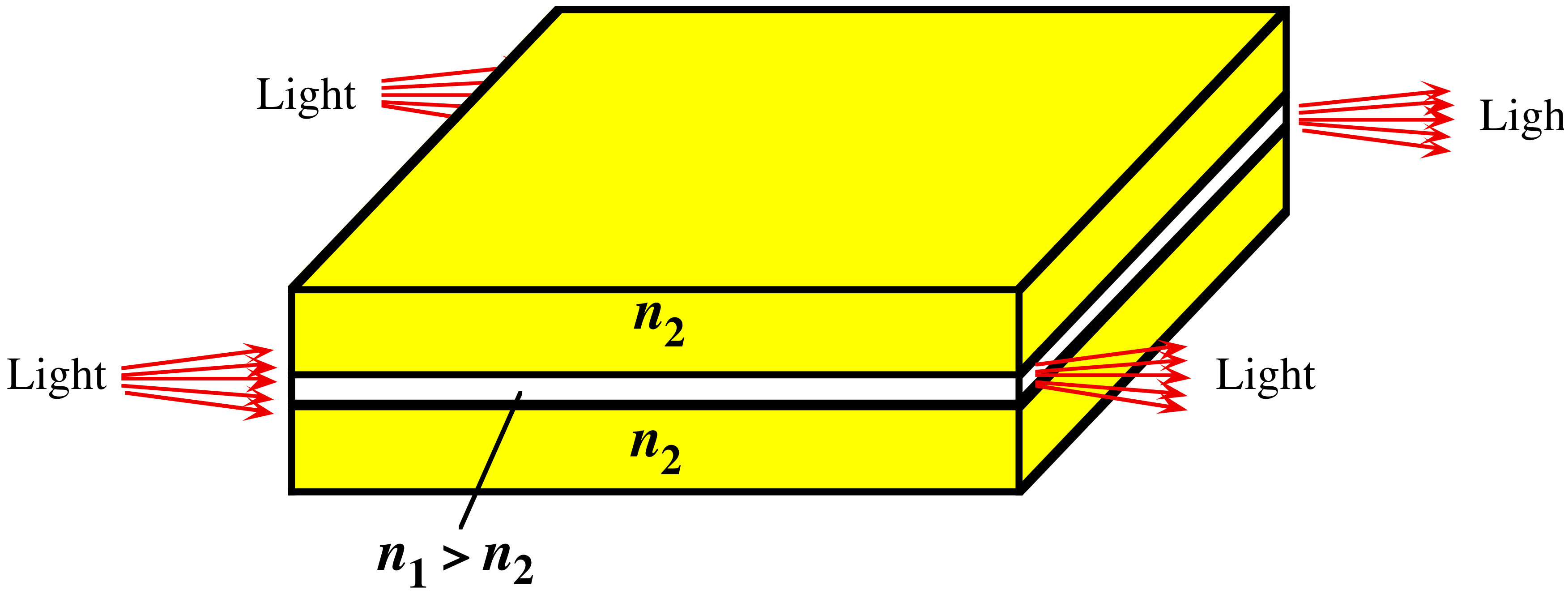
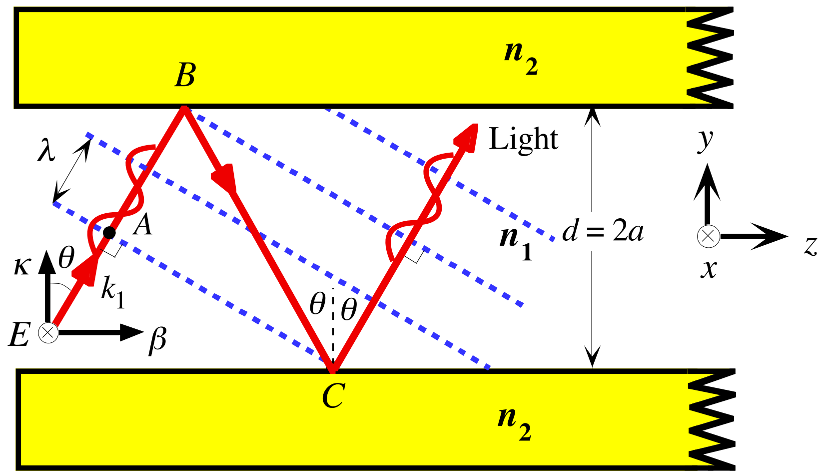
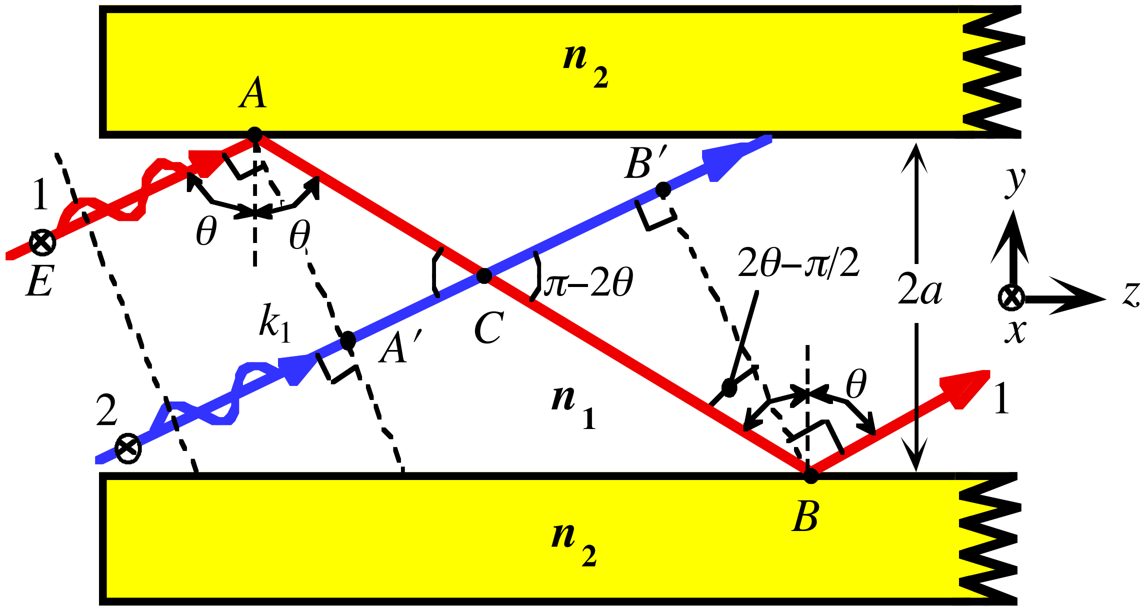


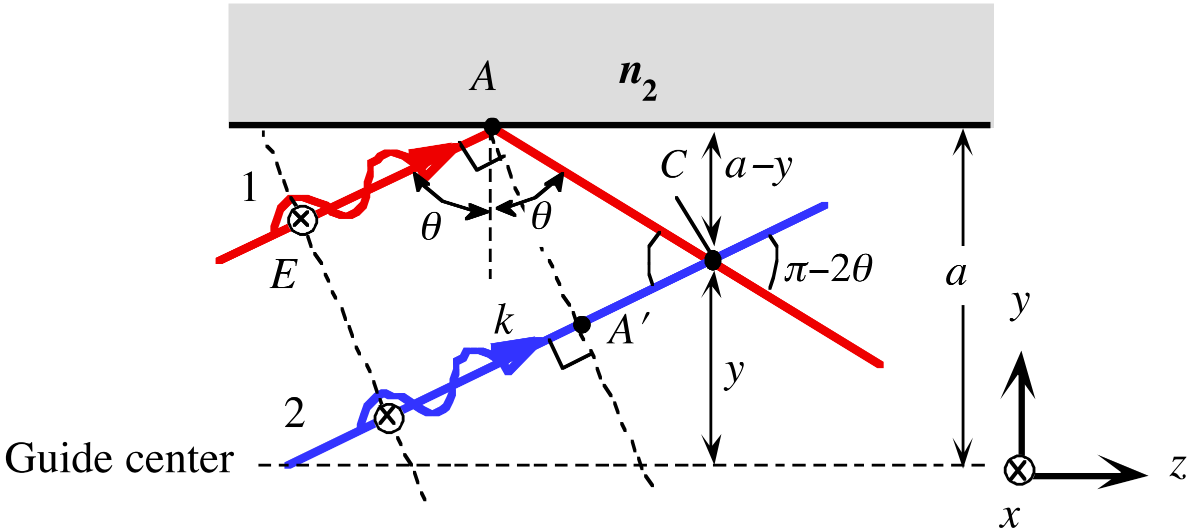
A planar dielectric waveguide has a central rectangular region of higher refractive index n_1 than the surrounding region which has a refractive index n_2. It is assumed that the waveguide is infinitely wide and the central region is of thickness $2a$. It is illuminated at one end by a monochromatic light source.



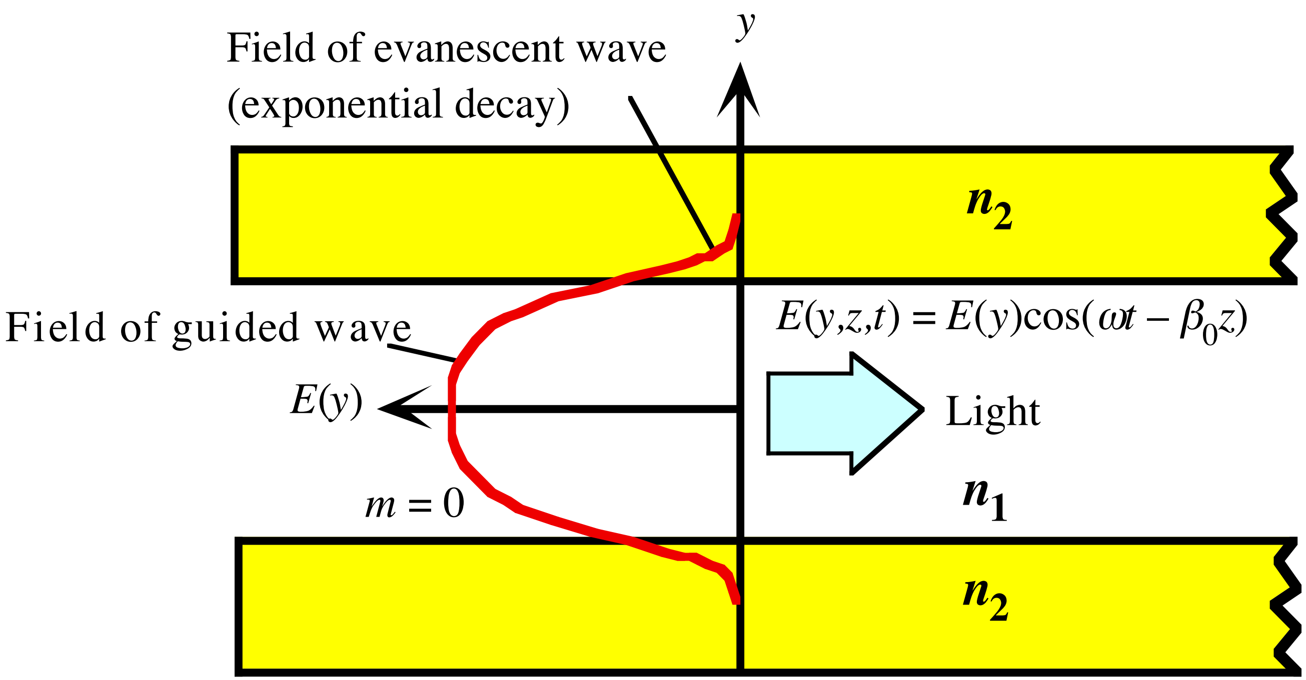
A light ray travelling in the guide must interfere constructively with itself to propagate successfully. Otherwise destructive interference will destroy the wave.



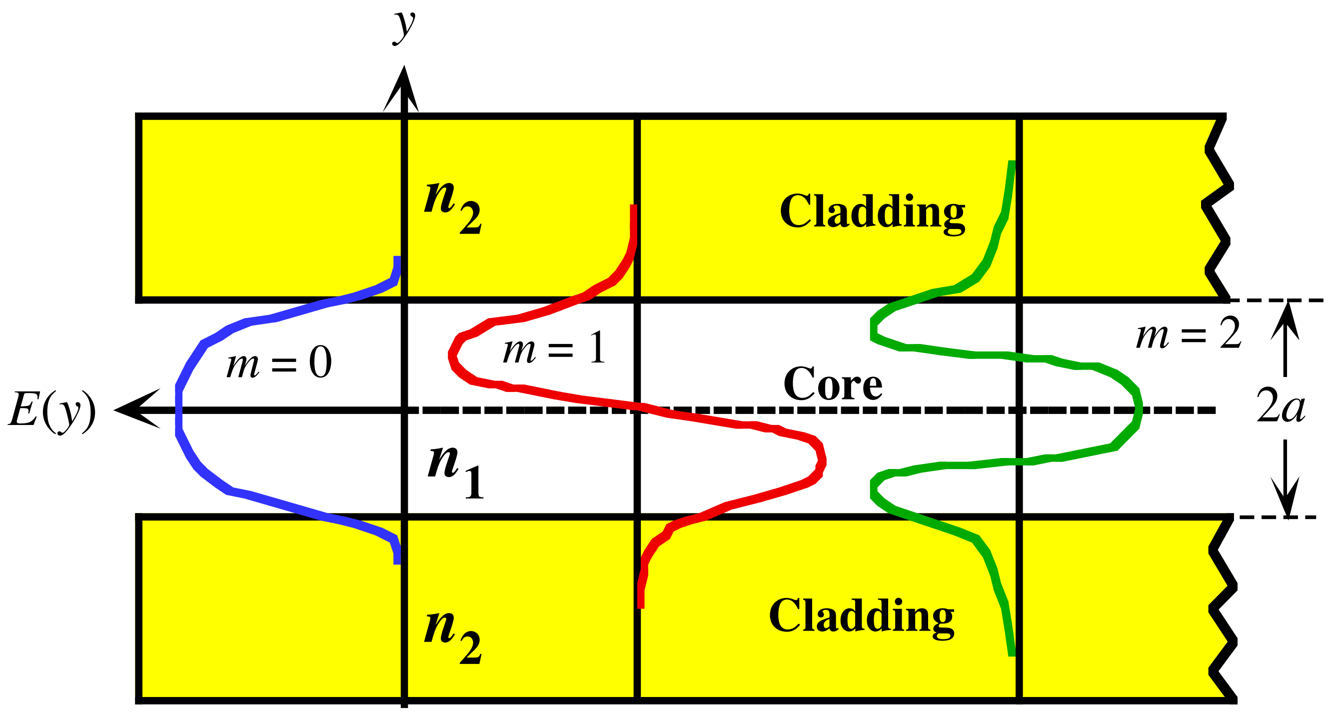
Two arbitrary waves 1 and 2 that are initially in phase must remain in phase after reflections. Otherwise the two will interfere destructively and cancel each other.



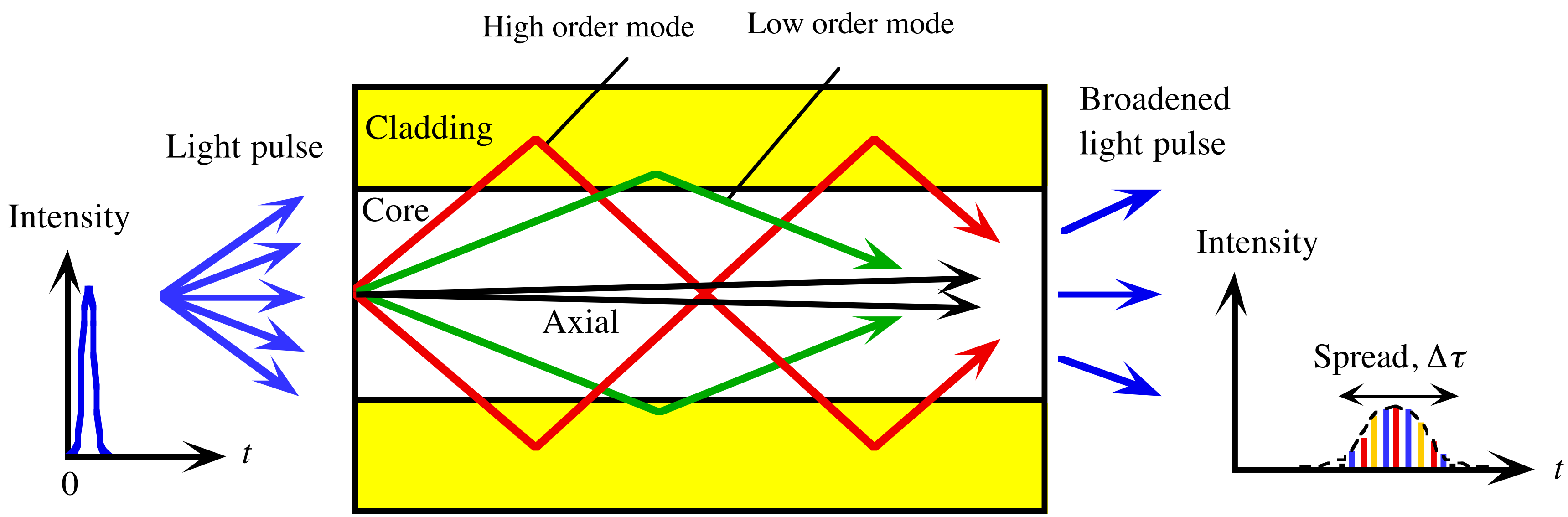
Interference of waves such as 1 and 2 leads to a standing wave pattern along the *y*-direction which propagates along *z*.



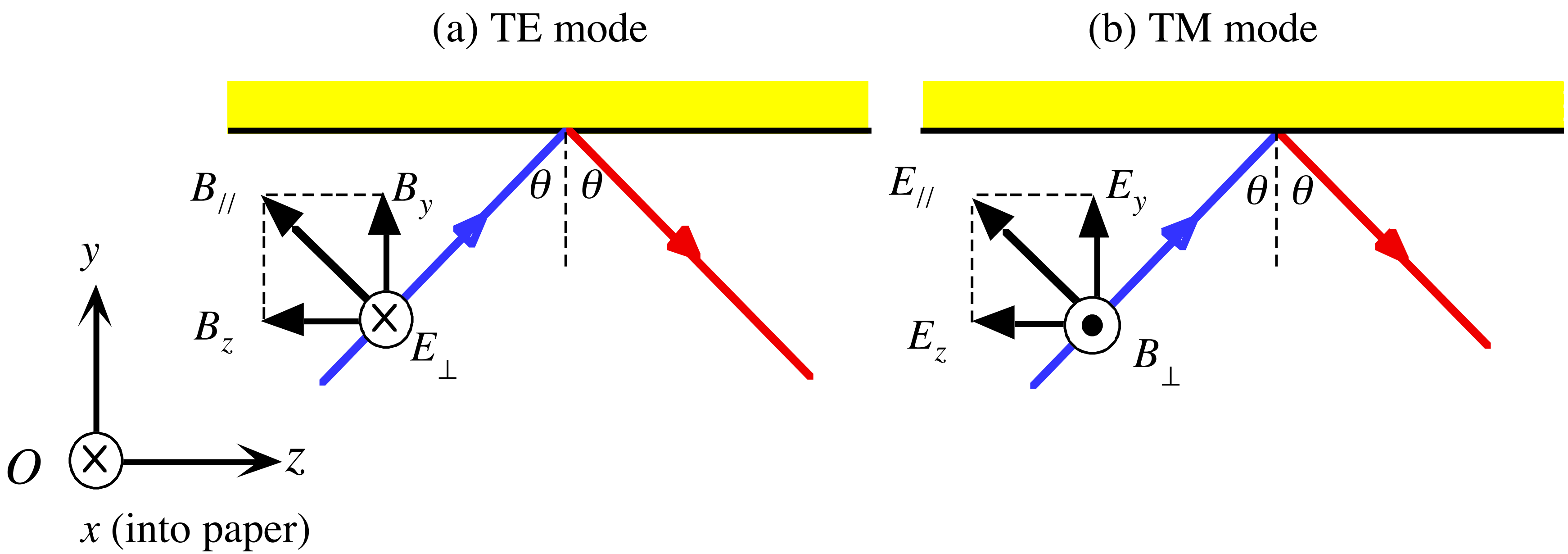
The electric field pattern of the lowest mode traveling wave along the guide. This mode has $m = 0$ and the lowest θ. It is often referred to as the glazing incidence ray. It has the highest phase velocity along the guide.



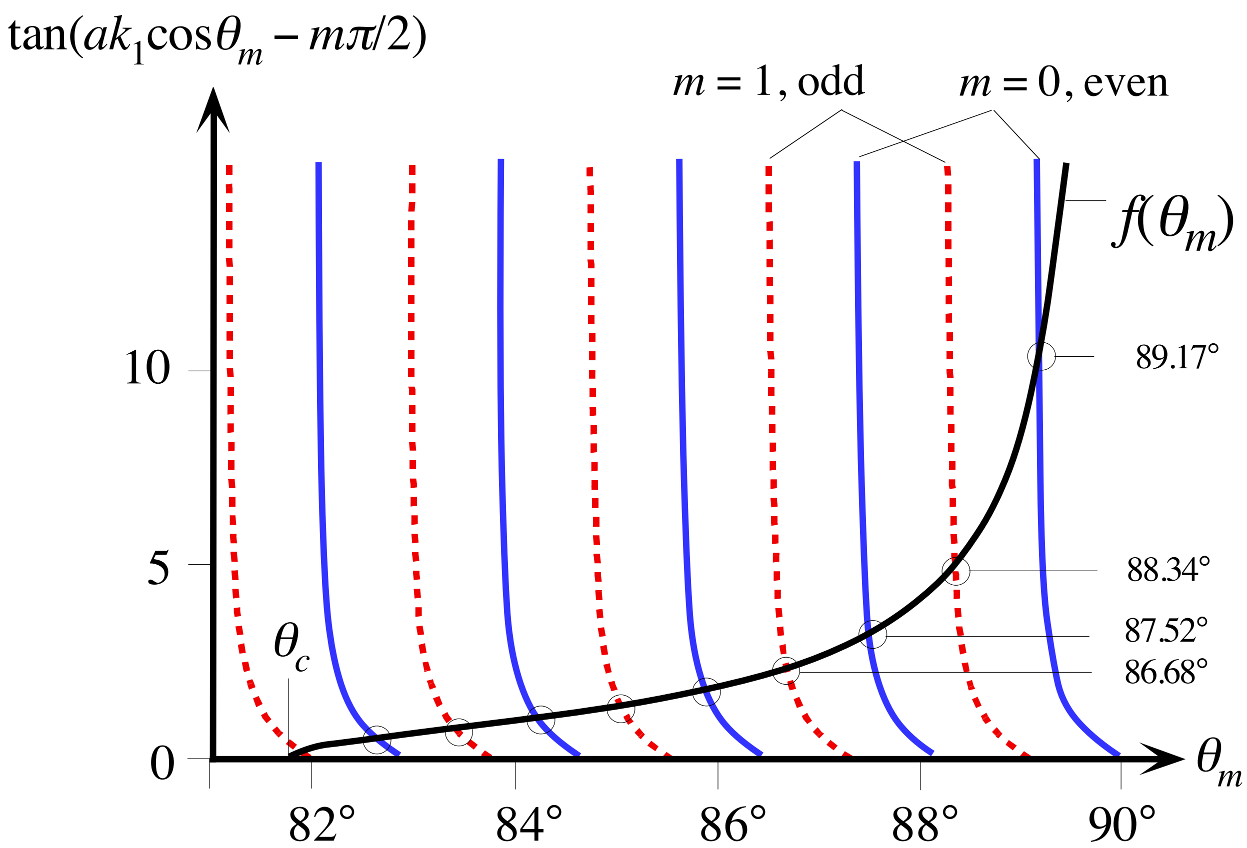
The electric field patterns of the first three modes ($m = 0, 1, 2$) traveling wave along the guide. Notice different extents of field penetration into the cladding.



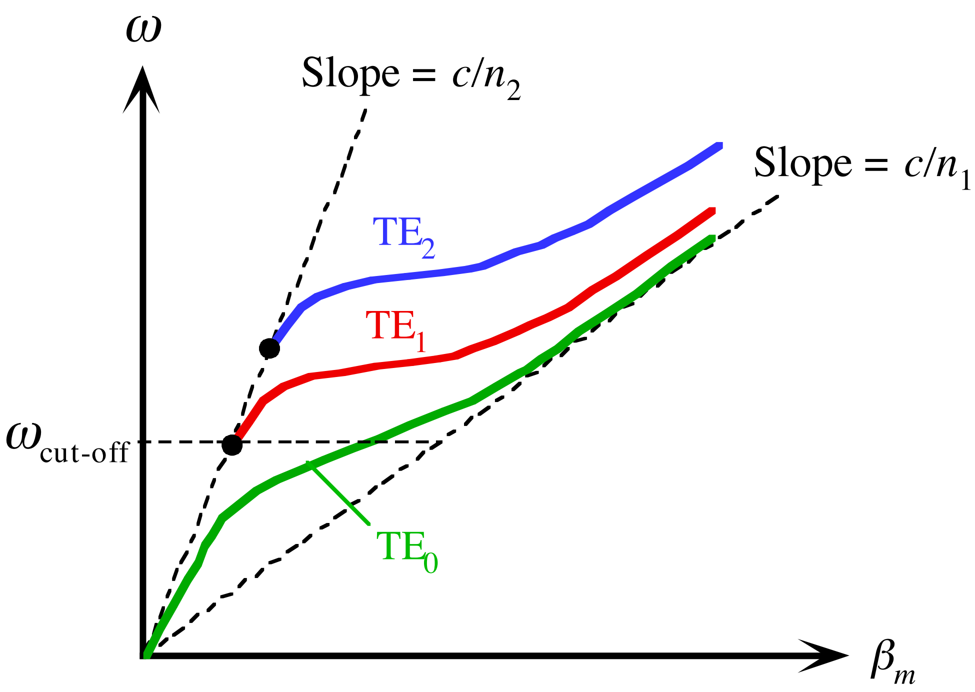
Schematic illustration of light propagation in a slab dielectric waveguide. Light pulse entering the waveguide breaks up into various modes which then propagate at different group velocities down the guide. At the end of the guide, the modes combine to constitute the output light pulse which is broader than the input light pulse.



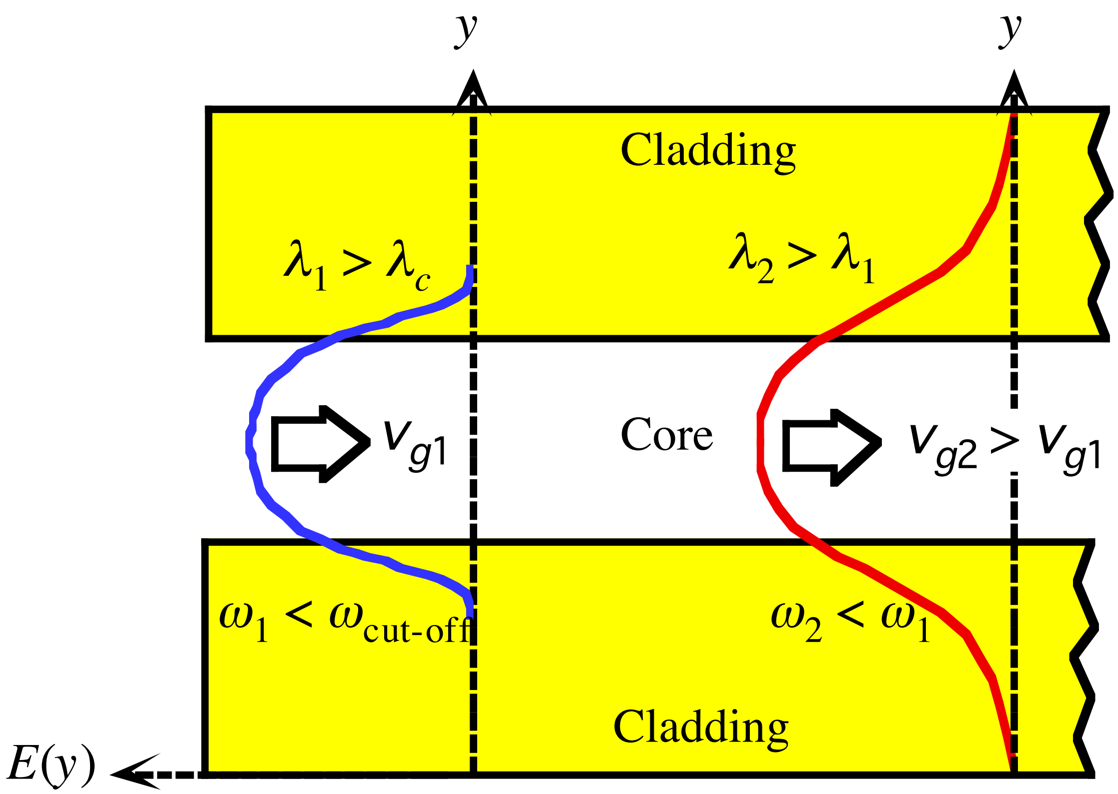
Possible modes can be classified in terms of (a) transelectric field (TE) and (b) transmagnetic field (TM). Plane of incidence is the paper.



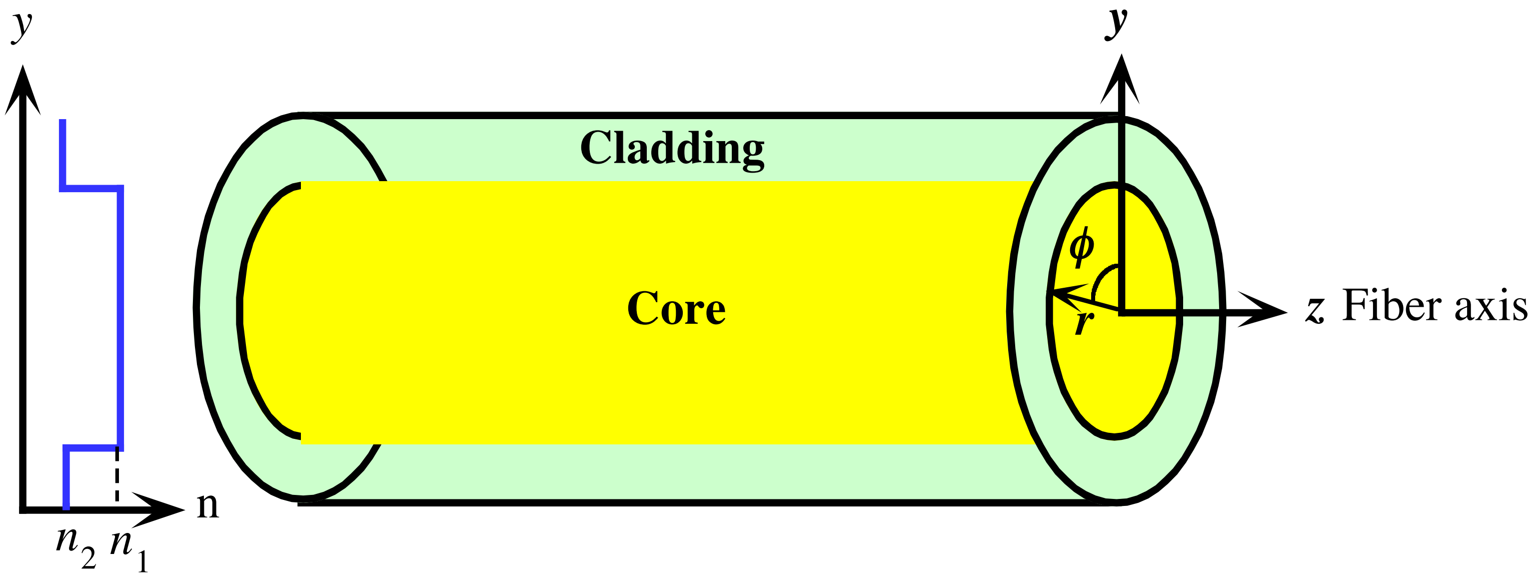
Modes in a planar dielectric waveguide can be determined by plotting the LHS and the RHS of eq. (11).



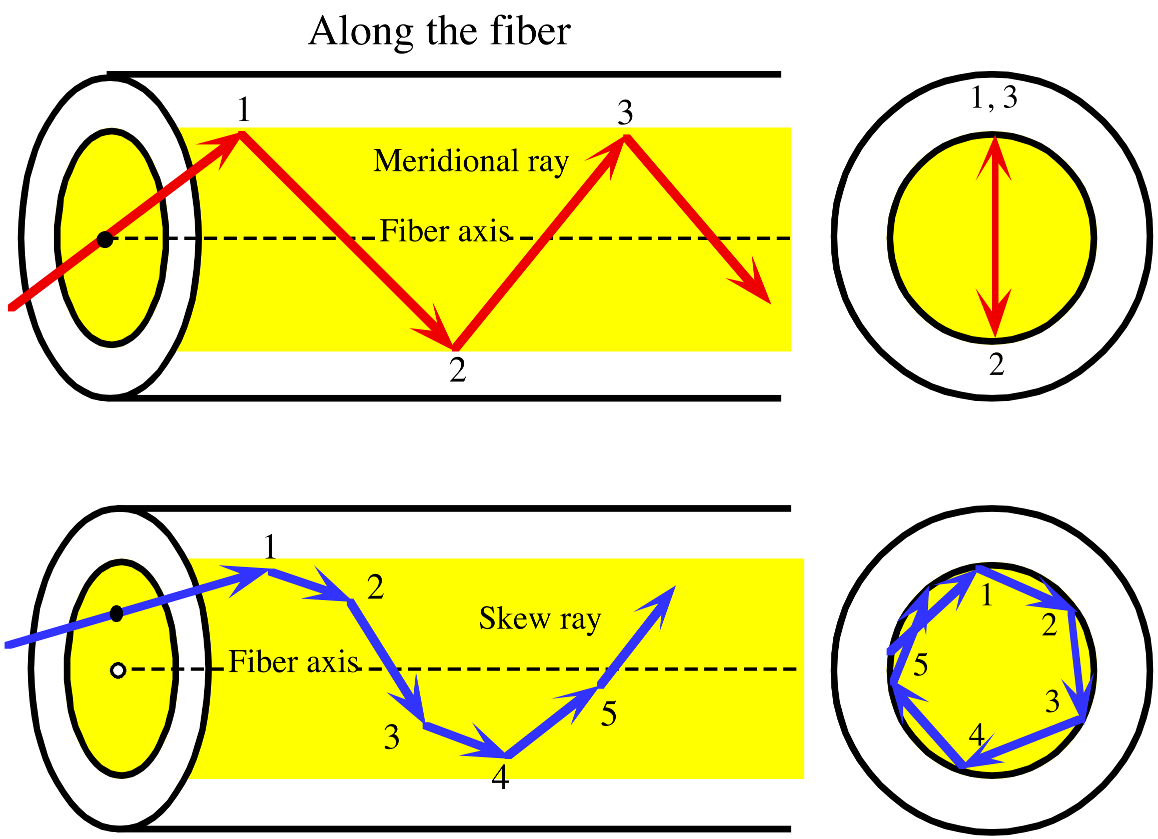
Schematic dispersion diagram, ω vs. β for the slab waveguide for various TE $_m$. modes. $\omega_{cut-off}$ corresponds to $V = \pi/2$. The group velocity v_g at any ω is the slope of the ω vs. β curve at that frequency.



The electric field of TE_0 mode extends more into the cladding as the wavelength increases. As more of the field is carried by the cladding, the group velocity increases.



The step index optical fiber. The central region, the core, has greater refractive index than the outer region, the cladding. The fiber has cylindrical symmetry. W use the coordinates r, ϕ, z to represent any point in the fiber. Cladding is normally much thicker than shown.



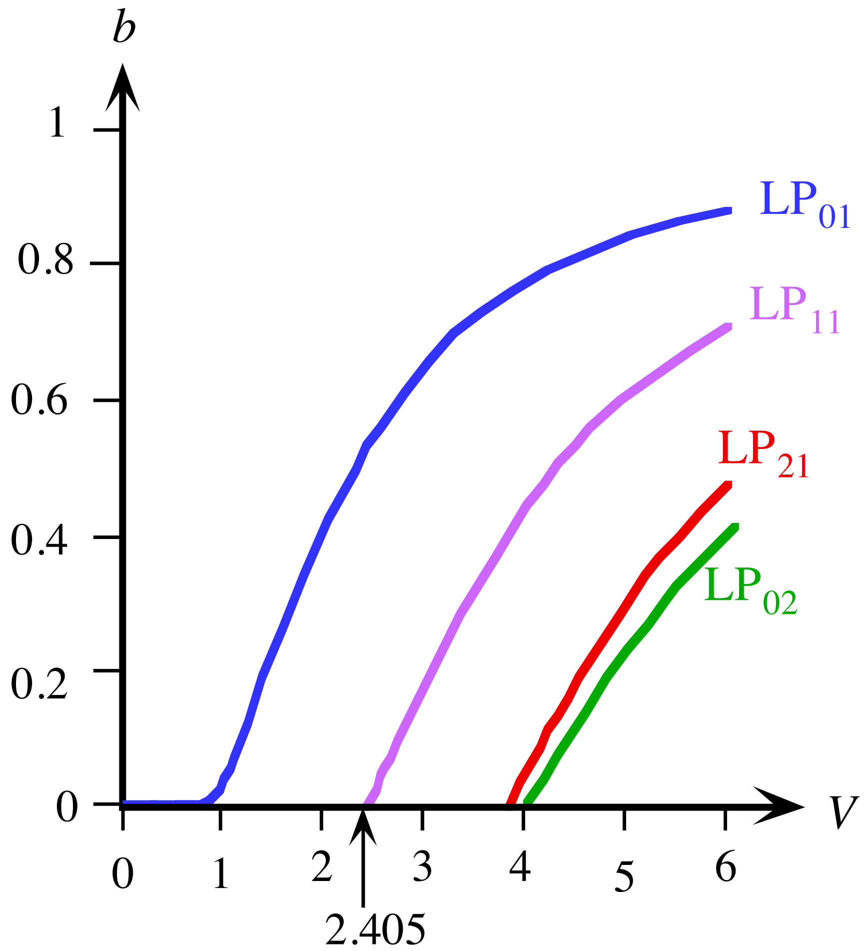
(a) A meridiona
ray always
crosses the fibe
axis.

(b) A skew ray
does not have
to cross the
fiber axis. It
zigzags around
the fiber axis.

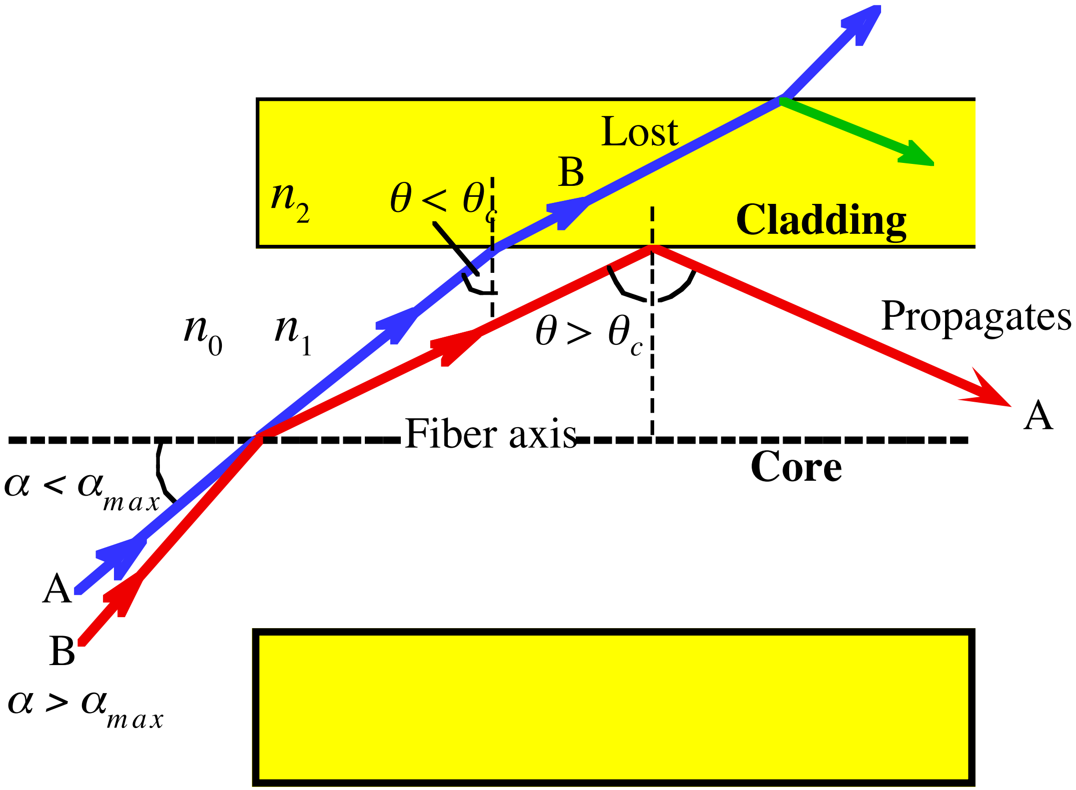
Ray path along the fiber

Ray path projected
on to a plane normal
to fiber axis

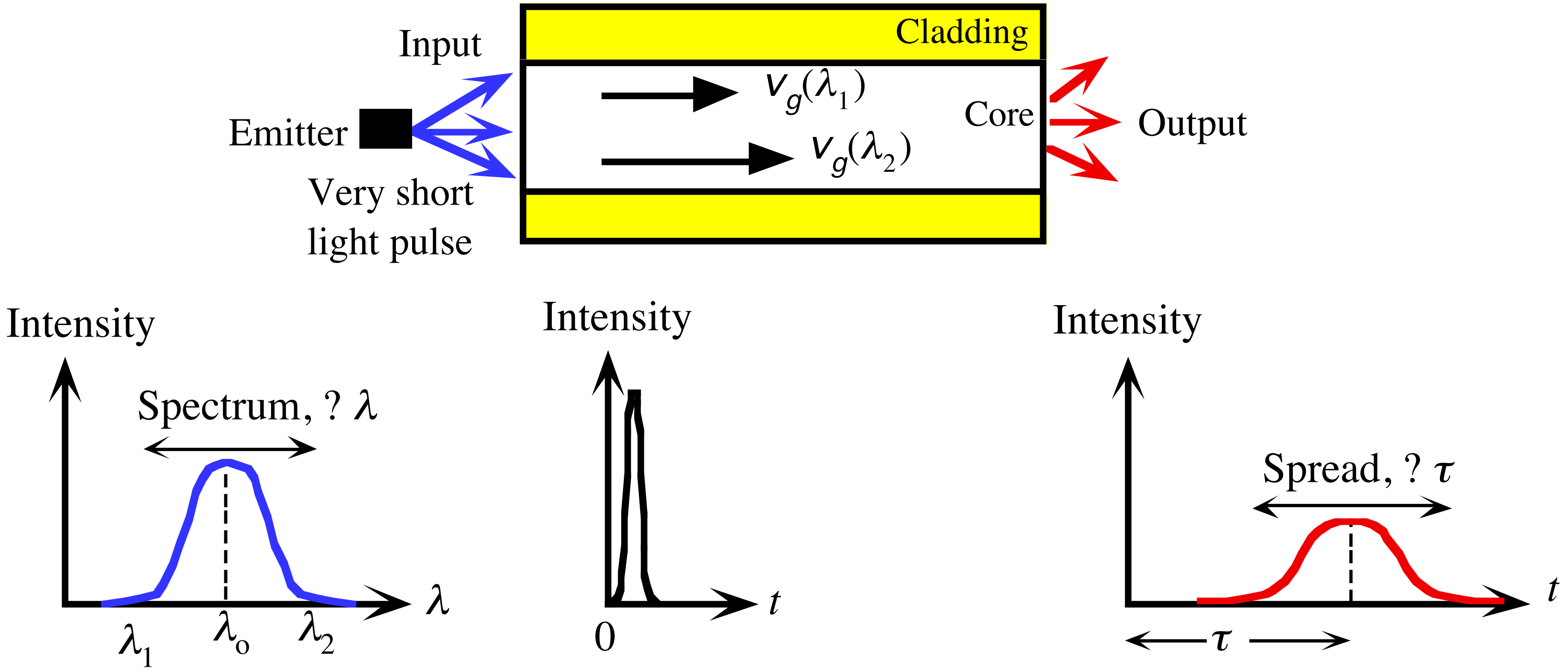
Illustration of the difference between a meridional ray and a skew ray.
Numbers represent reflections of the ray.



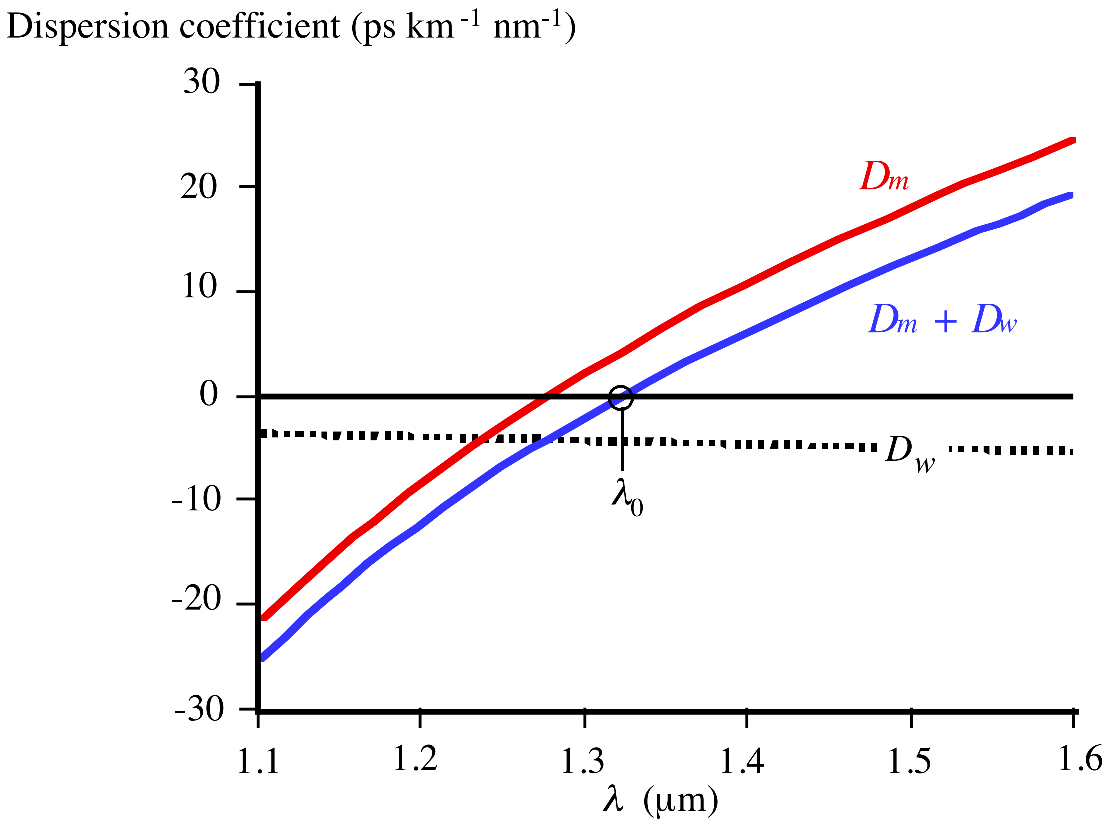
Normalized propagation constant b vs. V-number for a step index fiber for various LP modes.



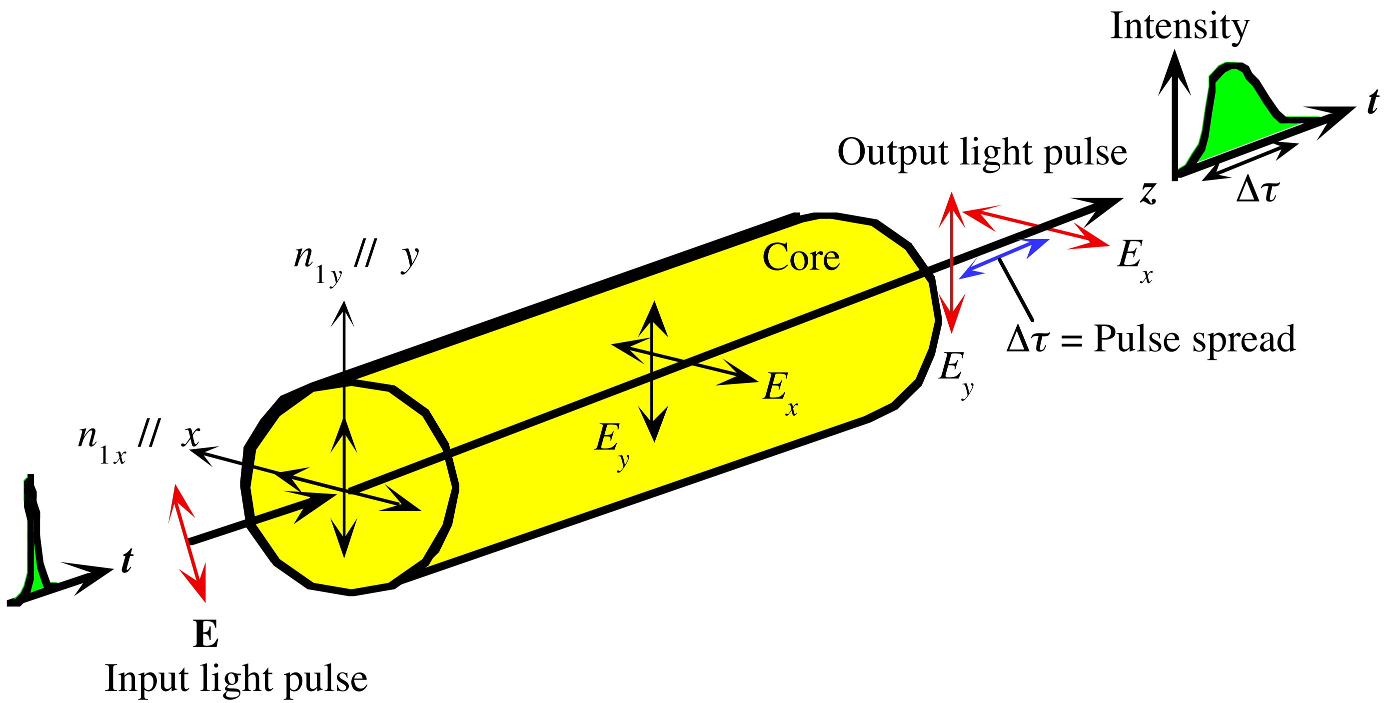
Maximum acceptance angle α_{max} is that which just gives total internal reflection at the core-cladding interface, i.e. when $\alpha = \alpha_{max}$ then $\theta = \theta_c$. Rays with $\alpha > \alpha_{max}$ (e.g. ray B) become refracted and penetrate the cladding and ar eventually lost.



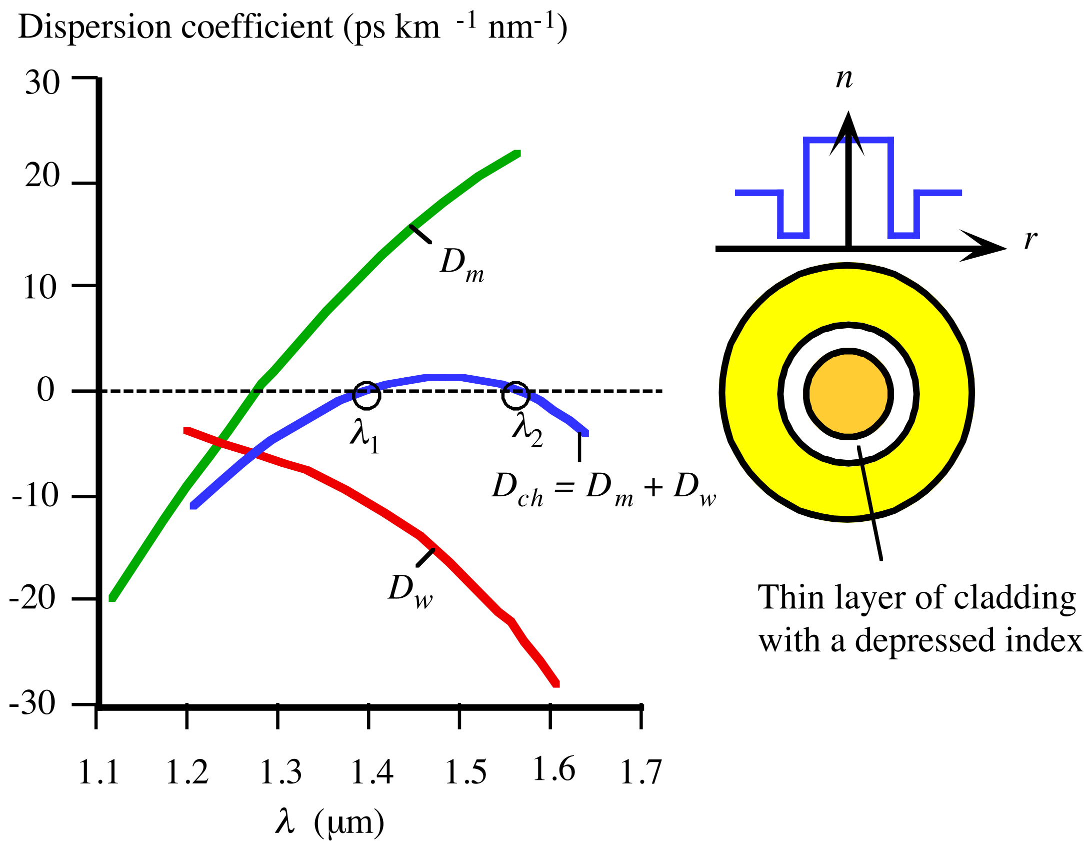
All excitation sources are inherently non-monochromatic and emit within a spectrum, ? λ, of wavelengths. Waves in the guide with different free space wavelengths travel at different group velocities due to the wavelength dependence of n_1. The waves arrive at the end of the fiber at different times and hence result in a broadened output pulse.



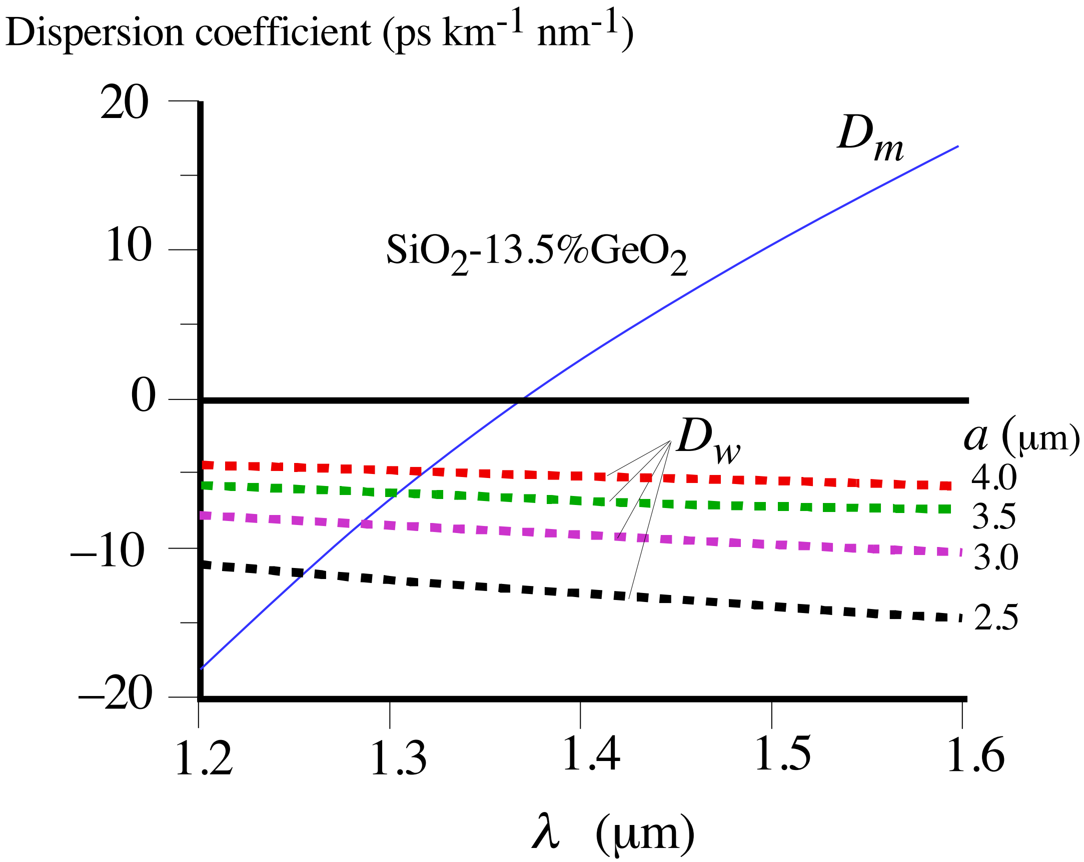
Material dispersion coefficient (D_m) for the core material (taken as SiO_2), waveguide dispersion coefficient (D_w) (a = 4.2 μm) and the total or chromatic dispersion coefficient D_{ch} (= $D_m + D_w$) as a function of free space wavelength, λ.



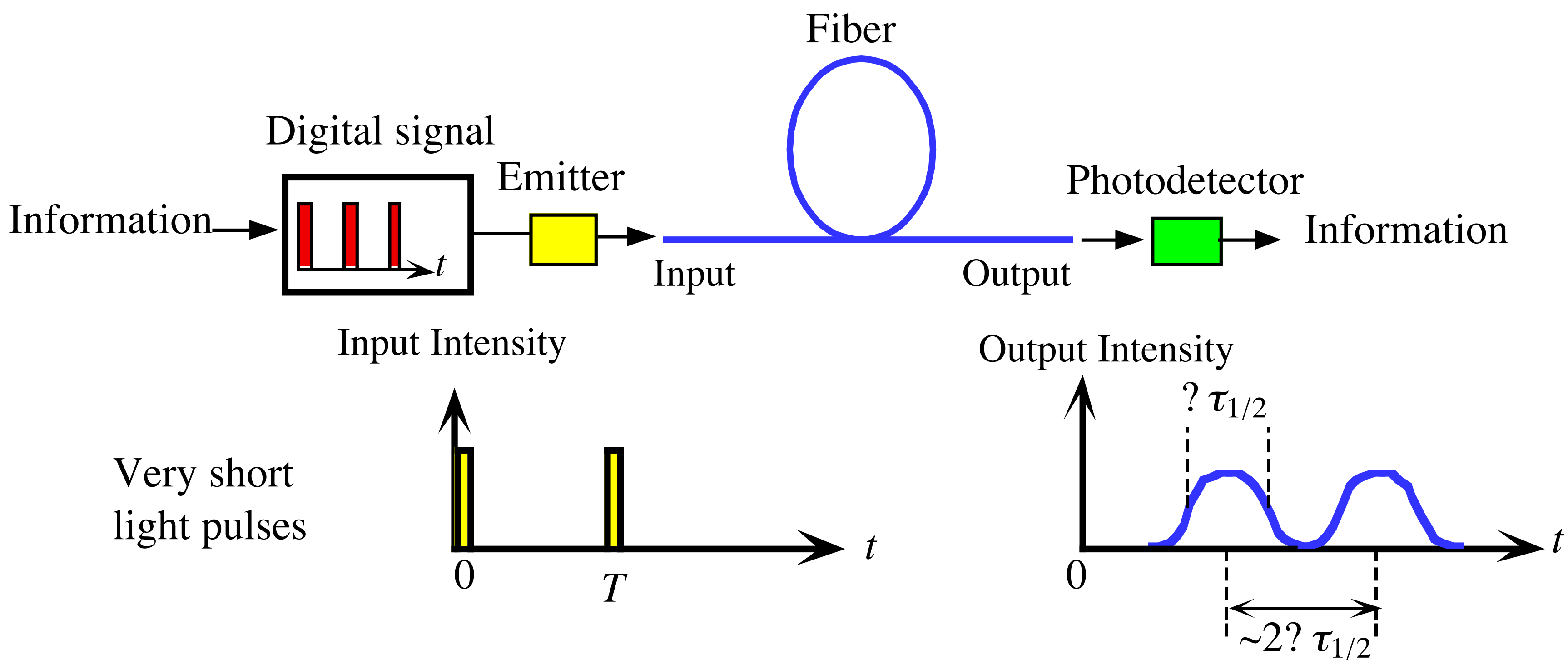
Suppose that the core refractive index has different values along two orthogonal directions corresponding to electric field oscillation direction (polarizations). We can take *x* and *y* axes along these directions. An input light will travel along the fiber with E_x and E_y polarizations having different group velocities and hence arrive at the output at different times



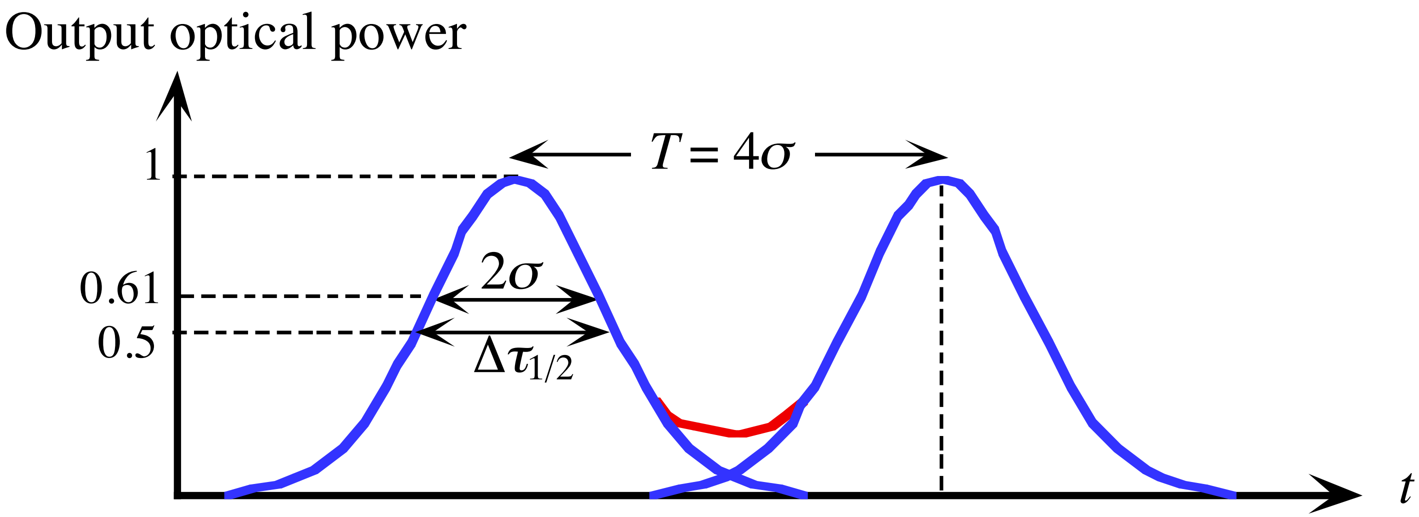
Dispersion flattened fiber example. The material dispersion coefficient (D_m) for the core material and waveguide dispersion coefficient (D_w) for the doubly clad fiber result in a flattened small chromatic dispersion between λ_1 and λ_2.



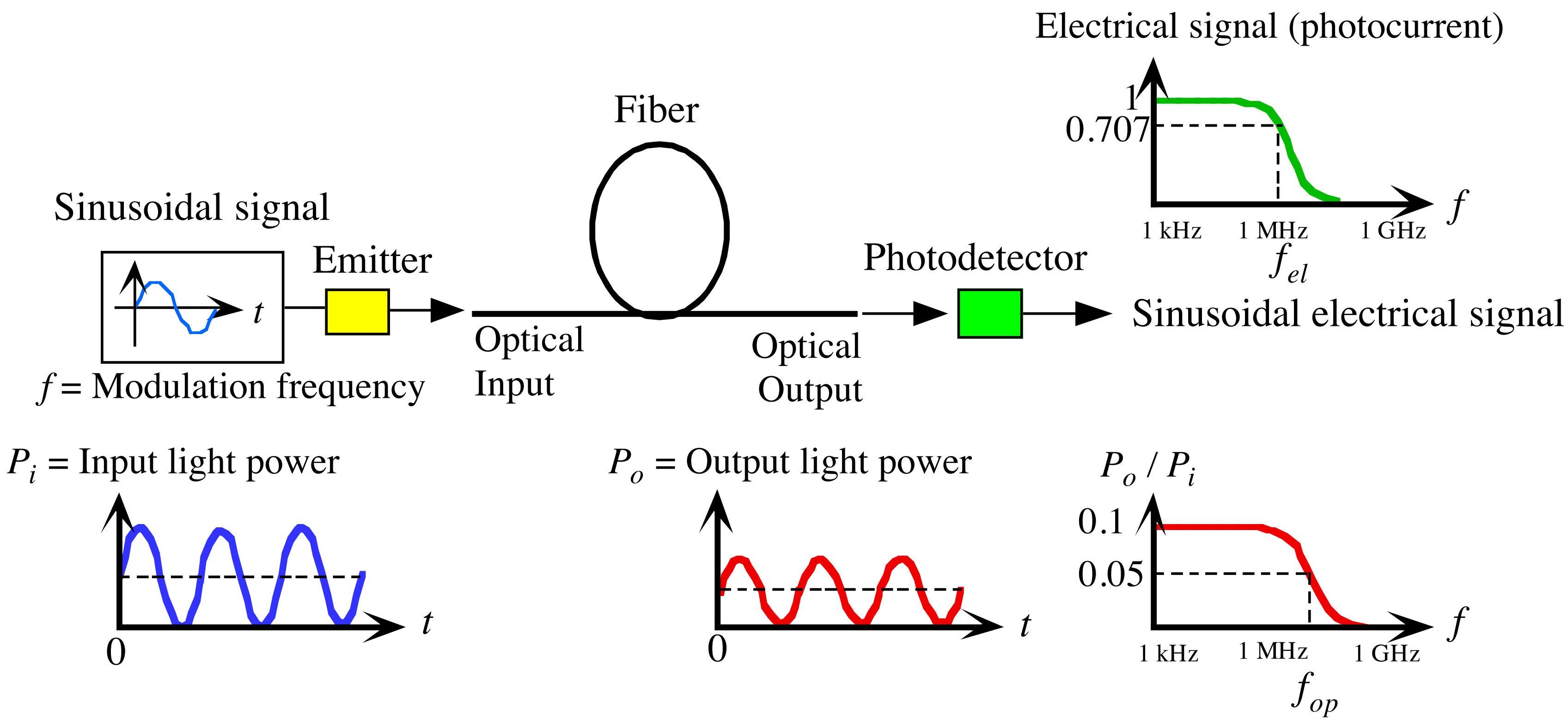
Material and waveguide dispersion coefficients in an optical fiber with a core SiO_2-13.5%GeO_2 for a = 2.5 to 4 µm.



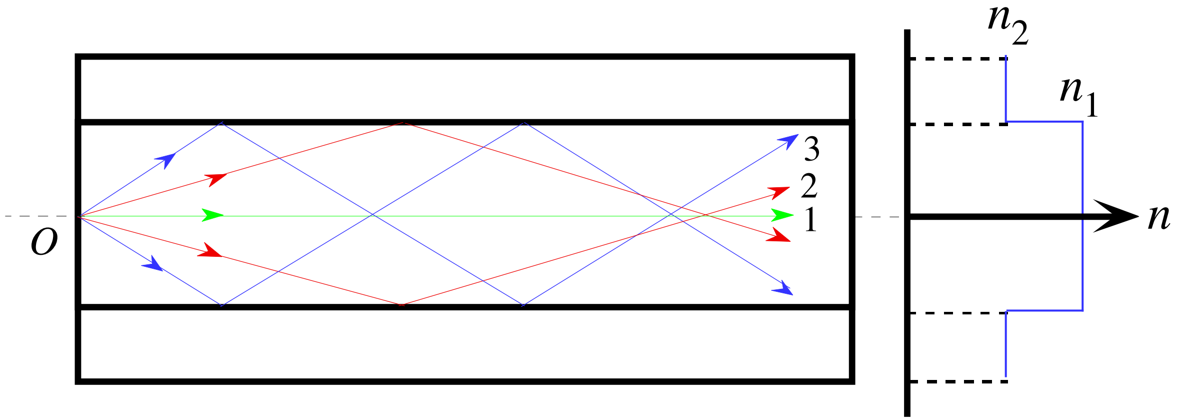
An optical fiber link for transmitting digital information and the effect of dispersion in the fiber on the output pulses.



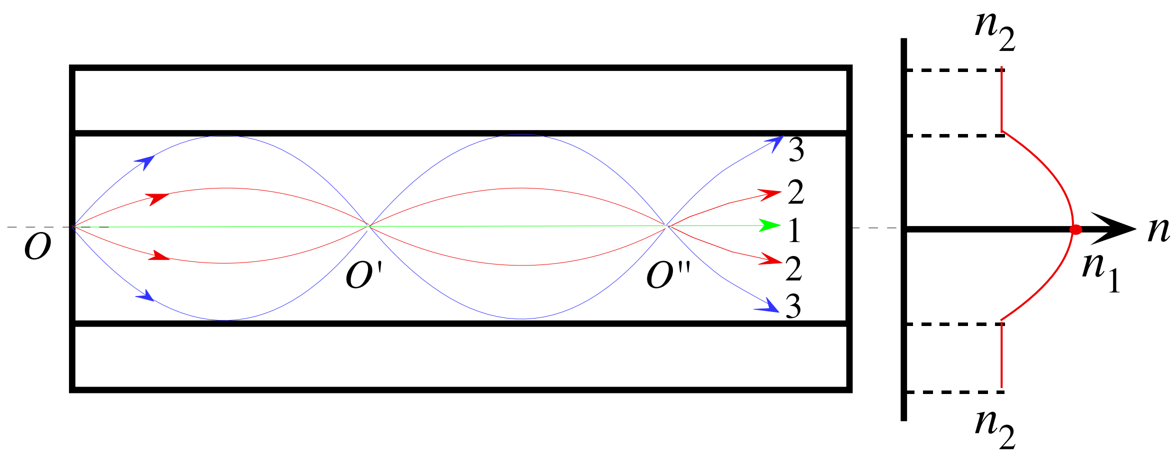
A Gaussian output light pulse and some tolerable intersymbol interference between two consecutive output light pulses (y-axis in relative units). At time $t = \sigma$ from the pulse center, the relative magnitude is $e^{-1/2} = 0.607$ and full width root mean square (rms) spread is $\Delta\tau_{rms} = 2\sigma$.



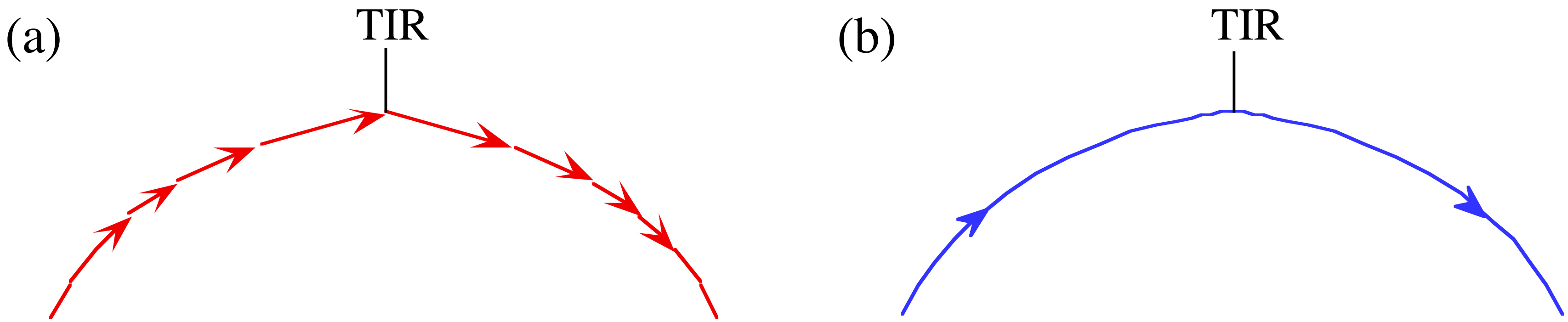
An optical fiber link for transmitting analog signals and the effect of dispersion in the fiber on the bandwidth, f_{op}.



(a) Multimode step index fiber. Ray paths are different so that rays arrive at different times.



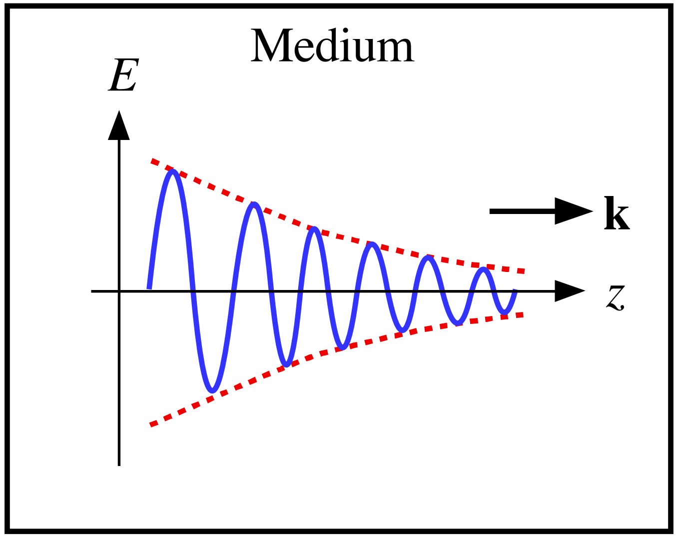
(b) Graded index fiber. Ray paths are different but so are the velocities along the paths so that all the rays arrive at the same time.



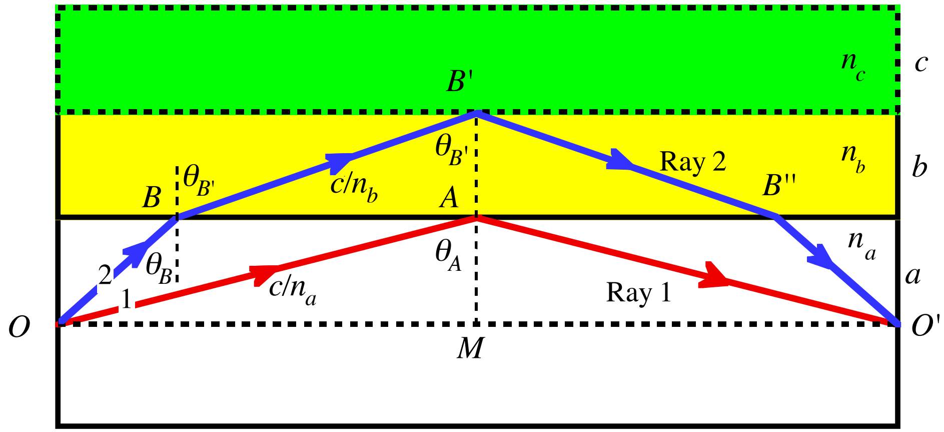
n decreases step by step from one layer to next upper layer; very thin layers.

Continuous decrease in *n* gives a ray path changing continuously.

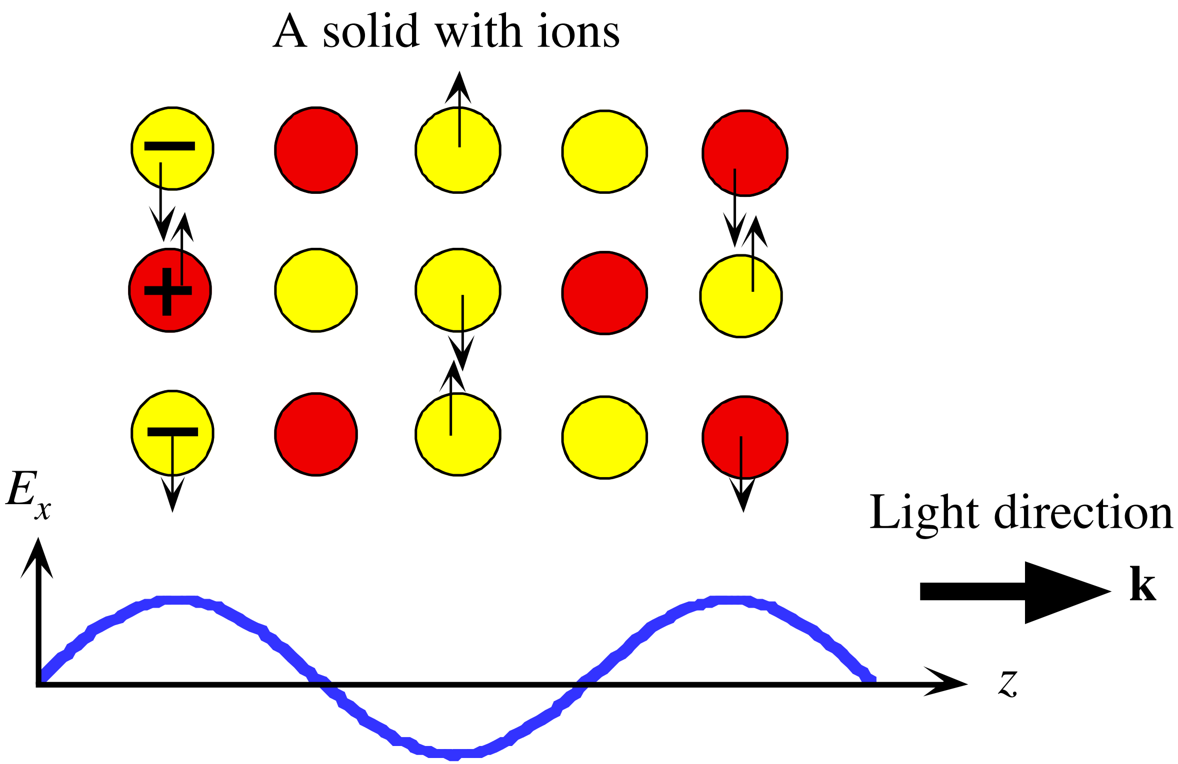
(a) A ray in thinly stratifed medium becomes refracted as it passes from one layer to the next upper layer with lower *n* and eventually its angle satisfies TIR.
(b) In a medium where *n* decreases continuously the path of the ray bends continuously.



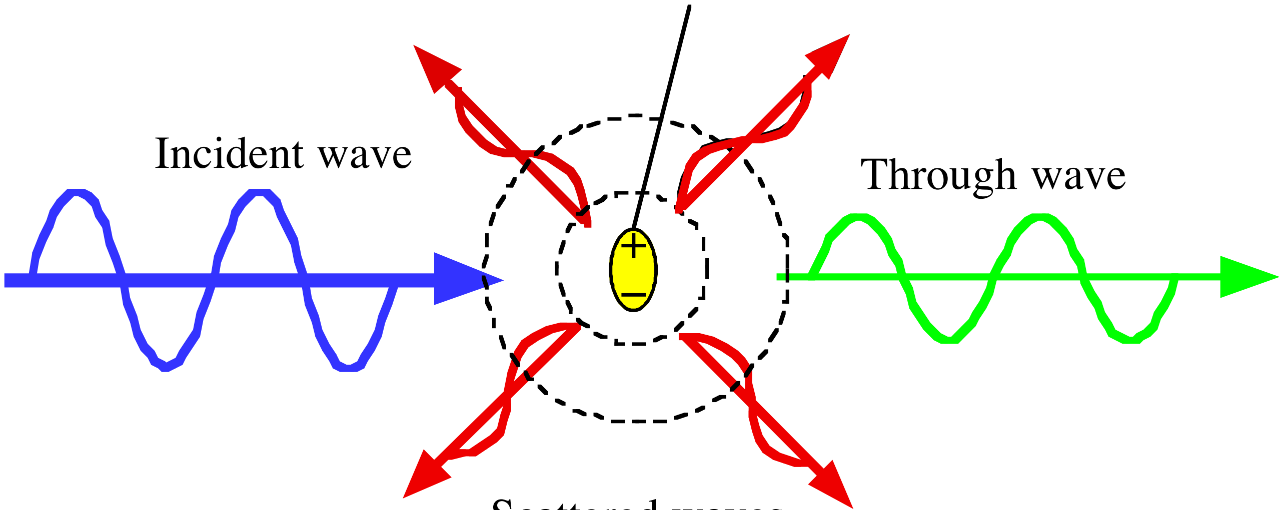
Attenuation of light in the direction of propagation.



We can visualize a graded index fiber by imagining a stratified medium with the layers of refractive indices $n_a > n_b > n_c$ ... Consider two close rays 1 and 2 launched from *O* at the same time but with slightly different launching angles. Ray 1 just suffers total internal reflection. Ray 2 becomes refracted at *B* and reflected at *B*'.



Lattice absorption through a crystal. The field in the wave oscillates the ions which consequently generate "mechanical" waves in the crystal; energy is thereby transferred from the wave to lattice vibrations.



Rayleigh scattering involves the polarization of a small dielectric particle or a region that is much smaller than the light wavelength. The field forces dipole oscillations in the particle (by polarizing it) which leads to the emission of EM waves in "many" directions so that a portion of the light energy is directed away from the incident beam.

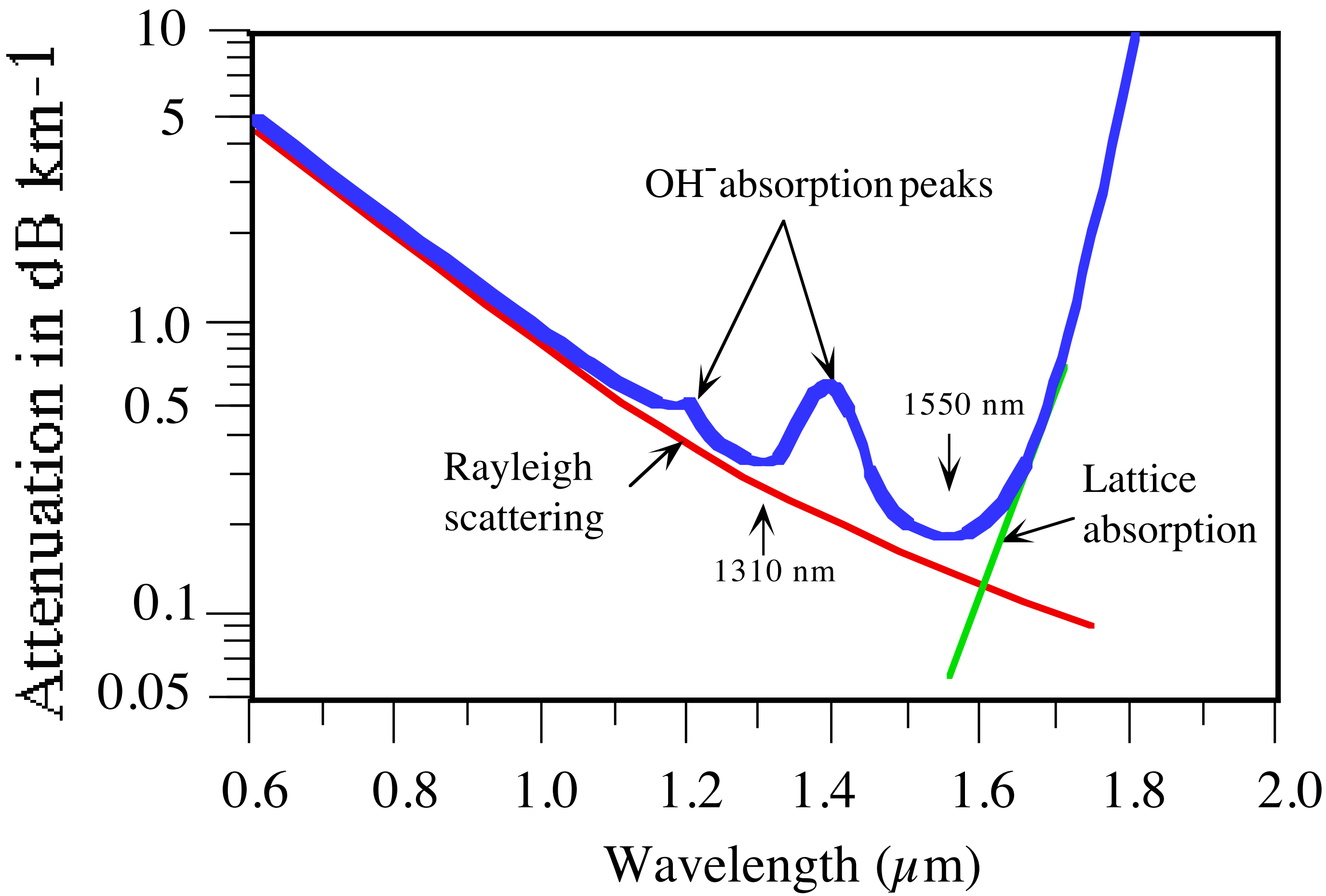
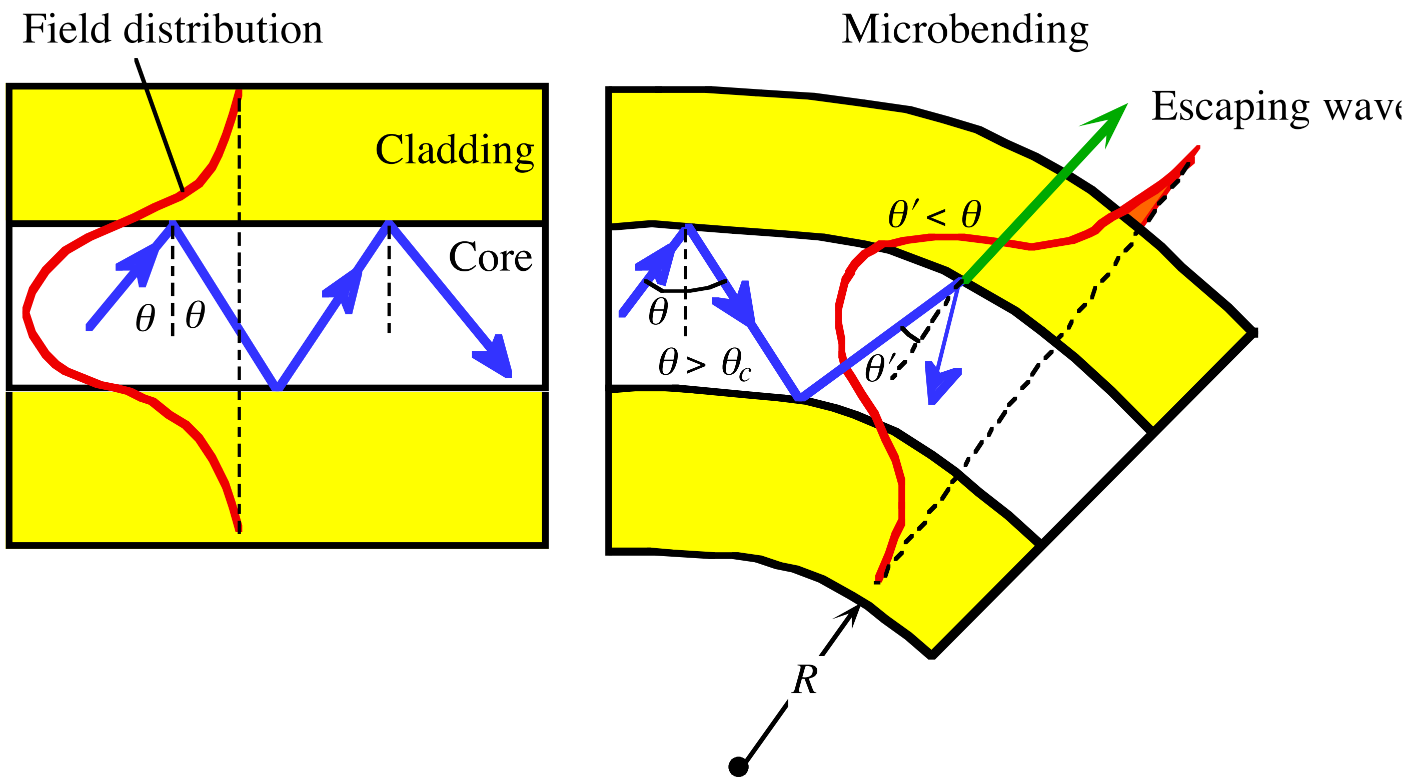
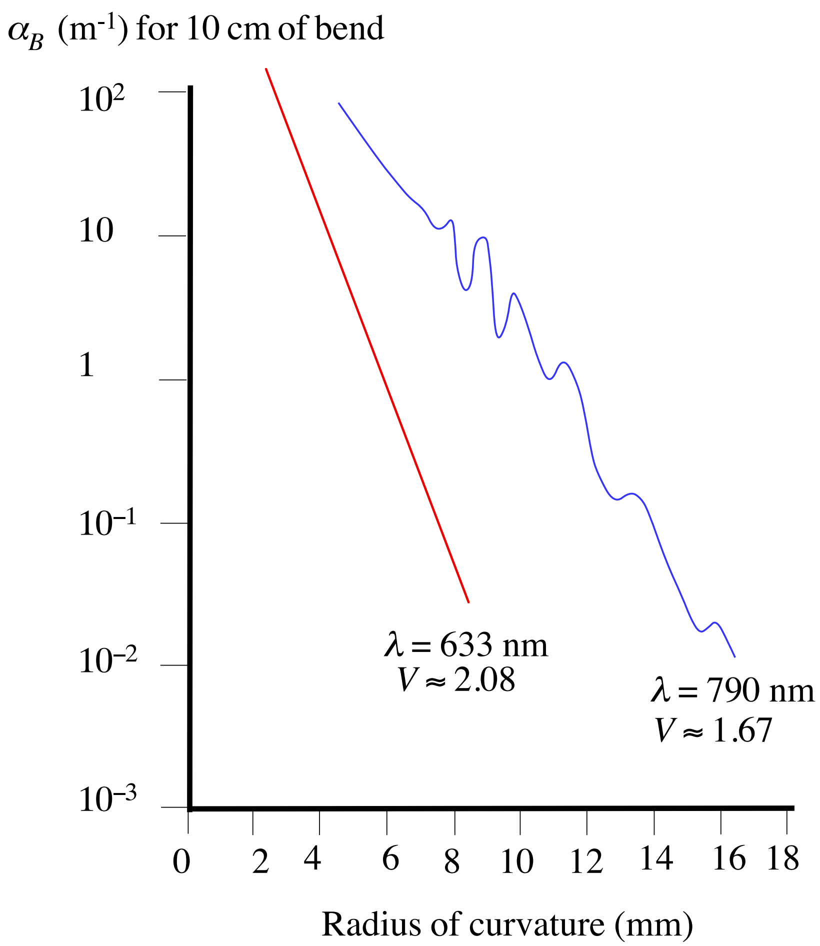


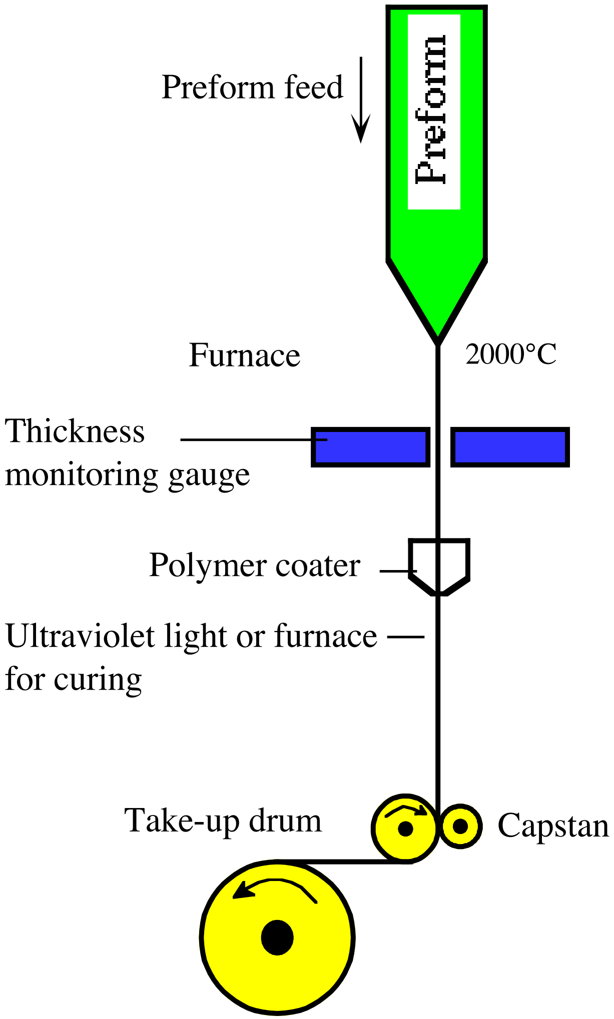
Illustration of a typical attenuation vs. wavelength characteristics of a silica based optical fiber. There are two communications channels at 1310 nm and 1550 nm.



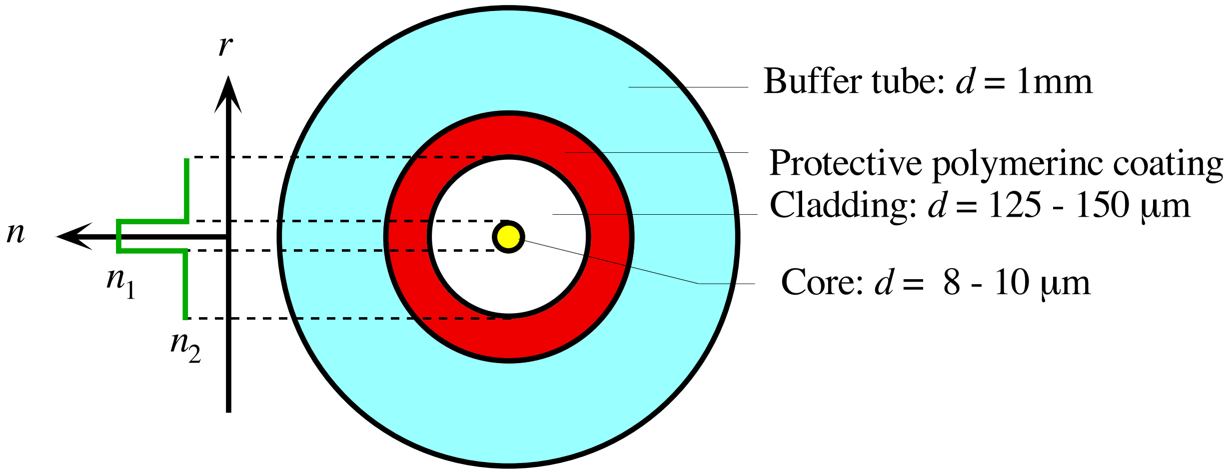
Sharp bends change the local waveguide geometry that can lead to waves escaping. The zigzagging ray suddenly finds itself with an incidence angle θ' that gives rise to either a transmitted wave, or to a greater cladding penetration; the field reaches the outside medium and some light energy is lost.



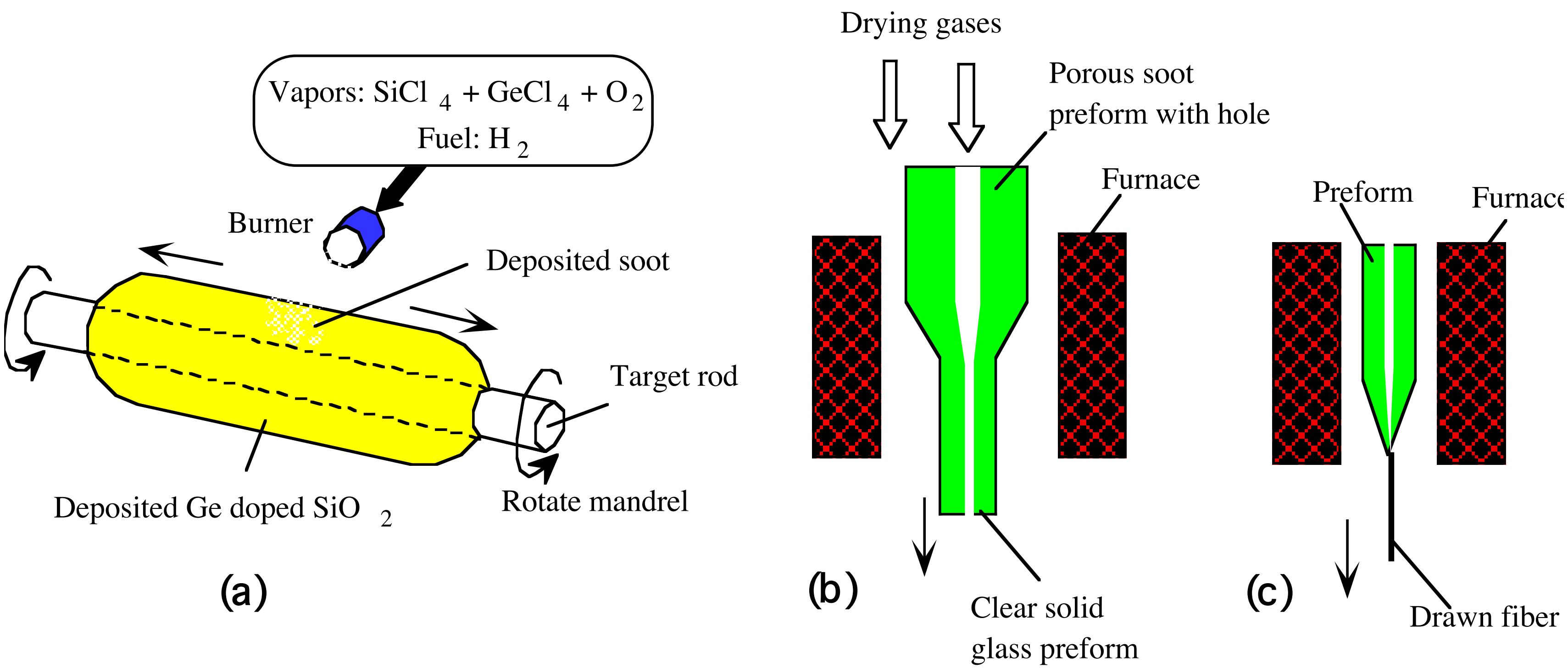
Measured microbending loss for a 10 cm fiber bent by different amounts of radius of curvature R. Single mode fiber with a core diameter of 3.9 μm, cladding radius 48 μm, $\Delta = 0.004$, $NA = 0.11$, $V \approx 1.67$ and 2.08 (Data extracted and replotted with Δ correction from, A.J. Harris and P.F. Castle, *IEEE J. Light Wave Technology*, Vol. LT14, pp. 34-40, 1986; see original article for discussion of peaks in α_B vs. R at 790 nm).



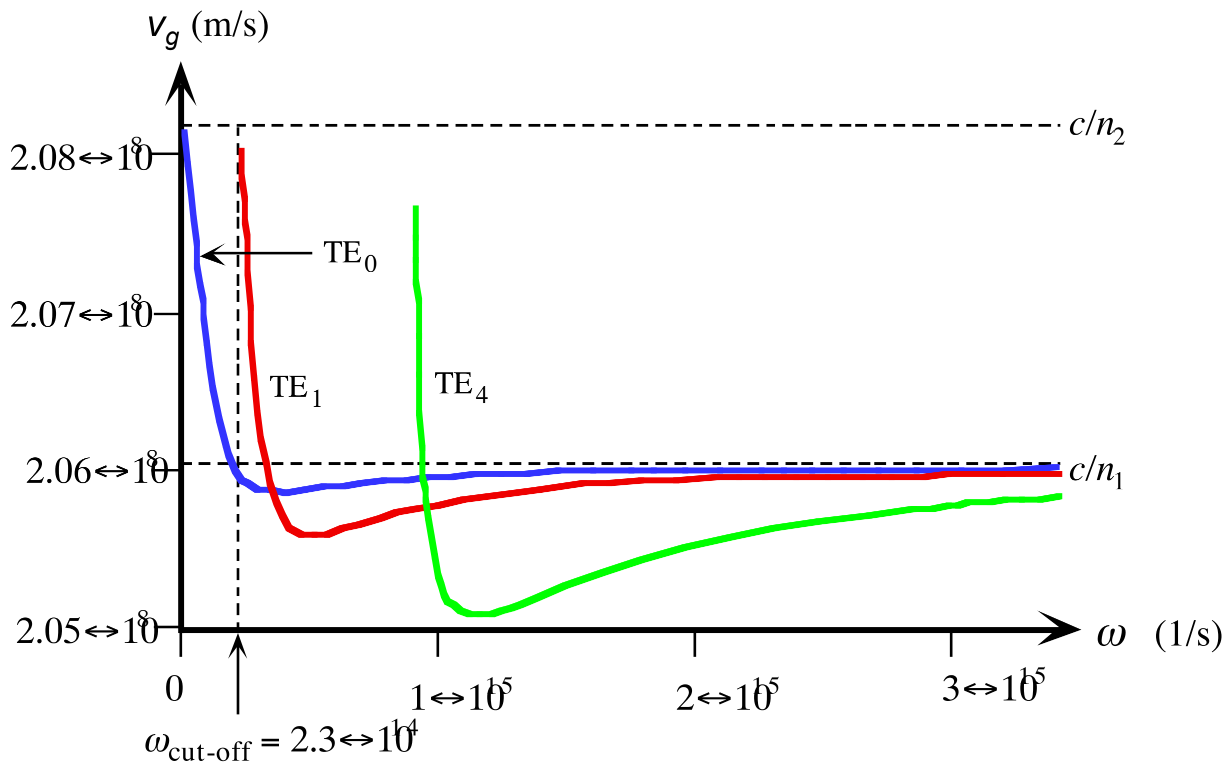
Schematic illustration of a fiber drawing tower.



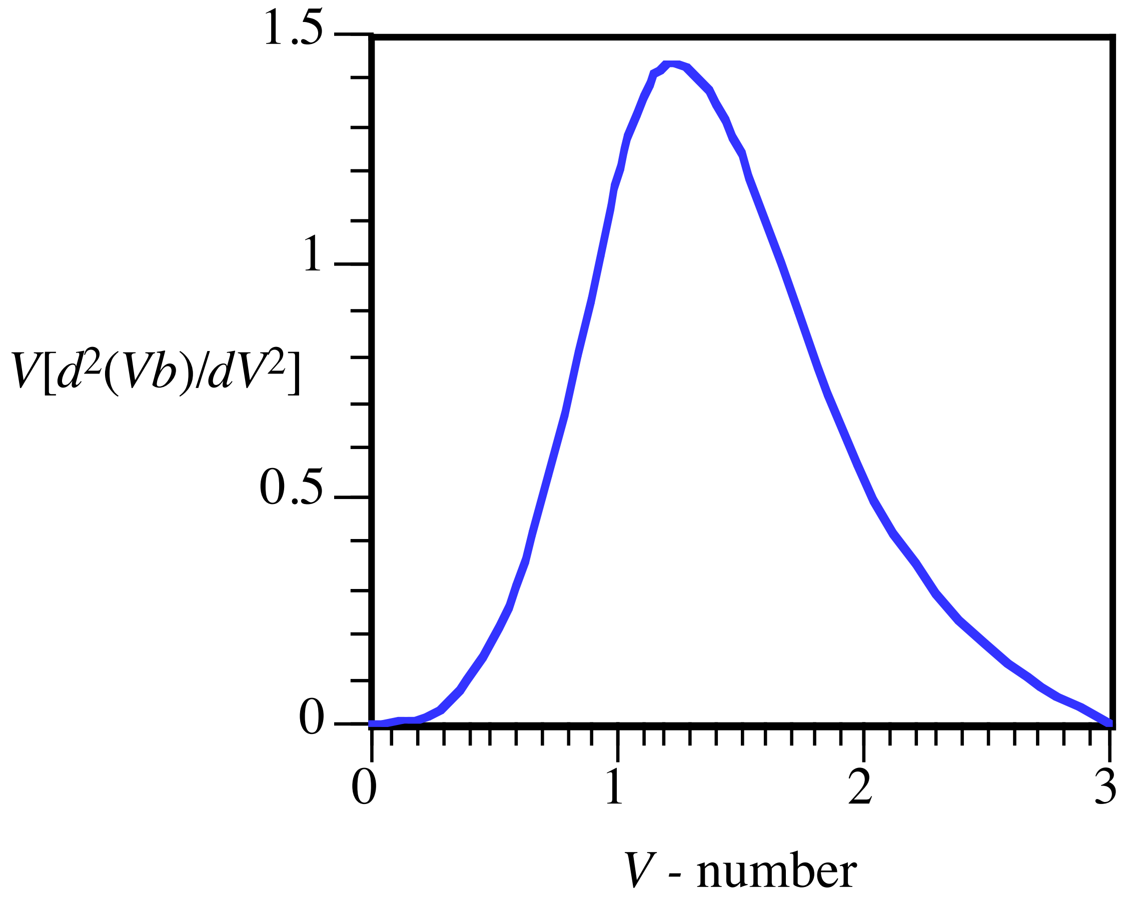
The cross section of a typical single-mode fiber with a tight buffer tube. (d = diameter)



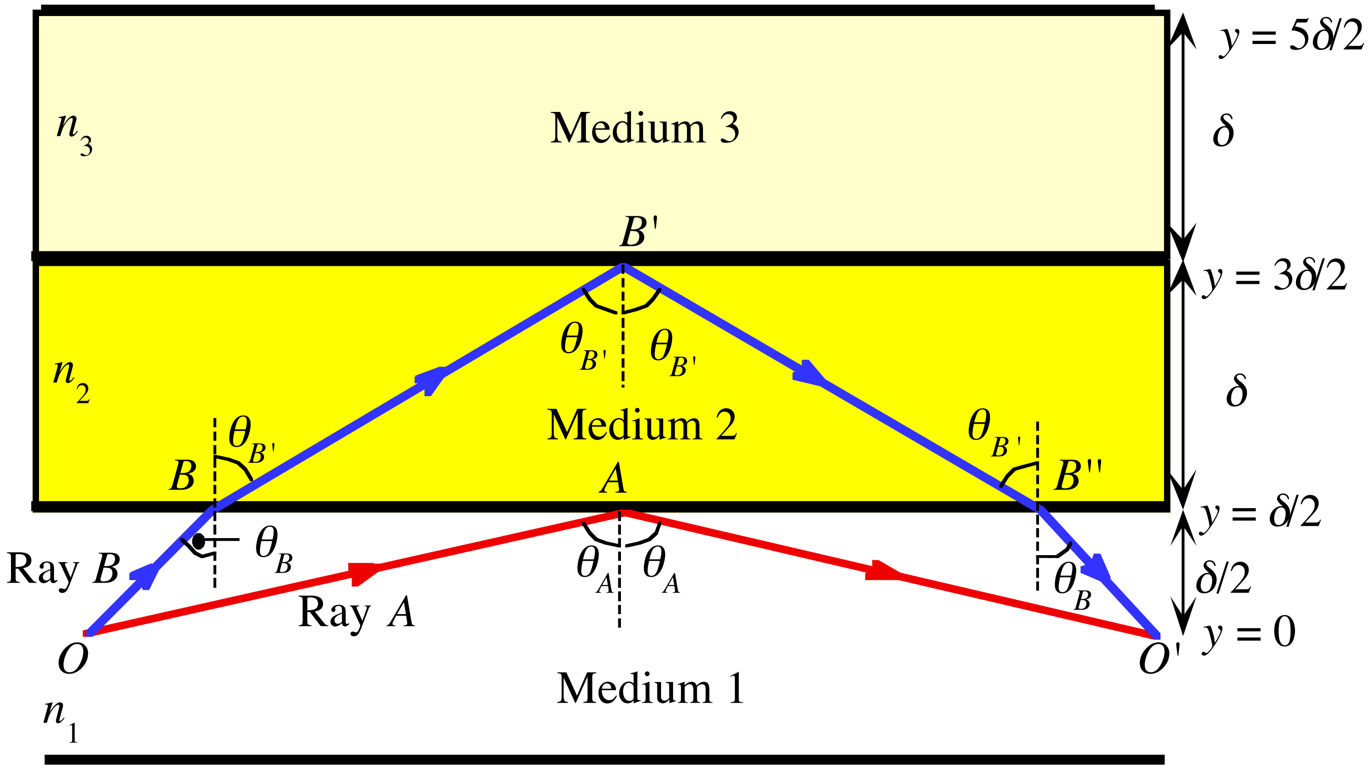
Schematic illustration of OVD and the preform preparation for fiber drawing. (a) Reaction of gases in the burner flame produces glass soot that deposits on to the outside surface of the mandrel. (b) The mandrel is removed and the hollow porous soot preform is consolidated; the soot particles are sintered, fused, together to form a clear glass rod. (c) The consolidated glass rod is used as a preform in fiber drawing.



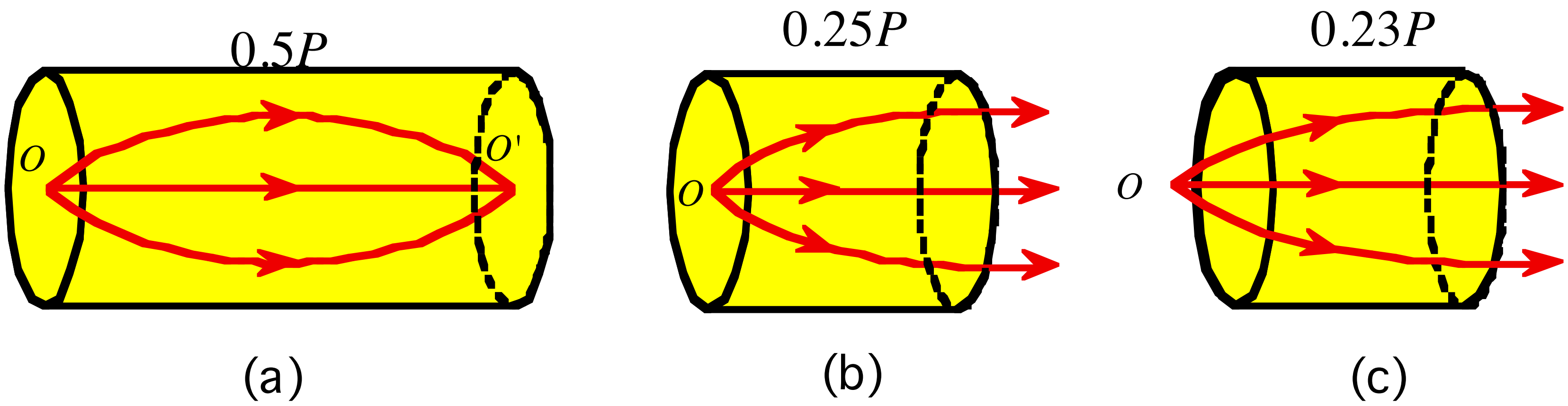
Group velocity vs. angular frequency for three modes for a planar dielectric waveguide which has $n_1 = 1.455$, $n_2 = 1.44$, $a = 10$ μm (Results from Mathview, Waterloo Maple math-software application). TE_0 is for $m = 0$ *etc*.



$[d^2(Vb)/dV^2]$ vs. V-number for a step index fiber (after W.A. Gambling et al., *The Radio and Electronics Engineer*, **51**, 313, 1981)



Step-graded-index dielectric waveguide. Two rays are launched from the center of the waveguide at O at angles θ_A and θ_B such that ray A suffers TIR at A and ray B suffers TIR at B'. Both TIRs are at critical angles.



Graded index (GRIN) rod lenses of different pitches. (a) Point *O* is on the rod face center and the lens focuses the rays onto *O*' on to the center of the opposite face. (b) The rays from *O* on the rod face center are collimated out. (c) *O* is slightly away from the rod face and the rays are collimated out.