

Bite-size Information

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Big Picture Science

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The Electromagnetic Spectrum

Help your students picture the many waves of radiant energy

Once students understand matter and energy, they are ready for an introduction to electromagnetic energy. Studies with different wavelengths (colors) of visible light can provide a good introduction to the invisible longer and shorter wavelengths.

In the beginning, there was the Big Bang (which is a curious name for it considering that there wasn't any ordinary matter to carry sound waves). This great release of energy included waves that were exceedingly short with extremely high energies. It was about 300,000 years later, after matter had condensed, before any light shown. Now, about fifteen billion years later, the ghost of that great energy release persists as cosmic background radiation. The waves have lengthened as the universe expanded until now they are in the microwave region of the electromagnetic spectrum.

If you can follow the above paragraph, you are able relate wavelength to energy and mentally picture the changes. That's what we want students to be able to do. Students need to see **light as a part of a continuum from short-wavelength gamma rays to the long-wavelength radio waves**. It helps to **start the study of radiant energy with visible light**. After students see the properties of different wavelengths (colors) of light, they will be better prepared for the idea of invisible waves with wavelengths that are longer or shorter than those of visible light.

Once students are familiar with waves and light, they are ready for an introduction to the electromagnetic spectrum (EMS). The tour of the EMS on page 5 explores the question, "**What is electromagnetic radiation?**" and goes on to describe the waves. You may wish to do the **chart of the electromagnetic spectrum** (p. 7) along with the tour. The scale on this chart will likely be different from any students have used before, since it is a log scale with each mark changing 10-fold. Lower elementary students don't even need to use measurements of waves on their chart at first. Upper elementary and middle school students are ready for more quantitative study. The wavelengths and frequency will be meaningful to them. Middle school students can tie this chart to study of logarithms and scientific notation.

The experiments I give in this issue involve waves, visible light, and color. I will continue with activities involving infrared radiation, microwaves, and radio waves in the next issue. Other topics related to EMS include astronomy and current imaging devices, optics, and the interactions of electromagnetic radiation with materials.

Light lessons

The topic of electromagnetic energy is so big that I couldn't stop at 6 pages, so this is an 8-page bonus issue. There are activities to help students understand some properties of the different wavelengths of visible light and an introduction to the EMS along directions for a chart.

Next time I will continue with activities that explore the interactions of light and matter and the invisible wavelengths.

You will have to judge the appropriate level to start and depth to take these studies (as if you don't have to do that with all subjects). Even the beginning activities are useful for older students if they have not explored light and color. You will have to pick chart labeling to fit students' math level.

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Exploring the wavelengths (colors) of light and waves

See the books on page 8 for information on the history of the study of light and its dual wave-particle nature. This will help students think about this difficult-to-understand, fun-to-see subject. It will also help to review the primary colors of light, additive and subtractive color mixing (see Nassau's book), and how prisms and diffraction gratings work.

Separating white light into the colors of the spectrum and why things look colored.

What we are trying to do here: First students separate white light into its component colors. Then they use colored filters to absorb some of the colors. Lastly they look through the colored filters to see what colors are reflected from colored pictures or objects.

SAFETY NOTE: It is not safe to look directly at the sun with any commonly available filters or sunglasses. Remind students that they may do permanent damage to their eyes if they look directly at the sun.

Materials: 1) You need a good light source, the best being sunlight. Alternates include a slide projector, a high intensity lamp, or a bright flashlight. (See box below for other ideas.) If you use a light other than sunlight, you will need to have the activity in a darkened room. 2) You also need one or more of the following (see supply information p. 4): glass prism; a spectroscope; or a diffraction grating. See Robert Wood's book, *Light FUNDamentals*, ISBN 0-07-071808-3 to see how to produce a spectrum with a mirror in a pan of water. 3) You need a good set of colored filters. I recommend the set from Edmund's Scientifics (see p.4).

What you do: Use your light source and your separating tools to produce a spectrum. Have students observe the full spectrum, then look at the spectrum after it has passed through each colored filter, and, importantly, record which colors pass through each filter. They can hold the filter over half of the prism to compare the full spectrum to the filtered one. Use deeply colored filters that pass red, green, blue, yellow, cyan, and magenta if you have those colors available. You can add other filters according to children's interest, but it may be best to start lower elementary with just a few colors. Useful filters from the Edmund's set include: #26 – light red; #90 – dark yellow green; #83 – medium blue; #12 – straw; #370 – Italian blue; #342 – rose pink; and #358 – rose indigo. I selected these filters because they pass certain wavelengths and block most others. Lighter filters pass too much white light; some colors pass too many wavelengths.

And then: 1) Give the students a collection of brightly colored pictures (or objects). Have them look through the colored filters at the pictures and record how red, yellow, green, and blue areas appear. Have students predict what they will see. You will need a well-lit area for this activity. Lower elementary students will especially enjoy this, although older students who have not done this activity will also benefit. 2) Have the students observe the sky through the colored filters and record what they see. 3) Have students look at small colored Christmas lights through the filters and see how the lights change appearance. It's so much fun looking at the colors that you may have to remind students to record their data.

Discussion – When students have had a chance to explore the effects of the colored filters on the spectrum and other colored objects, ask them to explain why things look different through the colored filters. Guide them as they discover that the red filter allows only red light to pass. The red filter makes green and blue objects look very dark and red objects to look lighter and whiter. That is because the green and blue objects reflect very little red. The light from the sky has some red light, even though it looks blue – which is why it looks pink through the red filter.

Using a prism when the sun isn't shining

If you have no direct sunlight in your classroom, you can still use a prism to separate white light. You can place the prism in the beam of a slide projector and slowly rotate it about the long axis. First you may see a broad band of light with a red and blue fringe at either end. As you rotate the prism, the band should narrow and the full rainbow of colors should be visible.

You can also hold the prism close to your eye and look at a light bulb. Slowly rotate the prism until you see all the colors of the spectrum. This works best where there is little light from other sources (in a hallway or darkened room) and when you are standing some distance from the light, not right under it. The light at the bottom of stair well worked well for me.

If this doesn't work for you, you can use the spectroscope and look at an incandescent light source to see a full spectrum. Once you can see the spectrum, you can hold filters in front of the prism or spectroscope, as described above.

Wave lengths of light and waves (cont.)

Spectroscope activities – See the mix of light from different bulbs and the colors that reflect off objects

Materials: spectroscope, incandescent and fluorescent lights, night spectrum card (Edmund's Y53 ,066), a bright light source, colored papers or flat objects with bright primary colors (book covers are one good source)

What you do: First, use the spectroscope to see the colors produced by incandescent and fluorescent bulbs. Fluorescent bulbs show two or more brighter bands of light, whereas incandescent spectra are more uniform. The mix of colors is different for the two types of light. For older students, point out the numbered scale and let them know that this gives the wavelengths of the light in hundreds of nanometers (nm). (See box on p. 7 for more on these units.) Visible light waves range from about 400-700 nm in length. The night spectrum card has a small diffraction grating in it and shows the spectrum of several types of lighting. You could have several of these in expensive cards and allow students to take them home to look at different outdoor lights at night. Discuss why objects look strange under cool white or sodium lights. Older children may want to explore the emission spectra of elements in fluorescent lighting.

For another look at color, shine the bright light on the colored papers (or place them in direct sunlight). Look at the light from each color using the spectroscope. Note that you will see the spectrum from an area that is just to the left of the slit. Students should be able to see that red light is reflected from red paper and that both green and red light are reflected from yellow paper. Sometimes the differences are subtle, since small amounts of other colors are also reflected, so try to select papers that show a clear difference. Discuss why the papers look the color they do.

Extension: Advanced 9-12 year-olds and older students can observe the colors in a flame when chemical elements are burned. They can see emission spectra and appreciate the discovery of helium and how we know about elements in stars. This helps students understand how we measure the “red shift” of stars that are moving away from Earth.

Demonstrating waves

Materials: a metal “Slinky” toy (or a rope). **What you do:** Have two students stretch the Slinky out along a hard surface or hold the rope in the air. One person starts ONE wave by flicking the Slinky to the side. Watch the wave travel down and back. Students should be able to see that the **wave is carrying energy** over a distance. If not, set an object near the Slinky, such that the wave of motion will push it away. Then have students try to produce shorter wavelength (more frequent) waves. They should note that they need to use more energy for this and the waves carry more energy.

Have the students draw a wave, aiding them as needed. Look at the diagram of a wave in the book, *Waves*, (see page 6) or another reference. Note the **parts of a wave – the crest, trough, and wavelength**. Another property of a wave to notice is its frequency, the number of waves that pass a point during a given time interval. For the longer waves of electromagnetic radiation, it is easier to measure the frequency than the wavelength.

Go over the idea that waves in a Slinky or water, or sound waves are all traveling in matter. The variations in position of the matter carry the wave, and these waves don't exist without the matter – there's no sound in a vacuum, in spite of the booms in space movies.

The **waves of the electromagnetic spectrum don't need matter to travel**. They move through empty space, all traveling at the speed of light. They vary in wavelength from the size of an atom's nucleus to longer than a mile. These waves are variations in electrical and magnetic fields, a concept that is very hard to picture since we can't see electrical and magnetic fields. The various wavelengths have different amounts of energy and distinguishing characteristics. Only a few of these waves are the right wavelengths to trigger electrical signals in the retina of a person's eye – that is, we can see them. The various wavelengths interact differently with matter. For example, visible light and the UVA band travel through glass, but UVB band and some infrared waves do not. Metals are especially good at stopping electromagnetic waves, but it takes different amounts and kinds of metals to stop the different waves.

“Secret” messages

If you write letters using red and green crayons, then look at them through the red and green filters, you will see that the filters cause the letters of the same color to blend with the paper. Letters of the opposite color look dark and easy to see. Students may wish to hide messages in an array of letters by writing the message in a color that will show up well when viewed with a color filter. The GEMS unit, **Color Analyzers**, describes this activity and includes the red and green filters. It also includes color puzzles and diffraction gratings along with an explanation of how they work. You can request a catalog for this and other GEMS guides at <http://www.lhs.berkeley.edu/GEMS/GEMS.html> or by calling (510) 642-0309.

Wavelengths of light and waves (continued)

Demonstrating properties of different wavelengths of light.

- This is a **key experiment**. It shows that the **different wavelengths of light carry different amounts of energy**. Introduce the idea that when light shines on materials, they absorb some of the energy and reflect or transmit the rest. Most materials simply absorb light and change it to heat. Others absorb the light and store it. Later they give it off as light. This is what happens in glow-in-the-dark (phosphorescent) objects. Older students can understand that the light energy pushes electrons out to higher energy levels. The electrons gradually return to their former positions, releasing the energy as photons of light. We know that white light will cause these phosphorescent objects to glow. Will all the colors of light have the same ability?

Materials: Glow-in-the-dark stars or other flat, phosphorescent objects; the following colored filters from Edmund's Scientifics 100 filter set – night blue #64 (transmits 4% of white light), primary green #91 (transmits 7% of white light), canary #312 (transmits 85% of white light), and medium red #27 (transmits 4% of white light). You may be able to use other filters, but check them by looking at the spectrum to see that they don't pass unwanted colors of light. For example, some red filters also pass blue light and vice versa. The red, green and blue filters I've listed only pass a narrow band of wavelengths – only one color. The yellow is not a primary color of light ; yellow filters pass red and green light, but block blue and purple.

What you do: Glue five glow-in-the-dark stars inside an opaque folder or between two pieces of heavy cardboard. One star stays uncovered as a control. Tape a colored filter over each of the other four. Make the tape into a hinge so the filters can be lifted to inspect the stars underneath. It is OK if the filter doesn't completely cover the star. I have my filters in cardboard slide mounts, like the ones used in slide projectors. This allowed me to put the tape on the cardboard instead of on the filters and also gives another control since no light passes through the cardboard mounts.

Keep the stars in the opaque folder for several minutes so that they lose any glow they may have. Then show the students the filters and stars, and explain that each filter allows only a few wavelengths (colors) of light to pass. Have them guess which color or colors of light will make the stars glow. Then hold the stars (with filters covering them) up to a bright light for several seconds. Take the stars to a dimly lit area and flip up the filters to see which stars are glowing.

The **results are not intuitive**. Most students think that the star under the light yellow filter will be brightest when, in fact, it does not glow at all. Only the star under the dark blue filter glows, and it is about as bright as the control. This result is **evidence for the existence of photons of light**. The energy per photon of light is greatest for the shortest wavelength (blue) and least for the longest wavelength (red). (Remember how much energy it took to produce short wavelength, high frequency waves in a rope?) Since energy cannot be created and the process is not 100% efficient, a shorter wavelength than the light given off must be used to "charge" the phosphorescent material. Since the glow from the stars is green, it takes the shorter waves of blue light to excite the electrons. Likewise, it takes an ultraviolet light source to cause fluorescent minerals or paints to glow in visible wavelengths.

Students may wish to explore other phenomena of white light and see if all colors can do the same thing. For instance, is a photoelectric eye or light meter equally affected by all colors? Earthworms avoid light, but do they react to all colors the same? Why can we use red lights in photographic dark rooms when developing black and white photos?

Materials for activities with the electromagnetic spectrum

The numbers are from the catalog of EdmundScientifics, 1-800-728-6999 or www.edsci.com

Prisms – Get glass ones, not the easily scratched, acrylic plastic ones. Edmund's rainbow prism with mount (38,400) is especially nice because it projects the spectrum on the wall.

Filters – Book of 100 color filters, 1½" X 3¼" (39,417). Each comes with a graph of the wavelengths transmitted, which middle school students can use. This set of filters can be cut and mounted in 2X2 slide mounts. You can get two slides from each filter. A larger size is available. The set includes translucent materials.

Spectroscope – The classroom spectrometer (52,521) is useful. Far-sighted persons need their glasses to read the scale, but it does allow estimation of the wavelengths and it has a good diffraction grating.

Night Spectra Quest Card – (53,066) This is a card with a small diffraction grating. It is printed with the spectra of different light types.

Rainbow Glasses – (35, 993) These are cardboard frames with diffraction gratings as lenses. You can copy the frame pattern and use it to make "glasses" with colored filters and poster board frames.

A tour of the electromagnetic spectrum

Before we start this tour, let's try to define our subject. The **electromagnetic spectrum is the entire range of wavelengths of electromagnetic radiation**. "Radiation" means moving outward from a source. In this case, it is energy that moves away from the matter that produces it. The energy moves in straight lines or **rays**, hence the name "radiation". The electromagnetic part means that the energy is carried in **oscillations of electrical and magnetic fields**. That's not the easiest thing to understand! We cannot sense either electrical or magnetic fields. A person who has magnetic resonance imaging doesn't feel a thing even though they have been subjected to an intense magnetic field. This makes it hard to visualize the oscillations of these waves. It is no wonder that the nature of electromagnetic radiation was first discovered mathematically by James Clerk Maxwell and then the non-visible wavelengths were found experimentally. That's a case for researching and exploring via mathematics.

All electromagnetic radiation travels at the speed of light and requires no matter to carry it. It all interacts with matter, but each wavelength has its own properties. For example, visible wavelengths and radio waves penetrate the atmosphere, but gamma and X-rays do not. Metals block electromagnetic radiation, but it depends on the thickness and kind of metal. The very high-energy waves (X-ray and gamma ray) require thicker, denser metals such as lead to block them. That's why the dentist puts that heavy lead apron on you when you get dental X-rays. If biological molecules absorb high-energy wavelengths (ultraviolet and shorter), the energy can break their bonds and damage them.

Let's start our tour with what we can perceive with our unaided eyes – **visible light**. When students realize that **light has wavelengths** and that the different colors of light have different wavelengths, it is easier to go on to electromagnetic radiation that they can't see. Visible wavelengths form a narrow band in the middle of the EMS.

At **wavelengths longer than visible light**, we first find **infrared light**. "Infrared" means "below the red", and if sunlight is separated with a prism, the infrared band falls just below the red end of the spectrum. Infrared radiation (IR) carries heat. When it is absorbed, the matter that absorbs it heats up. We can't see IR, but we can feel the heat it produces. The Earth radiates IR wavelengths, some of which clouds, CO₂, and methane absorb and radiate back to the Earth, producing the greenhouse effect. Remote controls for TV and other appliances use IR beams. The thermometers that they stick in your ear sense the IR waves coming from your eardrum and convert it to a temperature reading. Rattlesnakes and other pit vipers have special sensing organs that detect IR given off by their warm prey.

The next longer wavelengths are the **microwaves**. That name is deceiving. Microwaves aren't small waves compared to visible light, but they are smaller than other radio waves. The name was originally microwave radar, and radar uses radio waves, so microwaves are short radio waves. The wavelength of the microwaves in your oven is about 12 cm.

Note that the **wavelength ranges** for the types of electromagnetic radiation **don't have distinct boundaries**. They overlap with each other. The longer waves of IR have some properties in common with the shorter microwaves. It is like this throughout the spectrum. The properties gradually change from one type wave to another. You can see this in the visible spectrum. It is hard to tell where the blue wavelengths stop and the green ones begin. There is a band in the middle that is sort of blue-green.

The next longer waves are **radio waves**. These carry our TV and radio signals, as well as many other communications. To see how radio waves are used in the United States, see page 49 of the October 2000 issue of *Scientific American* magazine. Note the scale on the left of that page. We normally talk about the frequency (in Hertz or cycles per second) of radio waves instead of their wavelength. This is an easier number to use for radio waves. All waves have wavelength, frequency, and energy level, but we commonly use the energy level (in electron volts, eV) for the shortest waves, the wavelength for the ones in the middle, and the frequency for the longer waves.

The **waves** that are **shorter than visible light** begin with **ultraviolet light**. "Ultra" means "beyond", and ultraviolet light (UV) is electromagnetic radiation beyond the violet end of the spectrum. It is divided into four bands. UVA can pass through glass and causes skin aging. UVB is blocked by glass and causes sunburns, yet is necessary for us to make vitamin D in our skin. UVC is blocked by air and is very damaging to cells. The fourth band, called vacuum UV since it can only travel in a vacuum, is absorbed totally by the upper levels of the atmosphere.

The Sun produces abundant UV radiation. Our atmosphere screens the Earth from the wavelengths that are most damaging to life. Ozone, a molecule composed of three oxygen atoms, absorbs most of the UV before it reaches the Earth's surface. The ozone is formed when short UVC and vacuum UV wavelengths strike oxygen atoms in the stratosphere. It breaks down when UVB rays strike it, so some wavelengths of UV continually make ozone and others break it down. Recently the ozone layer has thinned, apparently because of chemical reactions with synthetic substances such as chlorofluorocarbons (CFCs) that break down ozone before it can absorb UVB. This presents a stress to life on Earth's surface. (continued on p.6)

Tour of EMS, continued from p.5.

The thinning ozone layer is bad news for our skin. The DNA of our cells strongly absorbs UVB, and it damages this vital molecule. Some cells with damaged DNA can become cancerous. We use sunscreens to block UV from reaching our skin. If we could see in UV wavelengths, the sunscreen would look black, not white. Light skin would look black as well, since our skin absorbs almost all UV that strikes it.

Bees can see UV and many flowers have markings that attract bees and that only show up under UV illumination. Some butterflies have markings that reflect UV. Some vertebrates see UV as well. There is a product marketed to keep Canada geese off grass. It reflects UV, so it makes the grass look funny to the geese and it also tastes bad to them.

As the wavelength shortens, the next category of electromagnetic radiation is **X-rays**. Children have usually encountered these in the dentist's office, or less fortunately, if they have had broken bones. Their discoverer, Wilhelm K. Roentgen, named these rays. (See p.8 for a biography of him.) X-ray machines slam a high-energy electron beam into a metal target to produce X-rays. They are used to find cracks in the metal of bridges, airplanes, and other structures as well as cracks in bones. Astronomers use X-rays to detect black holes. As matter is sucked into the black hole, it heats and collides with tremendous energy. Just outside the black hole, intense X-rays are released. X-ray astronomy advanced greatly when we were able to place telescopes in orbit above the atmosphere, since it absorbs X-rays. Optics for X-rays aren't the easiest to build. If a beam of these energetic photons shines straight at a mirror, most are absorbed by it instead of bouncing off. Conventional lenses absorb them as well. For an update on X-ray astronomy, see the November 2000 *Smithsonian* magazine, p.34 or *Science News*, Oct. 21, 2000, p.266.

Gamma rays have even shorter wavelengths and higher energies than X-rays. They are produced when unstable atomic nuclei decay and when supernovas explode. They are used medically in treating cancer, since their high energy disrupts molecules and kills cells. They can be focused on a tumor so that surrounding tissue doesn't get too big a dose. Gamma rays are used to kill bacteria, both in medical supplies and in food. Although irradiated foods are approved by the FDA and used extensively in Europe, the consumers in the US have been reluctant to buy them, probably because they think that the foods could become radioactive or that too many nutrients could be lost. Nether is true. Gamma irradiation could greatly reduce outbreaks of food-borne disease. Other industrial uses of gamma rays include inspection of timber and large shipping containers. Geologists lower gamma ray detectors into oil well bores to gather information about the kinds of rock layers present. Naturally occurring uranium in some rocks gives off gamma rays.

Gamma ray bursts are some of the most enigmatic and energetic events in the universe. In the period of seconds to minutes, a gamma ray burst releases more energy than our sun will in its whole lifetime. Since gamma rays don't penetrate the atmosphere, we didn't even know these bursts existed until satellites detected them. We are slowly learning more about the objects that spew forth such energy, aided by observations in the shorter wavelengths.

Measuring what you can't see

The study of the electromagnetic spectrum introduces several units of measurement that will likely be new to students. Scientists use these units to measure things that are too small to see. Here is a table to help you get a feel for measurement of the tiny. It shows the advantage of scientific notation as well.

Unit of measurement and abbreviation	Equivalent in meters	Something that is the size of the unit
Micrometer – μm	0.000001 or 10^{-6} m	Bacterium diameter
Nanometer – nm	0.000000001 or 10^{-9} m	DNA is 2 nm across
Angstrom - \AA	0.0000000001 or 10^{-10} m	Diameter of an atom
Picometer – pm	0.000000000001 or 10^{-12} m	
Femtometer – fm	0.000000000000001 or 10^{-15} m	Diameter of atomic nucleus

And if you need to measure the truly huge...

Kilo-	multiply by a thousand or 10^3	as in kilohertz (KHz); the frequency range for AM radio is 535-1605 KHz
Mega-	multiply by a million or 10^6	as in megahertz (MHz), the frequency range for FM radio is 88-108 MHz
Giga-	multiply by a billion or 10^9	as in gigahertz (GHz), longer microwaves range from about 3-10 GHz
Tera-	multiply by a trillion or 10^{12}	as in terahertz (THz), frequency of shorter microwaves or long IR

Charting the electromagnetic spectrum

As you introduce the EMS, this chart will help your students remember the various waves. Note that the scale is not linear, but each mark represents a 10-fold increase or decrease. (I decided to make the scale linear between marks however, to avoid using a log scale there.) You need slightly more than 2 meters of banner paper that is about 20 cm (8 inches) wide, contrasting paper to make markers for each type of radiation, and a meter stick or metric ruler.

1. Draw a line all the way across the paper about 10 cm (4 inches) from the top. Put the title above this line.
2. Add a label above the line that says "wavelength". Draw an arrow pointing to the right and label it "increasing". Add a second arrow that points to the left and label it "decreasing".
3. Mark the line off in 10-cm intervals, so that you have at least 19 marks. Label the marks 1-19 to help you keep track of where you are. For lower elementary, the numbers are enough labeling. Older children may want to add more quantitative labels, especially if they understand powers of 10. The scale represents wavelengths from 10^{-14} meters (0.00001 nm) on mark #1 to 10^4 meters on #19. That's 0.00000000000001 meters to 1,000 meters in decimals.
4. Cut strips of colored or textured paper (about 5 cm wide) to mark the types of radiation. The markers will touch one another. Most will have an acute angle at the ends, to show that the characteristics of each type shade into one another, and that the boundaries are not distinct. For visible light, use a rectangle and color it with a rainbow (spectrum). For infrared and ultraviolet, the strips are long trapezoids with one square end that joins the visible range. Cut the outside ends of radio and gamma rays in a zigzag to show they go past the end of the chart.

Type of EM radiation	Marker length	Location on the chart
Visible light	4 cm (rectangle)	3cm to the left of mark 9
		(with red to the right)
Infrared	23 cm (top edge)	Ends at mark 11
	30.5 cm (bottom edge)	Ends 2.5 cm left of mark 12
Microwave	40 cm (top edge)	Between mark 11 & 15
	42 cm (bottom edge)	Ends near mark 16
Radio waves	45+ cm (top edge)	Starts at mark 15
		Continues off the chart
Ultraviolet	20 cm (top edge)	Ends between mark 6 and 7
	24 cm (bottom edge)	Ends at mark 6
X-rays	24 cm (top edge)	Ends at mark 4
	30 cm (bottom edge)	Ends at mark 3
Gamma rays	30+ cm (top edge)	Starts at mark 4
		Continues off the chart

Some wavelengths you can add (Position on chart in parentheses)

Ultraviolet A – 320-400 nm	(3.2-4.0 cm rt. of mark 8)
Ultraviolet B – 290-320 nm	(2.9-3.2 cm rt. of mark 8)
Ultraviolet C – 200-290 nm	(2-2.9 cm rt. of mark 8)
Visible light, violet – 400-450 nm	(4-4.5 cm rt. of mark 8)
Visible light, green – 500-570 nm	(5-5.7 cm rt. of mark 8)
Visible light, red – 620-700 nm	(6.2-7 cm rt. of mark 8)
Infrared from your body – 10 μ m	(mark 10)
Microwaves in ovens – 12 cm	(2 mm right of mark 14)
Cell phones – about 40 cm	(4 cm right of mark 14)
FM radio signals – about 3 m	(3 cm right of mark 15)
Garage door openers – about 10 meters	(mark 16)
AM radio signals – around 300 m	(from 1cm to 6 cm left of mark 17)

Some things to add to the blank parts of the chart

Pictures to illustrate our uses of the wavelengths

The frequency scale

The energy levels of the shorter wavelengths

Show which wavelengths penetrate the atmosphere (See Branley's book for help.)

Resources for the electromagnetic spectrum

Dewey catalog numbers – electromagnetic spectrum (537, 539.2), infrared radiation (535.842); optics, including light and color (535); microwave technology (621.381).

Asimov, Isaac. 1989. ***How Did We Find Out About Microwaves?*** Walker and Company. ISBN 0-8027-6837-7. This gives a good history of the discovery of the properties of light and the electromagnetic spectrum. UE-MS.

Branley, Franklin M. 1979. ***The Electromagnetic Spectrum: Key to the Universe.*** Thomas Y. Crowell. ISBN 0-690-03868-2. This book is out-of-print, but worth seeking in libraries. UE-adult.

Burnie, David. 1999. ***Light.*** Eyewitness Science. Dorling Kindersley. ISBN 0-879448858. There is a section on the electromagnetic spectrum, as well as information on color. LE-adult.

Doherty, Paul, Don Rathjen, and the Exploratorium Teacher Institute. 1995. ***The Magic Wand and Other Bright Experiments on Light and Color.*** John Wiley & Sons. ISBN 0-471-11515-0. This is a collection that includes activities with colored filters, colored lights, and diffraction gratings. LE-MS

Gherman, Beverly. 1994. ***The Mysterious Rays of Dr. Röntgen.*** Atheneum. ISBN 0-689-31839-1. This is a short biography of the discoverer of X-rays. It includes information about their use. LE-UE

Morgan, Sally and Adrian. 1993. ***Using Light.*** (Designs in Science series). Facts on File. ISBN 0-8160-2980-6. Background information and experiments. Watch for errors in the metric-English conversions. UE-MS

Nassau, Kurt. 1997. ***Experimenting with Color.*** Franklin Watts. ISBN 0-531-11327-2. The background information is good for UE, and MS-adult levels can learn why things look colored. Note: the author implies that it is safe to look at the sun through filters or sunglasses. It is NOT safe to look at the sun this way.

Skurzynski, Gloria. 1996. ***Waves: The Electromagnetic Universe.*** National Geographic Society. ISBN 0-7922-3520-7. This is one the few children's books about electromagnetic radiation. It does a good job introducing waves and it features a number scientific instruments used by astronomers to detect various wavelengths. LE-UE

Internet resources

<http://imagers.gsfc.nasa.gov/ems/ems.html>

A good introduction to the electromagnetic spectrum

<http://observe.ivv.nasa.gov/nasa/education/reference/emspec/empectrum.html>

This simple text about EMS is part of an introduction to remote sensing

<http://www.eecs.umich.edu/mathscience/funexperiments/agesubject/lessons/newton/infrared.html>

Newton's Apple on infrared radiation

<http://info.lu.farmingdale.edu/depts/met/ind310/index.html>

This site gives information on ionizing and non-ionizing radiation – wavelength ranges for IR and UV bands

The burning question - <http://www.met.tamu.edu/personnel/faculty/alcorn/UVBdir/uvb.html>

How to determine how UV will affect your skin, With link to more technical UV info

<http://phys.educ.ksu.edu/vqm/java/colorcreator/vqscp.html>

This color creator allows you to mix red, green, and blue light on the computer monitor.

<http://www.howstuffworks.com/light.htm?printable=1>

How light works from the "How Stuff Works" site. You can print the information to cut down on the advertisements.

http://rabi.phys.virginia.edu/HTW//microwave_ovens.html

Just about everything you'd ever need to know about microwave ovens from Louis Bloomfield's How Things Work site

http://imagine.gsfc.nasa.gov/docs/science/know_11/empectrum.html

The three ways to measure electromagnetic radiation

http://imagine.gsfc.nasa.gov/docs/science/know_12/empectrum.html

A more advanced look at the electromagnetic spectrum and astronomical uses of the wavelengths

<http://www.aspsky.org/education/tnl/35/35.html>

A good introduction to the EMS for teachers – from the Astronomical Society of the Pacific. Click on the link at the bottom of the page to receive a free astronomy newsletter for teachers.