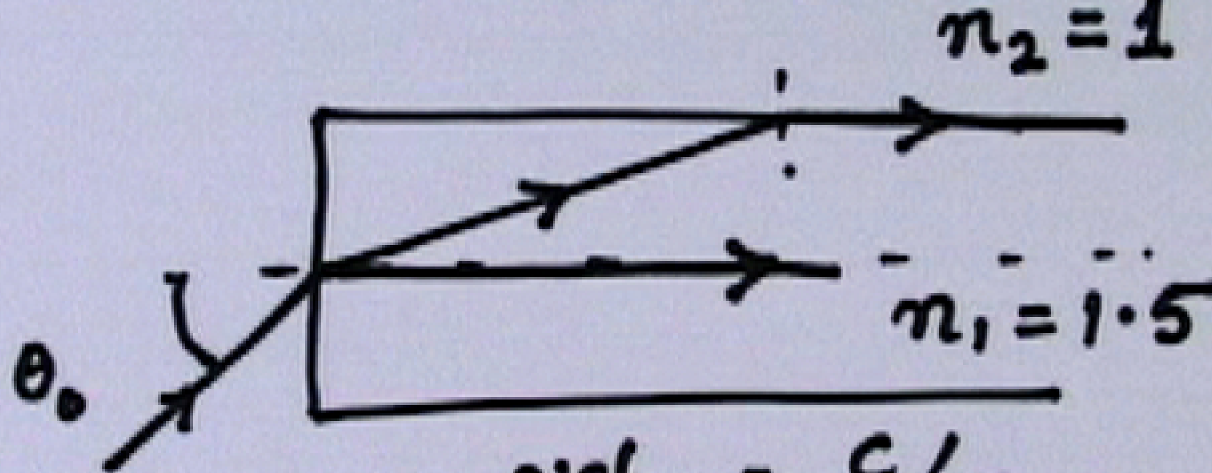


$$vel = c/n_1$$

$$\Delta T = \frac{n_1}{n_2 c}(n_1 - n_2)$$

$$= \frac{1 \cdot 5}{1 \times 3 \times 10^8} \times (1 \cdot 5 - 1)$$

$$= 2 \cdot 5 \text{ nsec per meter}$$

$$\Delta T = 2 \cdot 5 \, \mu\text{sec per km}$$

$$V = \frac{2\pi}{\lambda} \cdot (NA) \cdot a$$

$$NA = \sqrt{n_1^2 - n_2^2} = \sqrt{(1.5)^2 - 1} = 1.118$$

$$V = \frac{2\pi}{1.3} \times 1.118 \times 25 = 135$$

$$\text{No. of modes} \approx \frac{V^2}{2} = \frac{(135)^2}{2}$$

$$\approx 9112$$

when fiber is immersed in water

$$NA = \sqrt{(1.5)^2 - (1.33)^2} = 0.6936$$

$$V = \frac{2\pi}{1.3} \times 0.6936 \times 25 \approx 83.75$$

$$\text{No. of modes} \approx \frac{V^2}{2} \approx 3507$$

Normalized frequency

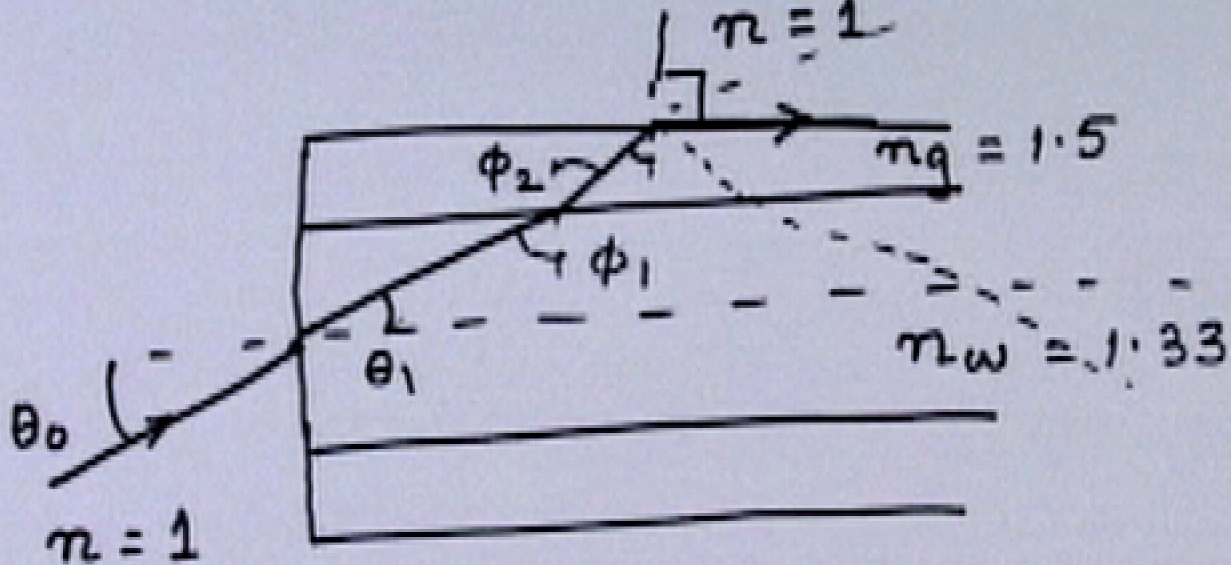
$$V = \frac{2\pi}{\lambda} \cdot NA \cdot a$$

$$NA = \sqrt{(1.48)^2 - (1.46)^2} = 0.2424$$

$$V = \frac{2\pi}{0.8} \times 0.2424 \times 25 = 47.6$$

$$V = 2.4 = \frac{2\pi}{\lambda} \times 0.2424 \times 25$$

$$\lambda = 15.87\ \mu m$$



$$\sin\theta_0 = n_\omega \sin\theta_1$$

$$n_\omega \sin\phi_1 = n_g \sin\phi_2 = 1$$

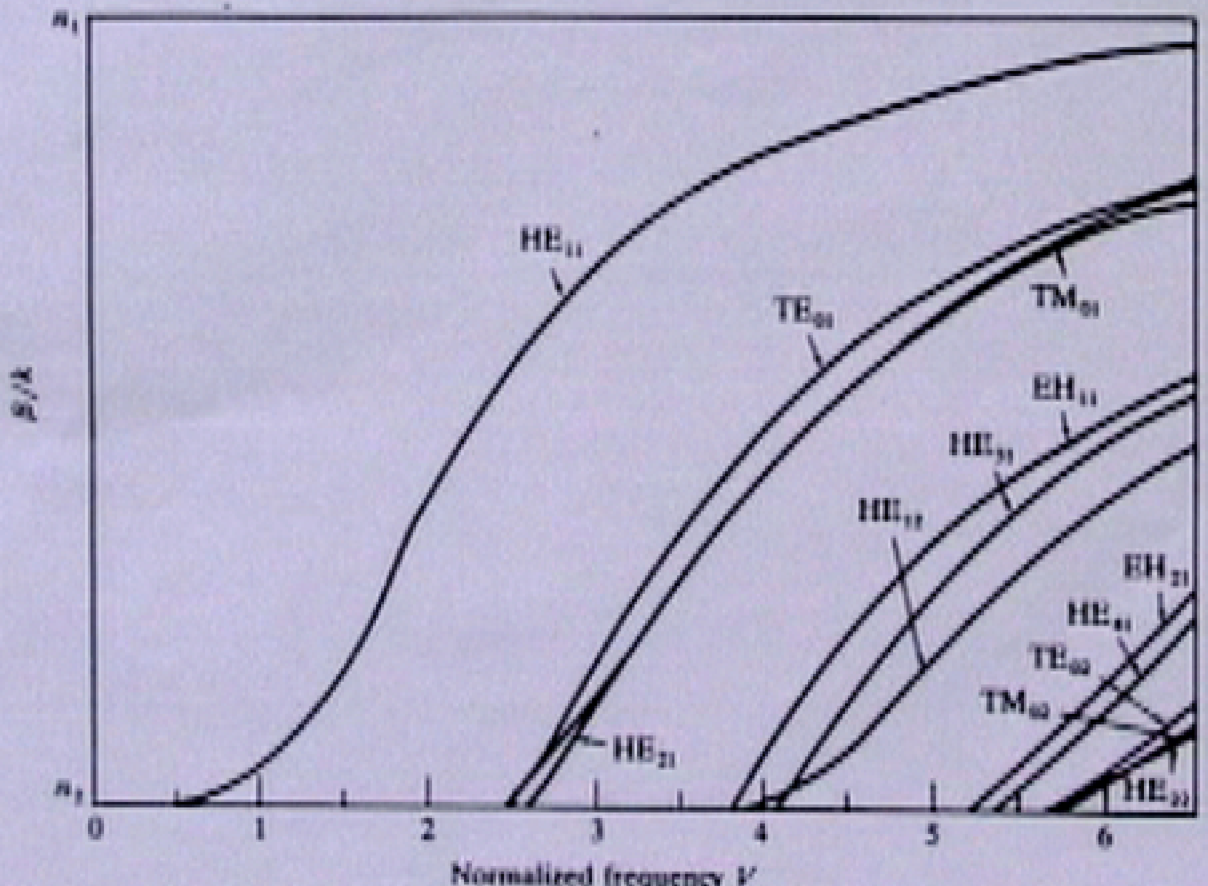
$$n_g \sin\phi_2 = 1 \sin \pi/2 = 1$$

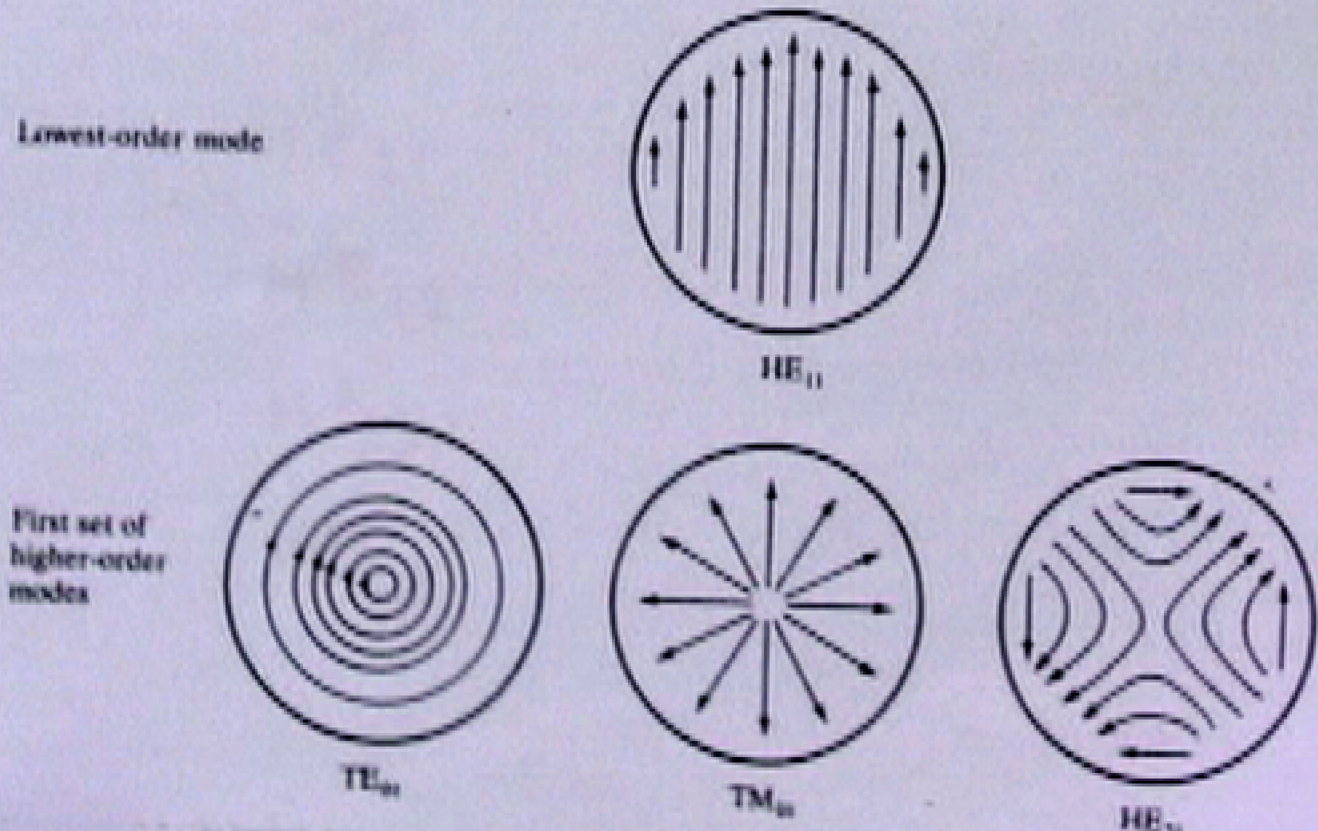
$$\sin\phi_1 = 1/n_\omega$$

$$NA = \sin\theta_0 = n_\omega \sin(\pi/2 - \phi_1) = n_\omega \cos\phi_1$$

$$= n_\omega \sqrt{1 - \sin^2\phi_1} = n_\omega \sqrt{1 - \frac{1}{n_\omega^2}}$$

$$= \sqrt{n_\omega^2 - 1} = 0.87$$


n_1
n_2
β/k
HE$_{11}$
TE$_{01}$
TM$_{01}$
HE$_{21}$
EH$_{11}$
HE$_{31}$
HE$_{12}$
EH$_{21}$
HE$_{41}$
TE$_{02}$
TM$_{02}$
HE$_{22}$
0
1
2
3
4
5
6
Normalized frequency V


Lowest-order mode
HE_{11}
First set of higher-order modes
TE_{01}
TM_{01}
HE_{21}

	Degeneracy
HE_{11}	2
TE_{01}	1
TM_{01}	1
HE_{21}	2
HE_{12}	2
HE_{31}	2
EH_{21}	2
	12

No. of modes

$$= \frac{V^2}{2} = \frac{25}{2}$$

$$= 12.5$$

Pulse delay $T = A + B\lambda^2 + C\lambda^{-2}$

Dispersion $D = \frac{dT}{d\lambda} = 2B\lambda - 2C\lambda^{-3}$

$D = 0$ at $\lambda = \lambda_0$

$\Rightarrow 2B\lambda_0 - 2C\lambda_0^{-3} = 0$

$$\boxed{B = C\lambda_0^{-4}}$$

slope of dispersion

$$S_0 = \left.\frac{dD}{d\lambda}\right|_{\lambda=\lambda_0} = 2B + 6C\lambda_0^{-4}$$

$$S_0 = 2C\lambda_0^{-4} + 6C\lambda_0^{-4}$$

$$C = \frac{S_0}{8}\lambda_0^4 \quad , \quad B = \frac{S_0}{8}$$

$$D(\lambda) = 2\cdot\frac{S_0}{8}\lambda - 2\frac{S_0}{8}\lambda_0^4\lambda^{-3} = \frac{S_0}{4}\lambda\left\{1 - \left(\frac{\lambda_0}{\lambda}\right)^4\right\}$$

$$b = 1 - e^{-V}$$

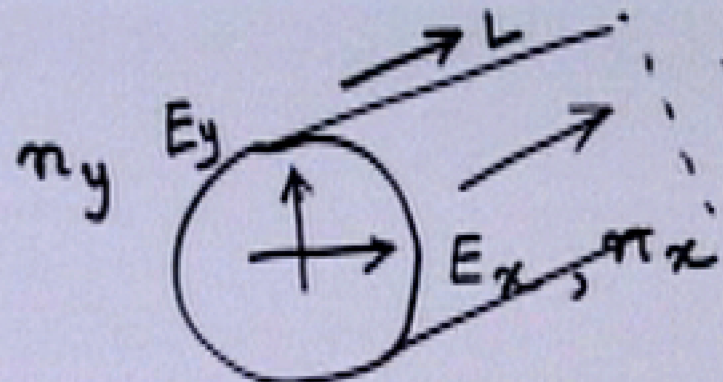
$$D = -\frac{n_2}{c\lambda} V \frac{d^2(bV)}{dV^2}, \qquad bV = V - Ve^{-V}$$

$$\frac{d}{dV}(bV) = 1 - \{e^{-V} - Ve^{-V}\}$$

$$\frac{d^2}{dV^2}(bV) = e^{-V} + \{e^{-V} - Ve^{-V}\} = \{2 - V\} e^{-V}$$

$$D = \frac{-n_2}{c\lambda} V (2 - V) e^{-V}$$

$$\frac{dD}{d\lambda} = 0$$



$$\beta_x = \beta_0 n_x$$

$$\beta_y = \beta_0 n_y$$

Phase change $= (\beta_x - \beta_y) L$

$$= \beta_0 \underbrace{(n_x - n_y)}_{10^{-6}} L$$

Let us take

$$\lambda = 1.5\,\mu m$$

$$\frac{\cancel{\pi}}{2} = \frac{2\cancel{\pi}}{\lambda} \times 10^{-6} \cdot L$$

$$L = \frac{\lambda}{4} \times 10^{6} = \frac{1.5 \times 10^{-6}}{4} \times 10^{6}$$

$$= 0.375\ m = \underline{37.5\ cm}$$ Linear

$\rightarrow 75\ cm$ — Circular