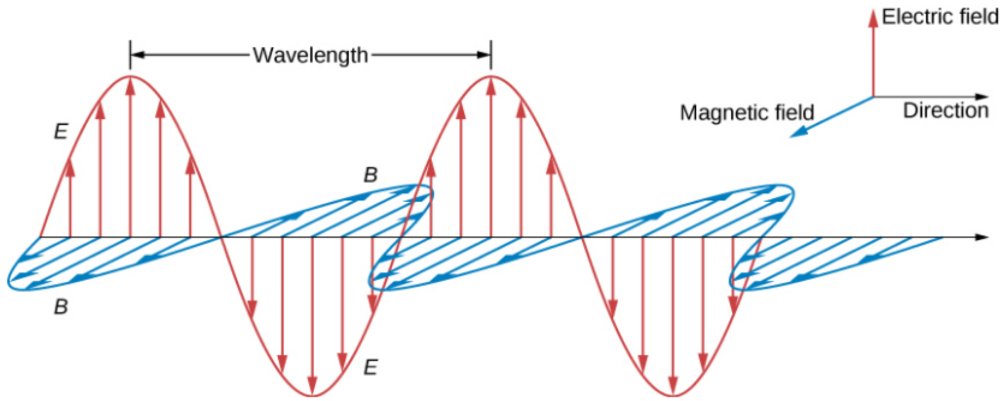
11.2.1: Electromagnetic Wave Properties

If we wiggle a charge, we would find electromagnetic waves heading off in all directions. Lets call the charge that creates the waves, the *source charge*. The simplest description of an electromagnetic wave involves an electric field that oscillates along one direction and a magnetic field that oscillates perpendicular to it. The energy is carried in a direction that is perpendicular to both the electric and the magnetic fields. Note that this makes the electromagnetic wave a transverse wave, since the electric field (amplitude) is perpendicular to the direction that the wave travels. A way to visualize these waves is shown below:



Plane wave image taken from OpenStax *University Physics vol. 2* and is licensed under CC-BY

Because electromagnetic energy can be described as a wave, it has all the properties and behaviors of a wave:

- Amplitude: The magnitude of the electric field (E) is used to describe the amplitude of the wave.
- Wavelength: The distance separating adjacent locations (λ) where the electric field is maximum.
- Frequency: The frequency (f) at which the source charge oscillates.
- Wave Speed: $v_{wave} = \lambda$ f
- Wave Interference: Overlapping waves can reinforce or cancel each other, just as in sound waves. Purely Constructive Interference results when two waves overlap perfectly, resulting in an increase of electric field amplitude (E + E = 2E). Purely destructive interference results from waves overlapping in a way that decreases the electric field to zero (E + (-E) = 0).

Electromagnetic waves are also described by their *intensity*. Intensity is a measure of how much energy the wave delivers to a particular area each second. Since energy changes per second is the definition of power, Intensity has units of power per unit of area, $I = \frac{\text{Watts}}{\text{meters}^2}$.

Electromagnetic waves also exert forces on, and transfer momentum to, charged objects. Atoms contain positive and negative charges, so all matter experiences a net force from interacting with an electromagnetic wave. Since a force per unit of area is defined as a pressure, electromagnetic waves exert a pressure on objects. This is called *radiation pressure*. The radiation pressure is twice as large for an object that reflects light when compared to an object that absorbs light. This is reminiscent of the forces exerted in elastic and inelastic collisions between masses.

The maximum radiation pressure for objects that reflects all light is written as $P_{rad} = 2\ \frac{I}{c}$, while the radiation pressure for an object that absorbs all light is $P_{rad} = \frac{I}{c}$

We can calculate the intensity of the wave by the following relationship:

$$I = \frac{1}{2}\ c\ \epsilon_0\ E^2$$

Just as we saw in our discussion of mechanical waves, the wave energy has to move through something. In the case of electromagnetic waves, the energy moves through space, and space has certain properties that determine how electric and magnetic fields behave. We've seen that the wave speed in space or on Earth is 3 x 10^8 meters per second. That is because ϵ_0 and μ_0 have certain values. As mentioned above, these values change in different materials and as a result, the speed of light through space is the largest it can be. In different materials, the electromagnetic wave travels more slowly.

Because light is a wave and obeys the wave speed relationship, light can be composed of a vast number of frequencies and wavelengths. It turns out that even in the same material, waves with different frequencies travel at slightly different speeds. This has an impact on the development of camera lenses and telescopes, and it is the difference of wave speeds in different materials that underlies all of optics and the basis for sight.

Being able to manipulate the speed at which electromagnetic energy travels through materials might open the door to improved data flow in optical networks, like fiber optic cables used to transport huge amounts of data. In 1998, a joint research project between Harvard University and the Rowland Institute for Science successfully slowed the speed of light to about 17 meters per second. In 2005, IBM successfully manufactured a microchip that can slow the speed of light. This continues to be an area of investigation since using light to transmit information instead of electrical impulses is faster and more energy efficient.
