Electromagnetic Waves

Unit: Light & Optics

NGSS Standards/MA Curriculum Frameworks (2016): HS-PS4-1, HS-PS4-3, HS-PS4-5

AP® Physics 2 Learning Objectives/Essential Knowledge (2024): 14.1.A, 14.1.A.3.i, 14.2.A, 14.2.A.1.iv, 14.4.A, 14.4.A.1, 14.4.A.1.i, 14.4.A.1.ii, 14.4.A.2, 14.4.A.3, 14.4.A.3.i, 14.4.A.3.ii, 14.4.A.3ii

Mastery Objective(s): (Students will be able to…)

- Describe the regions of the electromagnetic spectrum.

Success Criteria:

- Descriptions & explanations account for observed behavior.

Language Objectives:

- Explain why ultraviolet waves are more dangerous than infrared.

Tier 2 Vocabulary: wave, light, spectrum

Labs, Activities & Demonstrations:

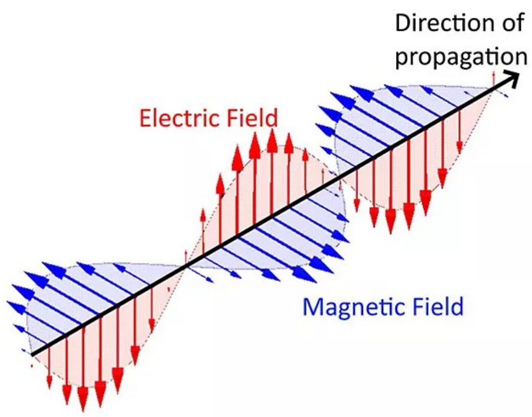
- red *vs.* green *vs.* blue lasers on phosphorescent surface
- blue laser & tonic water
- wintergreen Life Savers™ (triboluminescence)

Notes:

<u>electromagnetic wave</u>: a transverse, traveling wave that is caused by oscillating electric and magnetic fields.

Electromagnetic waves travel through space and do not require a medium.

The electric field creates a magnetic field, which is perpendicular to it. This magnetic field creates a perpendicular electric field, which creates another magnetic field, and so on. The repulsion between these induced fields causes the wave to propagate.



Electromagnetic waves (such as light, radio waves, *etc.*) travel at a constant speed, which is determined by the rate at which the electric and magnetic fields create each other. These rates are determined by the electric permittivity (ε) and magnetic permeability (μ) of the medium, which means the speed of light is different in different mediums. (See *Electric Permittivity* on page 159 and *Magnetic Permeability* on page 283. The speed of light in different mediums will be discussed further in the section on *Refraction*, starting on page 384.)

In a vacuum, the speed of light is:

$$c = \frac{1}{\sqrt{\mu_o \varepsilon_o}} \approx 3.00 \times 10^8 \, \tfrac{\text{m}}{\text{s}} \approx 186\,000 \, \tfrac{\text{mi.}}{\text{s}} \approx 1 \, \tfrac{\text{ft.}}{\text{ns}}$$

The variable c is used instead of v, to indicate that the speed of light is constant for a given medium.

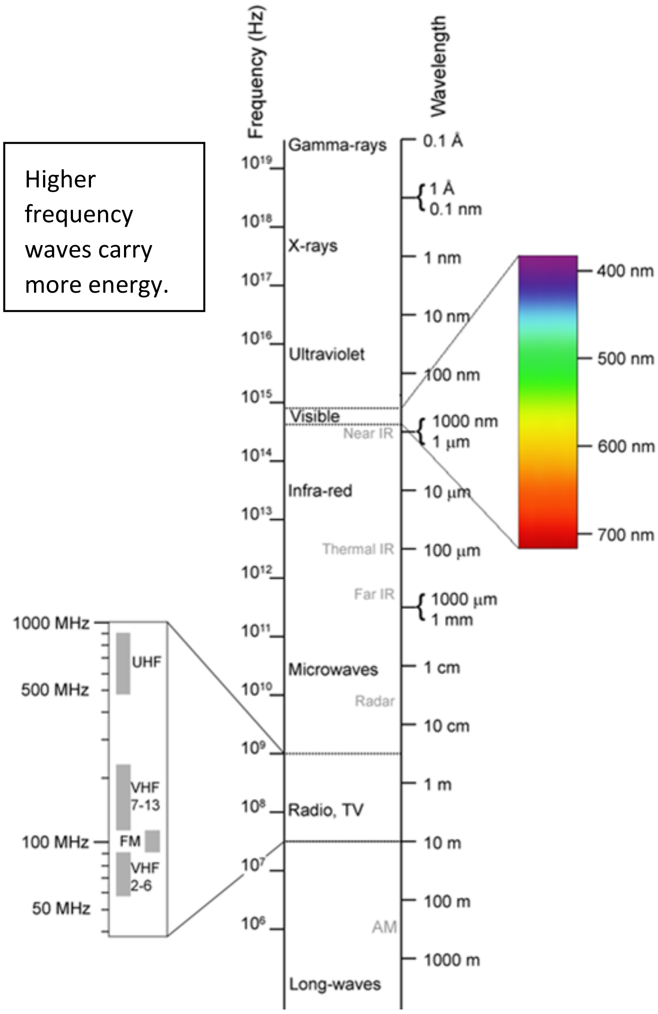
Recall that the speed of a wave equals its frequency times its wavelength:

$$c = \lambda f$$

<u>plane wave</u>: a wave whose value at any moment is the same through <u>*any*</u> plane that is perpendicular to the direction of propagation. Electromagnetic waves can be considered to be plane waves, which means that an electromagnetic wave consists of an infinite number of transverse waves, at every possible angle perpendicular to the direction of propagation.

electromagnetic spectrum: the entire range of possible frequencies and wavelengths for electromagnetic waves. The waves that make up the electromagnetic spectrum are shown in the diagram below:

Higher frequency waves carry more energy.



visible spectrum: wavelengths of light that can be detected by the human eye. These are wavelengths from roughly 400 nm to 700 nm.

The energy (E) that a wave carries is proportional to the frequency. (Think of it as the number of bursts of energy that travel through the wave every second.) For electromagnetic waves (including light), the constant of proportionality is Planck's constant (named after the physicist Max Planck), which is denoted by a script h in equations.

The energy of a wave is given by the Planck-Einstein equation:

$$E = hf = \frac{hc}{\lambda}$$

where E is the energy of the wave in Joules, f is the frequency in Hz, h is Planck's constant, which is equal to 6.626×10^{-34} J·s, c is the speed of light, and λ is the wavelength in meters.

Antennas

An antenna is a piece of metal that is affected by electromagnetic waves and is used to amplify waves of specific wavelengths. The optimum length for an antenna is either the desired wavelength, or some fraction of the wavelength such that one wave is an exact multiple of the length of the antenna. (*E.g.,* good lengths for an antenna could be $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$, *etc.* of the wavelength.)

Sample problem:

Q: What is the wavelength of a radio station that broadcasts at 98.5 MHz?

A:
$$c = \lambda f$$
$$3.00\times 10^{8} = \lambda(9.85\times 10^{7})$$
$$\lambda = \frac{3.00\times 10^{8}}{9.85\times 10^{7}} = 3.05\,\text{m}$$

Q: What would be a good length for an antenna that might be used to receive this radio station?

A: 3.05 m (about 10 feet) is too long to be practical for an antenna. Somewhere between half a meter and a meter is a good size.

$\frac{1}{4}$ wave would be 0.76 m (76 cm), which would be a good choice.