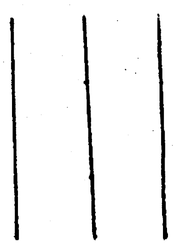
PHYS 2602 : PROPAGATION OF LIGHT, CHAPTER 33

WE'RE GOING TO STOP WORRYING ABOUT WHAT LIGHT IS MADE OF TO CONCENTRATE ON HOW IT BEHAVES. WE'LL BEGIN WITH THE PATH TAKEN BY A BEAM OF LIGHT, i.e., ITS PROPAGATION. TO SIMPLIFY MATTERS, WE'LL ASSUME WE HAVE SINGLE FREQUENCY (MONOCHROMATIC) LIGHT (WHICH A LASER BEAM IS AN EXAMPLE).

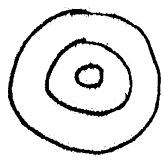
REPRESENTING WAVES – TO DRAW A PICTURE OF THE LIGHT'S PATH, IT USUALLY SUFFICES TO DRAW THE LIGHT'S RAYS. THESE ARE RELATED TO THE WAVE FRONTS.

WAVE FRONTS – SURFACES ON WHICH ALL POINTS THE WAVE IS AT THE SAME POINT IN ITS CYCLE. USUALLY WE PLOT THE LOCATIONS OF THE WAVE'S CRESTS.

FOR LIGHT, WE CHOOSE TO PLOT THE POINTS WHERE $E = E_0$.



PLANE WAVE

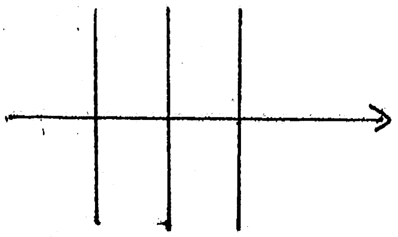


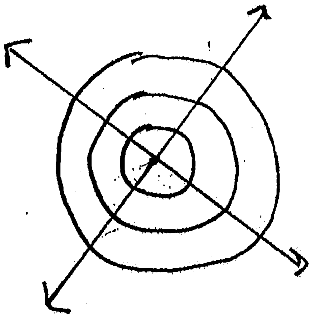
SPHERICAL WAVE

NOTE: BOTH OF THESE ARE 2D REPRESENTATIONS OF 3D SURFACES. THE SPHERICAL WAVE FRONTS, SHOULD BE CONCENTRIC SPHERES. THE PLANE WAVE FRONTS ARE PLANES THAT GO INTO AND OUT OF THE PAGE.

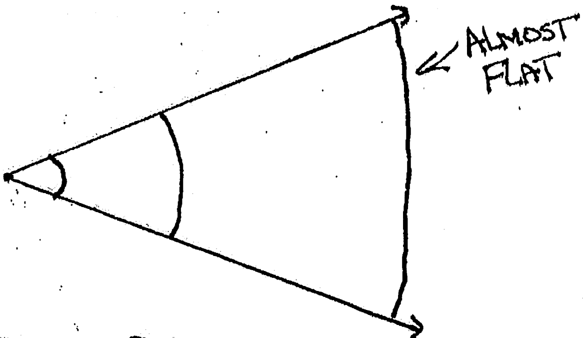
RAYS - LINES GIVING THE PROPAGATION DIRECTION.

BECAUSE LIGHT IS A TRANSVERSE WAVE, ITS WAVE FRONTS AND RAYS ARE ALLWAYS PERPENDICULAR TO EACH OTHER.





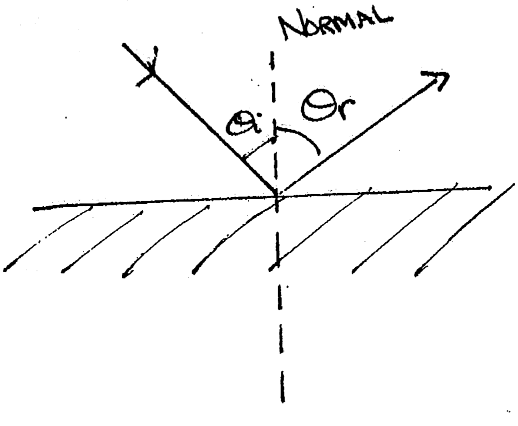
WE USE THE PLANE WAVE EQUATIONS NOT ONLY BECAUSE THEY ARE SIMPLE BUT BECAUSE VERY FAR FROM THEIR SOURCE, LIGHT IS APPROXIMATELY PLANAR.



AS A SPHERE'S RADIUS INCREASES, ITS CURVATURE DECREASES MAKING IT ALMOST STRAIGHT.

GEOMETRIC OPTICS - PROBLEMS IN WHICH THE WAVE FRONTS DON'T AFFECT THE PROPAGATION SO WE ONLY SKETCH THE RAYS.

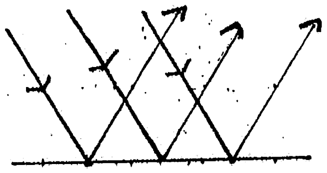
REFLECTION - WHEN LIGHT STRIKES A SHINY OBJECT, IT BOUNCE OFF, OR REFLECTS, OFF THE SURFACE. THE PATH TAKEN BY LIGHT IS VERY PARTICULAR AND IS GIVEN BY THE LAW OF REFLECTION.



LAW OF REFLECTION: $\boxed{\theta_i = \theta_r}$

ANGLES ARE MEASURED RELATIVE TO THE NORMAL = LINE PERPENDICULAR TO THE SURFACE.

THERE ARE TWO CATEGORIES OF REFLECTION.



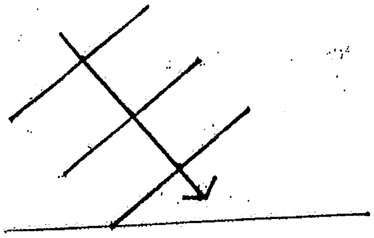
SPECULAR REFLECTION – PARALLEL RAYS ARE REFLECTED PARALLEL. FLAT MIRRORS PRODUCE SPECULAR REFLECTION.

DIFFUSE REFLECTION – PARALLEL RAYS ARE NOT REFLECTED PARALLEL BECAUSE FOR ROUGH SURFACES, THE NORMAL CHANGES FROM POINT TO POINT.

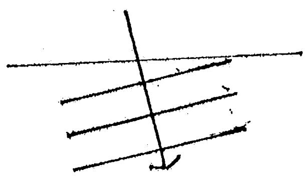
REFRACTION – NOT ALL LIGHT IS REFLECTED. SOME SURFACES ABSORB LIGHT AND ALLOW IT TO PROPAGATE ONWARD (TRANSPARENT MATERIALS). WHEN CHANGING MEDIA, THE LIGHT'S SPEED MUST ALSO CHANGE. THIS CHANGE IN SPEED CAUSES REFRACTION = CHANGE IN PROPAGATION DIRECTION.

ASIDE: THE OCCURANCE OF REFLECTION OR REFRACTION (OR ABSORPTION – THE DESTRUCTION OF A LIGHT WAVE BECAUSE A MOLECULE HAS ACQUIRED THE ENERGY IT CONTAINS) IS DEPENDENT ON THE LIGHT'S FREQUENCY. THIS DETERMINES AN OBJECT'S COLOR. FOR EXAMPLE, ROSES ARE RED BECAUSE THEY ABSORB ALL FREQUENCIES EXCEPT FOR RED (WHICH IS REFLECTED).

THE CHANGE IN DIRECTION CAN BE SEEN FROM THE WAVE FRONTS.



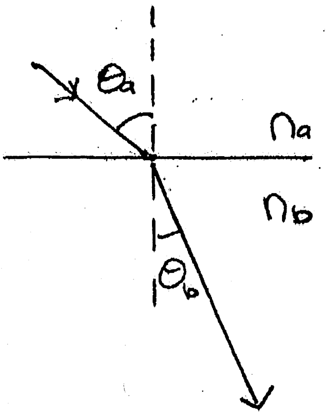
THIS PART TRAVELS SLOWER (OR FASTER) FIRST.



THE CHANGE IN SPEED CAUSES THE BEAM TO "SWIVEL".

THE CHANGE IN DIRECTION DEPENDS ON THE INDEX OF REFRACTION.

$n = c/v$ $\quad$ $n > 1$

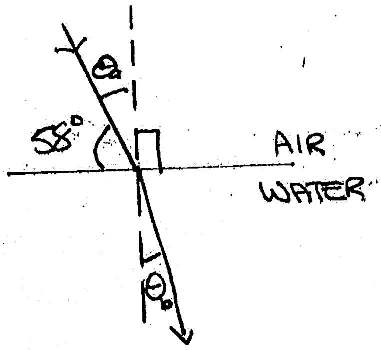


LAW OF REFRACTION (SNELL'S LAW) Willebrord

$$n_a \sin\theta_a = n_b \sin\theta_b$$

WHEN GOING FROM A FASTER MEDIUM TO A SLOWER ONE ($n_a < n_b$), $\theta_a > \theta_b$ ⇒ LIGHT BENDS TOWARDS THE NORMAL. (AND VICE-VERSA)

EXAMPLE – LIGHT STRIKES WATER AT 58° AS SHOWN. AT WHAT ANGLE DOES IT PROPAGATE IN THE WATER?



$\theta_a = 90° - 58° = 32°$, $n_a = 1$ (AIR IS APPROX VACCUM SPEED)

$\theta_b = ?$, $n_b = 1.333$ (p.1253)

$$(1)\sin 32° = (1.333)\sin\theta_b \Rightarrow \theta_b = \sin^{-1}\left(\frac{\sin 32°}{1.333}\right) = 23.4°$$

NOTE: THE FREQUENCY OF LIGHT DOES NOT CHANGE WHEN IT CHANGES MEDIA. FREQUENCY = $\frac{\#\text{cycles}}{\text{SECOND}}$ ⇒ FREQ. IS A MEASURE OF THE NUMBER OF CRESTS. WE DO NOT CREATE OR DESTROY CRESTS WHEN ENTERING A MEDIUM BECAUSE DOING SO WOULD VIOLATE CONSERVATION OF ENERGY.

$V = \lambda f$ ⇒ THE WAVELENGTH (DISTANCE BETWEEN CREST) MUST CHANGE.

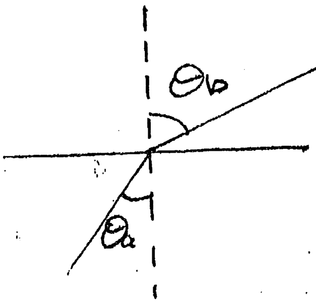
$$V_a = \lambda_a f_a, \quad V_b = \lambda_b f_b. \quad f_a = f_b \Rightarrow \frac{V_a}{V_b} = \frac{\lambda_a}{\lambda_b}$$

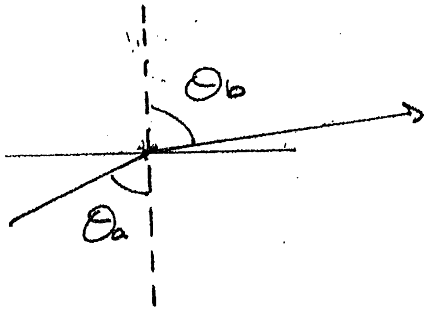
$$V_a = c/n_a, \quad V_b = c/n_b \Rightarrow \frac{n_b}{n_a} = \frac{\lambda_a}{\lambda_b} \Rightarrow \boxed{\lambda_b = \left(\frac{n_a}{n_b}\right)\lambda_a}$$

WHEN GOING FROM A FASTER MEDIUM TO A SLOWER ONE ($n_a < n_b$) ⇒

$\lambda_b < \lambda_a$,

Total Internal Reflection – Light striking a different medium is partially refracted AND reflected. When going from a slower medium to a faster one, it is possible to have 100% reflection.





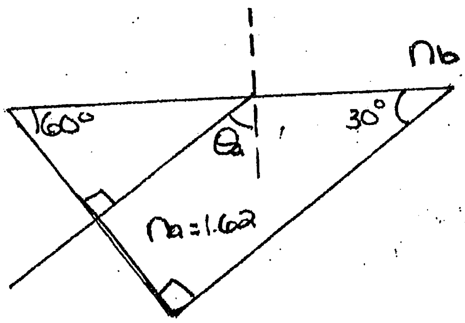
As θ_a increases, θ_b approaches 90°.

We define a critical angle θ_c as $\theta_a = \theta_c$ when $\theta_b = 90°$

$\Rightarrow n_a \sin\theta_c = n_b \sin 90° \Rightarrow$ $\boxed{\sin\theta_c = \frac{n_b}{n_a}}$

For $\theta_a > \theta_c$, the light is totally reflected.

Example: 33.46 p.1281

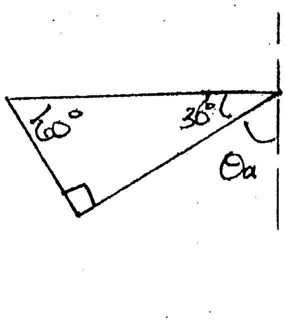


What n_b ensures total internal reflection?

$\theta_a = \theta_c$ when $\theta_b = 90° \Rightarrow n_a \sin\theta_a = n_b$

$\Rightarrow n_b = n_a \sin\theta_a$

θ_a is already determined by geometry



$\theta_a = 90° - 30° = 60°$

$\Rightarrow n_b = (1.62)\sin 60° = 1.40$