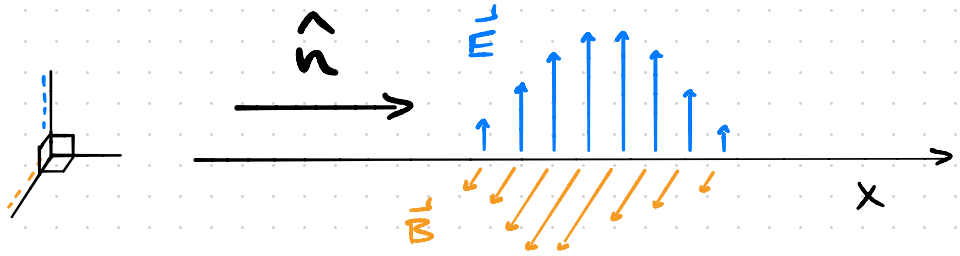
Lecture 27 Notes

Polarization of Light

IN OUR DISCUSSION OF BOTH RAY & WAVE OPTICS, WE HAVE MADE NO MENTION OF THE TRANSVERSE NATURE OF E.M. WAVES:

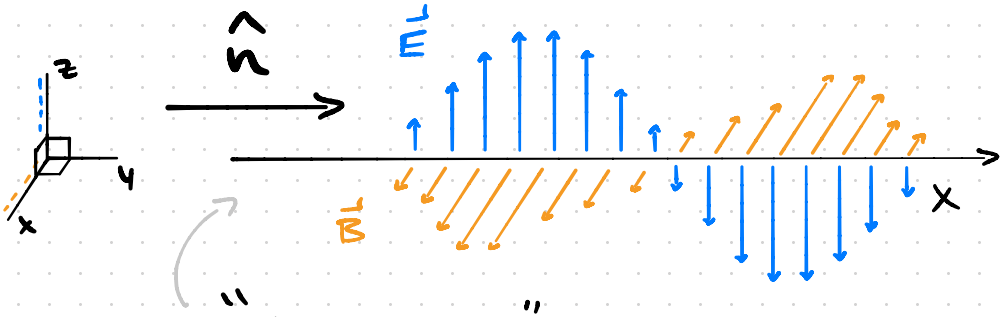


$\vec{E}$ & $\vec{B}$ lie $\perp$ to $\hat{n}$, the DIRECTION OF PROPAGATION.

- WHAT EFFECTS ARE ASSOCIATED W/ THE POLARIZATION OF LIGHT, i.e. THE DIRECTION IN WHICH A WAVE'S $\vec{E}$ FIELD OSCILLATES?

POLARIZED VS. UNPOLARIZED LIGHT

- LIGHT IS CONSIDERED POLARIZED WHEN ITS ELECTRIC FIELD LIES AT ALL INSTANTS IN TIME & POINTS IN SPACE ALONG SOME FIXED DIRECTION*:

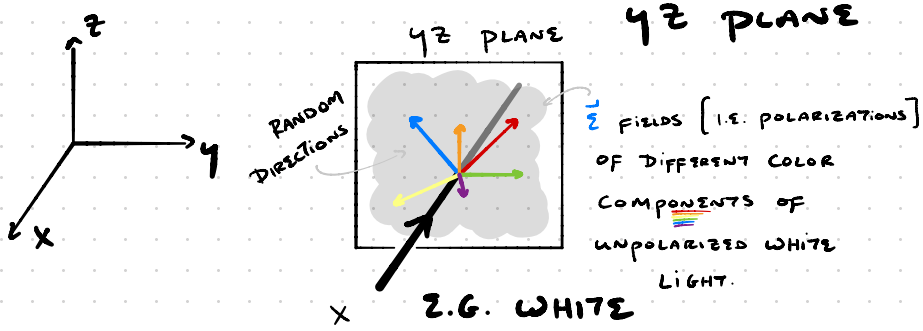


"LINEARLY" POLARIZED IN Z-DIRECTION

- EXAMPLES:
  - LASER LIGHT
  - MONOCHROMATIC LIGHT

* THIS DEFINITION IS ACTUALLY TOO RESTRICTIVE AND OMITS CIRCULARLY POLARIZED LIGHT. THE DEFINITION ABOVE MORE ACCURATELY DEFINES LINEARLY POLARIZED LIGHT.

- UNPOLARIZED LIGHT IS THE SUPERPOSITION OF MANY DIFFERENT MONOCHROMATIC WAVES, WHERE EACH WAVE HAS A RANDOM DIRECTION OF POLARIZATION:

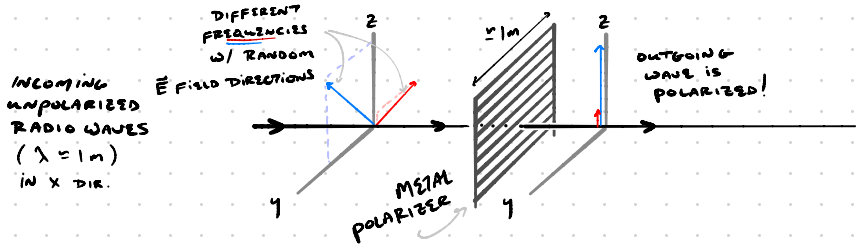


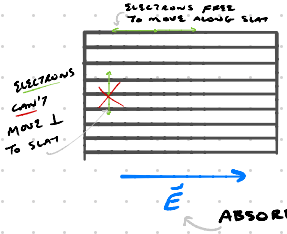
- MOST SOURCES OF LIGHT ARE UNPOLARIZED:
  - DIRECT SUNLIGHT
  - INCANDESCENT LIGHT-BULBS
  - LEDs
  - FLUORESCENT LIGHTS

- NOTE! JUST BECAUSE A LIGHT SOURCE APPEARS TO BE A SINGLE COLOR (E.G. A RED L.E.D.) DOES NOT MEAN IT IS MONOCHROMATIC & THEREFORE POLARIZED. SUCH LIGHT MAY CONSIST OF MANY WAVES OF SIMILAR COLOR (I.E. WAVELENGTH), EACH RANDOMLY POLARIZED.

Polarization By Selective Absorption

- So How Do We polarize Light That is unpolarized?
- W/ A polarizer of Course! :)
- A illuminating Example is a Metal polarizer for Radio waves:





Metal polarizer: Metal slats can absorb $\vec{E}$ fields running parallel to slats

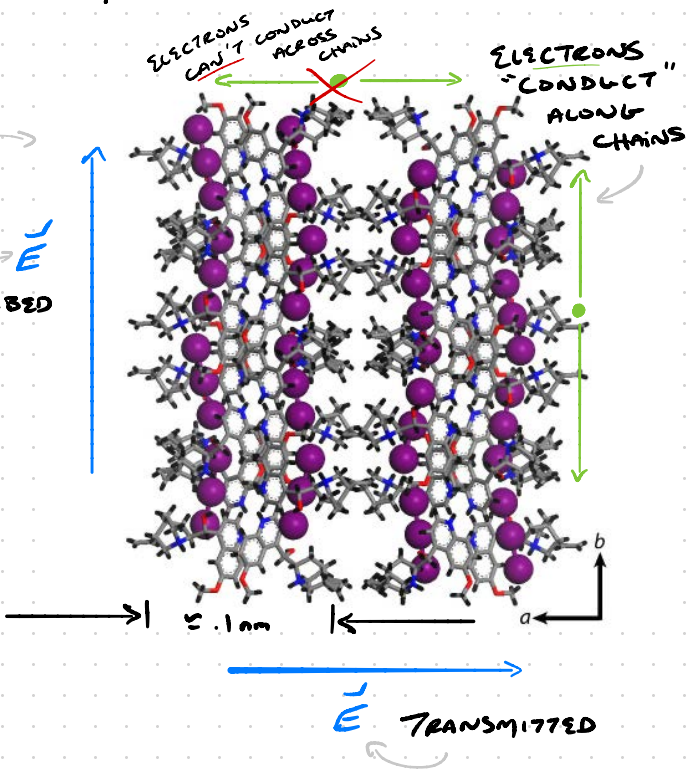
- Electrons "have room" to respond in this direction.

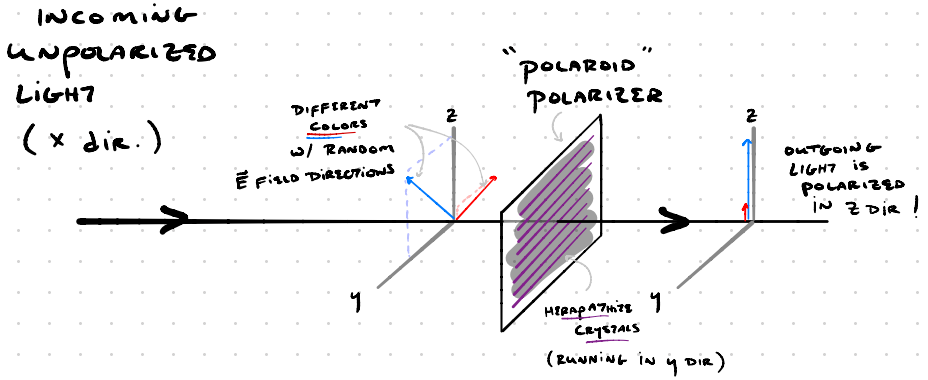
- Doesn't work for visible light (λ too short)
- Is their a material that looks like the Metal polarizer on a Microscopic scale?

POLAROIDS : POLARIZERS FOR VISIBLE LIGHT

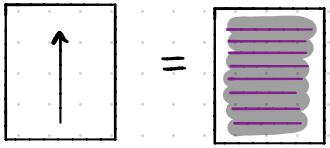
- CAN MAKE FILM OF HERAPATHITE CRYSTALS

- LONG CRYSTALS PLAY ROLE OF METAL SLATS, ABSORBING RADIATION POLARIZED IN A PARTICULAR DIRECTION.

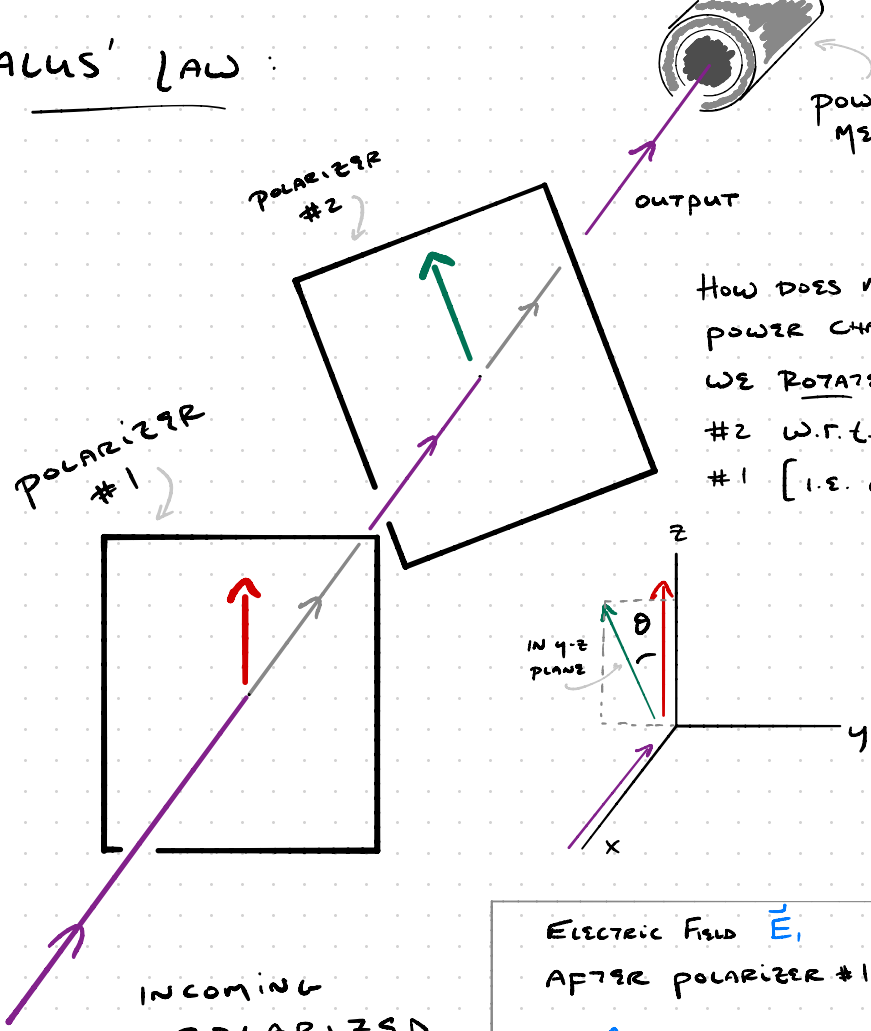




- SCHEMATICALLY, POLARIZERS ARE DENOTED BY SQUARES W/ AN ARROW DENOTING THE TRANSMITTED POLARIZATION:



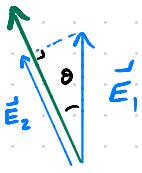
MALUS' LAW:



HOW DOES MEASURED POWER CHANGE AS WE ROTATE POLARIZER #2 W.R.T. POLARIZER #1 [I.E. W.R.T. θ]?

ELECTRIC FIELD $\vec{E}_1$ AFTER POLARIZER #1:

ELECTRIC FIELD $\vec{E}_2$ AFTER POLARIZER #2:



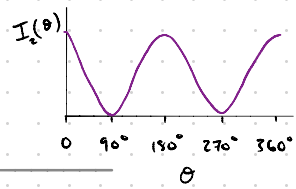
OUTPUT INTENSITY VS. θ:

$$|\vec{E}_2| = |\vec{E}_1| \cos\theta$$

$$I_2 \propto |\vec{E}_2|^2 \propto \cos^2\theta$$

MALUS' LAW

θ	P#1 vs. P#2	$I_2(\theta)$
0°	PARALLEL (∥)	MAX
90°	CROSSED (⊥)	MIN
180°	ANTI-∥	MAX
270°	CROSSED	MIN

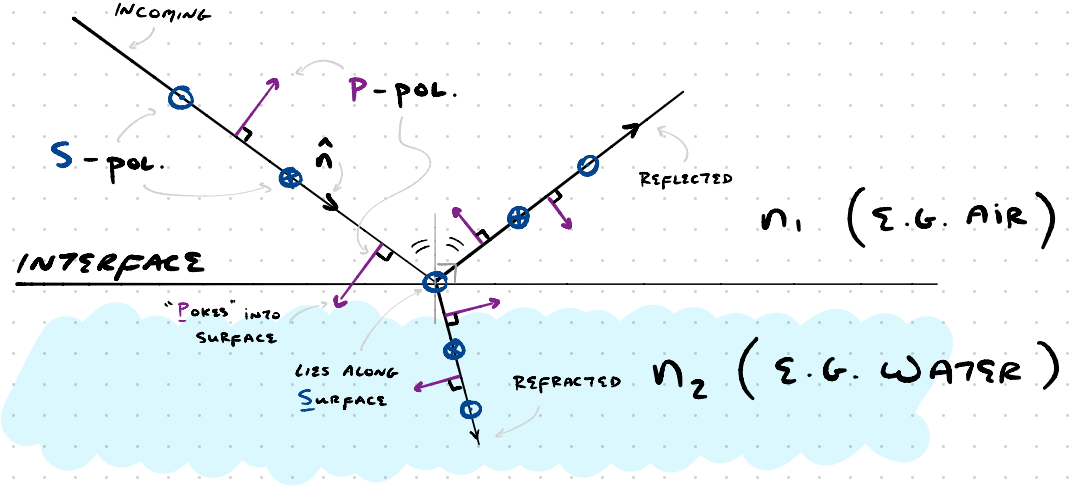


POLARIZATION BY REFLECTION:

S & P POLARIZATIONS:

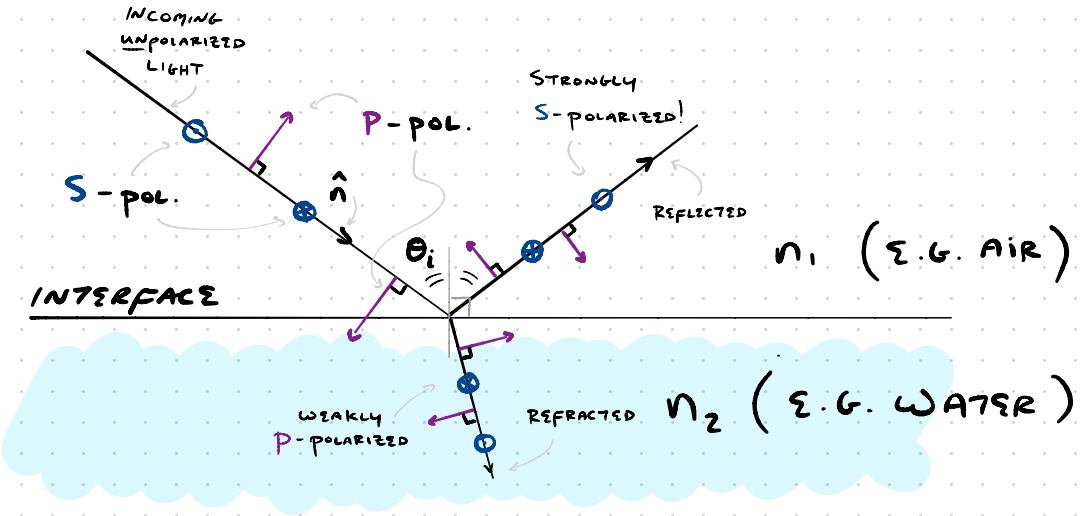
FOR LIGHT REFLECTING WE HAVE A NATURAL CATEGORIZATION (BASIS) OF POLARIZATIONS:

- "S" - POLARIZATION:
  - LIES || TO THE SURFACE WHERE REFLECTION OCCURS.
- "P" - POLARIZATION:
  - $\perp$ TO S-POLARIZATION. ("POKES" INTO SURFACE)
- BOTH S & P ARE $\perp$ TO PROP. DIR $\hat{n}$ [E.M. WAVES ARE TRANSVERSE AFTER ALL]

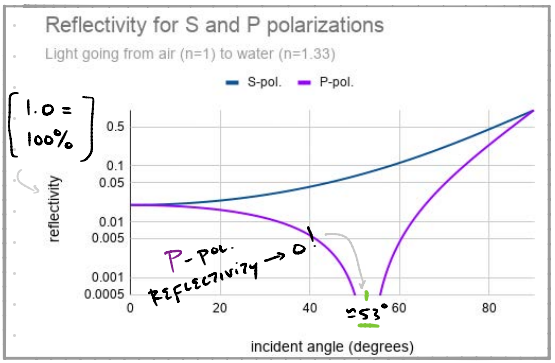


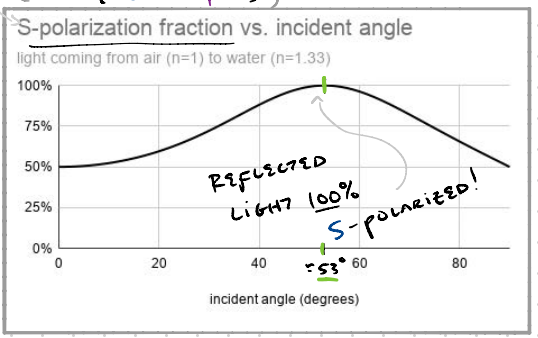
POLARIZATION BY REFLECTION:

- REFLECTIVITY OF INTERFACE DEPENDS ON POLARIZATION!
  - S-POL. REFLECTS BETTER THAN P.



$\left[I_s^{REFL} / \left(I_s^{REFL} + I_P^{REFL} \right) \right]$





- WHAT IS GOING ON HERE AROUND 53°?
  - WHY IS P-POL. LIGHT PERFECTLY TRANSMITTED?

POLARIZATION BY REFLECTION:

BREWSTER'S ANGLE

- FROM SNELL'S LAW:

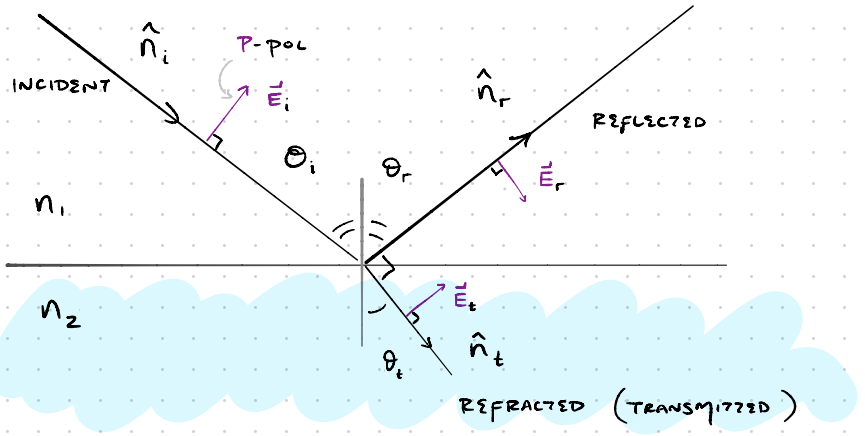
$$\theta_t = \arcsin\left[\frac{n_1}{n_2}\theta_i\right]$$

FOR AIR $[n_1 = 1]$ TO WATER $[n_2 = 1.33]$

@ $\theta_i = 53°$: $\longrightarrow \theta_t = 37°$

SO $\theta_i + \theta_t = \theta_r + \theta_t \approx 90°$

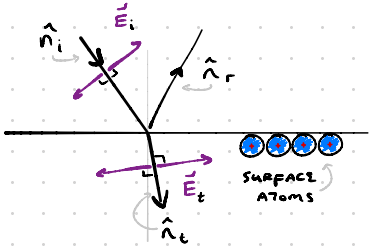
- ∅ REFLECTED P-POL $\curvearrowright$ $\hat{n}_t \perp \hat{n}_r \parallel \vec{E}_t$?!
  - WHAT IS THE CONNECTION HERE?

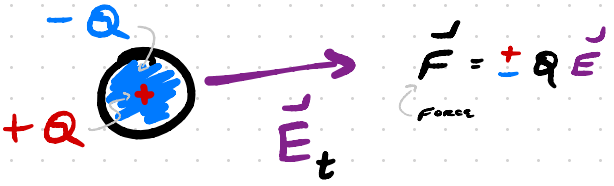


POLARIZATION BY REFLECTION:

BREWSTER'S ANGLE

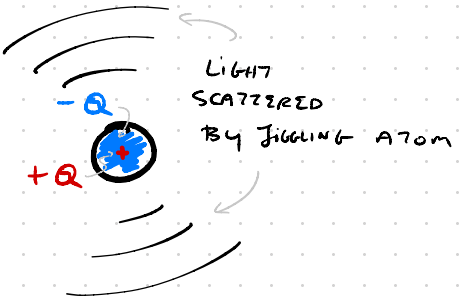
- MICROSCOPICALLY, REFLECTION IS CAUSED BY RADIATION FROM ATOMS/MOLECULES @ THE SURFACE:





1. OSCILLATING $\vec{E}_t$ "JIGGLES" SURFACE ATOMS BACK & FORTH...

2. ... AND THIS JIGGLING ENERGY IS RECONVERTED INTO SCATTERED LIGHT...



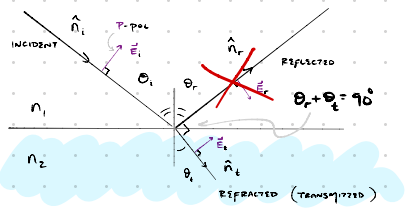
3. ... SOME OF WHICH CREATES THE REFLECTED WAVE & SOME WHICH MAKES UP THE REFRACTED [TRANSMITTED] WAVE...

4. ... BUT $\vec{E}$ FIELD OF SCATTERED WAVE IS $\parallel$ TO THE SAME $\vec{E}_t$ WHICH CAUSED THE JIGGLING...

[I.E. $\theta_r + \theta_t = 90^\circ$]

5. ... SO IF $\hat{n}_r \parallel \vec{E}_t$, THERE CAN BE NO REFLECTED WAVE, SINCE $\vec{E}_r \perp \hat{n}_r$!

[E.M. WAVES TRANSVERSE]



POLARIZATION BY REFLECTION:

BREWSTER'S ANGLE

- THE ANGLE @ WHICH $\theta_r + \theta_t = 90°$ & P-POL. REFLECTIVITY GOES TO ZERO IS KNOWN AS "BREWSTER'S ANGLE", DENOTED θ_B.

- BY SNELL'S LAW:

LAW OF REFLECTION $[\theta_i = \theta_r]$

$$n_1 \sin\theta_i = n_2 \sin\theta_t$$

$$n_1 \sin\theta_r = n_2 \sin\theta_t$$

@ $\theta_i = \theta_B$:

$\theta_t = 90° - \theta_r$

$= 90° - \theta_i$

$= 90° - \theta_B$

$$n_1 \sin\theta_B = n_2 \sin(90° - \theta_B)$$

$$n_1 \sin\theta_B = n_2 \cos(\theta_B)$$

TRIG. IDENTITY

$$\frac{\sin\theta_B}{\cos\theta_B} = \tan\theta_B = \frac{n_2}{n_1}$$

OR

$$\boxed{\theta_B = \arctan\left[\frac{n_2}{n_1}\right]}$$

QUICK CHECK:

FOR $n_1 = 1$ (AIR),

$n_2 = 1.33$ (H_2O),

$\theta_B = \arctan(1.33)$

$\approx 53.06°$ ✓