate gamma-ray radiation. Gamma rays are the most energetic form of radiation. These rays are billions of times more energetic than the type of light visible to our eyes. What is happening to produce this much energy? What happens to the surrounding environment near these phenomena? How will studying these energetic objects add to our understanding of the nature of the Universe and how it behaves?

The **Fermi Gamma-ray Space Telescope**, formerly GLAST, will open this high-energy world to exploration and help us to answer these questions. With Fermi, astronomers will have a superior tool to study black holes. Notorious for pulling matter in, black holes can accelerate jets of gas outward at fantastic speeds. Physicists will be able to study subatomic particles at energies far greater than those seen in ground-based laboratories. **Cosmologists** will gain valuable information about the birth and early evolution of the Universe.

Figure 1. Fermi Gamma-ray Space Telescope exploring space.
Image credit: NASA

STUDENT GUIDE

The Fermi mission has several objectives:

- Explore the most extreme environments in the Universe, where nature harnesses energies far beyond anything possible on Earth.
- Search for signs of new laws of physics and what composes the mysterious **dark matter.**
- Explain how black holes accelerate immense jets of material to nearly light speed.
- Help crack the mysteries of the stupendously powerful explosions known as gamma-ray bursts.
- Answer long-standing questions across a broad range of topics, including **solar flares**, **pulsars** and the origin of cosmic rays.

Little is known about gamma rays. Because of its unique instruments and position, Fermi will help scientists learn more about this unexplored **electromagnetic radiation**. Fermi will help scientists make advances in astronomy and high-energy physics. International scientists hope the powerful telescope may also yield unanticipated findings about black holes and dark matter.

Source: Fermi Gamma-ray Space Telescope Home Page http://fermi.gsfc.nasa.gov/

Vocabulary

black hole – A black hole is a region of space with gravitational force so strong that nothing can escape from it.

cosmologist – A cosmologist is a scientist or astronomer who studies large scale structures and dynamics of the universe, including the origins of the universe.

dark matter – Dark matter is the name given to the amount of mass whose existence is deduced from the analysis of galaxy rotation curves but which until now has escaped all detection. There are many theories about dark matter, but the subject is still a mystery.

electromagnetic radiation – Electromagnetic radiation is energy radiated in the form of waves. It consists of electric and magnetic fields traveling at the speed of light.

Fermi Gamma-ray Space Telescope – Fermi is a space telescope that consists of two parts: the Large Area Telescope, or LAT, and the Fermi Burst Monitor. The LAT has a wide field of view and can detect gamma rays. The Fermi Burst Monitor observes gamma ray bursts which are sudden, brief flashes of gamma radiation that occur about once a day.

STUDENT GUIDE

frequency (ν) – Frequency is the number of waves that pass a fixed point in a given period of time. The frequency of electromagnetic radiation is measured in hertz (Hz) which is defined as the number of waves per second.

joule (*J*) – The joule is a unit of energy. One joule is the energy expended when 1 Newton of force is applied to move an object a distance of 1 meter.

neutron star – A neutron star is the type of star formed when a massive star explodes as a supernova, leaving behind an ultra dense core.

photon – A photon is a quantum, or discrete amount, of light energy. Photons have no mass and behave like both a particle and a wave.

Planck's constant (*h*) – Planck's constant is a physical constant relating the energy of a photon to its frequency. The value of this constant is approximately 6.626×10^{-34} joule·second.

pulsar – A pulsar is a rotating neutron star which generates regular pulses of radiation.

solar flares – Solar flares are violent eruptions of gas on the sun's surface.

speed of light (*c*) – The speed of light is the speed of electromagnetic radiation in a perfect vacuum. The speed of light is the same for all frequencies of electromagnetic radiation, 3.0×10^8 m/s.

wavelength – Wavelength is the length of one wave of radiation, or the distance between two consecutive waves. Wavelength is usually measured in meters.

A. ENGAGE

Examine each of the images on the electromagnetic energy cards. Place the cards in a sequential order. Explain why you chose the order you did.

B. EXPLORE

Research your segment of the electromagnetic spectrum and fill in Table 1 on the next page.

Table 1. Information on One Section of the Electromagnetic Spectrum

Section of Spectrum	Wavelength Span (m)	Frequency Span (Hz)	Energy Span (J)	Encounter Examples	Examples of Size of 1 Wavelength

Table 2. Information on All Sections of the Electromagnetic Spectrum

Section of Spectrum	Wavelength Span (m)	Frequency Span (Hz)	Energy Span (J)	Encounter Examples	Examples of Size of 1 Wavelength

STUDENT GUIDE

Student Questions:

1. What do all electromagnetic waves have in common? How do they differ?

2. Compare and contrast electromagnetic waves with other kinds of waves.

3. What types of electromagnetic radiation does a flame emit?

4. Explain how observing an object through different wavelengths provides significantly more information than an image of the object in only one type of electromagnetic radiation. Give an example.

5. Why are astronomers interested in searching for and studying gamma rays? What can they learn from this study?

6. How does technology enhance the study of gamma rays? Give specific examples.

STUDENT GUIDE

C. EXPLAIN

Use the data collected by the class and the information given to answer the following questions.

INFORMATION: The sections of the electromagnetic spectrum are arranged in the following order of increasing energy – radio waves, microwaves, infrared, visible light, ultraviolet, X-rays, gamma rays.

1. What happens to the value of the wavelength as you move from radio waves to gamma rays?

2. What happens to the value of the frequency as you move from radio waves to gamma rays?

3. What happens to the amount of energy associated with each section of the electromagnetic spectrum as you move from radio waves to Gamma rays?

4. What type of mathematical relationship exists between wavelength and frequency?

5. What type of mathematical relationship exists between energy and frequency?

STUDENT GUIDE

Equations for electromagnetic radiation

$$c = \lambda\nu$$
$$E = h\nu$$

c = speed of light = 3.0×10^8 meters per second (m/s)
λ = wavelength in meters
ν = frequency in hertz or wavelengths/second (Hz)
E = energy of one photon of light in joules (J)
h = Planck's Constant = 6.63×10^{-34} Joule-seconds (J·s)

Student Calculations:

6. Find the shortest wavelength associated with visible light from the information gathered in class. Using this value and the information above, calculate the associated frequency. Does the value you calculated agree with the value given in class?

7. Find the lowest frequency associated with visible light from the information gathered in class. Using this value and the information above, calculate the associated energy. Does the value you calculated agree with the value given in class?

8. Perform the following calculations. In which part of the electromagnetic spectrum can each wave be found?

   a. The wavelength of radiation with a frequency of 610 kHz.

   b. The wavelength of radiation with a frequency of 2.34×10^{18} wavelengths/second.

STUDENT GUIDE

c. The frequency of radiation with a wavelength of 10.5 nm.

d. The frequency of radiation with a wavelength of 1520 m.

e. The energy of radiation with a frequency of $6.51x10^{14}$ wavelengths/second.

f. The energy of radiation with a wavelength of 820 nm.

Answer Key – Making Waves

B. EXPLORE

Table 1. Information on One Section of the Electromagnetic Spectrum

Answers will vary depending on the section assigned.

Section of Spectrum	Wavelength Span (m)	Frequency Span (Hz)	Energy Span (J)	Encounter Examples	Examples of Size of 1 Wavelength

Table 2. Information on the Other Sections of the Electromagnetic Spectrum

Section of Spectrum	Wavelength Span (m)	Frequency Span (Hz)	Energy Span (J)	Encounter Examples	Examples of Size of 1 Wavelength
Radio	$>1x10^{-1}$	$<3x10^{9}$	$<2x10^{-24}$	*Radio Communica-tions*	*A building*
Microwave	$1x10^{-3}$ to $1x10^{-1}$	$3x10^{9}$ to $3x10^{11}$	$2x10^{-24}$ to $2x10^{-22}$	*Heating food*	*Grain of sugar*
Infrared	$7x10^{-7}$ to $1x10^{-3}$	$3x10^{11}$ to $4x10^{14}$	$2x10^{-22}$ to $3x10^{-19}$	*Heat lamps*	*Protozoan*
Visible Light	$4x10^{-7}$ to $7x10^{-7}$	$4x10^{14}$ to $7.5x10^{14}$	$3x10^{-19}$ to $5x10^{-19}$	*Vision*	*Bacterium*
Ultraviolet	$1x10^{-8}$ to $4x10^{-7}$	$7.5x10^{14}$ to $3x10^{16}$	$5x10^{-19}$ to $2x10^{-17}$	*Tanning bed*	*Molecule*
X-Ray	$1x10^{-11}$ to $1x10^{-8}$	$3x10^{16}$ to $3x10^{19}$	$2x10^{-17}$ to $2x10^{-14}$	*Medical x-ray machine*	*Atom*
Gamma Ray	$<1x10^{-11}$	$>3x10^{19}$	$>2x10^{-14}$	*Nuclear explosion*	*Atomic nucleus*

ANSWER KEY

Student Questions:

1. What do all electromagnetic waves have in common? How do they differ?

   similarities: same speed, can travel in a vacuum, have an electrical component and a magnetic component

   differences: frequency, wavelength, energy, use/occurrence

2. Compare and contrast electromagnetic waves with other kinds of waves.

   similarities: measurable wavelength, frequency, energy, shape.

   differences: other waves require a medium to travel through, other waves don't all have the same speed, other waves can be seen (ocean waves) or heard (sound waves).

3. What types of electromagnetic radiation does a flame emit?

   A flame emits visible light and infrared radiation.

4. Explain how observing an object through different wavelengths provides significantly more information than an image of the object in only one type of electromagnetic radiation. Give an example.

   Answers will vary. One example is in astronomy. When scientists study stars and galaxies they collect information in all parts of the electromagnetic spectrum to better understand their structure.

5. Why are astronomers interested in searching for and studying gamma rays? What can they learn from this study?

   Answers will vary, but may include: discovering new laws of physics; explaining how black holes behave; understanding gamma-ray bursts; answering questions about pulsars; understanding the origin of cosmic rays; and explaining dark matter.

6. How does technology enhance the study of gamma rays? Give specific examples.

   Answers will vary, but may include: instruments on board the Fermi Telescope help scientists "see" the invisible; putting telescopes in orbit above Earth's atmosphere help scientists collect data that is not available from Earth's surface.

ANSWER KEY

C. EXPLAIN

1. What happens to the value of the wavelength as you move from radio waves to Gamma rays?

   The value of the wave decreases. That is, as the frequency increases, the wavelength decreases, or $\nu \propto 1 / \lambda$

2. What happens to the value of the frequency as you move from radio waves to Gamma rays?

   The value of the frequency increases. That is, as the frequency increases, the energy increases, or $E \propto \lambda$.

3. What happens to the amount of energy associated with each section of the electromagnetic spectrum as you move from radio waves to Gamma rays?

   The amount of energy increases.

4. What type of mathematical relationship exists between wavelength and frequency?

   An inverse mathematical relationship exists between wavelength and frequency.

5. What type of mathematical relationship exists between energy and frequency?

   A direct mathematical relationship exists between energy and frequency.

Student Calculations:

6. Find the shortest wavelength associated with visible light from the information gathered in class. Using this value and the information above, calculate the associated frequency. Does the value you calculated agree with the value given in class?

   $3.0x10^{8} = 4x10^{-7}\nu$

   $\nu = 7.5x10^{-14}$ *Hz*

7. Find the lowest frequency associated with visible light from the information gathered in class. Using this value and the information above, calculate the associated energy. Does the value you calculated agree with the value given in class?

$E = 6.63x10^{-34}(4x10^{14})$

$E = 2.7x10^{-19}J$

8. Perform the following calculations. In which part of the electromagnetic spectrum can each wave be found?
   a. The wavelength of radiation with a frequency of 610 kHz

      490 m – Radio

   b. The wavelength of radiation with a frequency of $2.34x10^{18}$ wavelengths/second

      $1.3x10^{-10}$ m – X-ray

   c. The frequency of radiation with a wavelength of 10.5 nm

      $2.9x10^{16}$ Hz – Ultraviolet

   d. The frequency of radiation with a wavelength of 1520 m

      $2.0x10^{5}$ Hz – Radio

   e. The energy of radiation with a frequency of $6.51x10^{14}$ wavelengths/second

      $4.31x10^{-19}$ J – Visible Light

   f. The energy of radiation with a wavelength of 820 nm

      $2.4x10^{-19}$ J – Visible Light