Attenuation

- Attenuation is the reduction in amplitude and intensity of a signal
- The attenuation of an optical fiber measures the amount of light lost between input and output
- Receivers require some minimum power level, to accurately detect the transmitted signal

Attenuation Units

If P(0) is the optical power in a fiber at the origin (at z=0), then the power P(z) at a distance z

$$\mathbf{P(z) = P(0)\, e^{-\alpha_p z}}$$

$\alpha_p = (1/z) \ln [P(0) / P(z)]$

Fiber attenuation coefficient

Attenuation coefficient in units of decibels per kilometer, denoted by dB/ Km, then

$$\boldsymbol{\alpha(dB/km) = (10/z) \log [P(0) / P(z)] = 4.343 \times \alpha_p\, (km^{-1})}$$

Attenuation

- Losses occur at the channel coupler, splices,
- and within the fiber itself
- These transmission losses limit path length
- Requirements for fiber material
  - Low loss
  - Ability to form into hair like long strands
  - Capable of slight variations to achieve different RIs
  - Continuous change in RI for Graded Index Fiber

Glass Attenuation

- Glass fibers have low absorption than plastic fibers
- Glass fibers are preferred for long haul communications
- Glass in formed by fusing molecules of silica (silicon dioxide SiO_2) and other material (titanium, thallium, germanium, boron etc

Objective: manufacture low-loss fiber

- Attenuation in Glass fiber
  - Absorption
  - Scattering
  - Geometric Effects –bending loss
  - Absorption
    - ✓ Atomic defects
    - ✓ Intrinisic absorption
    - ✓ Extrinisic absorption

Atomic defects

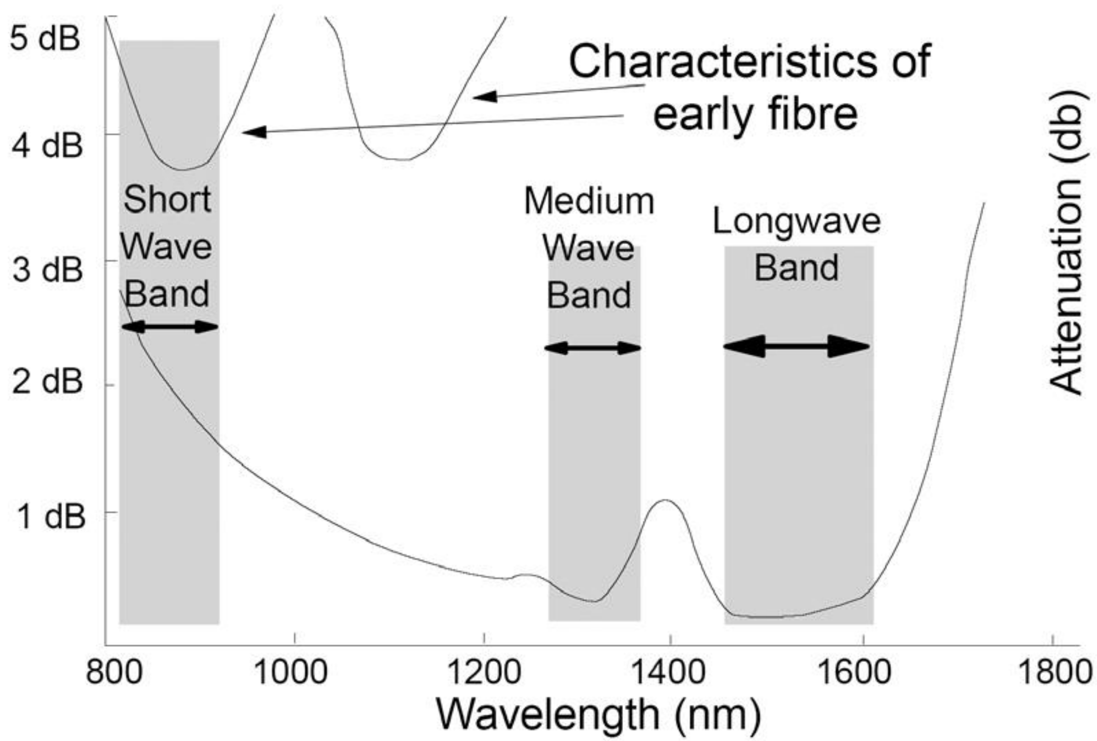
- Missing molecules
- Oxygen defects
- High density cluster
- negligible

Absorption-Extrinsic

- Impurities

  Impurities are major source of loss in practical fiber
- Types of impurities
  - Transition-metal ions
  - OH ions

OH ion attenuation



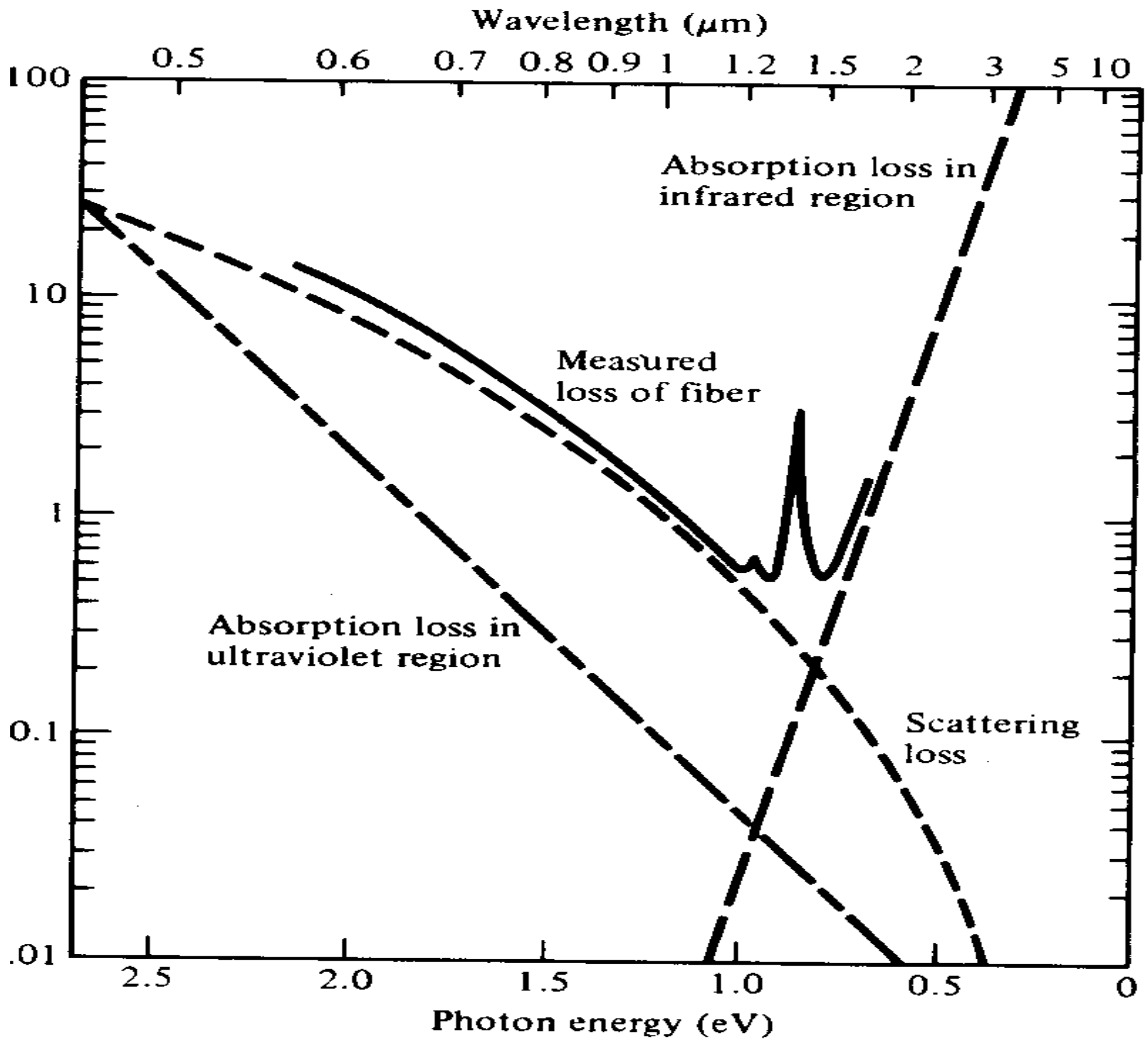
Intrinsic Absorption

- Due to SiO_2
- Glass absorbs heavily within specific wavelength regions
- UV region –Electronic absorption bands
- Infrared region- Vibration Bands
- A natural property of glass
- It is very strong in the short-wavelength ultraviolet portion
- Peak loss
- Ultraviolet region but unimportant

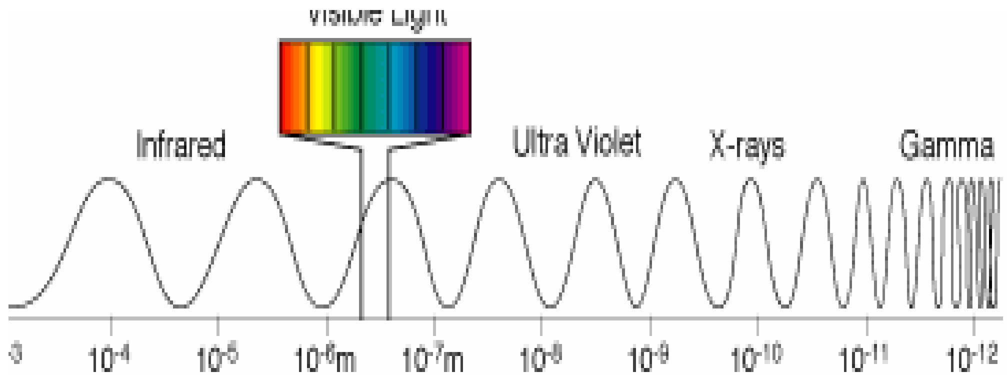
$$\alpha_{uv} = Ce^{E/E_0}$$

$$\alpha_{uv} = \frac{154.2x}{46.6x + 60} \times 10^{-2} \exp\left(\frac{4.63}{\lambda}\right)$$

$$\alpha_{IR} = 7.81 \times 10^{11} \times \exp\left(\frac{-48.48}{\lambda}\right)$$

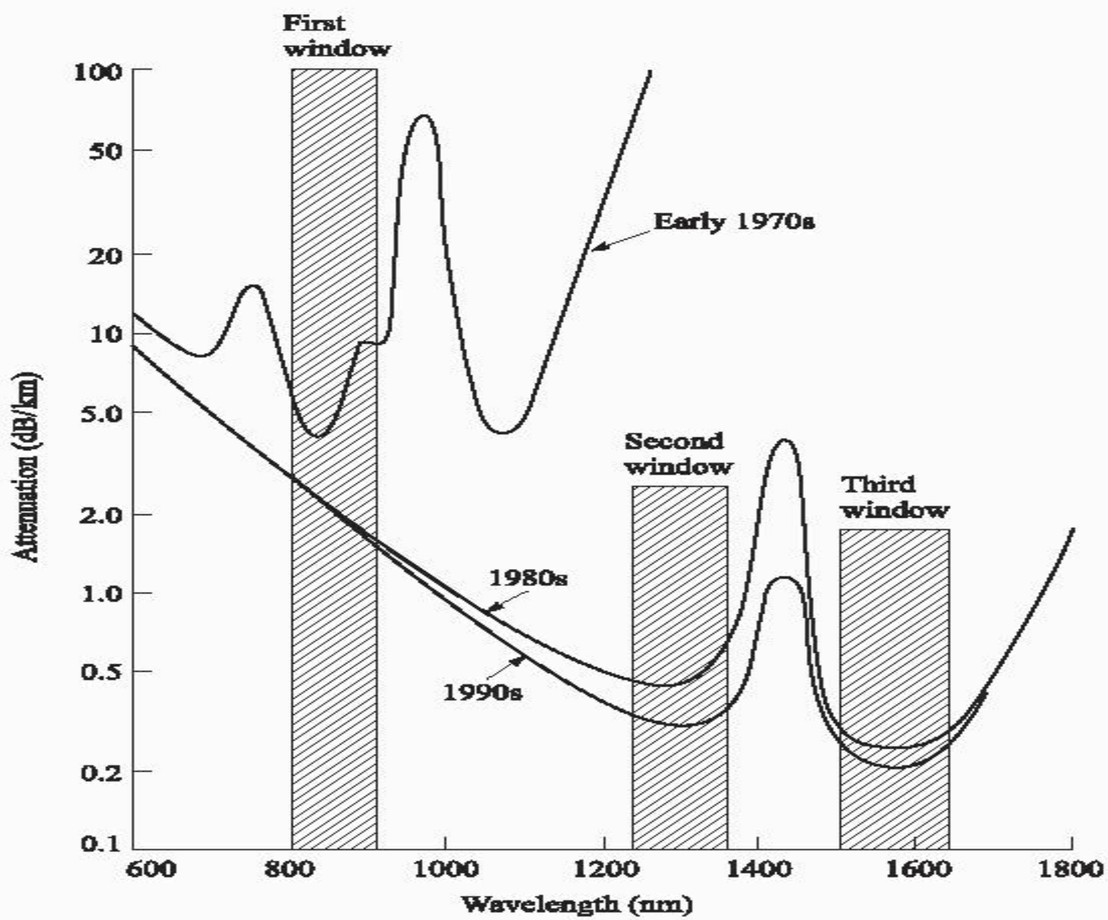

Wavelength (μm)
0.5
0.6
0.7
0.8
0.9
1
1.2
1.5
2
3
5
10
100
10
1
0.1
.01
Absorption loss in
infrared region
Measured
loss of fiber
Absorption loss in
ultraviolet region
Scattering
loss
2.5
2.0
1.5
1.0
0.5
0
Photon energy (eV)

Absorption


Infrared
Ultra Violet
X-rays
Gamma
10^{-4}
10^{-5}
10^{-6}m
10^{-7}m
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}

Absorption

- intrinsic absorption peak also occur between 7 and 12 μm in the infrared
- Infrared loss is associated with vibration of chemical bonds
- Intrinsic losses are mostly insignificant in wide region where fiber systems can operate
- Intrinsic losses restrict the extension of fiber systems toward the ultraviolet as well as toward longer wavelengths
- Fiber Optic Comm operates in a range of wavelengths from 0.5um to1.6um

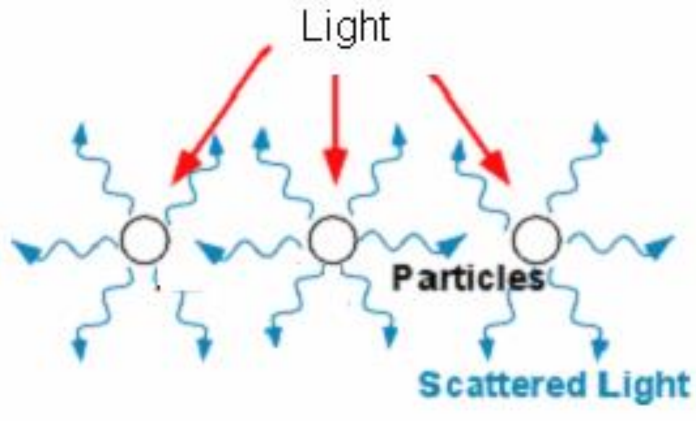

First window
Second window
Third window
Early 1970s
1980s
1990s
100
50
20
10
5.0
2.0
1.0
0.5
0.2
0.1
Attenuation (dB/km)
600
800
1000
1200
1400
1600
1800
Wavelength (nm)

Scattering

- Compositional fluctuation
- Structural inhomogneities
- Defects in manufacturing

Rayleigh Scatterring

- Caused due to Compositional fluctuationSiO_2,$Ge0_2$,P2O5
- fluctuations in refractive index due to density and compositional variations in the glass
- Rayleigh scattering is proportional to 1/λ4


Light
Particles
Scattered Light

inhomogeneties

- Introduced un intentionally during manufacturing
- Imperfect mixing and dissolution of chemicals
- Imperfect processing produces rough core cladding interface
- Scattering objects are larger than a wavelength
- These losses can be controlled by proper manufacturing techniques

- Single component class

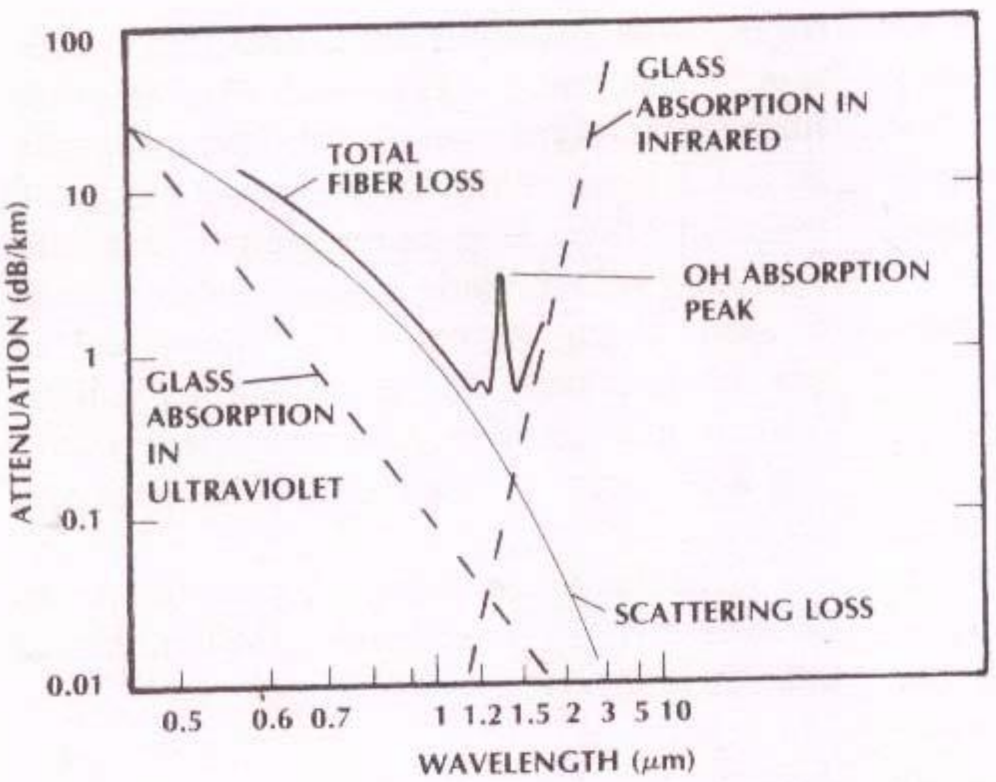
$$\alpha_{\text{scat}} = \frac{8\pi^3}{3\lambda^4}(n^2 - 1)^2 k_B T_f \beta_T$$

$$\alpha_{\text{scat}} = \frac{8\pi^3}{3\lambda^4} n^8 p^2 k_B T_f \beta_T$$

- Multicomponent class

$$\alpha = \frac{8\pi^3}{3\lambda^4}(\delta n^2)^2 \delta V$$

$$(\delta n^2)^2 = \left(\frac{\partial n}{\partial \rho}\right)^2 (\delta\rho)^2 + \sum_{i=1}^{m} \left(\frac{\partial n^2}{\partial C_i}\right)^2 (\delta C_i)^2$$



100
10
1
0.1
0.01
ATTENUATION (dB/km)
GLASS ABSORPTION IN INFRARED
TOTAL FIBER LOSS
OH ABSORPTION PEAK
GLASS ABSORPTION IN ULTRAVIOLET
SCATTERING LOSS
0.5
0.6 0.7
1 1.2 1.5 2 3 5 10
WAVELENGTH (μm)

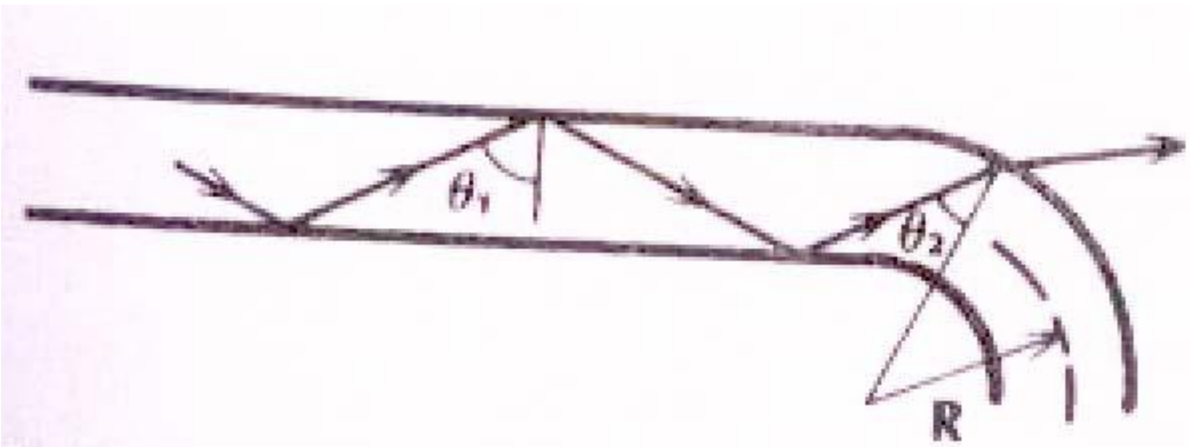
Bending loss

Two types of bends that cause attenuation

- Macroscopic
- Microscopic

Macroscopic Bends

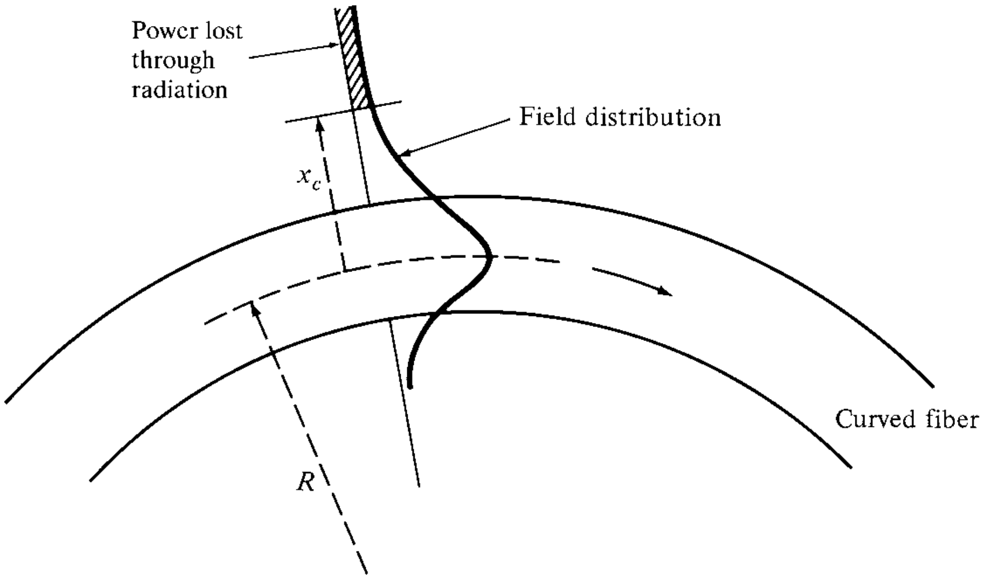
- Refers to large-scale bending
  E.g occurs intentionally when wrapping the fiber on a spool or pulling around a corner
- 125μm diameter fiber can be bent with radii of curvature 25 mm.
- The fiber will not fracture unless the bend radius is less than 10 mm
- The strength of fiber depends on the microscopic flaws, these flaws grows over time
- For commercial125μm fiber, minimum bend radius is 25mm



θ_1
θ_2
R

Bending Loss (Macrobending & Microbending)

- **Macrobending Loss**: The curvature of the bend is much larger than fiber diameter. Lightwave suffers sever loss due to radiation of the evanescent field in the cladding region. As the radius of the curvature decreases, the loss increases exponentially until it reaches at a certain critical radius. For any radius a bit smaller than this point, the losses suddenly becomes extremely large. Higher order modes radiate away faster than lower order modes.



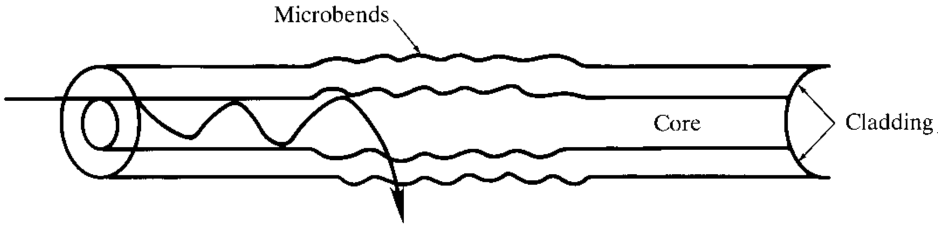
Optical Fiber communications, 3rd ed.,G.Keiser,McGrawHill, 2000

Microscopic bends

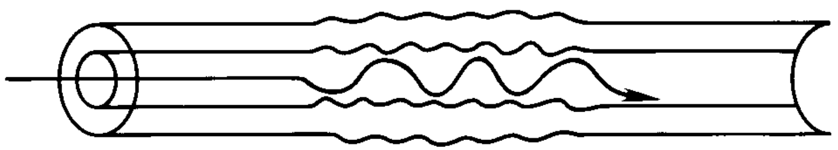
- Occurs when a fiber is sheathed within a protective cable
- The stresses set up during the cabling process cause small axial distortions (*microbends)*

Microbending Loss

- **Microbending Loss:** microscopic bends of the fiber axis that can arise when the fibers are incorporated into cables. The power is dissipated through the microbended fiber, because of the repetitive coupling of energy between guided modes & the leaky or radiation modes in the fiber.



Power loss from higher-order modes



Power coupling to higher-order modes

Optical Fiber communications, 3rd ed.,G.Keiser,McGrawHill, 2000

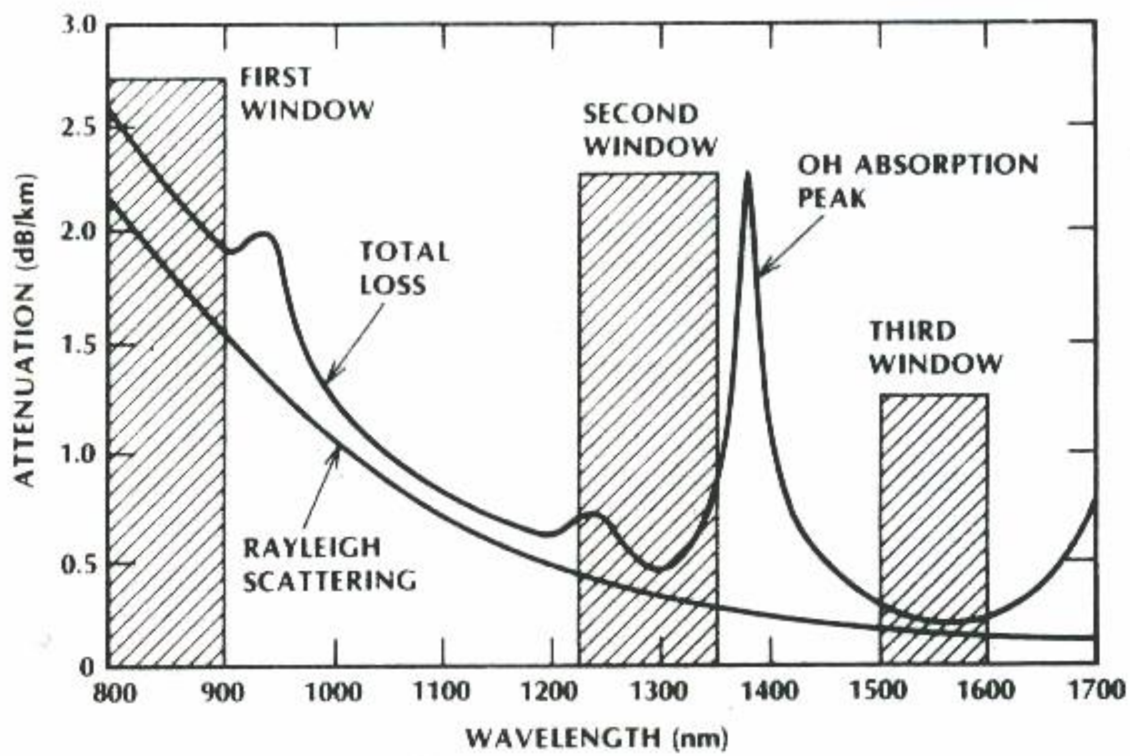
Microscopic bends

- Occurs when a fiber is sheathed within a protective cable
- The stresses set up during the cabling process cause small axial distortions (*microbends)*

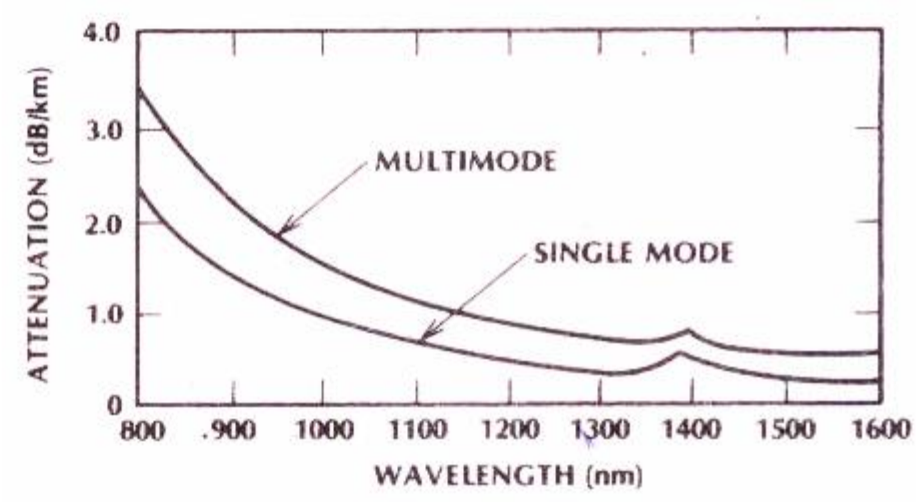
Total Attenuation

- Scattering and absorption combine to give total loss, or attenuation, which is the important number in communication systems
- Attenuation normally is measured in decibels per kilometer for communication fibers.

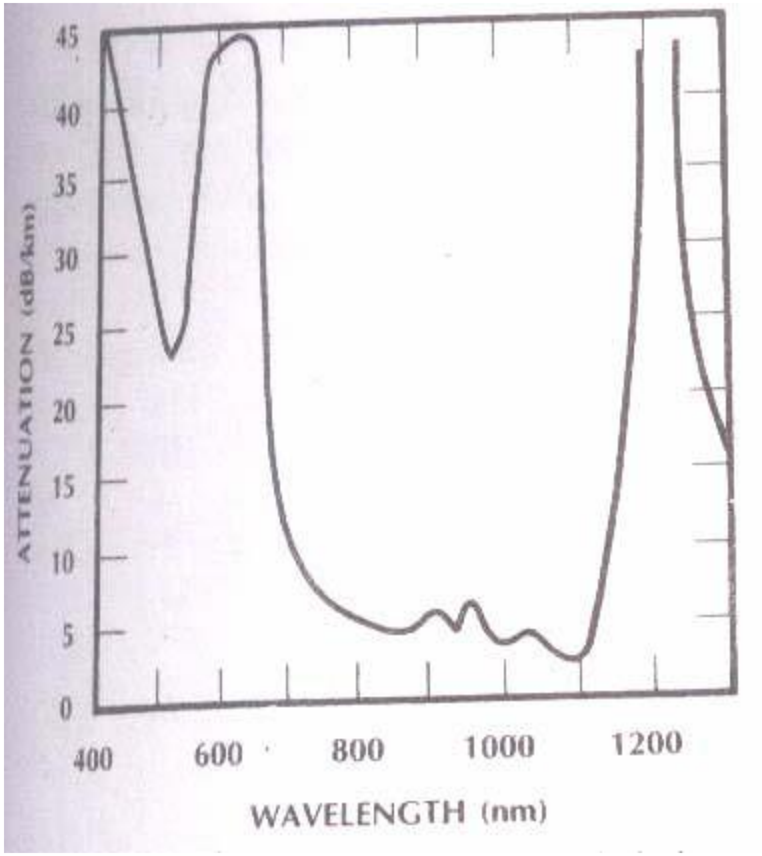
Total attenuation



Total attenuation

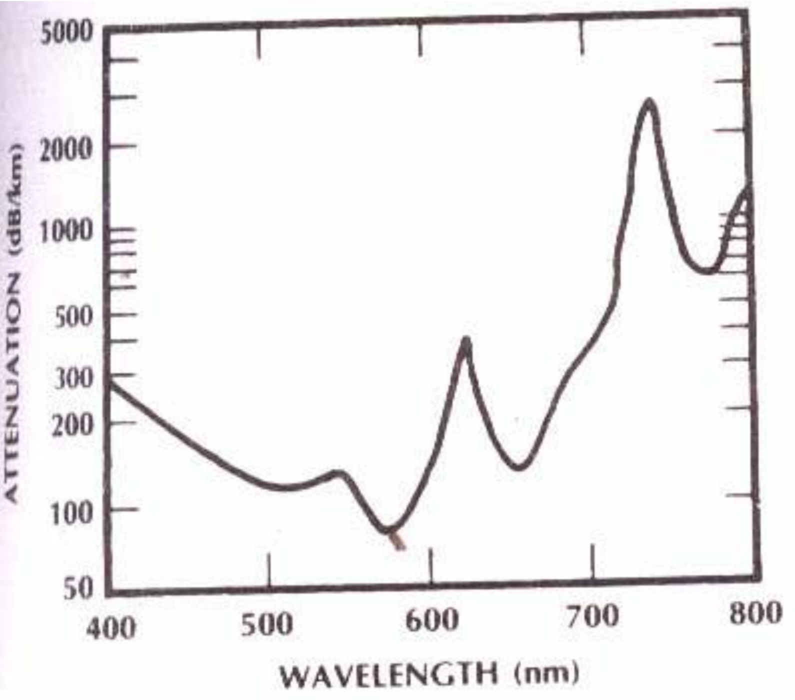


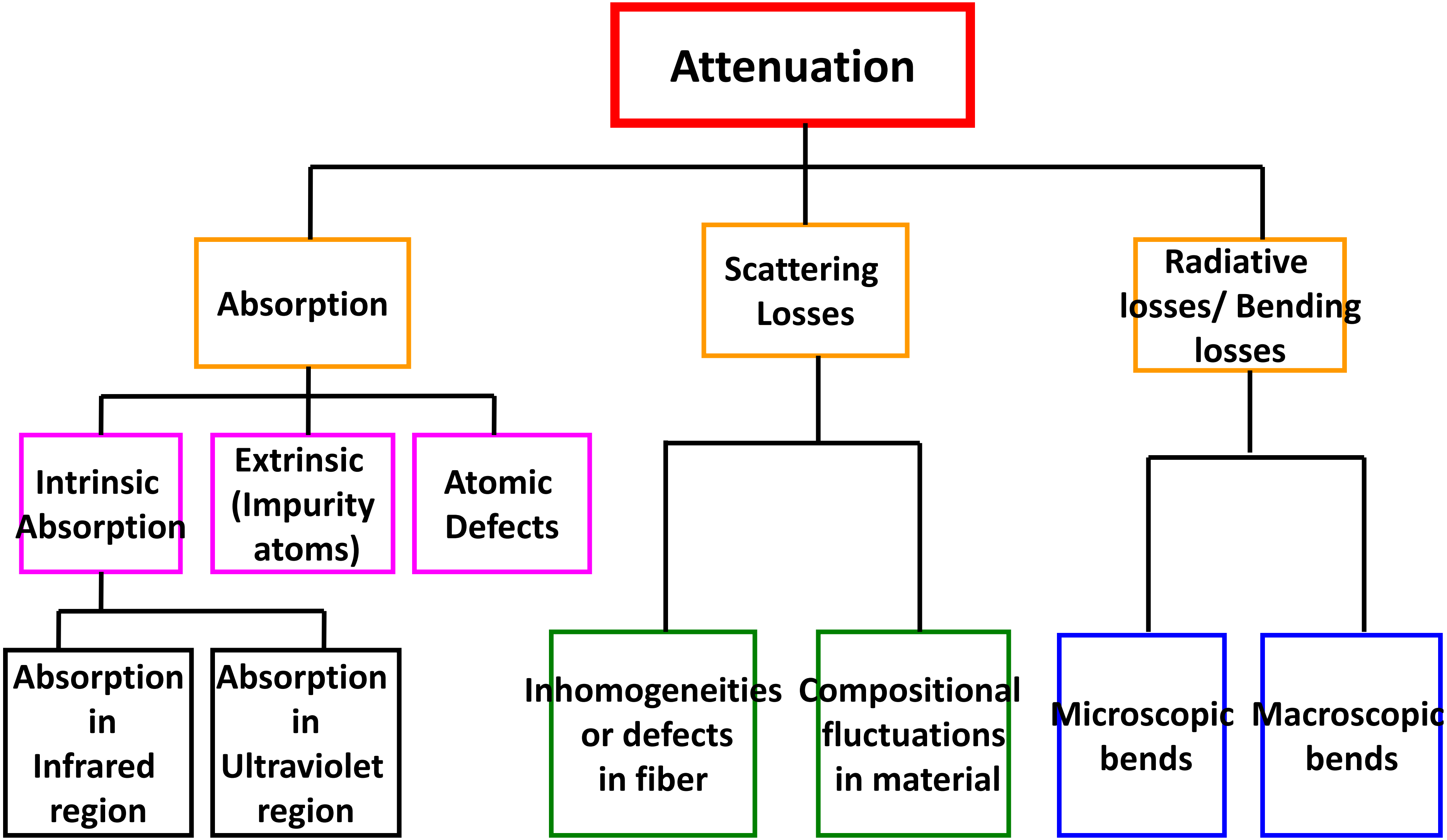
Total attenuation



Total attenuation

Spectral Attenuation for an all-plastic fiber cable




Attenuation
Absorption
Scattering Losses
Radiative losses/ Bending losses
Intrinsic Absorption
Extrinsic (Impurity atoms)
Atomic Defects
Absorption in Infrared region
Absorption in Ultraviolet region
Inhomogeneities or defects in fiber
Compositional fluctuations in material
Microscopic bends
Macroscopic bends