Teacher Guide and Answer Key

Demonstration: Modeling the Earth-Moon System

Materials required:

1. 3 cans of Play-Doh^{tm}
2. 3.8 meters of string
3. 1 toothpick

If you prefer, you can make your own Play-Doh^{tm}. The following website lists several recipes for making your own Play-Doh^{tm} or clay material.
http://www.kidsturncentral.com/crafts/craftrecipes.htm
If you have the 51 balls of clay ready, this demonstration with discussion takes approximately 30 minutes.

NOTE: You may want to either provide several pictures (models) which contain images of both the Earth and the Moon, and/or have the students find some and bring them to class. After the demonstration, students can compare the different models of the Earth-Moon System and decide which ones best represent the size and/or distance of the Earth and the Moon and which ones are the most misleading.

Pre-Assessment Activity: The Exponential Clothesline

Materials required for each group:

1. 1 5-meter piece of clothesline (or string)
2. 14 clothespins (or paper clips)
3. 14 index cards
4. Exponential Clothesline Conversion Table

As explained in The Exponential Clothesline, this is an excellent activity to determine the depth of understanding your students have of exponents and the use of scientific notation. A basic knowledge of exponents is necessary to understand the exponential and linear models of the electromagnetic spectrum which your students are going to construct. This activity can be completed in a 45-minute classroom period.

NOTE: If your students are successful in correctly placing the numbers and exponents on the clothesline, then you may decide not to hand out The Exponential Clothesline Conversion Table. Even if they are successful, the Conversion Table is a good review for fractions and decimals.
The website http://microcosm.web.cern.ch/Microcosm/P10/english/welcome.html has an interactive powers of ten visual journey that students can take by clicking on a powers of ten ruler.

Student Handout and Construction of the Electromagnetic Spectrum Model:

1. You can either have your students construct the template as shown in the diagram in the Student Handout, or you can print out the Model Construction Template and make two additional photocopies of the second page for each group. The students then only have to tape the four pieces of paper together. Without the construction of the template, this activity can be completed in a 45-minute classroom period without the extension, and approximately one hour with the extension activity.

2. The students mark off 24 2-cm intervals on the top line of their model and label them as indicated in the directions. They transfer the frequencies for the individual bandwidths in the Frequency Range Table onto this line and label each bandwidth. They should label the entire visible bandwidth of the spectrum, not each individual color within the visible band of the spectrum. They will now have bandwidths that mirror the apparent size of the bandwidths shown on the image at the top of the student handout. The image is an exponential model poster like the one the students just constructed. The poster is free. The information to order the poster is located at: http://www.tufts.edu/as/wright_center/svl/posters/posts.html

   NOTE: When the students mark a location on the model such as 5.6 x 10^{14}, they will probably place the mark halfway within the frequency range for 10^{14}. This is incorrect. Since this is an exponential model, 5 is actually more than halfway within the frequency range. Whether you bring this to the attention of your students depends upon their level of mathematical understanding.

3. The students convert the different frequencies for each of the EMR Bands in the Frequency Range Conversion Table to the same frequency, 10^{14}.
   A tutorial for converting exponents is included with the student handout if you decide to include it with the handout. The table below contains the correct conversions.

Frequency Range Conversion Table Answer Key

EMR Bands	10^{14} Conversions (Hertz)
Radio & Microwave	Near 0 to 0.030 X 10^{14}
Infrared	0.03 X 10^{14} to 4.6 x 10^{14}
Visible	4.6 x 10^{14} to 7.5 x 10^{14}
Red	4.6 x 10^{14} to 5.1 x 10^{14}
Orange	5.1 x 10^{14} to 5.6 x 10^{14}
Yellow	5.6 x 10^{14} to 6.1 x 10^{14}
Green	6.1 x 10^{14} to 6.5 x 10^{14}
Blue	6.5 x 10^{14} to 7.0 x 10^{14}
Violet	7.0 x 10^{14} to 7.5 x 10^{14}
Ultraviolet	7.5 x 10^{14} to 600 x 10^{14}
X-ray	600 x 10^{14} to 1,000,000 X 10^{14}
Gamma Ray	1,000,000 X 10^{14} to Infinity

NOTE: If your students have not yet encountered converting exponents, you may want to give them the completed table above and simply have them plot them on the model. This activity is about models and they can compare and contrast different models without performing the mathematics. The following URL contains basic information on exponents and a worksheet with answer key for additional practice: http://www.ieer.org/clssroom/scinote.html

4. – 7. The scale for the linear model is 10^{14} Hz = 10 cm; the frequencies plotted on the exponential scale result in the following distances from the beginning of the scale:
   * Radio & Microwave - 0.3 cm or 3 mm
   * Infrared - 46 cm
   * Visible
   * Red - 46 to 51 cm
   * Orange - 51 to 56 cm
   * Yellow - 56 to 61 cm
   * Green - 61 to 65 cm
   * Blue - 65 to 70 cm
   * Violet -70 to 75 cm
   * Ultraviolet - 6000 cm or 60 m
   * X-ray - 10,000,000 cm = 100,000 m = 100 km
   * Gamma Ray –1,000,000 X 10^{14} to infinity

   NOTE: The students will easily plot the radio/microwave, infrared, and visible bandwidths of the spectrum. They will not start to encounter difficulties until they start to notice that they will not be able to fit the ultraviolet bandwidth on their model. The UV band is actually 60 meters in width. If you want the students to experience the length of the UV band relative to the lower frequency bands they have plotted, have string available for them to measure and stretch out for 60 meters. The X-ray band is 100 kilometers in length; have some local maps and state highway maps available so the students can locate towns that are 100 kilometers away from their school. If you have internet access the students can go to Yahoo Maps and download a map centered on their school.

8. The linear model displays some surprising results compared to the exponential models that are shown in textbooks and on posters. In this model, for example, the radio bandwidth is extremely small, and the visible bandwidth is also small compared to the high energy bandwidths - the high energy bandwidths are huge. This is not a "better" model, it is a difference model. This model is useful in understanding why it is important to study all the electromagnetic emissions from a star, supernova remnant, or galaxy. Studying a deep sky object in only one bandwidth does not give a complete picture of the object – anymore than studying just one system within the human body gives a complete picture of how the human body functions. However, this model cannot fit on a page within a textbook, or even fit on a very long poster. Someone may ask why not have a model that plots the wavelengths of the bandwidths instead of frequency. Frequency is what astrophysicists are most interested in because it is related to

energy. A model that uses wavelength instead of frequency would be reversed because the higher the frequency the smaller the wavelength. The higher energy bandwidths would be extremely small and the radio/microwave bandwidths would go to infinity. A model using wavelength would have to reverse the sequence of the bandwidths – the gamma rays would be located at near 0. There are no correct or incorrect answers to this question. The idea is to start students thinking about the models they use and understand their advantages and disadvantages.

EXTENSION: To show students the importance of studying objects in all wavelengths you can find an excellent example at the following URL: http://chandra.harvard.edu/edu/formal/composites/casa_overlays.html This page contains four multiwavelength images of the Cas A supernova remnant. The images are to scale, and can be downloaded and printed on overhead transparencies. The transparencies can then be placed on top of each other on an overhead projector to show how much more information is available for scientists to study when multiple wavelength observations are used. The story of the Cas A supernova event and the historical context of how the remnant first became known as a radio image in 1937 through 1999 when the Chandra X-Ray Observatory imaged the remnant in X-ray and discovered the neutron star in the center is located at http://chandra.harvard.edu/edu/formal/casa_timeline/

Assessment: EMR Pasta

Materials Required:

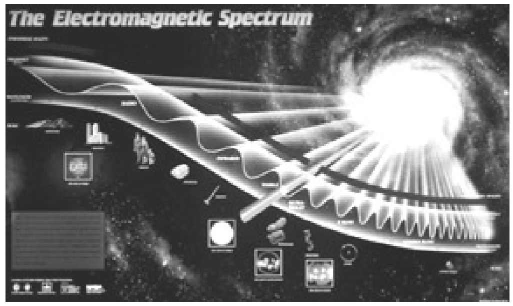
1. Boxes of different shaped pasta
2. Poster paper or pieces of cardboard
3. Glue guns or fast-setting glue

The EMR pasta assessment task is an excellent tool to assess student understanding of the distortions contained within models in general, and the electromagnetic spectrum in particular. Students construct their own versions of the electromagnetic spectrum using a variety of pasta shapes, and then present their models and provide an explanation of how their pasta analogy/model does and does not represent the electromagnetic spectrum. The alignments to the National Standards and Benchmarks are included, along with the scoring rubric. This activity can be completed in a 45-minute classroom period.

The Wavelength and Frequency demonstration included with EMR Pasta uses a pasta machine and pasta dough. This demonstration helps students understand that electromagnetic radiation is all the same thing … only the “shape” is different. It is a common misconception that since we “see” the visible spectrum, and “hear” part of the radio spectrum, and get sunburned by part of the UV spectrum – which we cannot either “see” or “hear” that the different bands are not the same phenomena.

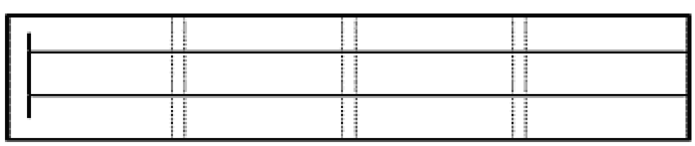
NOTE: If you want to involve your students in a more in-depth assessment process you may want to use two other assessment tasks - “Oh Say Can You See” or “Signals from the Cosmos”. These assessment activities require students to gather information and construct presentations.

Logarithmic and Linear Models of the Electromagnetic Spectrum (High School)



Models of the electromagnetic spectrum similar to the one pictured above are used extensively in textbooks and on posters, and like all other models it contains distortions. The model is extremely useful for showing the frequencies of the different bands of electromagnetic radiation (EMR), and the relationships between frequency and wavelength. However, this is a logarithmic model, and severely distorts the actual width of the different bands of radiation. The result is that looking at this model gives you the wrong idea that the radio band is very large compared to the X-ray band, for example. You are going to construct both models, logarithmic and linear, on the same chart and compare the two models.

1. Use either the template provided or the following instructions to construct the diagram shown below. Tape four pieces of 8 1/2" by 11" paper together end-to-end so that their long sides are on the bottom. The pieces of paper should overlap by 3 cm. Then draw a line down the left side of the chart about 2 cm from the edge (see diagram below). From the line you have just drawn, draw two horizontal lines extending to the right across the pages: one line 8 cm from the top of the chart, and the other line 10 cm below the first horizontal line.



2. The top line will be used to plot the logarithmic model. Along this line, mark off 24 2-cm intervals from the vertical line you drew. Starting at 2 cm, label each interval with increasing powers of ten, from 10^1 to 10^{24}. These numbers represent the frequency in Hertz of the electromagnetic spectrum. Use the information from the Frequency Range Table on the next page to divide your model into the individual bands of electromagnetic radiation. (Use the entire visible band, not the individual colors.)

Frequency Range Table

EMR Bands	Frequency Range (Hertz)
Radio & Microwave	Near 0 to 3.0×10^{12}
Infrared	3.0×10^{12} to 4.6×10^{14}
Visible	4.6×10^{14} to 7.5×10^{14}
Red	4.6×10^{14} to 5.1×10^{14}
Orange	5.1×10^{14} to 5.6×10^{14}
Yellow	5.6×10^{14} to 6.1×10^{14}
Green	6.1×10^{14} to 6.5×10^{14}
Blue	6.5×10^{14} to 7.0×10^{14}
Violet	7.0×10^{14} to 7.5×10^{14}
Ultraviolet	7.5×10^{14} to 6.0×10^{16}
X-ray	6.0×10^{16} to 1.0×10^{20}
Gamma Ray	1.0×10^{20} to...

3. Before you can construct the linear model, it is necessary to convert the frequencies that you used for the logarithmic model. Those numbers simply told you the range of frequencies, or amount of energy, that each of the bands of EMR covers within the spectrum. Now we want to compare the width of each of the individual bands of radiation relative to each other. We can do this by converting all of the bands of EMR to the same frequency range. We will arbitrarily select the frequency range of the visible band, 10^{14}. Convert the frequency numbers for all bands (except visible) in the Frequency Range ConversionTable below to 10^{14} and record them in the table. (There is a tutorial on converting exponents on the last page.)

Frequency Range Conversion Table

EMR Bands	10^{14} Conversions
Radio & Microwave	
Infrared	
Visible	4.6×10^{14} to 7.5×10^{14}
Red	4.6×10^{14} to 5.1×10^{14}
Orange	5.1×10^{14} to 5.6×10^{14}
Yellow	5.6×10^{14} to 6.1×10^{14}
Green	6.1×10^{14} to 6.5×10^{14}
Blue	6.5×10^{14} to 7.0×10^{14}
Violet	7.0×10^{14} to 7.5×10^{14}
Ultraviolet	
X-ray	
Gamma Ray	

4. Mark off 10 10-cm intervals from the vertical line. Starting at the first interval, label each mark as a whole number times 10^{14}, from 1×10^{14} to 10×10^{14}. Label the bottom of your model "Frequency in Hertz." You can now plot some of the 10^{14} frequencies you calculated on the bottom line of your constructed model. Plot the individual colors of the visible spectrum and color them. Compare the two models. Do the results surprise you?
5. How far does the ultraviolet band extend? Calculate the width of the ultraviolet band. What do you think you would need to measure the distance to the end of the UV part of the EMR?
6. X-rays are the next band of radiation. Calculate the distance from the end of the ultraviolet band to the end of the X-ray band. What do you think you would need to measure the distance to the end of the X-Ray band?
7. Based on your results for the width of the X-ray band, what would be your estimate for the width of the gamma ray band of radiation? What would you need to measure the distance?
8. Compare and contrast the distortions between the two models. What is the advantage in using the logarithmic model? What is the advantage in using the linear model? Can you think of any other ways to model the electromagnetic spectrum?

Using Scientific Notation

We use methods such as abbreviations and acronyms to make long words or long phrases easier to write. In this activity we have used the acronym EMR so we do not have to keep writing the words "ElectroMagnetic Radiation". We use acronyms such as NASA so we do not have to write out the words "National Aeronautics and Space Administration". We do the same thing with numbers, by using scientific notation (exponents.) For example, the number 1,000,000 written in scientific notation, or exponential form, is 1×10^6.

$100 = 10 \times 10 = 1 \times 10^2$

$1000 = 10 \times 10 \times 10 = 1 \times 10^3$

$10{,}000 = 10 \times 10 \times 10 \times 10 \times 10 = 1 \times 10^5$

What if we wanted to express the number 100 [1×10^2] as an exponent of 10^3? The difference between 10^2 and 10^3 is one exponent so we would move the decimal one place. Since we are expressing a number as a larger exponent, the decimal place is moved one place to the left, so 1×10^2 becomes 0.1×10^3

What if we wanted to express the number 10,000 [1×10^5] as an exponent of 10^3?

The difference between 10^5 and 10^3 is two exponents so we would move the decimal two places. Since we are expressing a number as a smaller exponent, the decimal place is moved two places to the right, so 1×10^5 becomes 100×10^3.