→ fibre optics
→ X-rays
→ superconductivity
→ electrostatics

2009

FIBRE OPTICS:

... flexible thread of transparent glass or plastic material
...al fibres are light equivalent of microwave waveguide
... an add advantage of having large bandwidth.

PRINCIPLE OF PROPAGATION OF LIGHT THROUGH AN OPTICAL FIBRE:

...asic principle of propagation of light through an
...al fibre is TOTAL INTERNAL REFLECTION.
Applying Snell's Law:

$$n_1 \sin i = n_2 \sin r$$

$$\frac{\sin i}{\sin r} = \frac{n_2}{n_1}$$

when $i = c$, $r = 90°$

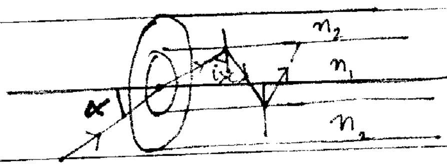
$$\frac{\sin c}{\sin 90°} = \frac{n_2}{n_1}$$

$$\sin c = \frac{n_2}{n_1}$$

$$C = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

When light travels from denser to rarer medium, it bends away from the normal. At a particular angle of incidence, called critical angle, ray gets refracted through an angle of 90°. This refracted ray is called GRAZING RAY. If $\angle i > c$, the ray gets totally internally reflected in the same medium.

Basic Structure of Optical Fibres:



CONDITIONS FOR TIR to take place at the walls of the Optical Fibres:

(i) Glass around the centre of fibre (core) should have higher refractive index than that of the material surrounding the fibre (cladding).

(ii) Light should be incident on the axis of fibre at an angle greater than the critical angle (c).

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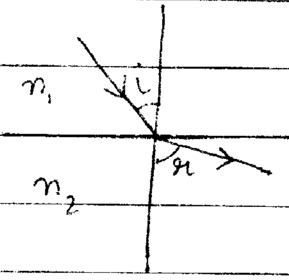
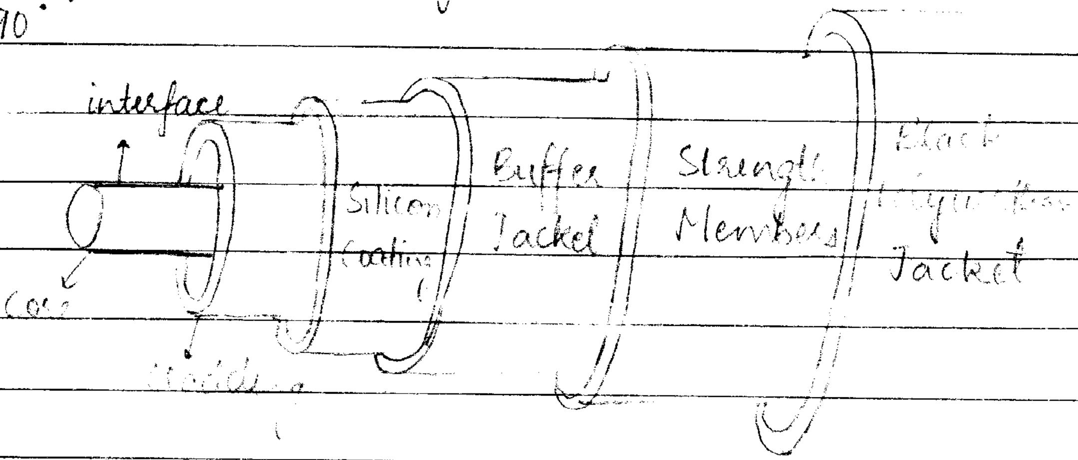
BASIC STRUCTURE OF OPTICAL FIBRE:



$n_1 > n_2$

* as angle of incidence increases, angle of refraction increases when travelling from denser to rarer medium.

ray of light that grazes along the interface of the al fibre goes as loss of light. This happens when , $r = 90°$



80-90% of the incident light passes through the core which is the innermost part of the optical fibre. It has a higher R.I. than the surrounding part so that it acts as Denser medium.

* Cladding has a slightly lower R.I. than the core so that it acts as a rarer medium so that T.I.R can take place at core-cladding interface. It also provides mechanical strength to the core.

* Silicon coating protects the core from moisture and impurities present in the surroundings; also provides mechanical strength to core.

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* With the buffer jacket, strength members, black polyurethane jacket of fibre installation and handling is easier.

Optical fibre is a thin, flexible, thread of transparent plastic or glass. They are light equivalent of ~~a~~ microwave waveguides having very large bandwidth.

(i) CORE - Innermost part of fibre is known as core. Incident light signal is basically propagated through the core. Refractive index of core should be slightly higher than the material surrounding the core (cladding) so that it acts as a denser medium.

(ii) CLADDING - Core is surrounded by a layer of material called cladding. R.I. of cladding should be slightly less than that of core so that it acts as a rarer medium across the core. This is required so that TIR may take place at the core-cladding interface.

(iii) SILICON COATING - Around the cladding, there is silicon coating which protects the cladding from moisture & impurities

(iv) Buffer jacket, Strength Members and Black Polyurethane Outer jacket provide overall mechanical strength to the fibre.

SELECTION OF FIBRE MATERIAL:

1. It should be possible to draw long, thin, flexible wires from the material.
2. For core and cladding, there should be slight

Let $n_1 = 1.47$
$n_2 = 1.46$
$\Delta = \frac{n_1 - n_2}{n_1} \simeq 0.01$ for TIR to take place

Material should be transparent at a particular wavelength to the wavelength of light (range) to be passed thru optical fibre, the material of fibre should be decided.
Mainly, three types of fibres are made:
Plastic core with Plastic Cladding
Glass core with ~~Glass~~ Plastic cladding
Glass core with Glass Cladding.

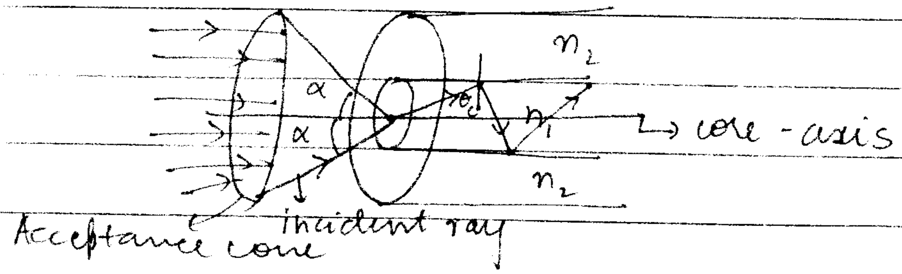
FRACTIONAL REFRACTIVE INDEX DIFFERENCE (Δ):

FRID $= n_1 - n_2$
n_1 = refractive index of core
n_2 = " " of cladding
$n_1 > n_2$

$$\boxed{\Delta = \frac{n_1 - n_2}{n_1}}$$

In order to have effective communication:
$\Delta < 1$
Practically, $\Delta \simeq 0.01$

ACCEPTANCE ANGLE (α): $n_1 > n_2$



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If $\angle i > \theta_c$, the ray gets totally internally reflect.

Maximum
Angle made by incident ray with the axis of core at core - outside medium interface so that ray is totally internally reflected at core - cladding interface is called the acceptance angle.

ACCEPTANCE CONE:

It is the cone around the axis of core having angle 2α (maximum) so that all the light signals ~~will~~ which are incident within the core are totally internally reflected at core - cladding interface.

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NUMERICAL APERTURE: / Figure of Merit

N.A. is defined as the sine of maximum of accep. angle i.e. α_{max}

$$N.A = \sin \alpha_{max}$$

Physically, it gives the light gathering ability of the optical fibre. Greater the diameter of core, more will ~~the~~ be the light gathering ability and hence more will be the numerical aperture.

Aperture - area exposed to the ~~inci~~ incident light.

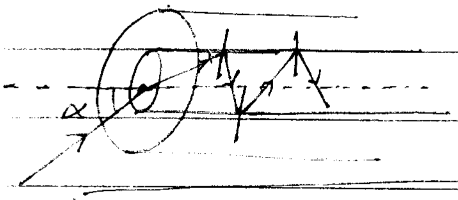
$$N.A. = \sqrt{\frac{n_1^2 - n_2^2}{n_0^2}}$$

n_1 = refractive index of core

n_2 = refractive index of cladding.

n_0 = " " of outside medium

TOTAL NUMBER OF REFLECTIONS: (N)



$$\boxed{N = \frac{L \tan\theta}{a} - 1}$$

~~Ko~~ L = length of fibre

θ = angle made by the incident ray with normal to core-cladding interface ($\angle i$)

a = radius of core.

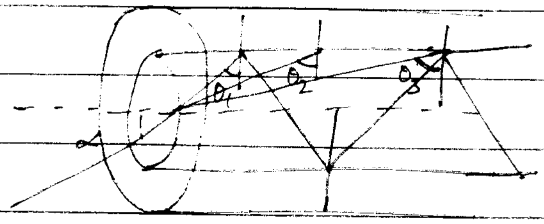
TYPES OF FIBRES:

(i) On the basis of Propagation of light (modes):

Modes - allowed paths of light through an optical fibre.
(No. of ways)

(a) Single Mode: If an optical fibre can sustain only one allowed path, then optical fibre is called single mode.

(b) Multimode: If an optical fibre can sustain many hundred allowed paths, then optical fibre is termed as Multimode.

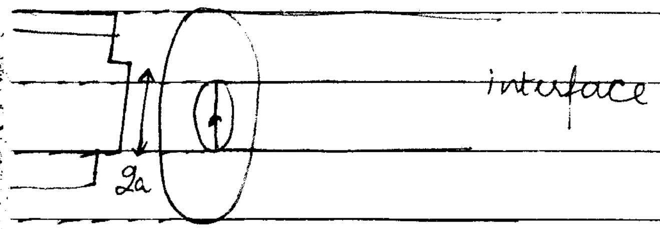


(ii) On the basis of core:

(a) Step-Index Fibre.

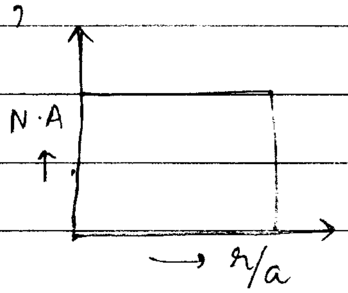
Step Index Fibre:

1. If the R.I. of core is constant throughout the core region and it abruptley changes to the R.I. of cladding at core-cladding inteface.



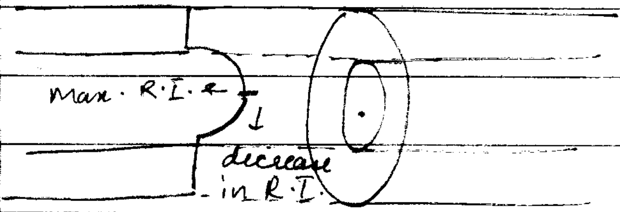
2. Numerical Aperture is given by: $N.A. = \sqrt{\frac{n_1^2 - n_2^2}{n_0^2}}$

3. If we draw graph b/w N.A. and r/a,



Graded Index Fibre:

1. R.I. of core is not constant throughout the core region i.e. R.I. of core goes on decreasing as a function of radial distance from the centre of core.



$$n(r) = n_1\left[1 - 2\Delta\left(\frac{r}{a}\right)^{\alpha}\right]$$

n_1 = refractive index of core

Δ = fractional R.I.D

$n(r)$ = R.I. at any point from the centre of core.

r = any distance from the centre of core.

α = any dimensionless param.

At $r = a$ i.e. at core-cladding interface

$$\boxed{n(r) = n_1\left[1 - 2\Delta\right]^{1/2}}$$

$(1+x)^n$ if $n < 1$

$1 + nx + \ldots$

Applying Binomial Thm:

$$n(r) = n_1\left(1 - \frac{1}{2} \times 2\Delta\right)$$

$$\boxed{n(r) = n_1(1 - \Delta)}$$

We know that:

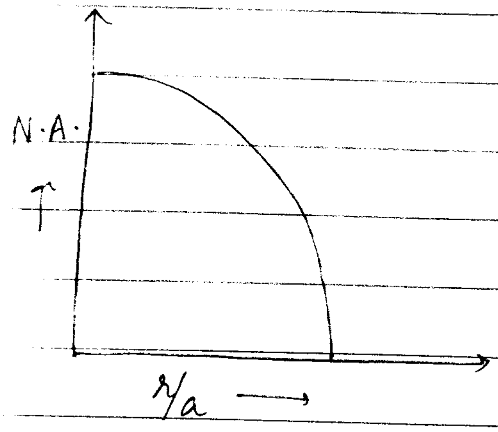
$$\Delta = \frac{n_1 - n_2}{n_1}$$

$\Rightarrow \quad \Delta n_1 = n_1 - n_2$

$\Rightarrow \quad n(r) = \cancel{n_1} - \cancel{n_1} + n_2$

$$\boxed{n(r) = n_2}$$

$$N.A. = \sqrt{\frac{n(r)^2 - n_2^2}{n_0^2}}$$



It can sustain multimode only.

$$N_m = \frac{V^2}{4}$$

These provide much larger bandwidths as compared to ~~(graded)~~ Step-index.

Step Index

4. It can sustain single mode as well as multimode.

5. Maximum no. of modes –

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

V = normalised frequency

6. Step index fibre comparatively provide less band width as compared to graded index. Data rate transmission is less.

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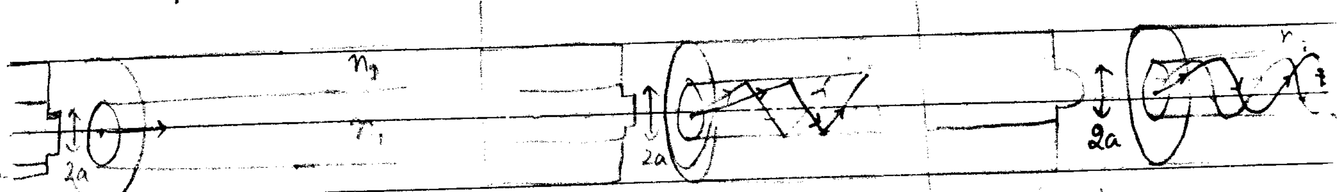
Why it is not possible to have graded index fibre as single mode optical fibre?

Step-Index Single Mode / Monomode	Step Index Multimode	Graded Index Multimode



core diameter = 8-12 μm	Core diameter = 50-100 μm	Core (2a) : 50-100 μm
cladding diameter = 125 μm	Cladding 2a = 125-400 μm	Cladding [illegible]

* It is not practically possible to fabricate core of very small diameter (8-12 μm) with varying refractive index.

Def. of Single and Multimodes.

RELATION B/W FRACTIONAL RID (Δ) and Numerical Aperture

$$\Delta = \frac{n_1 - n_2}{n_1}$$

$$N.A. = \sin \alpha_{max}$$

$$= \sqrt{\frac{n_1^2 - n_2^2}{n_0^2}}$$

$$n_1^2 - n_2^2 = (n_1 - n_2)(n_1 + n_2)$$

Multiplying and dividing by $2n_1$

$$n_1^2 - n_2^2 = \left(\frac{n_1 - n_2}{n_1}\right)\left(\frac{n_1 + n_2}{2}\right) 2n_1$$

$$n_1^2 - n_2^2 = \Delta \left(\frac{n_1 + n_2}{2}\right) 2n_1$$

$n_1 \approx n_2$ (As there is very slight diff. b/w core & cladding)

$$n_1^2 - n_2^2 = \Delta \left(\frac{2n_1}{2}\right) \times 2n_1$$

$$= 2\Delta n_1^2$$

$$\sqrt{\frac{n_1^2 - n_2^2}{n_0^2}} = \sqrt{\frac{2\Delta n_1^2}{n_0^2}}$$

$$\Rightarrow \boxed{N.A. = \frac{n_1}{n_0}\sqrt{2\Delta}}$$

NORMALISED FREQUENCY OR V-NUMBER:

It is a dimensionless parameter which tells us abt the type of Optical fibre.

* If $V < 2.405$, then OFC (Optical Fibre Cable) is single mode fibre

* If $V > 2.405$, then OFC is Multimode fibre.

$$\boxed{V = \frac{2\pi a}{\lambda} \times N.A.}$$

a = radius of core

λ = wavelength of incident light passing thru the core of OFC.

$$V = \frac{2\pi a}{\lambda} \times \sqrt{\frac{n_1^2 - n_2^2}{n_0^2}}$$

* If $V = 2.405$

then λ = cutoff wavelength / minimum wavelength.

Scientific Calculator
f82x

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① An optical fibre has N.A. of 0.15 and a core R.I. of 1.50. Find the N.A. of same optical fibre in a liquid of R.I = 1.30

N.A. = 0.15 (in air)

$n_1 = 1.50$

$n_2 = ?$

$n_0 = 1$

$$0.15 = \sqrt{\frac{2.25 - n_2^2}{1}}$$

$$0.15 = 2.25 - n_2^2$$

$$n_2^2 = 2.25 + 0.15$$

$$= 2.40$$

$$n_2 = 1.49$$

$$N.A. = \sqrt{\frac{(1.50)^2 - (1.49)^2}{(1.30)^2}}$$

② What will be the critical angle for a ray for whi[ch] $n_1 = 1.53$, and has cladding of R.I. = 2.5% less

$$n_2 = 1.53 - \frac{2.5}{100} \times 1.53$$

$$= 1.53 - \frac{25 \times 153}{10000}$$

$$= 1.53 - 0.382$$

$$= 1.15$$

11
15
62
76
306
382
1.53
0.38
0.15

A step index fibre supports approx. 1200 modes at 0 nm wavelength. If the light gathering capibility 0.20, calculate diameter of core.

$\lambda = 900 nm$

No. of modes = 1200

$N.A. = 0.20$

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

$$V = \sqrt{2 \times 1200}$$

$$= \sqrt{2400}$$

$$= \sqrt{24} \times 10$$

$$= 49$$

$$V = \frac{2\pi a}{\lambda} \times N.A.$$

$$= \frac{\pi d}{900 \times 10^{-9}} \times 0.2$$

$$= 3.14 \times d \times 0.2$$

4) A single mode OF is made with core diameter of 10 μm and it is coupled to diode laser that produces 1.3 μm light. If core glass has R.I. of 1.55, then find

(i) Maximum value reqd. for the normalised index difference (Δ)

(ii) Refractive index reqd. for the cladding glass.

(iii) Find the maximum ~~refractive index~~ value of α.

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$$\cancel{\Delta = \frac{n_1}{n_0}} \qquad N.A. = \frac{n_1}{n_0}\sqrt{2\Delta}$$

$$n_0 = 1$$

$$N.A. = n_1\sqrt{2\Delta}$$

$$(N.A)^2 = n_1^2 \times 2\Delta$$

$$\frac{(NA)^2}{n_1^2 \times 2} = \Delta$$

$$V = \frac{2\pi a}{\lambda} \times N.A.$$

$$2.405 = \frac{2\pi \times 5 \times 10^{-6}}{1.3\ \mu m} \times N.A.$$

$$N.A. = \frac{2.405 \times 1.3}{2\pi \times 5 \times 10^{-6}}$$

$$= 0.0995$$

$$\Delta = \frac{(0.0995)^2}{(1.55)^2 \times 2}$$

$$= 0.00206$$

$$\Rightarrow \quad N.A. = \sqrt{\frac{n_1^2 - n_2^2}{n_0^2}}$$

$$(0.0995)^2 = \frac{1}{} n_1^2 - n_2^2$$

$$n_2 = n_1(1-\Delta)$$

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Applied Physics - Numericals

1) $n_1 = 1.48$

$n_2 = 1.46$

$$N.A. = \sqrt{\frac{n_1^2 - n_2^2}{n_0^2}}$$

$$= \sqrt{\frac{(1.48)^2 - (1.46)^2}{(1)^2}}$$

$$= \sqrt{2.19 - 2.13}$$

$$= \sqrt{0.06}$$

$$= \frac{2.4}{10} = 0.24$$

$$\begin{array}{r} 2.19 \\ 2.13 \\ \hline 0.06 \end{array}$$

$$\sqrt{\frac{6}{100}}$$

$N.A. = \sin \alpha_{max}$

$0.24 = \sin \alpha_{max}$

$\alpha_{max} = \sin^{-1}(0.24)$

2) $N.A = 0.2441$

$n_0 = 1.3$

$$0.2441 = \sqrt{\frac{n_1^2 - n_2^2}{(1)^2}}$$

$\Rightarrow \quad 0.2441 = \sqrt{n_1^2 - n_2^2}$

$\Rightarrow \quad \sqrt{n_1^2 - n_2^2} = 0.2441$

$\Rightarrow \quad N.A. = \frac{0.2441}{\sqrt{(1.3)^2}}$

$$= \frac{0.2441}{1.3000}$$

$$= \frac{2441}{13000} = 0.187$$

~~0.244~~

24
64
96
288

(3) $N.A. = 0.2441$

$n_1 = 1.5$

$$N.A. = \sqrt{\frac{n_1^2 - n_2^2}{n_0^2}}$$

$$\Rightarrow 0.2441 = \sqrt{\frac{(1.5)^2 - n_2^2}{(1)^2}}$$

$$\Rightarrow (0.2441)^2 = (1.5)^2 - n_2^2$$

$$\Rightarrow (0.2441)^2 = \cancel{(1.5)^2 - n_2} \; 2.25 - n_2^2$$

$$\Rightarrow 0.059 = 2.25 - n_2^2$$

$$n_2^2 = 2.250 - 0.059 = 2.191$$

$$n_2 = \sqrt{2.191} = 1.48$$

1.4
1 | 02.1910
−1
24 | 119
−96
28 | 2310

$$\sin\alpha_{max} = 0.2441$$

$$\alpha_{max} = \sin^{-1}(0.2441) = 14.13^\circ$$

1.000
0.002
0.998

(4) $n_2 = 1.5$

$\Delta = 0.002$

$\alpha_{max} = ?$

$$\Rightarrow N.A. = \frac{n_1\sqrt{2\Delta}}{n_0} = \frac{1.503}{1}\sqrt{2 \times 0.002} = 1.503\sqrt{0.004} = 1.503$$

$$\Delta = \frac{n_1 - n_2}{n_1}$$

$$\Delta n_1 = n_1 - n_2$$

$$0.002 n_1 = n_1 - 1.5$$

$$1.5 = n_1(1 - 0.002)$$

$$1.5 = n_1(0.998)$$

$$n_1 = \frac{1.5}{0.998}$$

$$n_1 = 1.503$$

$\sqrt{\frac{4}{1000}}$

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$N.A. = 1.503 \times 0.0632$

$= 0.094$

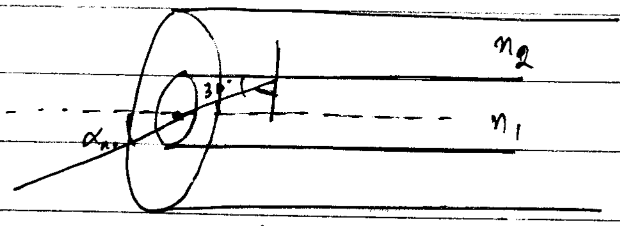
7) $N \cdot A = \sin \alpha_{max}$

$\alpha_{max} = \sin^{-1}(0.094)$

$= 5.45^\circ$

3) $\alpha_{max} = 30^\circ$

$n_1 = 1.50$, $n_2 = 1.49$, $n_0 = 1$



$\cancel{N \cdot A} = n_0 \sin \alpha_{max} = n_1 \times \sin(90^\circ - \theta)$

Applying Snell's law — $1 \times \sin 30^\circ = n_1 \cos\theta$

$$\frac{1}{2} = 1.5 \cos\theta$$

$$\Rightarrow \frac{1}{2 \times 1.5} = \cos\theta$$

$$\Rightarrow \frac{1}{3} = \cos\theta$$

$$\theta = \cos^{-1}\left(\frac{1}{3}\right)$$

$$= 70.5^\circ$$

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(8) $N \cdot A = 0.16$

$n_1 = 1.45$

$d_c = 6cm$

$\lambda = 0.9\mu m$

$\Rightarrow$ ~~N.A.~~

$$V = \frac{2\pi a}{\lambda} N \cdot A.$$

$$= \frac{2\pi a \times 0.16}{0.9 \times 10^{-6}}$$

$$= \frac{3.14 \times \cancel{6}^{2} \times 10^{-2} \times 0.16}{0.3\ \cancel{0.9} \times 10^{-6}}$$

$$= \frac{314 \times 2 \times 0.16 \times 10^{-2}}{30 \times 10^{-6}}$$

$$= \frac{628 \times 0.16 \times 10^{4}}{30}$$

$$= 3.349 \times 10^{4}$$

(9) $n_1 = 1.5$

$n_2 = 1.49$

$\lambda = 1.5 \times 10^{-6} m$

$a = 25 \times 10^{-6} m$

$$V = \frac{2\pi a}{\lambda} \sqrt{\frac{n_1^2 - n_2^2}{n_0^2}}$$

$$= \frac{2 \times 3.14 \times 25 \times \cancel{10^{-6}}}{1.5 \times \cancel{10^{-6}}} \times \sqrt{(1.5)^2 - (1.49)^2}$$

$$= \frac{6.28 \times \cancel{25}^{5} \times 10}{\cancel{15}\ 3} \times \sqrt{2.25 - 2.22}$$

$$= 2.093 \times 50 \times 0.1732$$

$$= 18.12 \approx 18$$

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$$N_m = \frac{V^2}{2} = \frac{(18)^2}{2} = \frac{\cancel{18}^{9} \times 18}{\cancel{2}} = 162$$

f) $L = 1km = 10^3 m$

$n_1 = 1.5$

$n_2 = 1.4$

diameter of core = 4mm

$a = 2mm$

$= 2 \times 10^{-3}$

$$N = \frac{L \tan\theta}{a} - 1$$

$$= \frac{10^3 \tan 30^\circ}{2 \times 10^{-3}} - 1$$

$$= \frac{10^3 \times 1}{2 \times 10^{-3} \times 1.732} - 1$$

$$= \frac{10^6}{3.464} - 1$$

$= 288682$

0.002
2 x 15
1000 10
149 225
149
1.497 76°

$\frac{2.25}{1.49}$

$= 1.05$

) $\Delta = 0.002$

App. Snell's law

$n_0 \sin\alpha = n_1 \times \sin i$

$\sin 15^\circ = 1.5 \times \sin i$

$$\sin i = \frac{1.5 \cancel{\times \sin i}}{\sin 15^\circ}$$

$$\Delta = \frac{n_1 - n_2}{n_1}$$

$$0.002 = \frac{1.5 - n_2}{1.5}$$

$0.003 = 1.5 - n_2$

$n_2 = 1.498$

Applying Snell's law at core-cladding interface:

$$\frac{1.5 \times 1.5}{\sin 15} = \sin r \; 1.49$$

$$\sin r = \frac{1.05}{\sin 15^\circ}$$