# PROPERTIES OF ELECTROMAGNETIC WAVES

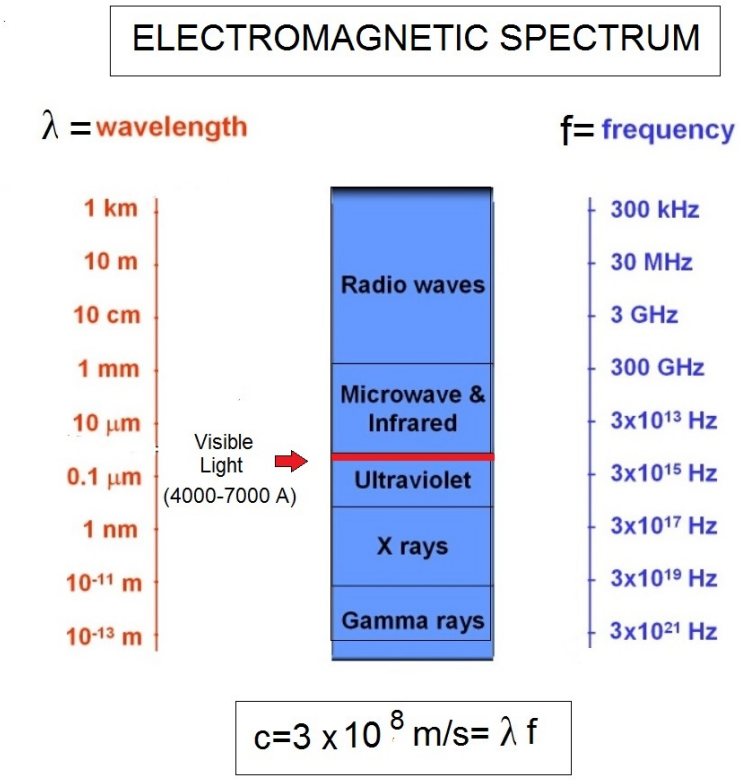
In 1862 the Scottish-English physicist and mathematician James Clerk Maxwell proposed four basic equations which tied together what was known about electricity and magnetism. Among the most important consequences of these equations was that they predicted the existence of transverse electromagnetic waves which propagate through vacuum at the speed of light. His equations, reduced to their simplest form, state that-

$$\frac{\partial^2 Z}{\partial t^2} = c^2 \frac{\partial^2 Z}{\partial x^2}$$

, where $c=3x10^8$ m/s is the constant speed of light in vacuum and Z represents either the electric field E or magnetic field H both of which are functions of space and time. The solution to this partial differential equation is-

$$Z=Z_0 \sin(x-ct)$$

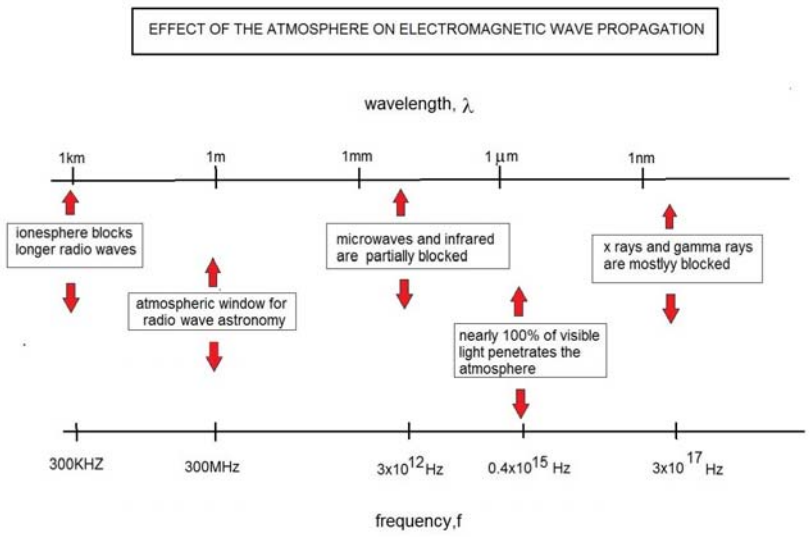
, where $Z_0$ is a constant. This result indicates one has an electromagnetic wave travelling to the right with speed c having wavelength $\lambda$ and a frequency $f=c/\lambda$. Since c is a constant it must be that wavelength varies inversely with frequency. Thus a $\lambda$=1m em wave has a frequency of $3x10^8$ Hz=300MHz. Here Hz stands for Hertz(1857-1894), the first person to experimentally verify the existence of em waves. AM radio waves lie in the 100KHz range and FM carrier waves lie at around 100MHz. The frequency of the em waves used in microwave ovens is 2450 MHz with a wavelength of 12.2cm. This frequency is strongly absorbed by water and hence accounts for the heating of food which contains mainly water. The same micro-wave frequencies are associated with present day cell phones, although upcoming wireless transmitter technology associated with 5G will operate at even higher frequencies of up to 26GHz. This last frequency corresponds to a $\lambda$ of 1.2mm. Strong atmospheric absorption prevents cell phone and wireless technology from going to even higher frequencies than twenty-six gigahertz. A graph showing the full range of wavelength and frequencies for em waves in vacuum follows-




As one sees the Maxwell Electromagnetic Waves have a wide range of frequencies extending well over 22 orders of magnitude. Also visible light that we can see has only the very narrow range of $0.4\mu m<\mu<0.7\mu m$. ( In the old days one used to measure light wavelengths in terms of angstroms , where $1A=10^{-10}$ meter).

All practical applications of em waves require them to be transmitted through media other than vacuum be it gases , liquids or solids. EM propagation through such materials can lead to scattering and adsorption in addition to an overall slowing of the wave speed. For visible light one expresses the em propagation speed as v=c/n, where n is the index of refraction. For the transmission through air at STP we have the almost vacuum number of n=1.00029 while transmission through water has n=1.33. Water also absorbs visible light weakly. This is still sufficient for a diver working at a depth of 300ft below the water surface to see no sunlight.

Another important thing to know about em waves deals with their penetration capability through the Earth's atmosphere. EM waves have two major windows where the transmission is nearly 100%. These are the region around one meter wavelength used in radio astronomy and a second window extending from microwaves( $\lambda$=30cm) down to visible light ($\lambda$=0.5μm).The second window however has some subregions where the waves are partially or completely blocked. The overall penetration capability is summarized in the following graph-




EM waves used as carriers for cell phones operating in the 600MHz up to 26GHz range have good atmospheric transmission capability. However the distance between cell phone towers will have to be become shorter when 5G is introduced since there some weakening of signals will occur because of atmospheric absorption.

A final topic of discussion deals with the interaction of em waves with living cells in the human body. Down to the wave lengths corresponding to ultraviolet light, electromagnetic waves cannot produce ionizing radiation but they can cause heating and even burns under high intensity and long term exposure. This fact is reflected by microwave ovens which use 12cm em waves to heat food. Such non-ionization radiation's will cause internal heating of the molecules in cells being agitated. This is reflected by the production of internal heating as is the case for 2450MHz waves used in microwave s cooker ovens. In humans such exposure will also cause heating and possible internal burns when subjected to high enough intensity. One especially has to worry about the occurrence of cataracts in the eye since the cornea is poorly supplied with blood cells which are able to cool the cornea at a rapid enough rate. I remember as a student working with diathermy units producing such radiation to excite, but not ionizing, flowing gases. My first scientific paper dealt with this afterglow phenomenon well over sixty years ago. I always made sure during those experiments to properly shield the wave guide with wire mesh to keep the microwave radiation from escaping out into the room. At radiation frequencies greater than ultraviolet light one needs to worry about true ionizing radiation. This is especially so for x-rays such as used at dental offices. The American geneticist and Nobel Prize recipient Hermann J. Mueller showed in the 1927 the deleterious effect that x-rays had on fruit flies causing gene mutations which led to strange offspring. Before that time people used x-rays nonchalantly including shoe x-raying to see how a foot is fitting. My advice to readers would be to avoid being too near unshielded microwave cookers, cell phone towers, high intensity radar units and to minimize the use of x-rays. The em backscatter machines employed at airports use millimeter wavelength em waves These cause no ionizing radiation as earlier x-ray backscatter machines did. In addition the exposure time is so short that they are relatively

safe except for possible future cataract problems for frequent flyers. Also one can always request a pat down as an alternative.

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