ELECTROMAGNETIC WAVES

An electromagnetic wave is composed of oscillating, comoving electric and magnetic fields that are oriented perpendicularly to each other.

Introduction

Electromagnetic waves have two components: an oscillating electric field and a perpendicular, comoving magnetic field which oscillates at the same frequency, but with a phase shifted by 90°. They describe the movement of a packet of energy between two points. In the discussion of EM waves, we are normally concerned with its wavelike behaviour rather than its elecromagnetic properites.

Waves are periodic functions, so we can determine all of a wave's properties from one cycle of the wave, as in the figure below. The *period, T*, is the length of time that it takes to complete one cycle, the *amplitude* (normally denoted by A), in this case, is the maximum value of the wave's electric field, and the wavelength, λ, is the distance in real space traveled by the wave in one cycle.

We can determine some useful quantities from the measurable ones. For instance, the *frequency,* ν, of a wave is simply the inverse of the period.

$$f=1/T$$

$$\nu=1/T$$

The frequency, wavelength, and energy of an EM wave can be calculated from the following equations; the first equation states that the product of an electromagnetic wave's frequency and wavelength is constant, equal to the speed of light, c. The second pair of equations tells us the energy as a function of wavelength and frequency respectively. Note that these describe light moving through a vaccuum.

$$c=\lambda f$$

$$E=hc/\lambda=hf$$

Wave Equations

Mathematically, Maxwell's equations for a system without any sources of electric or magnetic fields.

$$\nabla\times\vec{B} - 1c = \partial\vec{E}\ \partial t 4\pi c\vec{j}$$

$$\nabla\cdot\vec{E} = 4\pi\rho$$

$$\nabla\times\vec{E} + 1c\partial\vec{B}\ \partial t = \vec{0}$$

$$\nabla\cdot\vec{B} = 0$$

These equations simplify down to the more familiar and useful wave equation

$$uk(x,t)=Aeik(x-\nu t)+B-ik(x-\nu t)$$

The Electromagnetic Spectrum

We use a variety of different terms to describe EM radiation depending on its energy. Visible light, X-rays, and microwaves are all EM waves. Despite the names, all EM radiation is physically the same--oscillating electric and magnetic waves. However, the way that EM waves at different energies interact with matter compels us to name them differently. For instance, X-rays pass through many objects that visible light cannot, like our bodies. This occurs because atoms are only likely to absorb EM waves with frequencies matching their own resonance frequencies.

Infographic depicting wavelength, frequency, and the visible spectrum. Courtesy of the University of Oregon

EM Waves in a Medium

When electromagnetic waves travel through a medium--anything other than a true vacuum--they slow down to less than the speed of light in a vacuum, *c*, depending on the material's **index of refraction,** *n.* Their speed follows the simple equation,

$$v=c/n$$

. The index of refraction is a measure of how the electric and magnetic fields within the medium affect traveling EM waves. Media with higher indicies of refraction affect EM waves more strongly.

Refraction

EM waves passing between two media with different refractive indicies will refract, or change direction, due to the change of the speed of light in that medium. Refraction depends on the indicies of refraction for both media as well as the angle of incidence of the light onto the second medium. The figure below demonstrates light refracting through water as it comes from the air. The difference in the two angles is given by the formula below. In this case, the index of refraction for air is effectively 1 (more exactly, it is exactly 1.000277) and for water is 1.33.

$$\sin\theta1\sin\theta2=v1v2=n1n2$$

Beam of light passing between air and water. Note the change in angles between the incident and refrated beam. For a beam incident on water from the air,

$$\sin(\theta2)=11.33\sin(\theta1)$$

Source: http://physwiki.ucdavis.edu/Electricity_and_Magnetism/Electromagnetic_Waves