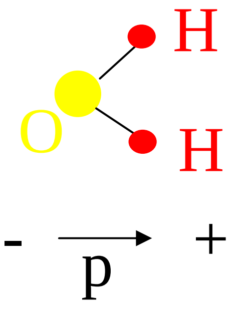
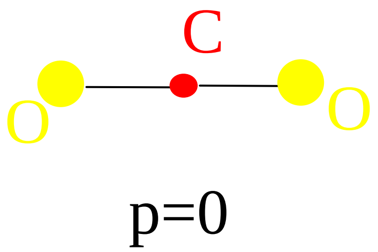
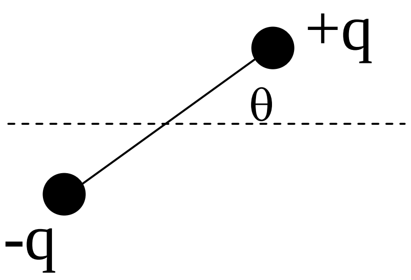
Orientational Polarizability

- No restoring force: analogous to conductivity







For a group of many molecules at some temperature:

$$f = e^{\frac{-U}{k_b T}} = e^{\frac{pE\cos\theta}{k_b T}}$$

After averaging over the polarization of the ensemble molecules (valid for low E-fields):

$$\boxed{\alpha_{DC} \sim \frac{p^2}{3k_b T}}$$

Analogous to conductivity, the molecules collide after a certain time t, giving:

$$\boxed{\alpha_o = \frac{\alpha_{DC}}{1-i\omega\tau}}$$

Dielectric Loss

- For convenience, imagine a low density of molecules in the gas phase
- C-M can be ignored for simplicity
- There will be only electronic and orientational polarizability

$$\varepsilon_r = 1 + \chi_e + \chi_o = n^2 + \frac{N\alpha_{DC}}{3\varepsilon_o(1 - i\omega\tau)}$$

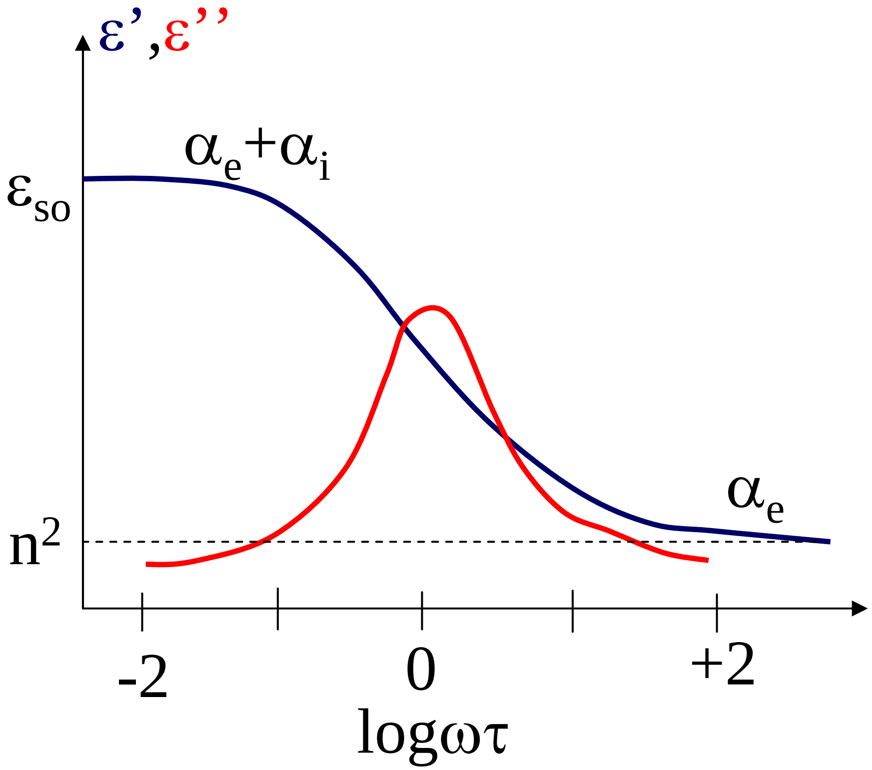
$$\omega\tau << 1, \; , \; \varepsilon_r = \varepsilon_{so} = n^2 + \frac{N\alpha_{DC}}{3\varepsilon_o}$$

$$\therefore \; \varepsilon_r = n^2 + \frac{\varepsilon_{so} - n^2}{1 - i\omega\tau}$$

We can write this in terms of a real and imaginary dielectric constant if we choose:

$$\varepsilon_r = \varepsilon' + i\varepsilon''$$

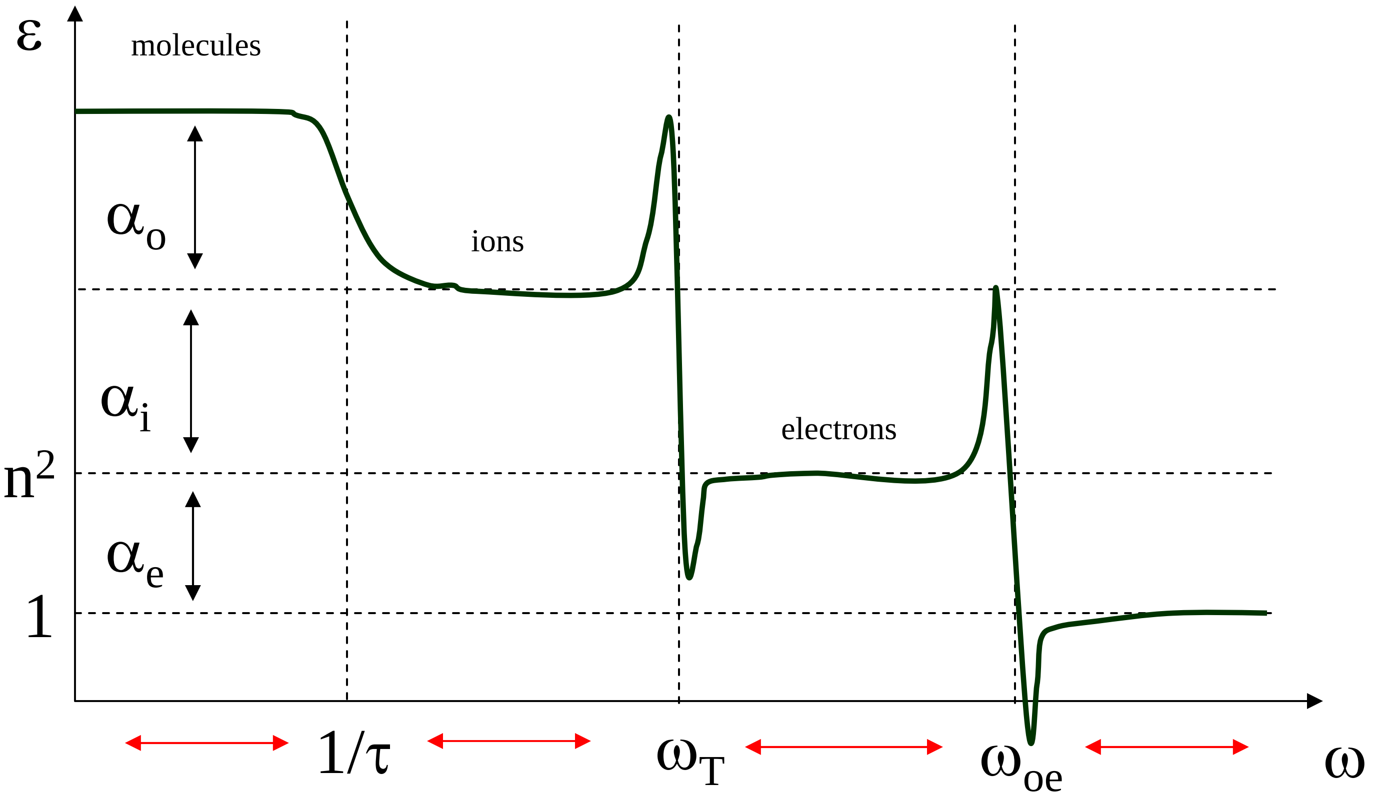
$$\varepsilon' = n^2 + \frac{\varepsilon_{so} - n^2}{1 + \omega^2\tau^2}; \; \varepsilon'' = \frac{\varepsilon_{\mathrm{so}} - n^2}{1 + \omega^2\tau^2}\omega\tau$$



Water molecule: τ=9.5x10^{-11} sec, ω~10^{10}
microwave oven, transmission of E-M waves

Dielectric Constant vs. Frequency

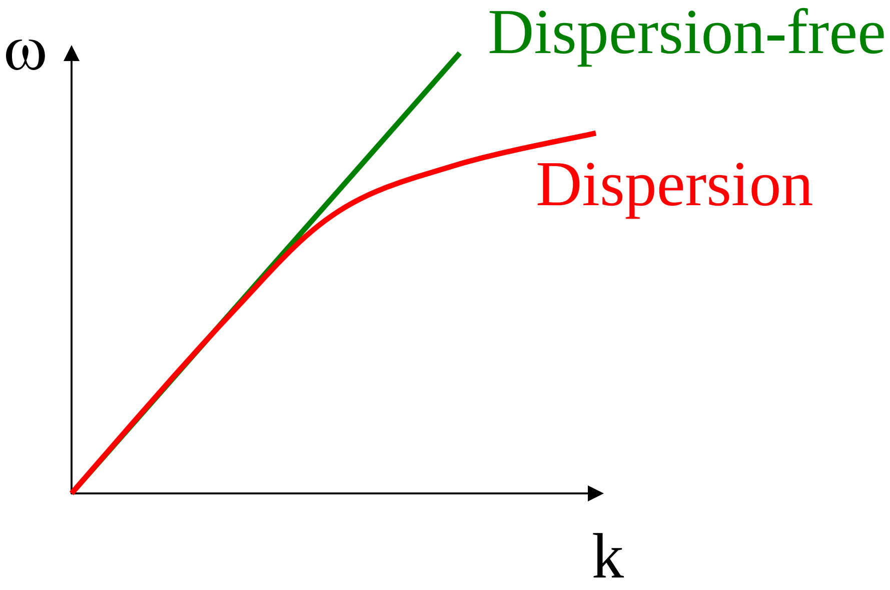
- Completely general ε due to the *localized* charge in materials



Dispersion-free regions, $v_g = v_p$

Dispersion

- Dispersion can be defined a couple of ways (same, just different way)
  - when the group velocity ceases to be equal to the phase velocity
  - when the dielectric constant has a frequency dependence (i.e. when dε/dω not 0)



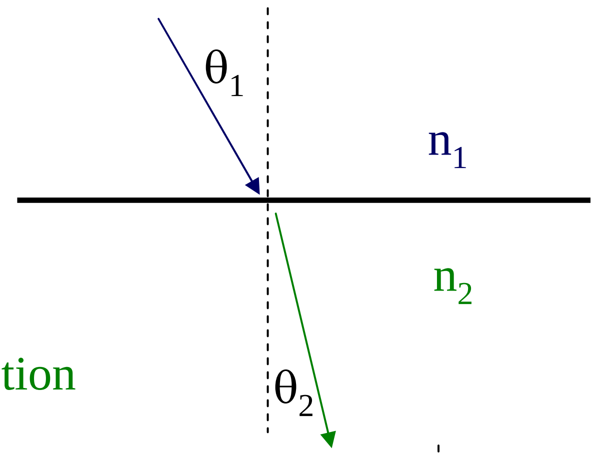
$$\omega = \frac{c}{\sqrt{\varepsilon_r}}k$$

$$v_p = \frac{\omega}{k} = \frac{c}{\sqrt{\varepsilon_r}} = \frac{\partial\omega}{\partial k} = v_g$$

$$v_p = \frac{\omega}{k} = \frac{c}{\sqrt{\varepsilon_r(\omega)}} \neq \frac{\partial\omega}{\partial k} = v_g$$

Characteristics of Optical Fiber

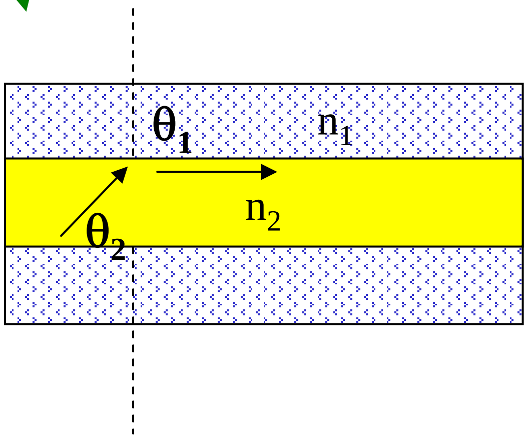
- Snell’s Law



Refraction

Boundary conditions for E-M wave gives Snell’s Law:

$$\boxed{n_1 \sin\theta_1 = n_2 \sin\theta_2}$$



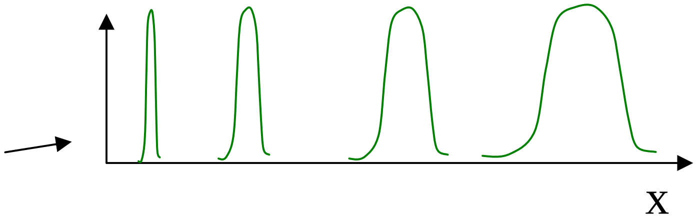
Internal Reflection: θ_1=90°

$$\boxed{\theta_2 = \theta_c = \sin^{-1}\frac{n_1}{n_2}}$$

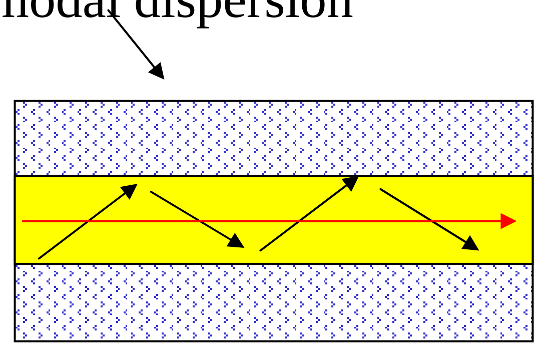
Glass/air, θ_c=42°

Characteristics of Optical Fiber

- Attenuation
  - Absorption
    - OH- dominant, SiO_2 tetrahedral mode
  - Scattering
    - Raleigh scattering (density fluctuations) $\alpha_R \sim \text{const.}/\lambda^4$ (<0.8 μm not very useful!)
- Dispersion
  - material dispersion (see slide i13)
  - modal dispersion

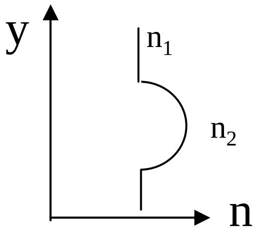


- Light source always has $\Delta\lambda$
- parts of pulse with different l propagate at different speeds



Black wave arrives later than red wave

Solution: grade index



Characteristics of Optical Fiber

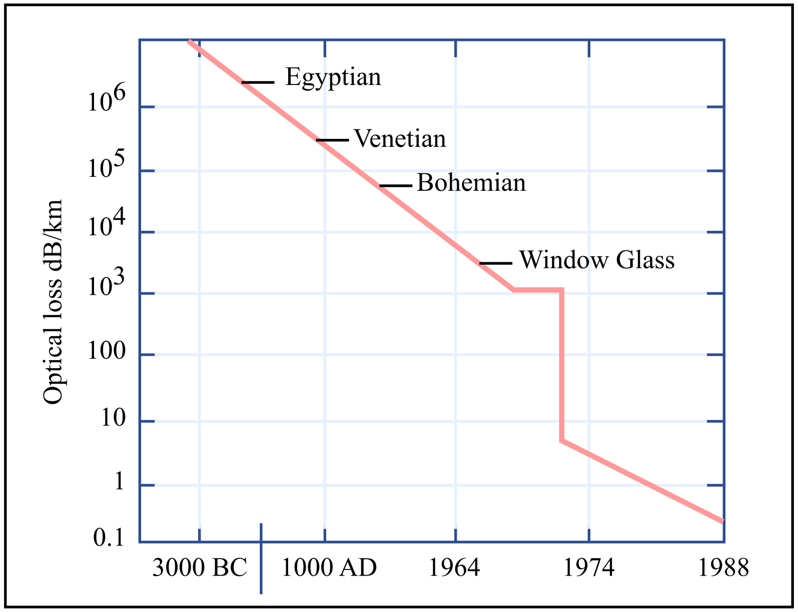


Figure by MIT OpenCourseWare.

Characteristics of Optical Fiber

Image removed due to copyright restrictions.

Please see any diagram of the typical optical attenuation curve, such as http://www.nikhef.nl/~nooren/dispersie3_files/image010.jpg

Characteristics of Optical Fiber

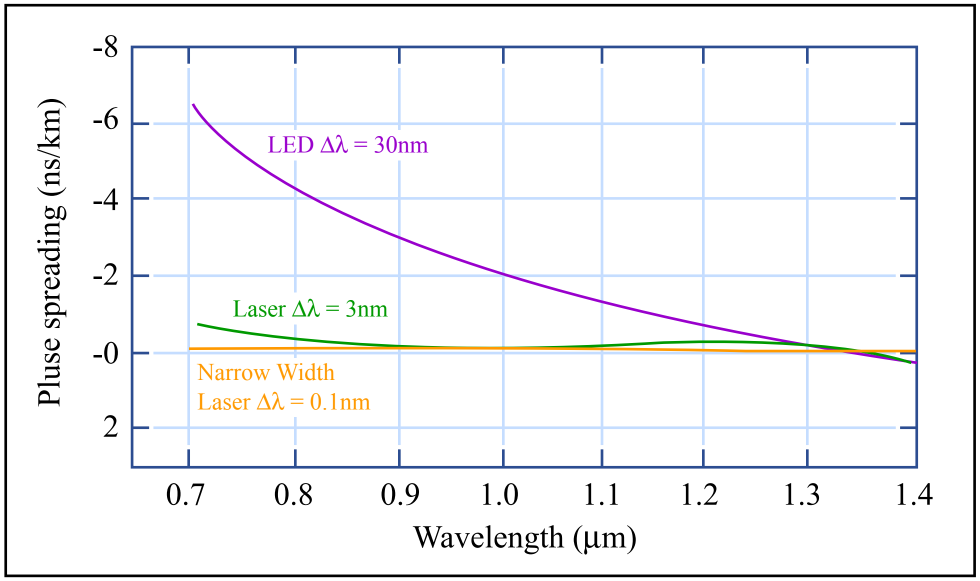


Figure by MIT OpenCourseWare.

Ferroelectrics

- ‘Confused’ atom structure creates metastable relative positions of positive and negative ions

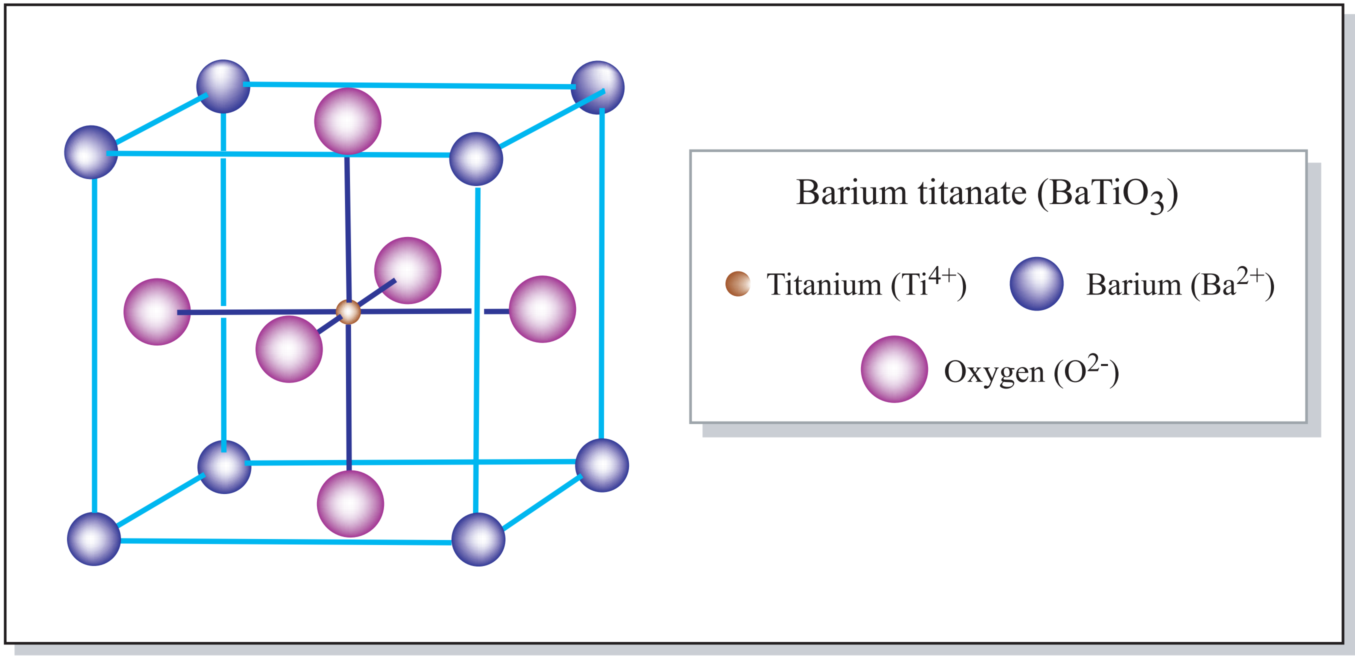
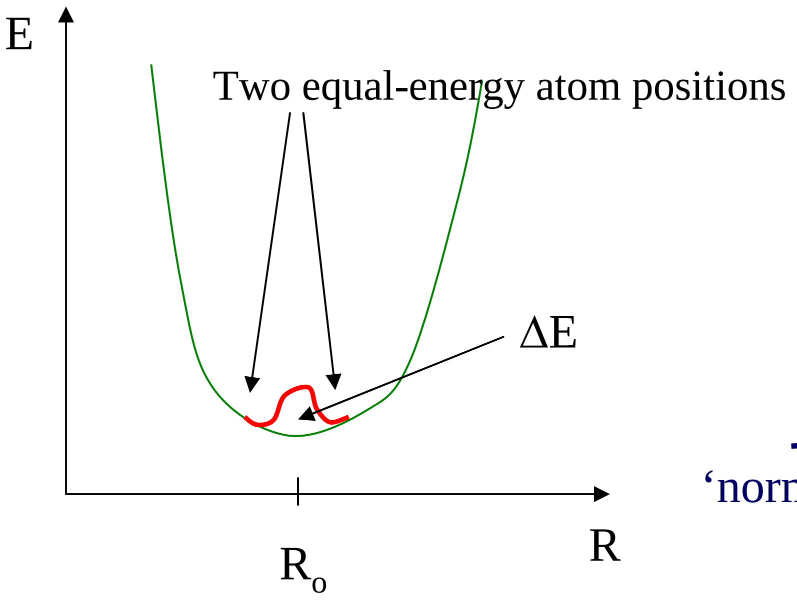


Figure by MIT OpenCourseWare.

Ferroelectrics

- Each unit cell a dipole!
- Very large Ps (saturated polarization, P(E=0))
- No iron involved; ‘Ferro’ since hysterisis loop analogous to magnetic materials



Can flip cell polarization by applying large enough reverse E-field to get over barrier