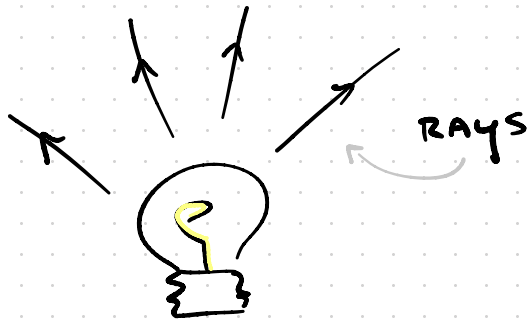
Lecture 24

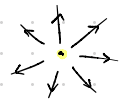
Ray optics, Reflection, & Refraction

Ray optics

- Optics is mainly concerned w/ the relationship between light, the objects around us, & the experience of Vision.
  - How does what we see relate to our surroundings & their illumination?
- A very simple model* can account for almost all* our everyday experience ("Ray Optics"):
  - Radiating objects emit light as rays:



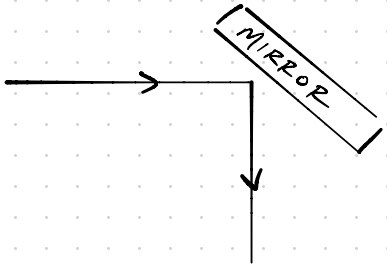
- More rays → brighter
- "point source": small object emitting rays equally in all directions:
  - e.g. light bulb when viewed from far away.



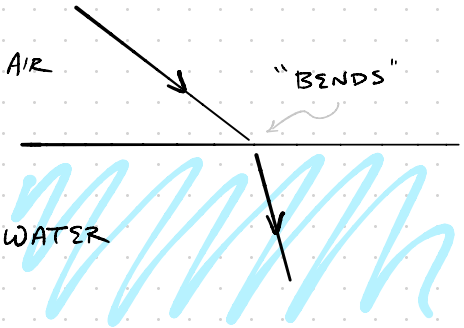
* Note that this model makes no mention of the electromagnetic nature of light.
* In its simplest form, ray optics cannot explain the effects of diffraction, interference, & polarization.

- RAYS TRAVEL IN STRAIGHT LINES UNTIL THEY THEY REFLECT, REFRACT, OR ABSORB:

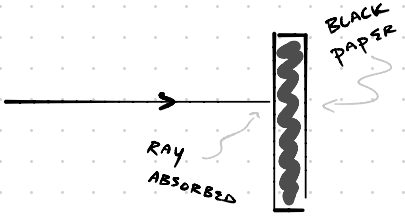
REFLECTION:



REFRACTION:

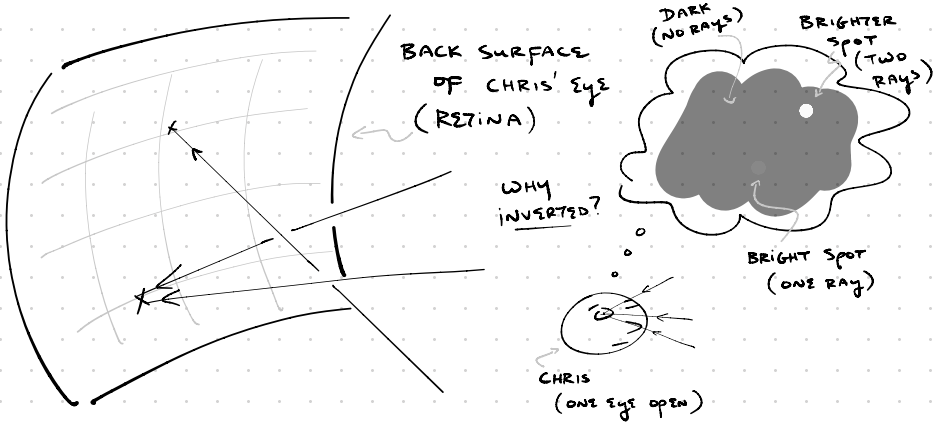


ABSORPTION:



*IGNORING COMPLICATIONS OF "STEREO" (TWO-EYED) VISION.

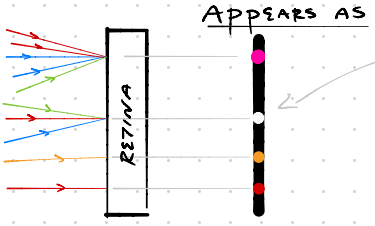
- WHAT WE SEE* IS A REPRESENTATION OF THE RAYS STRIKING THE BACK OF OUR EYES:



COLOR:

- ASSOCIATED W/ EACH RAY IS A COLOR, TAKING A VALUE ON THE SPECTRUM OF THE RAINBOW: ROYGBIV (I.E. NO GRAY OR BROWN RAYS).

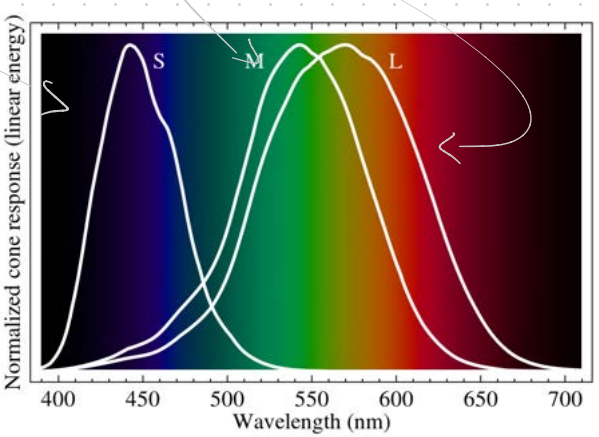
- PERCEPTION OF COLOR IS REPRESENTION OF THE MIXTURE OF RAY COLORS STRIKING THE BACK OF YOUR EYE, POINT BY POINT



- E.G. WHITE IS EVEN MIXTURE OF ALL RAY COLORS.

- DETAILS ON COLOR:
  - ASSOCIATED W/ EACH RAY COLOR IS A WAVELENGTH (λ) OF THE E.M. WAVE ASSOCIATED W/ THE RAY.
  - BIOLOGY: YOUR RETINA DETECTS LIGHT VIA:
    - RODS [$\emptyset$ COLOR SENSITIVITY] +
    - CONES [3 TYPES]:
      - S [BLUE SENSITIVE]
      - M [GREEN SENSITIVE]
      - L [RED SENSITIVE]

- SIGNALS FROM S, M, & L CONES COMBINE TO DETERMINE PERCEIVED COLOR



* AKA "CAMERA OBSCURA"

IMAGE FORMATION

- TEMPORARILY IGNORING COMPLICATIONS DUE TO LENS OF THE EYE, WE CAN TREAT EYE AS A "PIN-HOLE CAMERA*":

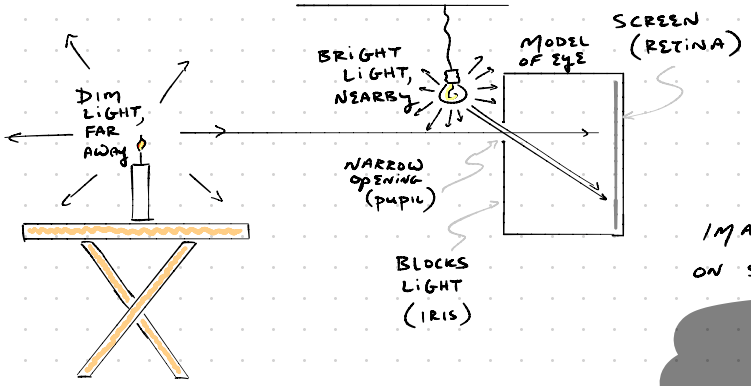
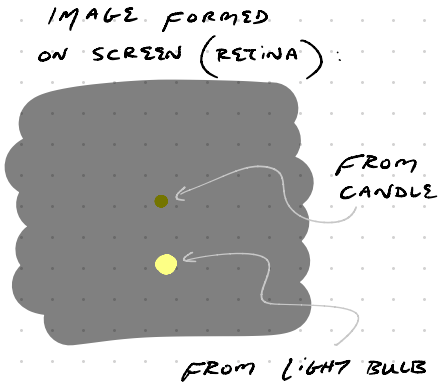


IMAGE INVERTED:

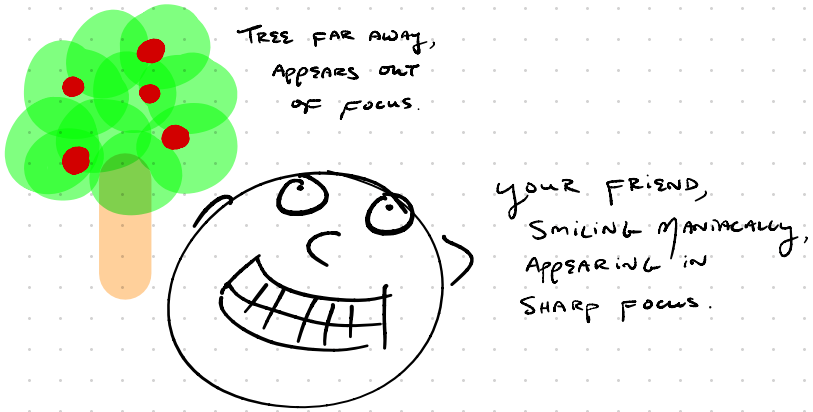
BULB APPEARS BELOW CANDLE, OPPOSITE TO OBJECTS' ARRANGEMENT IN SPACE*



- PUPIL + IRIS ACT AS AN "APERTURE", BLOCKING RAYS SO THAT THERE IS A DEFINITE RELATIONSHIP BETWEEN DIRECTION OF RAYS ENTERING EYE AND WHERE THEY CAME FROM.

* YOUR BRAIN FLIPS THIS INVERTED IMAGE FOR YOUR CONVENIENCE :)

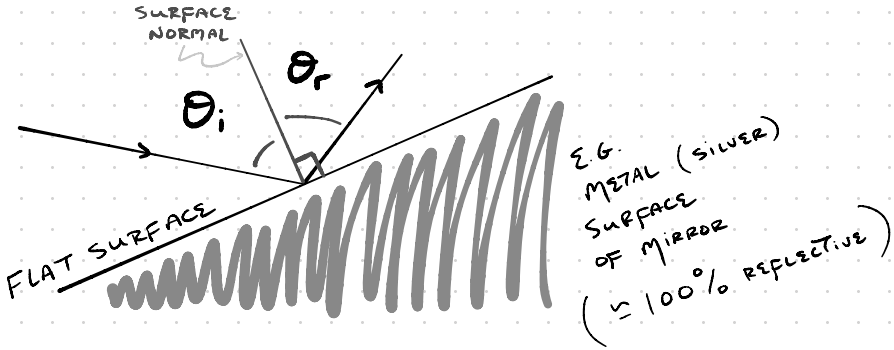
- PINHOLE CAMERA MODEL OF EYE PROVIDES QUALITATIVE EXPLANATION OF IMAGE FORMATION, BUT DOES NOT EXPLAIN WHY SOME OBJECTS ARE "IN FOCUS" [SHARPLY DEFINED], WHILE OTHER OBJECTS ARE "OUT OF FOCUS" [APPEAR FUZZY / BLURRY]:



- LATER WE SEE HOW REFRACTION OF LIGHT AT THE LENS OF THE EYE ACCOUNTS FOR FOCUSSING EFFECTS OF VISION.

• REFLECTION

• WHEN RAYS STRIKE A FLAT* SURFACE, SOME BOUNCE OFF ACCORDING TO "LAW OF REFLECTION":



LAW OF REFLECTION

$$\theta_i = \theta_r$$

"ANGLE OF INCIDENCE EQUALS ANGLE OF REFLECTION"

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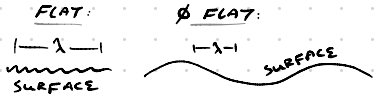
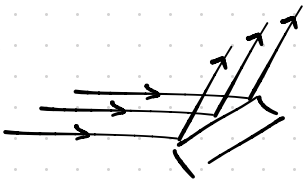
*FLAT MEANS NO BUMPS LARGER THAN THE WAVELENGTH OF LIGHT:



Specular & Diffuse Reflection

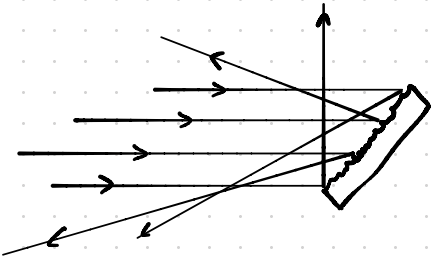
Specular Reflection:

- As described on previous page – light scatters according to law of reflection:



Diffuse Reflection

- For non-flat ("rough") surfaces, light scatters off surface in [roughly] all directions:

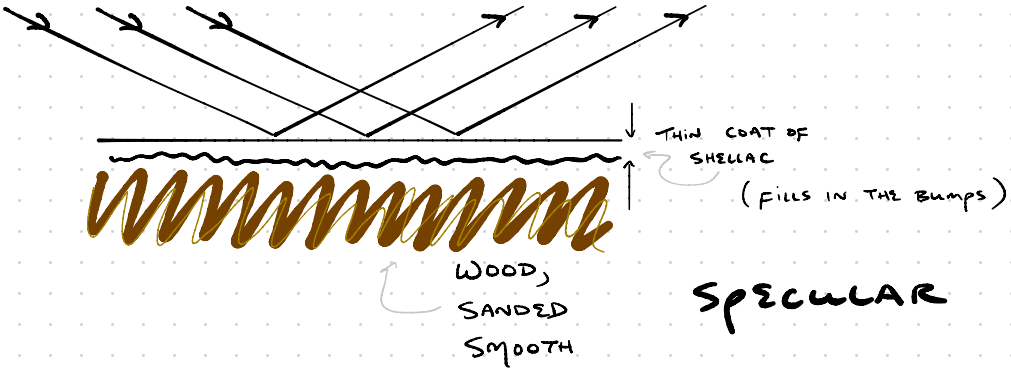


- EVERY POINT ON A DIFFUSELY REFLECTING SURFACE ACTS AS A POINT SOURCE WHEN ILLUMINATED:

E.G. PIECE OF RAW, UNFINISHED WOOD:

DIFFUSE

- COMPARE TO PIECE OF WOOD THAT IS SANDED SMOOTH AND COATED W/ SHELLAC*:



SPECULAR

* BUG SECRETIONS!

REFRACTION / DISPERSION

- SPEED OF LIGHT DEPENDS ON MATERIAL IT TRAVELS IN.
- MATERIAL IS CHARACTERIZED BY "INDEX OF REFRACTION", DENOTED n, WHERE:

$$v = \frac{c}{n}$$

(v: speed of light in material w/ index of refraction $= n$; c: speed of light in vacuum)

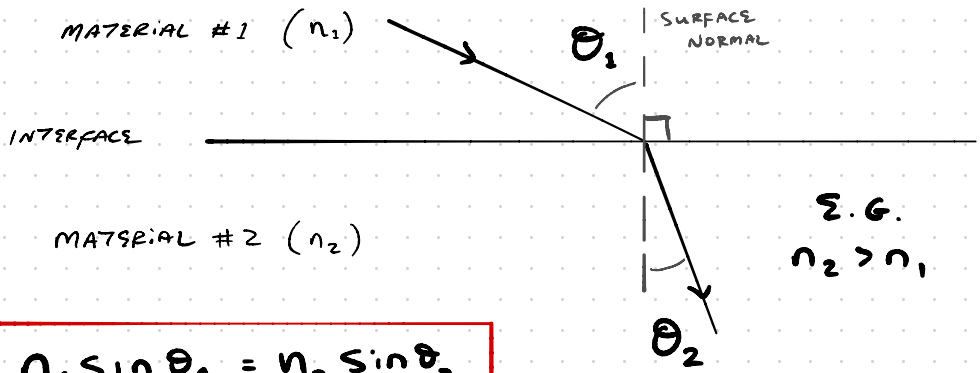
- $n \geq 1$ (LIGHT* NEVER TRAVELS FASTER THAN c)
- SOME IMPORTANT INDEXES OF REFRACTION:

	n
VACUUM [EMPTY SPACE]	1
AIR (@ STP)	1.00029
WATER (@ 20°C)	1.33
GLASS	$\approx$ 1.5–1.6

* OR ANYTHING, FOR THAT MATTER!

REFRACTION / SNELL'S LAW*

- AT A FLAT INTERFACE BETWEEN TWO MATERIALS W/ INDEXES OF REFRACTION $n_1 \neq n_2$, LIGHT WILL BEND ACCORDING TO SNELL'S LAW*:



$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

- "LIGHT BENDS TOWARDS (AWAY FROM) MATERIAL OF HIGHER (LOWER) INDEX OF REFRACTION."

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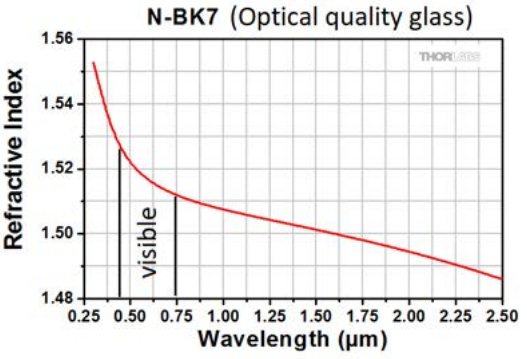
* IN ADDITION TO REFLECTING
* EVIDENCE INDICATES THAT PERSIAN PHYSICIST IBN SAHL (IN 984 A.D.) WAS THE FIRST TO DESCRIBE THIS LAW.

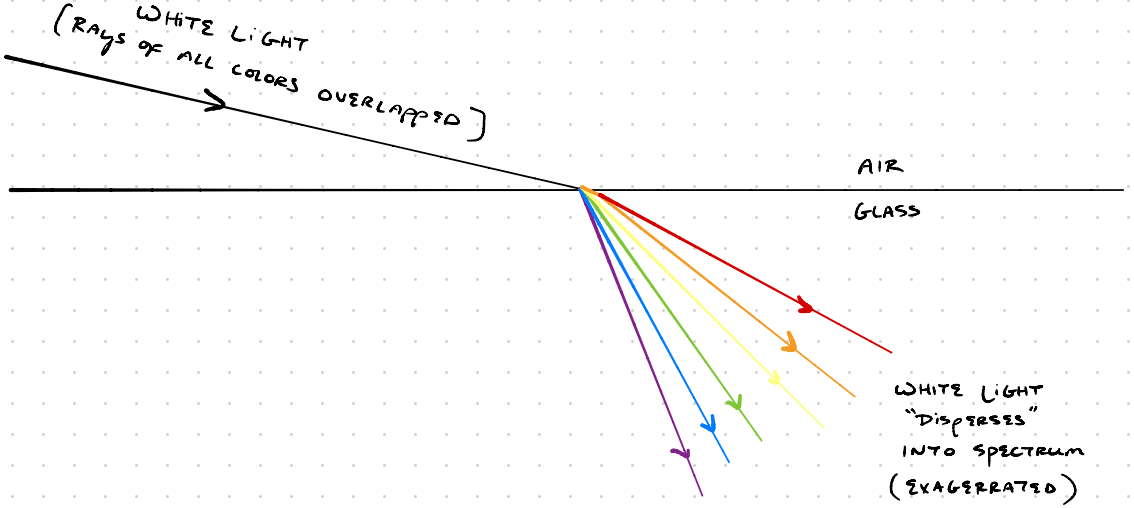
Dispersion

- INDEX of REFRACTION ALSO VARIES W/ COLOR (I.E. WAVELENGTH λ).

E.G. GLASS

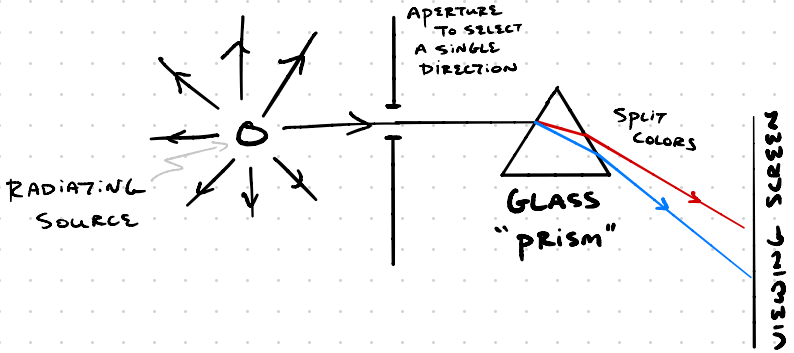
- Typically n DECREASES W/ INCREASING λ →





Application: Prism Spectrometer

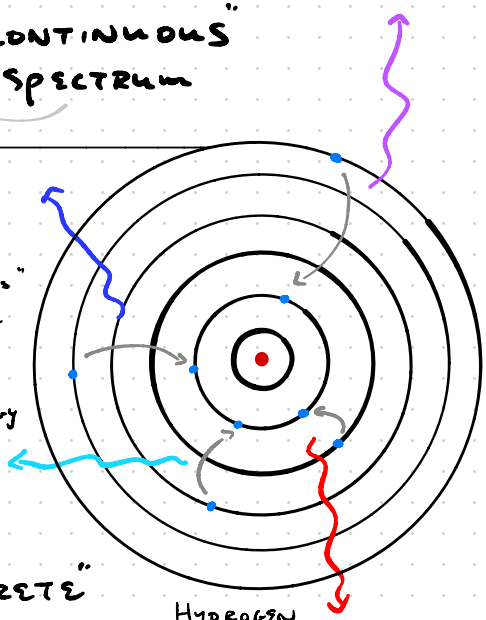
- Can analyze "spectrum" of radiating objects:



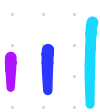
E.G. Spectrum of lightbulb

"Continuous" spectrum

Viewing screen



E.G. Spectrum of Hydrogen lamp:

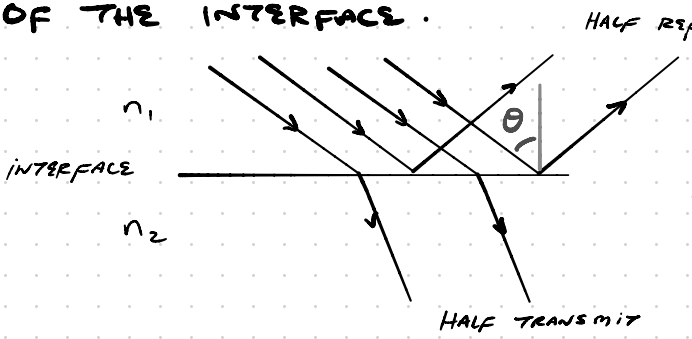


"Discrete" spectrum

Viewing screen

REFLECTIVITY

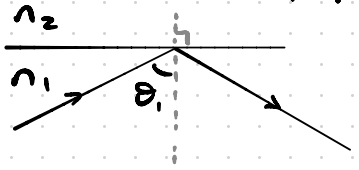
- THE FRACTION OF RAYS THAT REFLECT @ AN INTERFACE IS CALLED THE REFLECTIVITY (R) OF THE INTERFACE.



E.G. $R = 50\%$

- DEPENDS ON ANGLE OF INCIDENCE (θ) AS WELL AS n_1 & n_2 *

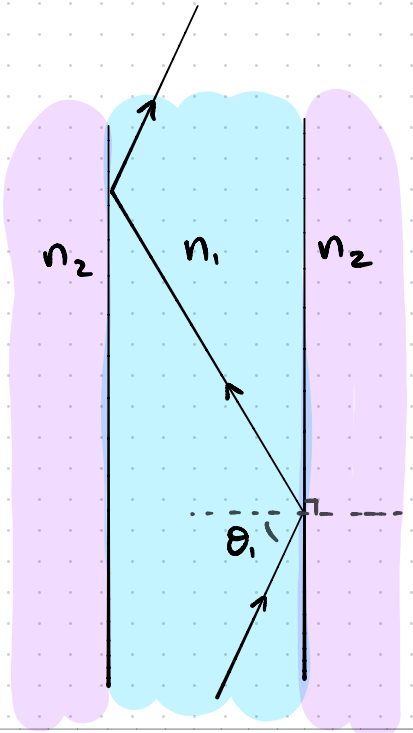
- EXAMPLE: TOTAL INTERNAL REFLECTION.



"CRITICAL ANGLE"

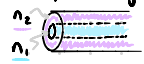
FOR $\theta_1 > \arcsin\left(\frac{n_2}{n_1}\right) \equiv \theta_c$

RAYS REFLECT W/ 100% PROBABILITY!



APPLICATION: FIBER OPTICS →

- CONSTRUCTED FROM A "CORE" OF INDEX n_1 SURROUNDED BY CLADDING OF INDEX $n_2 < n_1$. RAYS ENTERING CORE @ ANGLE $\theta_1 > \theta_c$ CAN TRAVEL ALONG FIBER INDEFINITELY BECAUSE OF TOTAL INTERNAL REFLECTION.



* AS WELL AS THE POLARIZATION OF THE INCOMING LIGHT. POLARIZATION IS NOT COVERED IN THESE NOTES.