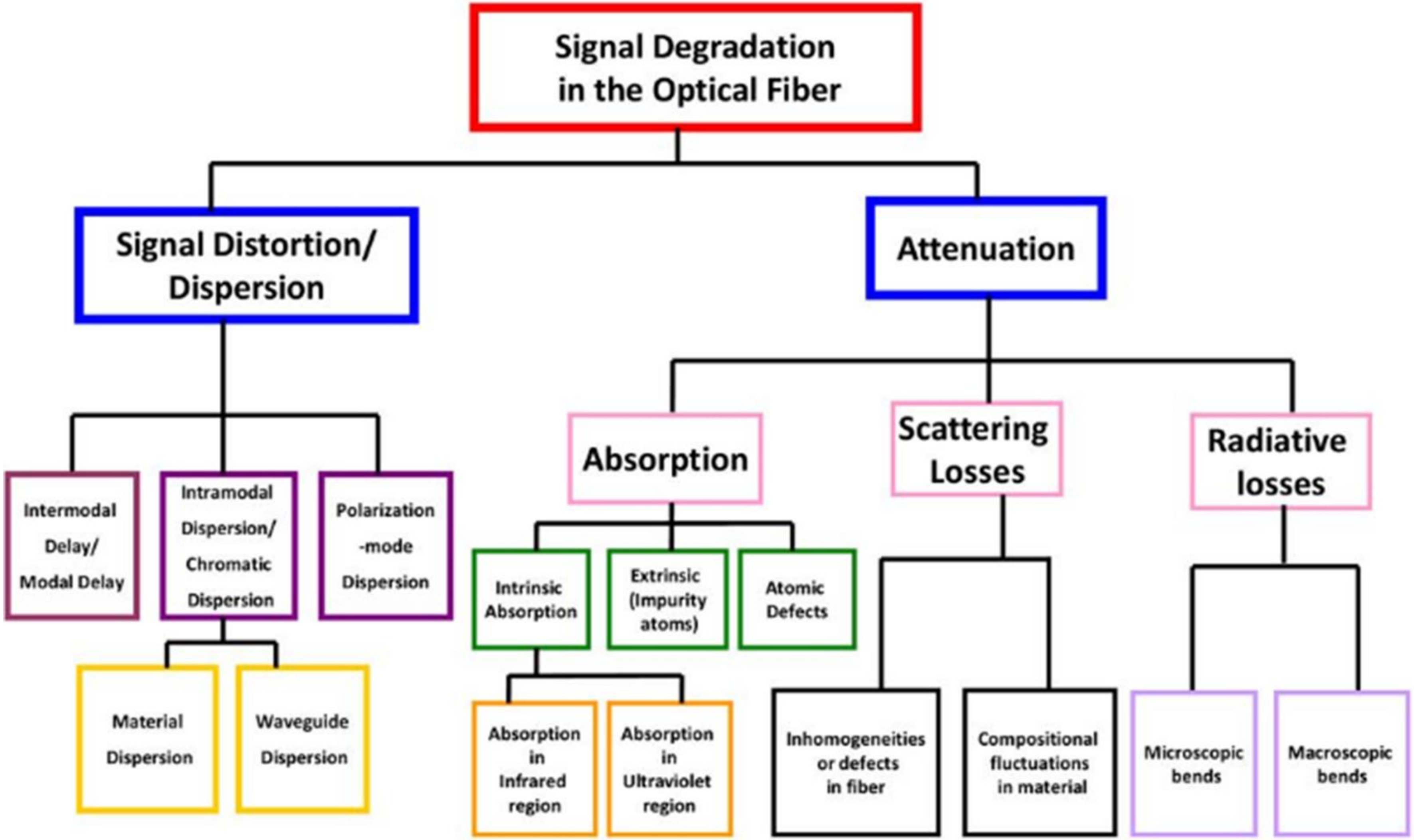
UNIT 2

TRANSMISSION CHARACTERISTICS OF OPTICAL FIBERS

(SIGNAL DEGRADATION IN OPTICAL FIBER)



Introduction

In previous Chapter we discussed the structure of optical fibers and examined the concepts of how light propagates along a cylindrical dielectric optical waveguide. Here, we shall continue the discussion of optical fibers by answering two very important questions:

1. **What are the loss or signal attenuation mechanisms in a fiber?**
2. **Why and to what degree do optical signals get distorted as they propagate along a fiber?**

- One of the important property of optical fiber is signal attenuation. It is also known as **fiber loss or signal loss.** The signal attenuation of fiber determines the maximum distance between transmitter and receiver. The attenuation also determines the number of repeaters required, maintaining repeater is a costly affair.
- Another important property of optical fiber is distortion mechanism. As the signal pulse travels along the fiber length it becomes more broader. After sufficient length the broad pulses starts overlapping with adjacent pulses. ***This creates error in the receiver. Hence the distortion limits the information carrying capacity of fiber.***

2.1Attenuation

- Attenuation is a measure **of decay of signal strength or loss of light power** that occurs as light pulses propagate through the length of the fiber.

- In optical fibers the attenuation is mainly caused by two physical factors **absorption and scattering losses.** Absorption is because of fiber material and whereas scattering is associated both with the fiber material and with structural imperfections in the optical waveguide. Nearly 90% of total attenuation is caused by **Rayleigh scattering only**. Micro-bending of optical fiber also contributes to the attenuation of signal.

- The rate at which light is absorbed is dependent on the **wavelength of the light and the characteristics of particular glass.** Glass is a silicon compound; by adding different additional chemicals to the basic silicon dioxide the optical properties of the glass can be changed.

- The Rayleigh scattering is wavelength dependent and **reduces rapidly as the wavelength of the incident radiation increases.**

- The attenuation of fiber is governed by the materials from which it is fabricated, the manufacturing process and the refractive index profile chosen. **Attenuation loss is measured in dB/km.**

2.1.1 Attenuation Units

As light travels along a fiber, **its power decreases exponentially with distance**. 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 farther down the fiber is**

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

where

$$\alpha_p = \frac{1}{z}\ln\left[\frac{P(0)}{P(z)}\right]$$

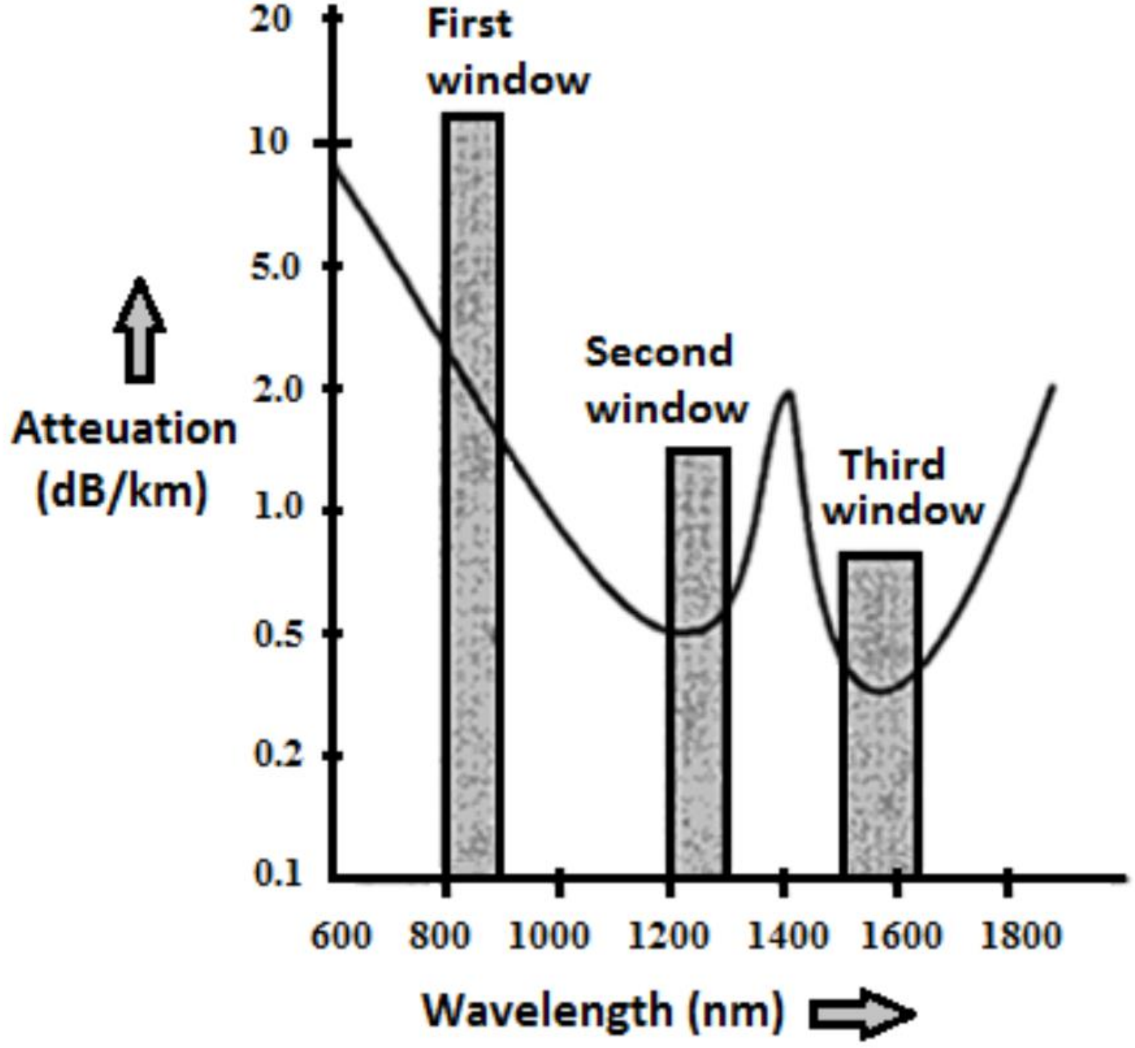
is the fiber attenuation coefficient given in units of, for example, km^{-1}. Note that the units for $2z\alpha_p$ can also be designated by **nepers**.

For simplicity in calculating optical signal attenuation in a fiber, the common procedure is to express the attenuation coefficient in units of decibels per kilometer, denoted by dB/km. Designating this parameter by α, we have

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

This parameter is generally referred to as the fiber loss or the fiber attenuation. It depends on several variables, as is shown in the following sections, and it is a function of the wavelength.

Figure shows the Optical fiber attenuation as a function of wavelength yields nominal values of 0.40 dB/km at 1310 nm and 0.25 dB/km at 1550 nm for standard single-mode fiber.



Fiber attenuation as a function of wavelength

Example 1 : A low loss fiber has average loss of 3 dB/km at 900 nm. Compute the length over which :–

a) Power decreases by 50 %   b) Power decreases by 75 %.

Solution : α = 3 dB/km

a) Power decreases by 50 %.

$$\Rightarrow \frac{p(0)}{p(z)} = 50\ \% = 0.5$$

α is given by,

$$\alpha = 10 . \frac{1}{z} \log \left[\frac{P(0)}{P(z)}\right]$$

$$3 = 10 . \frac{1}{z} \log [0.5]$$

z = 1 km ... Ans.

b)

$$\frac{P(0)}{P(z)} = 25\ \% = 0.25$$

Since power decrease by 75 %.

$$3 = 10 \times \frac{1}{z} \log[0.25]$$

Z = 2 km ………………… Ans.

Example 2.1.2 : *For a 30 km long fiber attenuation 0.8 dB/km at 1300 nm. If a 200 μwatt power is launched into the fiber, find the output power.*

Solution :

$$z = 30 \text{ km}$$

$$\alpha = 0.8 \text{ dB/km}$$

$$P(0) = 200 \ \mu W$$

Attenuation in optical fiber is given by,

$$\boxed{\alpha = 10 \times \frac{1}{z} \log\left[\frac{P(0)}{P(z)}\right]}$$

$$0.8 = 10 \times \frac{1}{30} \log\left[\frac{200 \ \mu W}{P(z)}\right]$$

$$2.4 = \log\left[\frac{200 \ \mu W}{P(z)}\right]$$

$$\frac{200 \ \mu W}{P(z)} = 10^{2.4}$$

$$\therefore \quad P(z) = \frac{200 \ \mu W}{251.1886} = \mathbf{0.7962 \ \mu W} \quad \text{... Ans.}$$

Example 2.1.3 : *When mean optical power launched into an 8 km length of fiber is 12 μW, the mean optical power at the fiber output is 3 μW.*

Determine -

1) Overall signal attenuation in dB.

2) The overall signal attenuation for a 10 km optical link using the same fiber with splices at 1 km intervals, each giving an attenuation of 1 dB.

Solution : Given : $z = 8$ km

$P(0) = 120\ \mu W$

$P(z) = 3\ \mu W$

1) Overall attenuation is given by,

$$\boxed{\alpha = 10 \cdot \log\left[\frac{P(0)}{P(z)}\right]}$$

$$\alpha = 10 \cdot \log\left(\frac{120}{3}\right)$$

$$\alpha = \mathbf{16.02\ dB}$$ ... **Ans.**

2) Overall attenuation for 10 km,

Attenuation per km $\alpha_{dB} = \frac{16.02}{z} = \frac{16.02}{8} = 2.00$ dB/km

Attenuation in 10 km link = 2.00 × 10 = 20 dB

In 10 km link there will be 9 splices at 1 km interval. Each splice introducing attenuation of 1 dB.

Total attenuation = 20 dB + 9 dB = **29 dB** ... **Ans.**

Example 2.1.5 : *Optical power launched into fiber at transmitter end is 150 μW. The power at the end of 10 km length of the link working in first window is – 38.2 dBm. Another system of same length working in second window is 47.5 μW. Same length system working in third window has 50 % of launched power. Calculate fiber attenuation for each case and mention wavelength of operation.*

Solution : Given data :

$$P(0) = 150\ \mu W$$

$$z = 10\ km$$

$$P(z) = -38.2\ dBm \Rightarrow \begin{cases} -38.2 = 10 \log \dfrac{P(z)}{1\ mW} \\ P(z) = 0.151\ \mu W \end{cases}$$

$$z = 10\ km$$

$$\boxed{\alpha = 10 \times \frac{1}{z} \log \left[\frac{P(0)}{P(z)}\right]}$$

Attenuation in 1st window :

$$\alpha_1 = 10 \times \frac{1}{10} \log \left[\frac{150}{0.151}\right]$$

$$\alpha_1 = \mathbf{2.99\ dB/km}$$

Attenuation in 2nd window :

$$\alpha_2 = 10 \times \frac{1}{10} \log \left[\frac{150}{47.5}\right]$$

$$\alpha_2 = \mathbf{0.49\ dB/km}$$

Attenuation in 3rd window :

$$\alpha_3 = 10 \times \frac{1}{10} \log \left[\frac{150}{75}\right]$$

$$\alpha_3 = \mathbf{0.30\ dB/km}$$

Wavelength in 1st window is 850 nm.

Wavelength in 2nd window is 1300 nm.

Wavelength in 3rd window is 1550 nm.

2.1.2 Absorption

- **Absorption loss** is related to the **material composition** and **fabrication process** of fiber. Absorption loss results in dissipation of some optical power as heat in the fiber cable. Although glass fibers are extremely pure, some impurities still remain as residue after purification. **The amount of absorption by these impurities depends on their concentration and light wavelength.**

Absorption in optical fiber is caused by these three mechanisms.

i. Absorption by **atomic defects** in the glass composition

ii. **Extrinsic absorption** by impurity atoms in the glass material

iii. Intrinsic absorption by the basic constituent atoms of the fiber material.

i- Absorption by Atomic Defects

- Atomic defects are **imperfections in the atomic structure** of the fiber materials such as missing **molecules, high density clusters of atom groups**. These absorption losses are negligible compared with intrinsic and extrinsic losses.
- The absorption effect is most significant when fiber is exposed to ionizing radiation in nuclear reactor, medical therapies, space missions etc. The radiation dames the internal structure of fiber. The damages are proportional to the intensity of ionizing particles. This results in increasing attenuation due to atomic defects and absorbing optical energy. The total dose a material receives is expressed in rad (Si), this is the unit for measuring radiation absorbed in bulk silicon

1 rad (Si) = 0.01 J.kg

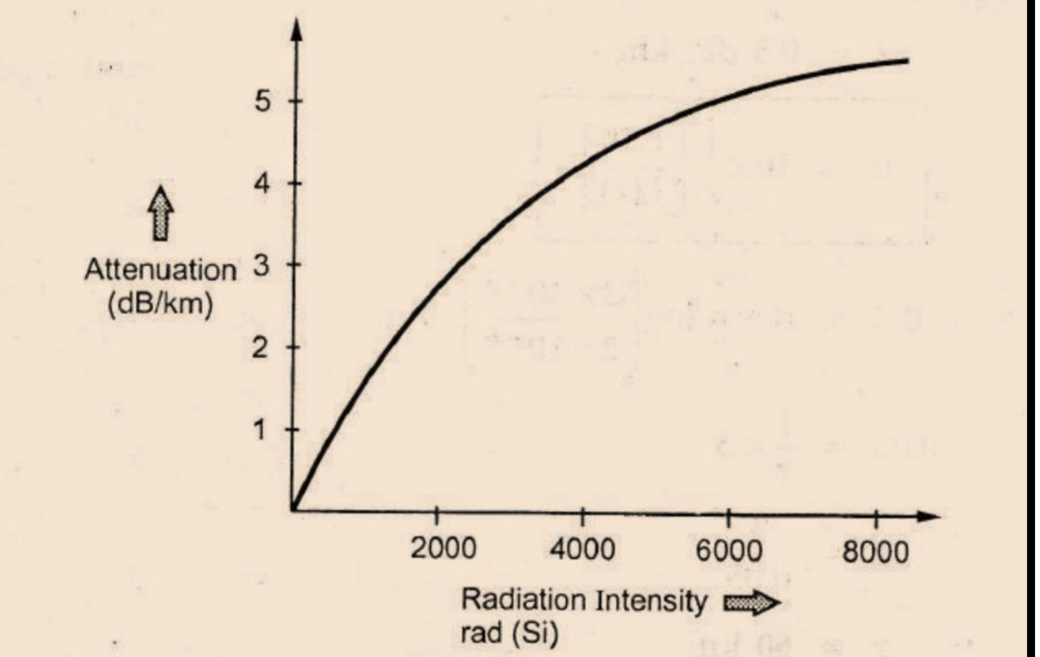


Fig. 2.2.1 Ionizing radiation intensity Vs fiber attenuation

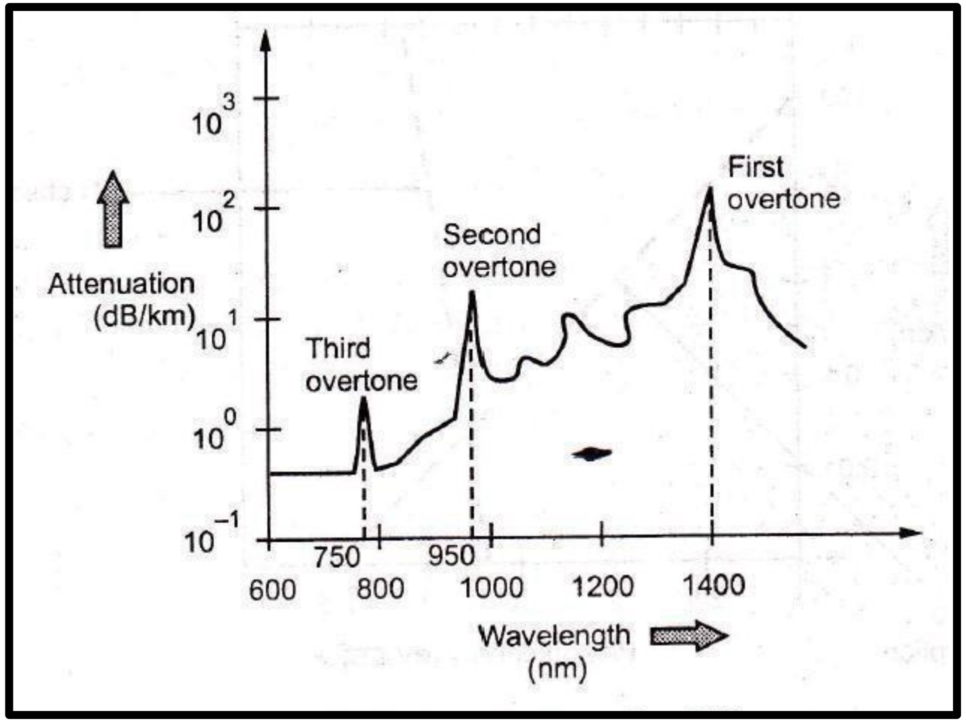
The higher the radiation intensity more the attenuation as shown in

ii- Extrinsic Absorption

- Extrinsic absorption occurs due to **electronic transitions between the energy level and because of charge transitions from one ion to another.** A major source of attenuation is from transition of metal impurity ions such as iron, chromium, cobalt and copper. These losses can be up to 1 to 10 dB/km. **The effect of metallic impurities can be reduced by glass refining techniques.**

- Another major extrinsic loss is caused by **absorption due to OH (Hydroxil) ions impurities dissolved in glass.** Vibrations occur at wavelengths **between 2.7 and 4.2 µm.** The absorption peaks occurs at 1400, 950 and 750 nm. These are first, second and third overtones respectively.

- Fig. shows absorption spectrum for OH group in silica. Between these absorption peaks there are regions of low attenuation.



iii- Intrinsic Absorption

- Intrinsic absorption occurs when material is in absolutely pure state, no density variation and inhomogeneities. Thus intrinsic absorption sets the fundamental lower limit on absorption for any particular material.

- Intrinsic absorption results from electronic absorption bands in UV region and from atomic vibration bands in the near infrared region.

- The electronic absorption bands are associated with the band gaps of amorphous glass materials. Absorption occurs when a photon interacts with an electron in the valence band and excites it to a higher energy level. UV absorption decays exponentially with increasing wavelength (λ).

- In particular, the ultraviolet loss contribution in dB/km at any wave length (given in mm) can be expressed empirically (derived from observation or experiment) as a function of the mole fraction x of GeO_2 as

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

λ is operating wavelength.

α_{uv} is in dB/km.

- In the IR (infrared) region above 1.2 μm the optical waveguide loss is determined by presence of the OH ions and inherent IR absorption of the constituent materials. The inherent IR absorption is due to interaction between the vibrating band and the electromagnetic field of optical signal this results in transfer of energy from field to the band, thereby giving rise to absorption, this absorption is strong because of many bonds present in the fiber.

An empirical expression for the infrared absorption in dB/km for GeO2-SiO2 glass with λ given in μm is

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

Example Consider two silica fibers that are doped with 6 percent and 18 percent mole fractions of GeO_2, respectively. Compare the ultraviolet absorptions at wavelengths of 0.7 μm and 1.3 μm.

Solution: for the ultraviolet absorption, we have the following:

(*a*) For the fiber with $x = 0.06$ and $\lambda = 0.7$ μm

$$\alpha_{uv} = \frac{1.542(0.06)}{46.6(0.06) + 60} \exp\left(\frac{4.63}{0.7}\right) = 1.10 \text{ dB/km}$$

(*b*) For the fiber with $x = 0.06$ and $\lambda = 1.3$ μm

$$\alpha_{uv} = \frac{1.542(0.06)}{46.6(0.06) + 60} \exp\left(\frac{4.63}{1.3}\right) = 0.07 \text{dB/km}$$

(*c*) For the fiber with $x = 0.18$ and $\lambda = 0.7$ μm

$$\alpha_{uv} = \frac{1.542(0.18)}{46.6(0.18) + 60} \exp\left(\frac{4.63}{0.7}\right) = 3.03 \text{ dB/km}$$

(*d*) For the fiber with $x = 0.18$ and $\lambda = 1.3$ μm

$$\alpha_{uv} = \frac{1.542(0.18)}{46.6(0.18) + 60} \exp\left(\frac{4.63}{1.3}\right) = 0.19 \text{ dB/km}$$