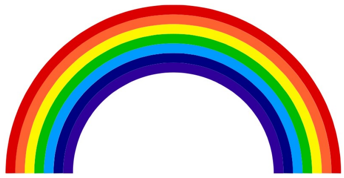
IALP 2011 - Wavelength

P. Stallinga

MIEET 1º ano

Modern telecommunications are more and more done through electromagnetic radiation. Where conventionally communication was taking place by metal wires ('cables'), modern communication is every time more 'wireless' and fiber-optics, both use electromagnetic radiation. As we all know, electromagnetic radiation ('light') can be seen as particles (also known as 'photons') or as waves. In this document we will study the wave character of light.



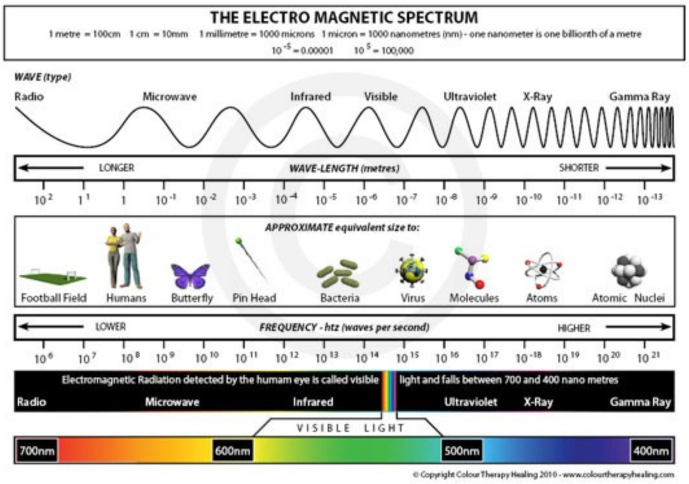
If I'd go to the end of a rainbow
as Dame Fortune did intend
Murphy would be there to tell me
the pot's at the other end!

The wavelength of light varies with its color. In fact, only a small part of the electromagnetic spectrum is visible by human eyes and can we speak of 'color'. See the figure below. Telecommunications ('telegraph' of Marconi and terrestrial television) are in the invisible radio frequencies. Modern wireless communications (WiFi, 3G, UMTS, etc.) are in the microwave range. Fiber-optic communications mostly in the infrared.

The wavelength (λ), frequency (f), speed (of light)(c) and energy (E) of a photon are linked in the following ways:

$\lambda = c/f$	(m)
$f = c/\lambda$	(Hz)
$E = hf$	(J)

In the experiments, be careful to not look directly into the laser beam:



http://www.colourtherapyhealing.com

Exercises

1) The maximum rate of information transfer is depending on the frequency of the 'carrier' used, according to Nyquist*

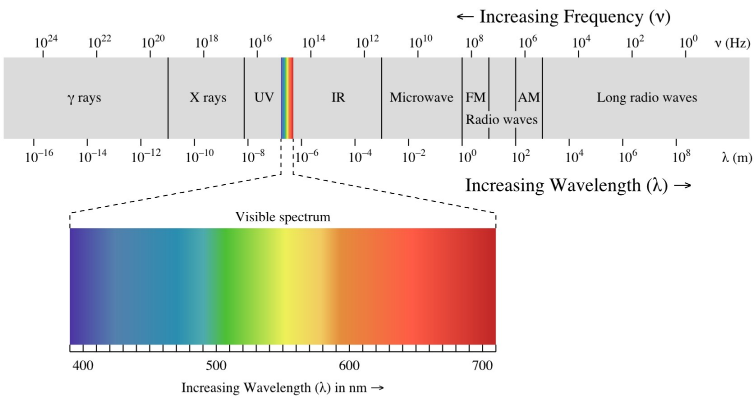
$$T = 2\Delta f,$$

with T the information rate and Δf the bandwidth (Assume equal to the carrier frequency f). Determine for the communication channels below the maximum bitrate (b/s).
How long does it take at each technology to pass a DivX film (700 MB)?
2) To properly receive the signal, an antenna with at least half a wavelength is needed (to be able to have standing waves). Determine for each of the channels the antenna size needed. 3) Give two reasons why nobody has a mobile telephone that works at ELF.

Technology	Bit rate	DivX time	Antenna size
Submarine communication (very low frequency VLF and extremely low frequency ELF)			
Marconi's Telegraph			
Radio Antena 1:			
TV RTP1:			
cellular TMN:			
MEO fiber-optics			N/A

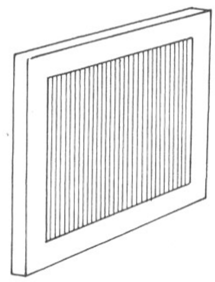
Since working with invisible light is … quite difficult to do with our eyes, we will focus on visible light. The visible part of the electromagnetic spectrum ranges from wavelengths between about 400 nm to 700 nm, see the Figure below. (1 nm = 10^{-9} m).

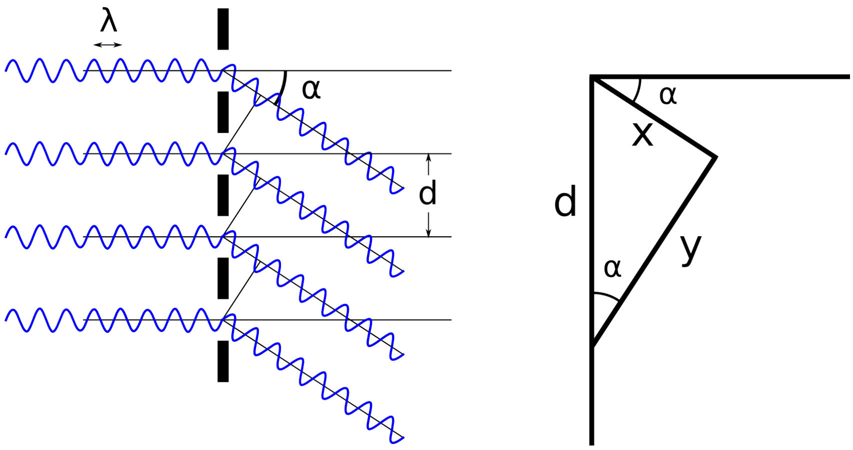
* A better theory is the Shannon-Hartley Theorem that includes the noise levels. See Wikipedia Shannon-Hartley Theorem (http://en.wikipedia.org/wiki/Shannon-Hartley_theorem)



Wikipedia

We can use a diffraction grating to determine the wavelength of the light. A diffraction grating is a plate with alternating transparent and opaque lines, as shown here on the right. When light is incident on the grating on the other side constructive interference will occur at a target at an angle for which the difference in distance from the target to adjacent slits is a multiple of the wavelength (λ). For the target far away from the grating ($L \gg \lambda$) we have the situation below:





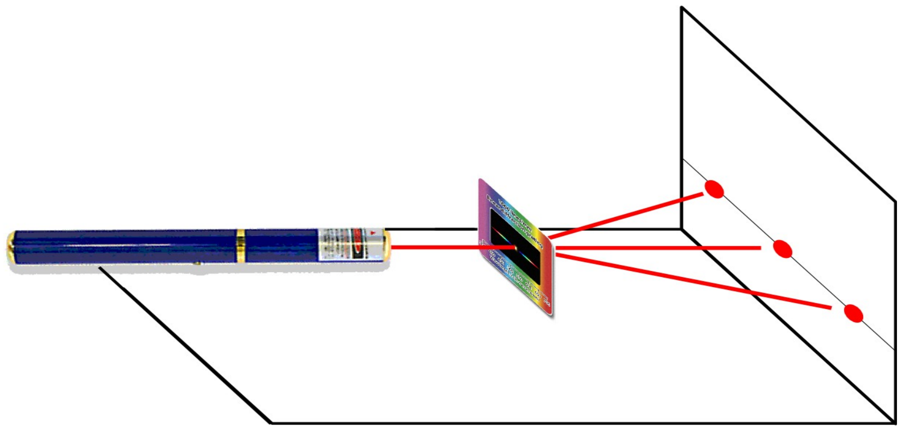
From the above image it is easy to show that this occurs for an angle for which

$$d \sin(\alpha) = n\lambda$$

When we point a light source with a single color (=wavelength) to a grating, we will see dots at angles that obey the above equation with $n = 0, 1, 2, ...$

Exercises

4) Determine the wavelength of a laser pointer using the diffraction setup shown below



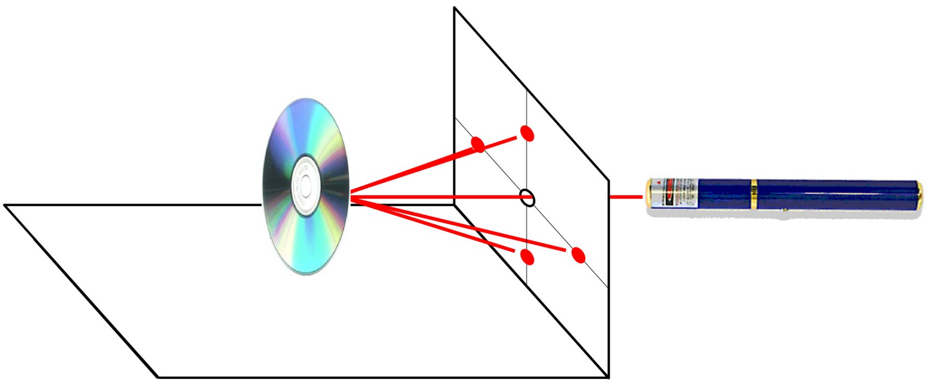
NB: The grating has 1000 lines per mm.

Every CD or DVD consists of many tiny pits and thus also works as a 2 dimensional mirror grating. We can use the same technique of diffraction to determine the density of these dots and thus determine the information on the CD/DVD. (Note: 1 byte is 8 bits)

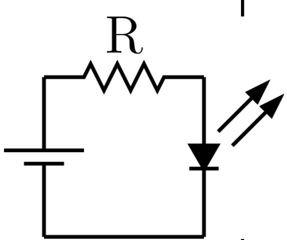
Surface of CD
http://drewdaniels.com/cdfacts.html

Exercises

5) Determine the density of information on a CD or DVD using the diffraction setup shown below



6) Determine the wavelengths of a light-emitting diode. To do this connect a 5 V source through a 100 Ω resistance connected to a LED. Design your own setup for determining this.



And, finally, some advice:

http://academics.rmu.edu/~short/signage/