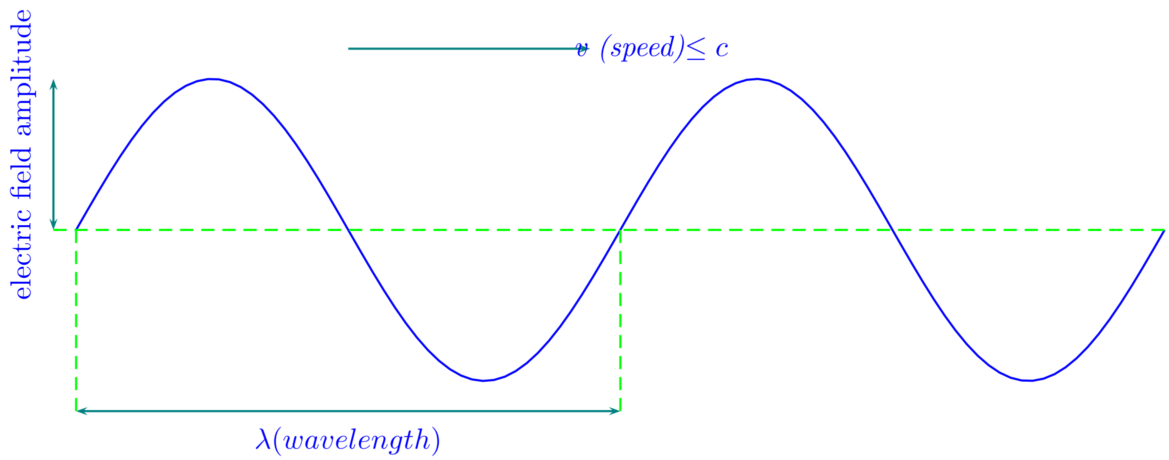
# Electromagnetic Radiation

## Electromagnetic Waves

A disturbance in an electric field takes time to propagate from the postion of the disturbance to an observer. One can create a disturbance by simple moving a positive charge with your hand. A person a distance $r$ away would feel a change in the force on a positve charge held in the hand at time $t = r/c$, where $c = 2.9979 \times 10^8 m/s \approx 3 \times 10^8 m/s$ is the *speed of light*.

Electromagnetic waves are traveling electric and magnetic fields which transport energy. All such waves move as speeds less than or equal to $c$.




Maxwell's equations tell us that if there exists an oscillating electric field as pictured above, there must also exist an oscillating magnetic field perpendicular to both the electric field and the direction of propagation. Thus, electromagnetic radiation is described by a transverse wave with mutually-perpendicular electric and magnetic fields. The *polarization* of the wave is defined as the direction of the electric field. These waves are called *plane waves* because the electric field is the same at every point in a plane perpendicular to the direction of propagation. The power per unit area (perpendicular to the direction of propagation) transported by a wave is proportional to the square of the maximum electric field amplitude.

Electromagnetic waves can be created by an oscillating electric dipole or magnetic dipole. Just as radio waves are launched by driving an electrical current back and forth through a wire, electromagnetic radiation at an frequency can be created by rapidly flipping the direction of a dipole.

The rate at which the electric field changes from pointing upward to downward and back to upward again is the *frequency* of the radiation. Frequency, $\nu$, is measured in *Hertz or per second*. Hertz was the scientist who first transmitted electromagnetic waves from an emitter to a receiver. As with any wave, the wavelength, frequency and speed of propagation are related through

$$\lambda\nu = c\,.$$

For example, a microwave has a frequency of about 1 *gigahertz* $= 1GHz = 1 \times 10^9/s$. So, the wavelength is

$$\lambda = \frac{c}{\nu} = \frac{3 \times 10^8 m/s}{1 \times 10^9/s} = 0.3m\,.$$

The *electromagnetic spectrum* is a description of electromagnetic radiation over the entire frequency range, from about 1 $Hz$ to beyond $10^{24} Hz$. Important frequency ranges are: the radio frequencies $10kHz$ to $1GHz$; the microwaves between $1GHz$ and $10GHz$; infrared light with wavelength between $100\mu m$ and $1\mu m$; visible light with wavelength between 700 and $400nm$; ultraviolet light with wavelength between 400 and 10$nm$; x-rays with wavelength between 10 and .01$nm$; gamma rays with wavelengths less than .01$nm$.

### Photons - the particle nature of light

The fact that electromagnetic radiation also behaves as a stream of particles became apparent from two important observations and analyses. The spectrum of light emitted from a hot object has a particular shape referred to as the "black body radiation spectrum". In order to fit a mathematical function to the observed spectrum, Planck had to assume that the radiation was "quantized", that is, described by packets of energy $E = h\nu$. Here, $h = 6.627 \times 10^{-34} Joule\, sec$ is the Planck constant and $\nu$ is the frequency. The photoelectric effect is the observation that an atom, molecule or crystal can only be ionized if the frequency of the radiation is above a value characteristic of that material. Radiation of lower frequency cannot ionize the material even if it is made very intense. Einstein concluded that light exists as a stream of particles of energy $E = h\nu$ and that ionization can only be achieved if the energy of a photon is greater than the "work function" for the material, which is just the energy $W = h\nu_\circ$ where $\nu_\circ$ is the minimum frequency required for ionization.