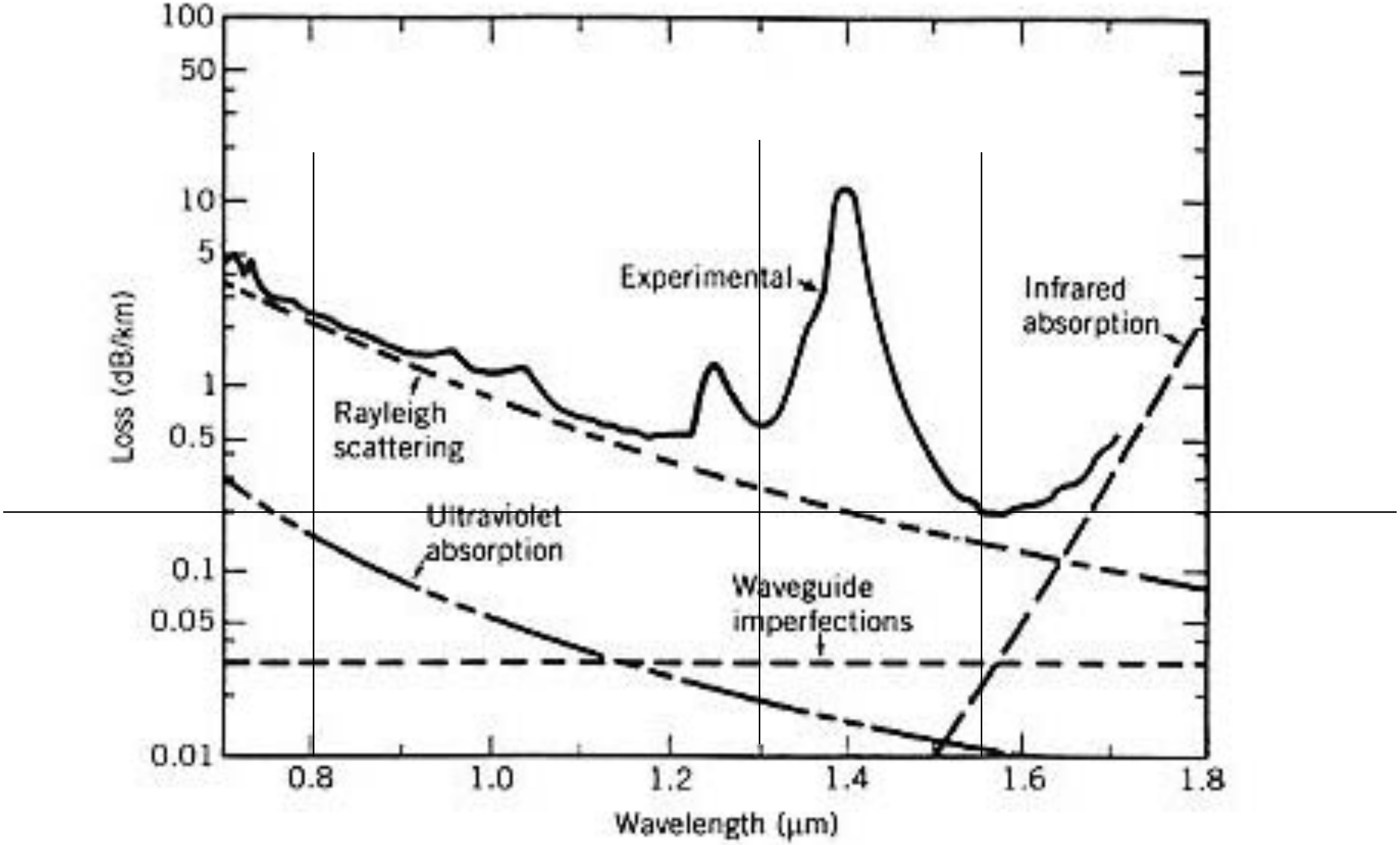
Attenuation and Loss Budgets

Attenuation



Behavior and Units

$$\frac{dP}{dz} = -\alpha P$$

α = attenuation coeff
P = optical power

$$P_{out} = P_{in}\, exp(-\alpha L)$$

- $a_{(dB/km)} = (-10/L)\, log_{10}(P_{out}/P_{in}) = 4.343\ \alpha$
- $a \equiv$ *“fiber loss”*

Optical Transmission: Limiting Factors

- **Dispersion: pulse broadening**
- **Attenuation: loss**

Power loss ultimately determines max distance

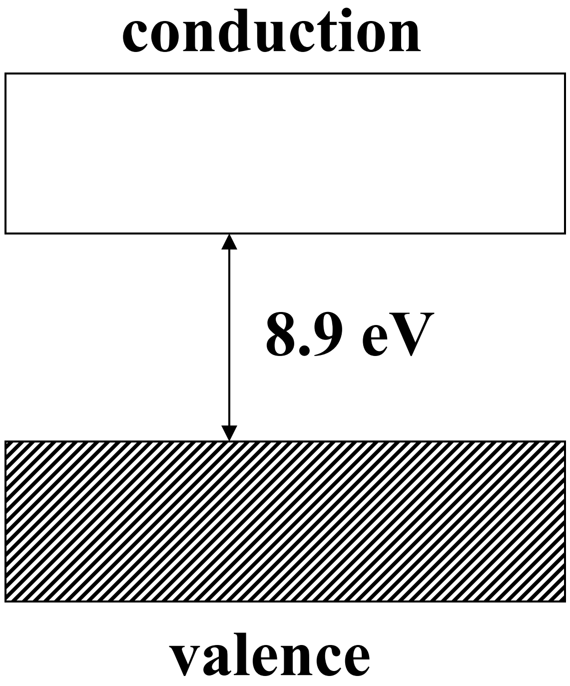
Attenuation

- **Material Absorption**
- **Rayleigh Scattering**
- **Waveguide Imperfections**

Material Absorption

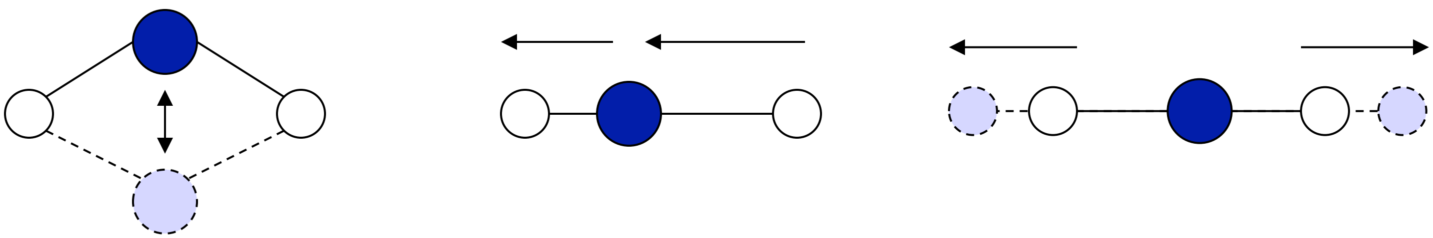
- Electronic Transitions
- Vibrational Transitions
- Impurities

Electronic Transitions



Material	E_{gap} (eV)	λ_{min}(μm)
PbS	0.37	3.34
GaAs	1.42	0.87
Si	1.12	1.10
Ge	0.67	1.85
InAs	0.35	3.54
Diamond	5.5	0.23
SiO_2	8.9	0.14

Vibrational Transitions



Bending **A. Stretch** **S. Stretch**

- Fundamental = 40 THz → 9 μm
- Overtones = 3.2, 3.8, and 4.4 μm

with tails far from resonance

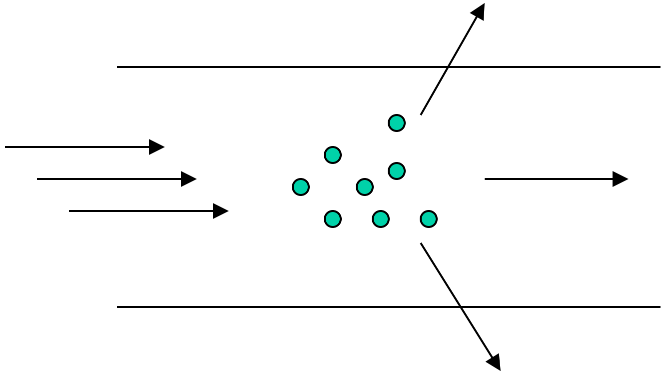
Impurities

- Fe, Cu, Co, Ni, Mn, Cr: 0.6 - 1.6 micron, 1 dB/km when < 1 ppb
- OH: 50 dB/km at 1390 nm when < 1 ppm

  < 10 dB/km when < 10 ppb
- GeO_2, P_2O_5, B_2O_3

Rayleigh Scattering

- **Density fluctuations**
- **Dominant at short wavelengths**
- **Solution: Use long wavelengths**
- **But: large IR loss in SiO_2**
- **Solution: ZBLAN**



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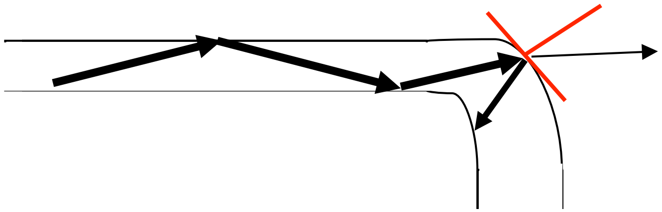
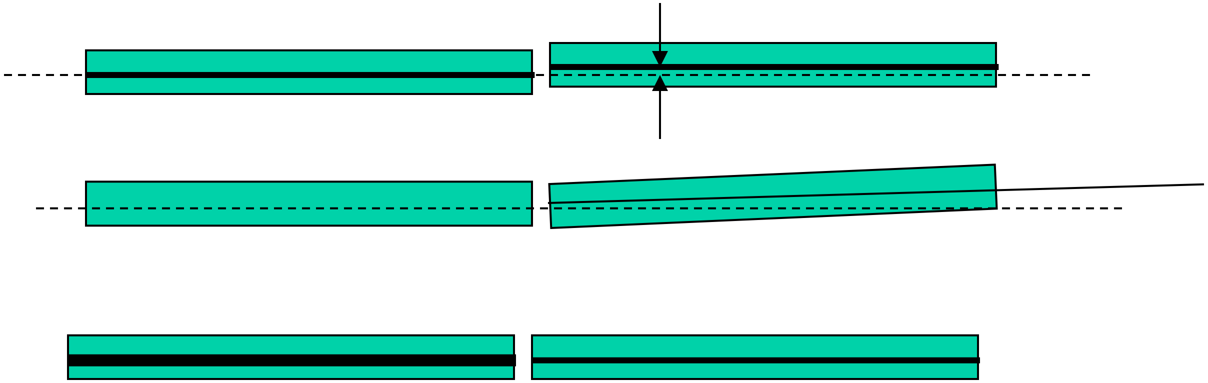
Waveguide Imperfections

- **Mie scattering** - **Density fluctuations and random variations in WG dimensions of ~ λ and longer**
- **Macrobends** - **Bending loss chracterized by R_c (critical bend radius), < 0.01 dB/km for radii > 5 mm**
- **Microbends** - **Random axial distortions when pressed against rough surface, up to 100 dB/km if not careful, use V close to singlemode cutoff for tight mode confinement**



Coupling Losses

- Longitudinal
- Lateral misalignment
- Angular misalignment
- Mode field mismatch



Mode Field Mismatch

- Coupling different types of fiber such as between transmission fiber and EDFA
- Laser diode mode does not match the fiber propagation mode shape: edge emitting lasers vs VCELs (easier to match with VCSELs)
- Fiber output needs to be coupled to the photodiode

Coupling Losses

- **mode field mismatch**

  $a_{mfd} = -20 \log\{(2\, w_1 w_2)/(w_1^2 + w_2^2)\}$

- **lateral misalignment**

  $a_{transverse} = 4.34\,(u/w);\ w_1 = w_2$

- **angular misalignment**

  $a_{angular} = 4.34\,(\pi n w \theta/\lambda)^2$

  θ in radians

  n is index of intervening medium

- **longitudinal misalignment**

  $a_{gap} = 10 \log(1+D^2)$

  $D = D_{gap}\lambda/(2\pi n w^2)$

ECCE Physics

Example 1: Power Budget

- A 1.3 μm lightwave system uses a 50 km fiber link and requires 0.3 μW at the receiver. The fiber loss is 0.5 dB/km. Fiber is spliced every 5 km and has two connectors of 1-dB loss at both ends. Splice loss is only 0.2 dB. Determine the minimum power that must be launched in the fiber.

Example 2: Power Budget

- A 1.3 μm lightwave system is based on a fiber link with 0.5 dB/km loss.
- LED 1.59 mW output with a 16 dB coupling loss
- Connector and splice losses ~ 6 dB total
- PD minimum power required = -30 dBm to meet specified bit error rate (BER of 10^{-9} typical)
- Assume 4 dB loss margin (e.g. LED aging, fiber degradation)