Electromagnetic Spectrum

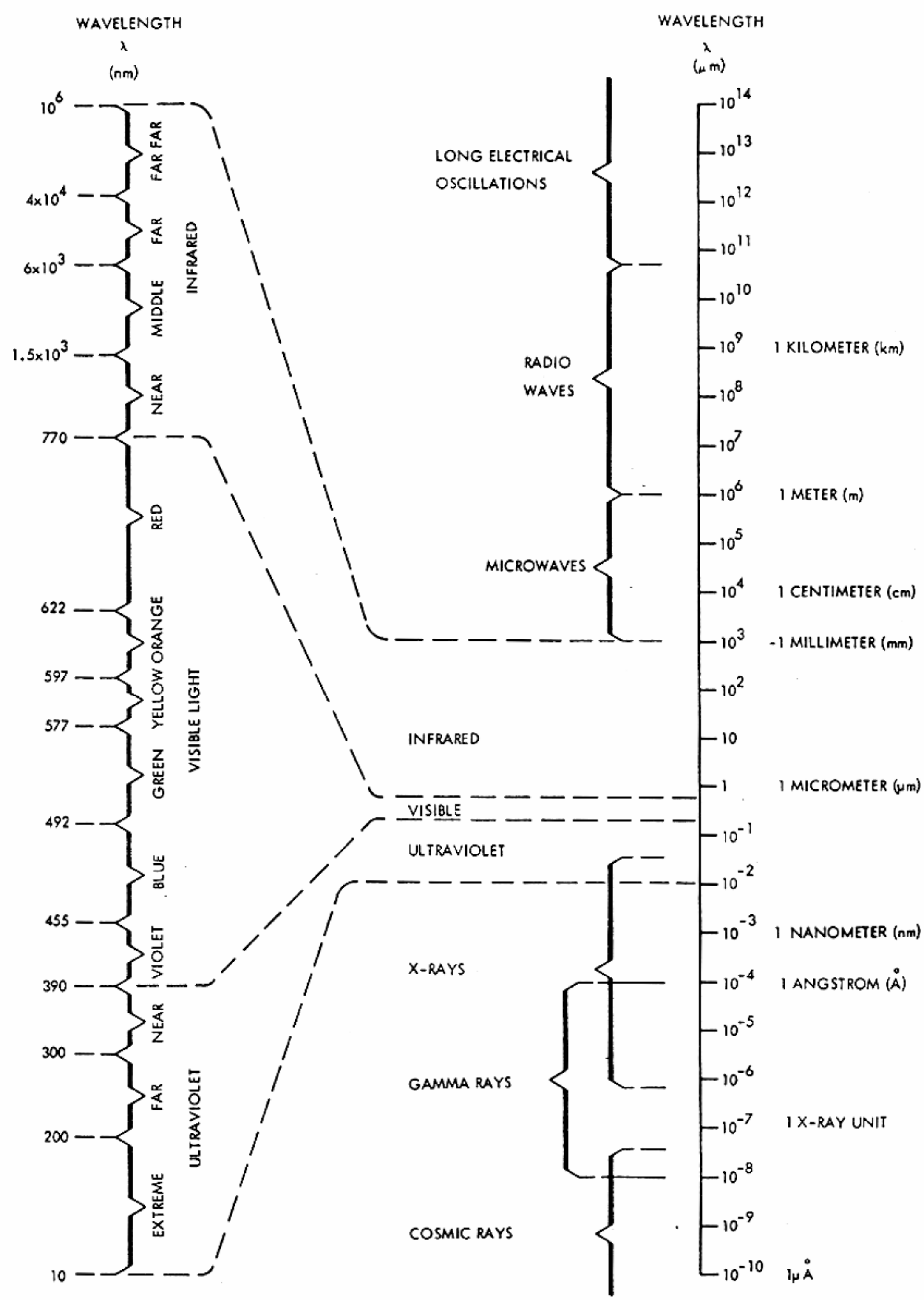


Fig. 1-6 Electromagnetic spectrum.

Plane Waves

- Plane waves:
- Same E field intensity in a plane perpendicular to direction $\vec{r}$
- If $\vec{r}$ is in the x direction then E is constant in z, y planes

$$E(x,y,z,t) = E_0 \exp(i[\omega t - kx]) = E_0 \exp\left(i\left[\omega t - \frac{2\pi}{\lambda}x\right]\right)$$

- In general the wave equation for plane wave is

$$E(x,y,z,t) = E_0 \exp\left(i\left[\omega t - \vec{k} \bullet \vec{r}\right]\right)$$

- Where wave vector in direction of motion is $\left|\vec{k}\right| = \frac{2\pi}{\lambda}$

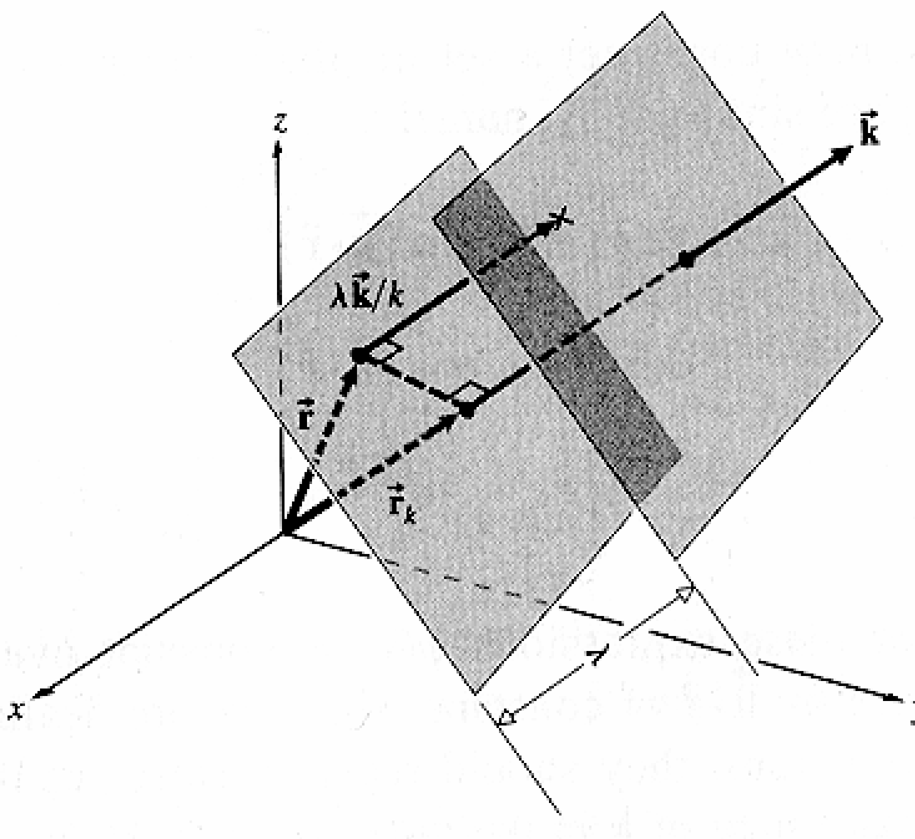


Figure 2.21 Plane waves.

Energy Flow and the Poynting Vector

- To get from E fields to light intensity talk about energy flows
- This occurs with the Poynting Vector S defined as

$$\vec{S} = \frac{1}{\mu_0}\left(\vec{E} \times \vec{B}\right) = c^2 \varepsilon_0 \left(\vec{E} \times \vec{B}\right)$$

- Where μ_0 is the magnetic permeability of free space
- When in a material replace by μ of the material
- This S represents the energy flowing past a point
- The energy lost in a material is dS/dx
- Occurs because the E and B field a nolonger perpendicular

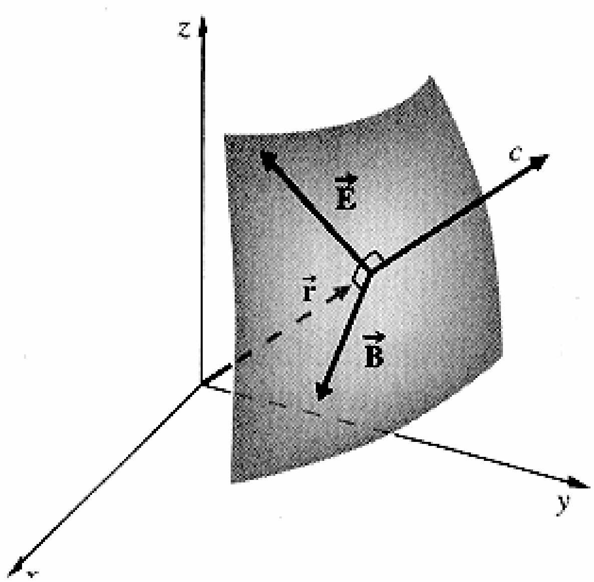


Figure 3.15 Portion of a spherical wavefront far from the source.

Irradiance or Light Intensity

- What we see is the time averaged energy of pointing vector

$$\langle S(t)\rangle = \int_{t-T/2}^{t+T/2} S(t)\,dt$$

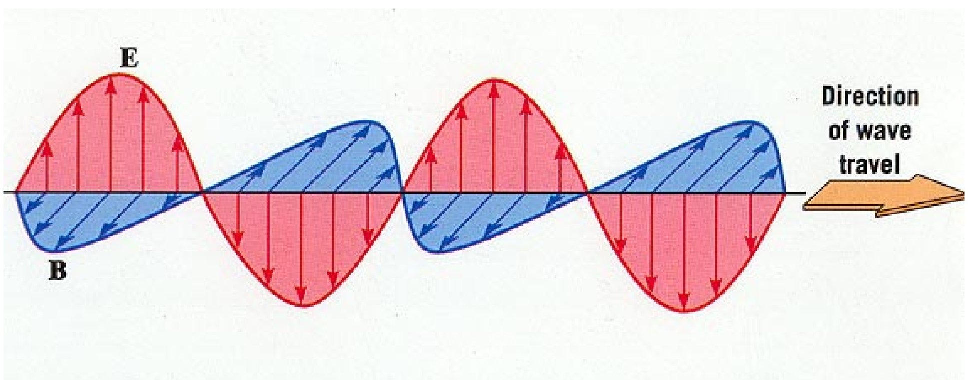
- Where T is the period of the wave
- Called the irradiance I in Watts/unit area/unit time

$$I = \langle S\rangle = \varepsilon_0 c\langle E^2\rangle = \frac{c}{\mu_0}\langle B^2\rangle$$

- For sin waves this results in

$$I = \langle S\rangle = \varepsilon_0 c\langle E^2\rangle = \frac{c\varepsilon_0}{2}E^2$$

- Not true in absorbing materials because
- E & B have different relationship & phase there



Basic Optics: Index of Refraction

- Denser materials have lower speeds of light
- Index of Refraction n

$$n = \frac{c}{v}$$

where

c = speed of light in vacuum

v = velocity in medium

- Even small changes can create difference in n
- Higher index shortens the wavelength

$$\lambda' = \frac{\lambda}{n'}$$

- Use this reduction if to get higher resolution in microfabrication
- Immersion lithography: put lens in water so it has smaller λ'
- 195 nm light acts as 147 nm light

Substance	Index of refraction	Substance	Index of refraction
Solids:		Liquids at 20°C:	
Ice (H_2O)	1.309	Methyl alcohol (CH_3OH)	1.3290
Fluorite (CaF_2)	1.434	Water (H_2O)	1.3330
Rock salt (NaCl)	1.544	Ethyl alcohol (C_2H_5OH)	1.3618
Quartz (SiO_2)	1.544	Carbon tetrachloride (CCl_4)	1.4607
Zircon ($ZrO_2 \cdot SiO_2$)	1.923	Turpentine	1.4721
Diamond (C)	2.417	Glycerine	1.4730
Fabulite ($SrTiO_3$)	2.409	Benzene	1.5012
Rutile (TiO_2)	2.616 2.903	Carbon disulfide (CS_2)	1.6276

Index of Refraction and Emag waves (Hecht 3.5)

- The velocity in a material is set by the emag parameters
- Velocity of light is given by

$$v = \frac{1}{\sqrt{\varepsilon\mu}}$$

- Thus the index of refraction is

$$n = \frac{c}{v} = \sqrt{\frac{\varepsilon\mu}{\varepsilon_0\mu_0}} = \sqrt{\varepsilon_r\mu_r}$$

- Most optical materials are non magnetic
- For non magnetic materials this means

$$n \propto \sqrt{\varepsilon_r}$$

What Happens to Slow Light Down

- In material the E wave of affects the electrons of material
- In an insulator (eg. glass) electrons do not flow
- Energy is transferred to the e's and back to light
- Results in a drag on the photons moving through material

- Metals have many free electrons (electron sea)
- In metals energy to the free electrons causes them to move
- This results in a loss of energy to the materials
- Light dies out

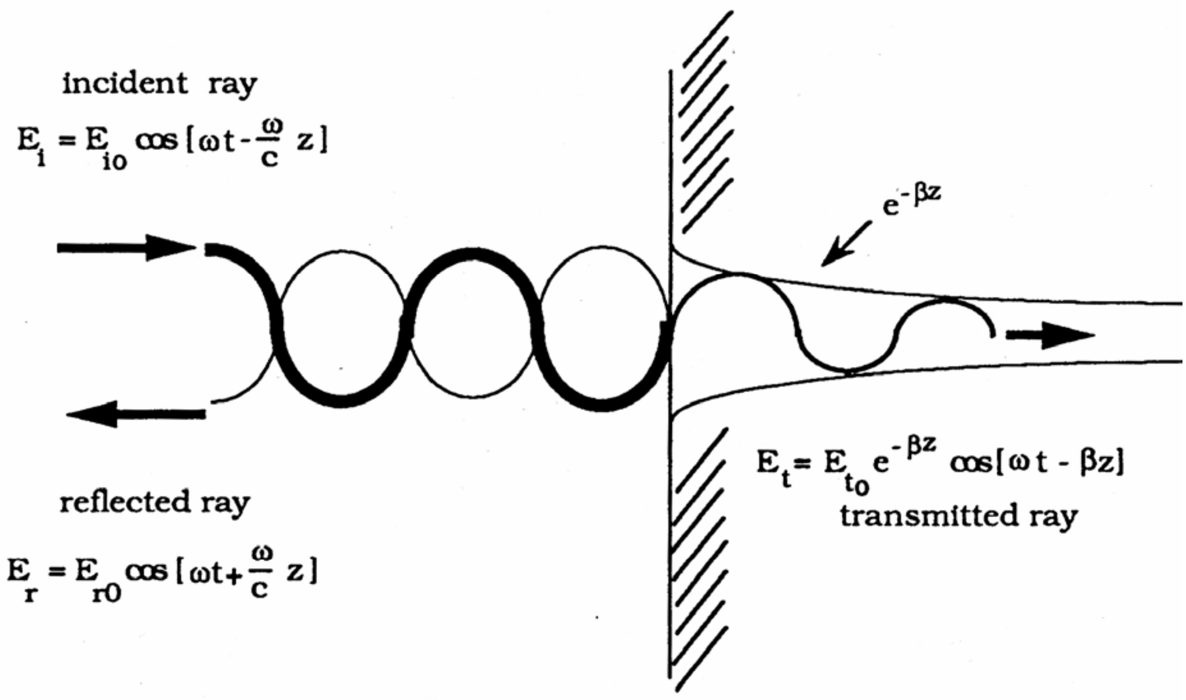


Fig. 2.1. The phase and amplitude of an electromagnetic ray striking an air/solid interface and undergoing reflection and transmission.

Polarization of Light

- Polarization is where the E and B fields aligned in one direction
- All the light has E field in same direction
- Black Body light is not polarized
- But if pass though a material with parallel structure may polarize
- Causes mostly light with same alignment to pass through
- Caller polarizing filters
- Changes unpolarized light into polarized light
- Polarization also often occurs on reflection or on scattering
- Polarizing filters have direction
- If have two filters at 90^o then almost no light passes through

Light Passing Through Crossed Polarizers

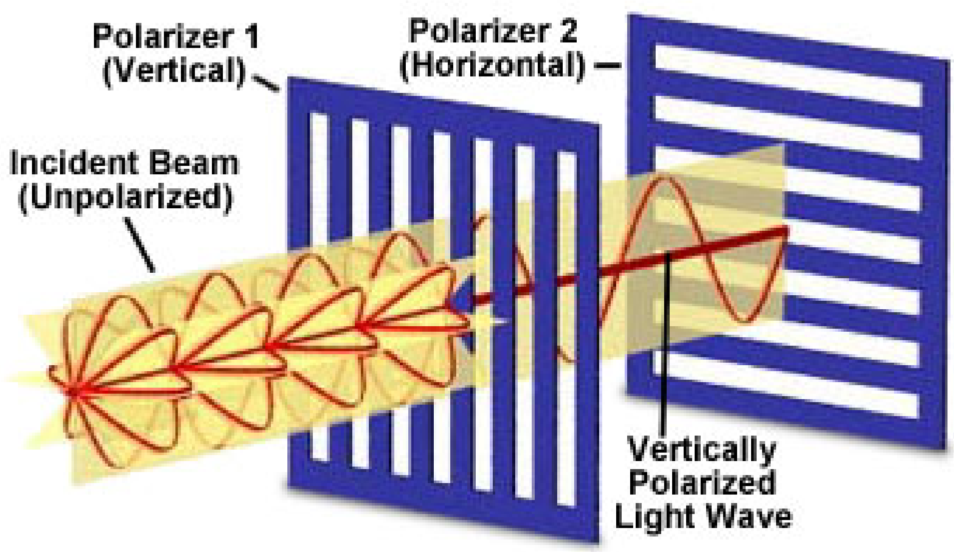


Figure 1