What is Electromagnetic Radiation?

Why are we doing this?

Atoms are extremely small. So small, in fact, that even the most powerful microscopes cannot directly examine the subatomic particles constituting the atom. Instead, atomic theory and the atomic models we use to describe atoms and their properties are based on other observations of atoms. In particular, spectroscopy (the study of the interaction between matter and electromagnetic radiation) has been used to examine and understand atomic structure and properties. Thus, it is useful to understand the properties of electromagnetic radiation.

Your Learning Outcomes

You will be able to:

1. Describe and utilize the relationship between the speed of a wave and its wavelength.
2. Describe and utilize the relationship between the frequency of a wave and its wavelength.
3. Describe and utilize the relationship between the energy of a wave and its frequency.

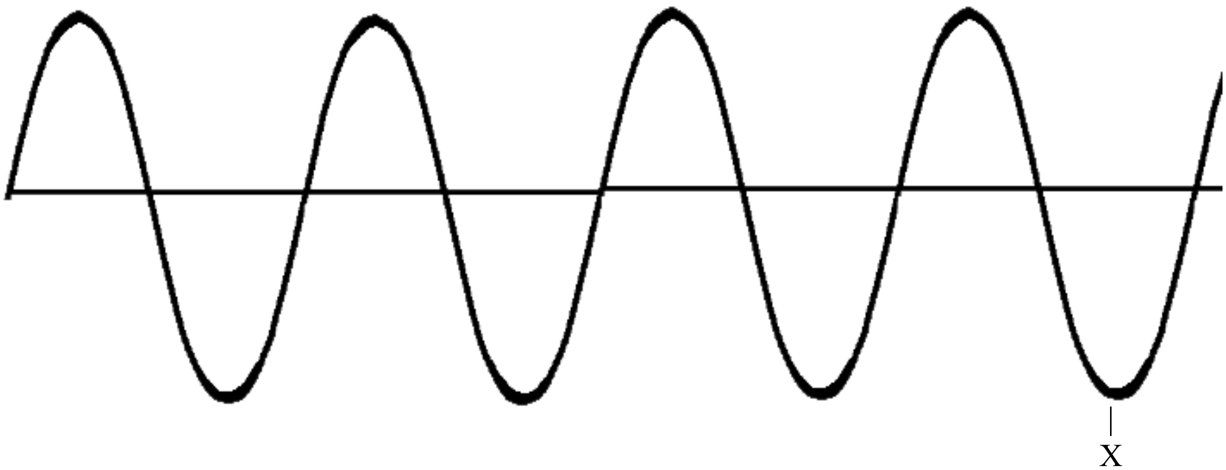
The Plan

1. Assign roles*.
    a. ***Manager*** – This person will keep the team on task and provide direction to the group. This person is responsible for uploading the group's work to Gradescope. Make sure you make a note of everyone in the group. You must add everyone's name when submitting your answers to Gradescope.
    b. ***Spokesperson*** – This person will represent the group be responsible for speaking for the group to the rest of the class.
    c. ***Recorder*** – This person will be responsible for recording the team's answers to the Critical Thinking Questions in an organized and coherent manner.
    d. ***Analyst*** – This person will be responsible for critical analysis of the team's work (i.e., the Devil's Advocate). This person should make sure everyone understands what is happening before the group moves forward.
2. Complete the Critical Thinking Questions as a group.
3. Submit your team's work via Gradescope. Groups may choose to work in a Word document or write out their answers on a separate sheet of paper. All work must be upload to Gradescope as a PDF file.

**Students may choose to complete this activity independently if they are unable to attend discussion due to illness or injury; in which case, the student must perform all roles and complete all aspect of the activity. To receive full credit, documentation as to the need for the absence from discussion must be included with the submission and your TA must be notified of the absence.*

Model 1: A Wave and Its Wavelength

The figure below represents part of a **wave**. The entire wave can be thought of as extending infinitely in both directions. One important characteristic of a wave is its **wavelength (λ)**, which is the distance between two consecutive peaks (or troughs) in the wave.



1. Individually, on the figure above, draw a line connecting two points whose separation is equal to the wavelength of the wave. If there is more than one way to do this, draw a second line. Share your answer with the group members and confirm that it is correct.
   Draw a line between two consecutive peaks or troughs.

2. Suppose that the wave depicted above were traveling to the right at a speed of 35 cm/sec, and that the $\lambda = 2.5$ cm.
   a. How long would it take for 1 wavelength (or 1 cycle of the wave) to travel past the point X?
      0.071 sec

   b. How many wavelengths (or cycles) would travel past the point X during a time interval of 1 second?
      14

   c. Would your answer to part a.) increase, decrease, or remain the same if $\lambda > 2.5$ cm. Explain your reasoning.
      If $\lambda > 2.5$ cm, it would take longer than 0.71 sec for one wavelength to pass point X. If $\lambda >$ 2.5 cm, fewer wavelengths would pass point X during one second.

   d. Would your answer to part b.) increase, decrease, or remain the same if $\lambda > 2.5$ cm. Explain your reasoning.
      The number of wavelengths that would pass point X is equal to (35 cm/s)/wavelength. If the wavelength is greater than 2.5 cm the number of wavelengths would decrease.

3. The **frequency (ν)**, of a wave is defined as the number of wavelengths per second which travel past a given point.

   a. For a wave traveling at a given speed, c, is there a relationship between frequency and wavelength? If so, what kind of relationship?
   The longer the wavelength the smaller the frequency.

   b. Provide a mathematical expression showing the relationship between ν, λ, and c for a wave. (Hint: consider how you determined the answers to Questions 2a and 2b.)
   $\nu = c/\lambda$.

Model 2: Electromagnetic Radiation and Photons

Light can be thought of as an **electromagnetic wave** or **electromagnetic radiation** having a particular wavelength and frequency. In addition, Albert Einstein proposed almost a century ago that electromagnetic radiation can viewed as a stream of particles known as **photons**, each of which has a particular amount of energy associated with it. Specifically, he proposed the following equation:

$E_{photon} = h\nu$ where h is called Planck's constant.

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Table 1. Regions of the electromagnetic spectrum.

Region	**Wavelength Range**
Radiowaves	3 km – 30 cm
Microwaves	30 cm – 1 mm
Infrared (IR)	1 mm – 750 nm
Visible (VIS)	750 nm – 400 nm
Ultraviolet (UV)	400 nm – 10 nm
X-rays	10 nm – 0.1 nm
Gamma rays	<0.1 nm

Table 2. Wavelengths, frequencies, and energies of electromagnetic radiation.

Wavelength (nm)	**Frequency (10^{14} s^{-1})**	**Energy (10^{-19} J)**
333.1	9.000	5.963
499.7	6.000	3.976
999.3	3.000	1.988

$$1 \text{ nm} = 10^{-9} \text{ m}$$

$$1 \text{ J} = 1 \frac{kg \cdot m^2}{s^2}$$

4. A certain photon has a wavelength of 100 nm. In what region of the electromagnetic spectrum should this photon be classified (see Table 1)?
   The ultraviolet region.

5. According to the data in Table 2 and the equation proposed by Einstein, what is the value of Planck's constant (include the units)? (Don't just look up the value of Planck's constant. Use the data provided to derive Planck's constant. Show your work.
   $h = 6.626 \times 10^{-34}$ Js

6. Based on the data in Table 2 and the relationship between speed, frequency, and wavelength, what is the speed of electromagnetic radiation (i.e., light waves). (Again, don't look up this value. Use the data to show how this value is experimentally determined.)
   $c = 2.998 \times 10^{8}$ m/s

Information

Quantities *a* and *b* are **proportional** when $a = kb$, where k is some constant. The two quantities are said to be **inversely proportional** when $a = k/b$.

7. Write the mathematical equation that relates the energy of a photon and its frequency. Is the energy of a photon proportional or inversely proportional to ν?
   $E = h\nu$
   The energy of a photon is proportional to its frequency.

8. Write the mathematical equation that relates the energy of a photon and its wavelength. Is the energy of a photon proportional or inversely proportional to λ?
   $E = (h c)/\lambda$
   The energy of a photon is inversely proportional to its wavelength.

9. Indicate whether the following statement is true or false and explain your reasoning:

   "For waves traveling at the same speed, the longer the wavelength, the greater the frequency."

   False. The shorter the wavelength, the greater the frequency.

10. Complete the following table:

Energy (J)	**Wavelength (m)**	**Frequency (s^{-1})**	**Region of Electromagnetic Spectrum**
9.94×10^{-20}	2.00×10^{-6}	1.50×10^{14}	Infrared
3.97×10^{-19}	0.500×10^{-6}	6.00×10^{14}	Visible
9.94×10^{-19}	2.00×10^{-7}	1.50×10^{15}	Ultraviolet
1.99×10^{-16}	1.00×10^{-9}	3.00×10^{17}	X-ray

11. Which is more energetic, a red photon ($\lambda \sim 700$ nm) or a blue photon ($\lambda \sim 400$ nm)? Explain.
A blue photon is more energetic. The energy is inversely proportional to the wavelength.

12. It requires 0.50 MJ/mole of energy to remove an electron from a gaseous atom of sodium. Can a photon with a wavelength of 500 nm ionize (e.g., remove the electron from) a sodium atom? Explain your reasoning.
No. The energy required to ionize a sodium atom is 8.30×10^{-19} J. A photon with a wavelength of 500 nm has only 3.96×10^{-19} J.