Electromagnetic Spectrum

Student Objective
The student:
- will know that the sun's energy is transferred to Earth by electromagnetic waves
- will understand that there are eight main types of electromagnetic waves that are classified on the electromagnetic spectrum by their wavelengths
- will be able to explain how each of the types of electromagnetic radiation is used or found in our everyday lives.

Materials:
- electromagnetic spectrum chart
- internet access
- reference books
- overhead projector, computer with LCD projector or other presentation equipment
- chart paper, computer programs, and other materials for creating presentation visuals

Key Words:
compressional waves
electromagnetic radiation
electromagnetic spectrum
electromagnetic waves
frequency
gamma rays
hertz
infrared waves
longitudinal waves
microwaves
photon
radio waves
speed of light
transverse waves
visible light
ultraviolet light

Time:
1 class period for engaging discussion
1 - 2 class periods for research and presentation preparation
Homework as needed
1 class period for presentations

Background Information

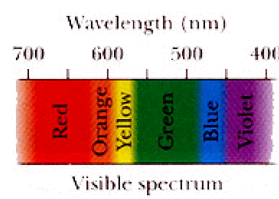
Electromagnetic radiation can be described in terms of a stream of massless particles, each traveling in a wave-like pattern and moving at the speed of light. Each massless particle contains a certain amount (or bundle) of energy. Each bundle of energy is called a photon, and all electromagnetic radiation consists of these photons. The only difference between the various types of electromagnetic radiation is the amount of energy found in the photons. Radio waves have photons with low energies, microwaves have a little more energy than radio waves, infrared has still more, then visible, ultraviolet, x-rays, and the most energetic of all, gamma rays.

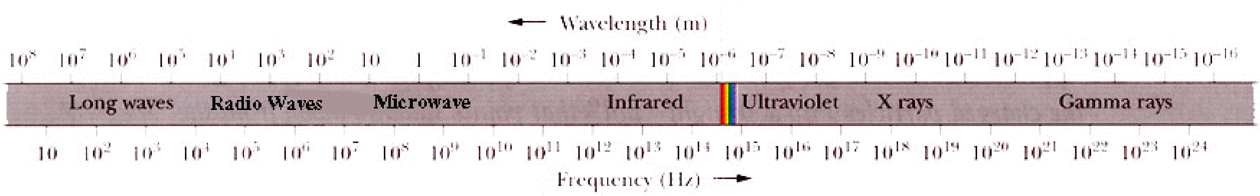
Electromagnetic radiation from space is unable to reach the surface of the Earth except at a very few wavelengths, such as the visible spectrum and radio frequencies. Astronomers can get above enough of the Earth's atmosphere to observe some infrared wavelengths from mountain tops or by flying their telescopes in a spacecraft.

The small portion of the electromagnetic spectrum that we can detect with our eyes is called the optical or visible light spectrum. This spectrum ranges in color from reds and oranges up through blues and purples. Each of these colors actually corresponds to a different energy of light and make up only a small portion of the electromagnetic spectrum–visible light. Of all the colors in the visible spectrum, red light is the least energetic (lowest frequency) and violet is the most energetic (highest frequency). Below the red end of the visible part of the spectrum lie infrared and radio waves, both of which have lower energy than visible light. Above the violet end of the visible spectrum lies the higher energies of ultraviolet light, x-rays and gamma rays.

Light can be described not only in terms of its energy, but also its wavelength and its frequency. There is a one-to-one correspondence between each of these representations; wave frequency and wavelength are related inversely while wave frequency and energy are directly related. X-rays and gamma-rays are usually described in terms of energy, optical and infrared light in terms of wavelength, and radio in terms of frequency. This is a scientific convention that allows the use of the units that are the most convenient for describing whatever energy is being observed.

Wavelength is the distance between two peaks or crests of a wave, and is measured with a base unit of meters. Frequency is the number of cycles or waves to pass some point in a second. The basic unit of frequency is cycles per second, or Hertz. In astronomy, gamma rays are often measured in electron volts, or eV.





Procedure (research and presentation preparation)

1. **Engage:** Lead a classroom discussion on transverse waves, electromagnetic radiation, and the electromagnetic spectrum to discover prior knowledge. Implement the internet resource sites during the discussion. Some points to cover are:
   - transverse waves can travel through a vacuum such as space (compressional waves such as sound waves must travel through a medium)
   - only lower frequencies of radiation are able to penetrate our atmosphere from space, mostly the visible spectrum and the radio frequencies
   - electromagnetic radiation is a wave of massless particles (photons) of energy that travel at the speed of light
   - the amount of energy in the photons varies with the different wavelengths (frequencies); conversely, all types of electromagnetic radiation are basically the same except for their frequency (wavelength) and therefore the amount of energy

in the photons
- the longer wavelengths have photons with less energy, the shorter wavelengths have photons of greater energy
- the small part of the electromagnetic spectrum that we can detect with our eyes is the optical (or visible) spectrum. However, some animals can see in the infrared and/or UV range.
- the frequency of a wave is the number of wave crests that pass a point during one second
- as the energy or frequency of the electromagnetic wave increases, its wavelength decreases. This is called an inverse relationship
- our Sun and other stars produce electromagnetic waves that can be detected using space telescopes

2. Divide the students into seven to ten groups, depending on class size.
3. **Explore:** Explain to the students that they will be researching one of the seven types of waves in the electromagnetic spectrum and giving a group presentation. Towards this goal, they must organize their group and develop team goals for their research. Tell the students that their group presentation will be rated by the rest of the class on these three criteria:
   - content knowledge - information from the six research questions
   - creativity & originality
   - presentation skills - thoughts and ideas are clearly spoken and shown
4. Assign each group a type of electromagnetic energy:
   - radio waves
   - microwaves
   - infrared waves
   - visible light
   - ultraviolet light
   - x rays
   - gamma rays

   For larger classes or to have smaller groups, include these:
   - cosmic waves
   - part of the spectrum that provides heat for solar thermal devices
   - part of the spectrum that 'powers' photovoltaics
5. Give the class time to research and prepare their presentations. They should begin by answering the questions in their Laboratory Manual, then use this information as the content knowledge for their presentation.
6. Assist as necessary by observing and listening to student interactions.
7. **Explain and Elaborate:** All students should participate during the research and presentation process. The students should use terminology correctly and reveal an understanding of the wave energy being investigated.

Procedure (presentation day)

1. Have all students take notes during the group presentations including what they like and dislike about each presentation.

2. After all the presentations are completed, hand out copies of the rating sheet and have each student 'x' out the presentation that they are doing (they can not assess their own presentation!)
3. Have students discuss and rate the other group presentations on a scale of 1 - 10 (with 10 being the highest) for each of the criteria and complete their self evaluation section.
4. Collect the group ratings; tally the scores and announce the group with the highest score in each category. Lead a classroom discussion of what was done to make an effective presentation giving credit to as many groups as possible. Agree or disagree with the class ideas as needed. Possible discussion points:
    - What group (or groups) covered their topic and used terminology the best?
    - What group (or groups) had the most creative and original ideas? Why?
    - What group (or groups) demonstrated quality presentation skills? Why?
    - What group (or groups) demonstrated working effectively and making necessary compromises?
    - Do the class' tallied scores agree with the discussion?

Evaluation and Student Assessment

Post these criteria or discuss them with your students before they begin this project. You may use a checklist or develop a rubric for evaluation.

1. How are students communicating within the group?
    - Are they explaining their ideas and listening to others effectively?
    - Are they modeling collaborative work habits and working effectively?
    - Are they being open and responsive to new ideas?
2. Are the students using critical thinking and problem solving skills?
    - Are they making reasonable choices and decisions within the group?
    - Are they verifying points of view and offering new or different solutions to improve the quality of the presentation?
    - Are they analyzing the information and resources discovered during the research process?
3. Are the students developing the social skills needed to work as a team?
    - Are they monitoring their own role and being productive?
    - Are they setting high standards and goals for delivering a quality presentation?
    - Are they using their strengths or the strengths of others to accomplish the team's goals?

Collect the group evaluation forms and use these forms to rank the group's presentation performance. Use these peer review scores to launch your class discussion. These scores may be added to your own assessment score or used alone.

Suggested Overall Assessment:

40% student performance in the group working as a team member (teacher observation and group evaluation answers)
40% group presentation performance (use Presentation Evaluation as a rubric)
20% peer review results

Related Research

1. Should the federal government be allowed to control the frequency bandwidths for communication? Support your argument.
2. How are thermograms (infrared photographs) used to help in energy efficient building design?
3. Defend the importance of gamma rays in treating cancer, even though many patients suffer serious side effects to such treatment.
4. If radio waves are not compressional waves like sound waves, explain what their role is in enabling us to hear music from a radio station.
5. How is the depletion or thinning of the ozone layer related to increased ultraviolet radiation? What measures can we take to stop the depletion of the ozone layer? What can we do to prevent exposure to ultraviolet radiation?
6. Research the ozone layer of our atmosphere and which frequencies it blocks and which it lets through. Recently, ozone holes have been in the news. What are the consequences to the Earth under the holes in the ozone?
7. Research the System International (SI) Prefix units used in the metric system. Convert the wavelength units listed in the Electromagnetic Spectrum from scientific notation to their proper prefix units ranging from *femto* units to *mega* units.
8. Compare and contrast laser light, fluorescent light and incandescent light.
9. How do laser printers and dvd players use laser light?
10. Why are parabolic shaped dishes used to receive low energy electromagnetic waves such as radio waves or television signals?

Math Extension

1. Draw to scale the smallest wavelengths of visible light differentiating the colors we see, using the data below:

Wavelengths (in nanometers) of Visible Light	
Violet	390 - 455 nm
Blue	455 - 492 nm
Green	492 - 577 nm
Yellow	577 - 597 nm
Orange	597 - 622 nm
Red	622 - 700 nm

2. Select a country in the world you would like to visit. Find the distance from your town to the capitol of the other country. Given the $V_{light}=3 \times 10^8$ m/s and Velocity = distance/time; calculate the time it would take any wave in the Electromagnetic Spectrum to travel this distance.

Related Reading

- **Alien Vision: Exploring the Electromagnetic Spectrum with Imaging Technology** by Austin Richards (SPIE Publications, 2001)
  This book takes readers on a visual tour of the electromagnetic spectrum beyond the range of human sight, using imaging technology as the means to 'see' invisible light. These technologies have applications ranging from fire fighting and law enforcement to botany and medicine.

Internet Sites

http://imagers.gsfc.nasa.gov/ems/index.html
NASA's Imagine the Universe site. Information on the electromagnetic spectrum and the different frequencies of waves on it.

http://www.pbs.org/wgbh/nova/gamma/spectrum.html
PBS Nova Online. Self guided tour of the electromagnetic spectrum.

http://missionscience.nasa.gov/ems/01_intro.html
An introduction to the Electromagnetic Spectrum which includes information covering each wave category. Updated NASA images and applications are included.

http://science.howstuffworks.com/radiation.htm
How Radiation Works includes information on each categorical wave in the electromagnetic spectrum with numerous links within its information to learn more.

http://photovoltaics.sandia.gov/docs/FAQ.html
Sandia National Labs photovoltaic FAQ page includes information on the part of the spectrum used by photovoltaics.

http://www.ucmp.berkeley.edu/education/dynamic/session5/sess5_electromagnetic.htm
San Francisco school district's page on solar radiation and the electromagnetic spectrum.

Electromagnetic Spectrum

Answers - Problem Set

1. 0.015654 sec
2. 62.55 mph
3. Answers will range in AM from 190m to 550m and in the FM range from 2.78m to 3.4m

Electromagnetic Spectrum

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Nature of Science																					
Standard 1	**SC.912.N.1.**				**X**																
Earth and Space																					
Standard 5	**SC.912.E.5.**								**X**												
Physical Science																					
Standard 10	**SC.912.P.10.**	**X**																**X**	**X**		
Language Arts Standards		**LA.912.2.2.2, LA.912.5.2.2, LA.912.5.2.3**																			
Mathematics Standards		**MS.912.A.1.2, MA.912.A.2.2**																			

Science Standards
Standard 1: The Practice of Science

- SC.912.N.1.4 - Identify sources of information and assess their reliability according to the strict standards of scientific investigation.

Standard 5: Earth in Space and Time

- SC.912.E.5.8 - Connect the concepts of radiation and the electromagnetic spectrum to the use of historical and newly-developed observation tools.

Standard 10: Energy

- SC.912.P.10.1 - Differentiate among the various forms of energy and recognize that they can be transformed from one form to others.
- SC.912.P.10.17 -.Explore the theory of electromagnetism by explaining electromagnetic waves in terms of oscillating electric and magnetic fields.
- SC.912.P.10.18 - Explore the theory of electromagnetism by comparing and contrasting the different parts of the electromagnetic spectrum in terms of wavelength, frequency, and energy, and relate them to phenomena and applications.

Language Arts Standards
Literary Analysis - Standard 2: Nonfiction

- LA.910.2.2.2 - The student will use information from the text to answer questions or to state the main ideal or provide relevant details.
- LA1112.2.2.2 - The student will use information from the text to answer questions or to state the main ideal or provide relevant details.

Communication - Standard 2: Listening and Speaking

- LA.910.5.2.2 - The student will research and organize information for oral communication appropriate for the occasion, audience, and purpose.
- LA910.5.2.3 - The student will use appropriate eye contact, body movements, voice register, and oral language choices for audience engagement in formal and informal speaking situations.
- LA1112.5.2.2 - The student will apply oral communication skills in interview, formal presentation and impromptu situations according to designated rubric criteria.
- LA1112.5.2.3 - The student will use research and visual aids to deliver oral presentations that inform, persuade or entertain, and evaluate ones own and others oral presentations according to designed rubric criteria.

Mathematics Standards

Algebra - Standard 1: Real and Complex Number Systems

- MA.912.A.1.2 - Compare real number expressions.

Algebra - Standard 2: Relations and Functions

- MA.912.A.2.2 - Interpret a graph representing a real-world situation.

Electromagnetic Spectrum

compressional waves - another term for longitudinal waves. Waves such as sound waves that require a medium to transfer energy.

electromagnetic spectrum - the full range of frequencies, from radio waves to gamma rays, that characterizes light.

electromagnetic waves - waves consisting of oscillating electric and magnetic fields that move at the speed of light through space.

frequency - a property of a wave that describes how many wave patterns or cycles pass by in a period of time. Frequency is often measured in Hertz (Hz), where a wave with a frequency of 1 Hz will pass by at 1 cycle per second.

gamma rays - the highest energy, shortest wavelength electromagnetic radiations. Usually, they are thought of as any photons having energies greater than about 100 keV.

hertz - the derived SI (international standard) unit of frequency, defined as a frequency of 1 cycle per second.

infrared waves - electromagnetic radiation at wavelengths longer than the red end of visible light and shorter than microwaves (roughly between 1 and 100 microns). Almost none of the infrared portion of the electromagnetic spectrum can reach the surface of the Earth, although some portions can be observed by high-altitude aircraft or telescopes on high mountaintops.

longitudinal waves - waves such as sound waves that require a medium to transfer energy.

microwaves - electromagnetic radiation which has a longer wavelength (between 1 mm and 30 cm) than visible light, but shorter than radio waves. Microwaves can be used to study the Universe, communicate with satellites in Earth orbit, and cook popcorn.

photon - a tiny particle or bundle of radiant energy

radio waves - electromagnetic radiation which has the lowest frequency, the longest wavelength, and is produced by charged particles moving back and forth; the atmosphere of the Earth is transparent to radio waves with wavelengths from a few millimeters to about twenty meters. Radio waves are used to broadcast radio and television as well as being emitted by stars and gases in space.

speed of light - 299,792,458 meters per second

transverse waves - waves such as light waves that can transfer energy in a vacuum without a medium.

visible light - electromagnetic radiation at wavelengths which the human eye can see. We perceive this radiation as colors ranging from red (longer wavelengths; ~ 700 nanometers) to violet (shorter wavelengths; ~400 nanometers.).

ultraviolet light - electromagnetic radiation at wavelengths shorter than the violet end of visible light; the atmosphere of the Earth effectively blocks the transmission of most ultraviolet light.

x-rays - electromagnetic radiation of very short wavelength and very high-energy; X-rays have shorter wavelengths than ultraviolet light but longer wavelengths than gamma rays.

Electromagnetic Spectrum

Rate each group on a 1 - 10 scale (with 10 being the highest) for each of the three categories. Total each groups score across.

	Content Knowledge	Creativity & Originality	Scientific Presentation Skills	Total Score
	Terms and ideas are correct and complete	Ideas are unique and interesting	Ideas are clearly spoken & shown	
Radio Waves				
Microwaves				
Infrared Waves				
Visible Light				
Ultraviolet Light				
X Rays				
Gamma Rays				
Cosmic Rays				
Solar Thermal				
Photovoltaics				

Evaluate your own group by answering the questions below:

1. How did you make sure all group member's shared in the responsibility of completing this project?

2. What issues or tasks challenged the group?

3. What went well?

4. How could you improve your group’s overall performance?

Electromagnetic Spectrum

With your group, use the questions below to help you gather information as you research and prepare your presentation. Your presentation will be evaluated on the correct use of terms and concepts as well as the creative/original presentation of ideas.

1. What are the characteristics or physical properties of your selected radiation? (i.e. wavelength, frequency, velocity and other key facts)

2. Where is this type of radiation located on the electromagnetic spectrum in relation to neighboring types of waves?

3. What properties of the wave define why it is found within this area of the spectrum?

4. How was this type of radiation discovered? Who are some of the important scientists who have conducted research into this form of radiation?

5. How can you create this type of radiation on Earth? How can you receive it?

6. How is it used or found in our everyday lives or in certain industries? Identify and explain at least four uses.

7. What are the benefits and/or hazards of these waves?

8. How are these waves used in the field of astronomy to learn more about our Universe?

Electromagnetic Spectrum

Given:

- waves in the Electromagnetic Spectrum can travel at $V_{light} = 3 \times 10^8$ m/s
- Velocity = Distance/Time (V=d/t)
- 1.0 miles = 0.6km
- 1.0 km = 1000m (10^3m)
- 1 day = 24 hours

1. The driving distance between the District of Columbia and San Francisco,CA is 4,692 km (2,815 miles). The time it would take to drive this distance at legal speed limits is 45 hours. Given the information above, calculate how long it would take a radio wave to travel this same distance. Show your calculations.

2. What is the average driving velocity of the vehicle (from the problem above) traveling from Washington, DC to San Francisco, CA?

3. Select a favorite radio station. Using the information below, find the wavelength of the wave that carries your radio station's signals to your radio.
   - AM radio stations use their call numbers and kilohertz units (550 - 1600 x 10^3 Hz)
   - FM stations use their call numbers and megahertz units (88 - 108 x 10^6 Hz)
   - All radio station signals travel at the speed of light: ($V_{light} = 3 \times 10^8$ m/s)
   - Velocity = Wavelength x Frequency