Reminders:

1) Assignment #12 → due Monday

2) Start Optics (Chapter 33)

3) Last HW (#13 posted) → due Monday, May 3rd
Reflection

\[ \theta_i = \theta_r \]

Refraction

\[ n_1 \sin \theta_1 = n_2 \sin \theta_2 \]
Index of Refraction

• Speed of light, $c$, in vacuum is $3 \times 10^8 \text{m/s}$

• Speed of light, $v$, in different medium can be $v < c$.

• Index of refraction, $n = \frac{c}{v}$.

• Frequency, $f$, does not change in wave eqn. of $v = f \lambda$,

• Wavelength, $\lambda$, depends on medium, $\lambda = \frac{v}{f} = \frac{c}{nf} = \frac{\lambda_0}{n}$

• In some media, $n$, depends on $f$, this is called dispersion.
Waves, wave front, rays (Y&F section 33.2)

Plane waves moving in +x direction

\[ \vec{E}(x, y, z, t) = E_0 \hat{y} \cos(kx - \omega t) \]
\[ \vec{B}(x, y, z, t) = B_0 \hat{z} \cos(kx - \omega t) \]

Wave front is a surface of constant phase

E field Wave front (y-z plane surface of constant phase)

Ray propagation
Huygen’s Principle (Y&F section 33.7)

- Huygen’s principle; a wave front can be a source of secondary wavelets the spread out in all directions at the speed of propagation in the medium. The envelope of leading edges forms a wave front.
- This principle was stated by Huygen in 1678, it is derivable from Maxwell’s eqn. It is a geometrical description of ray propagation.

Plane wave example;

Secondary wavelets create another wave front (plane)
Reflection from Huygen’s Principle

Consider wave fronts, separated by $vt$, the incident wave fronts in contact with the surface will create a wavelets according to Huygen’s Principle and leads to another “reflected” wave front. The result is $\theta_i = \theta_r$.
Refraction from Huygen's Principle

Now the speed changes, from medium a to medium b, so the Speed may change and the wavefront spacing differs.

\[ L \sin \theta_a = v_a t = c t / n_a \]
\[ L \sin \theta_b = v_b t = c t / n_b \]

Medium a, \( v_a = c / n_a \)

Medium b, \( v_b = c / n_b \)

\[ n_a \sin \theta_a = n_b \sin \theta_b \]

Snell's Law
Snell's Law (law of refraction)

Medium $a$, $v_a = c/n_a$

Medium $b$, $v_b = c/n_b$

Snell's Law

$$n_a \sin \theta_a = n_b \sin \theta_b$$
A ray of light passes from air into water with an angle of incidence of 30°. Which of the following quantities does not change as the light enters the water.

a) Wavelength
b) frequency
c) speed of propagation
d) direction of propagation.
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a) Wavelength
b) frequency
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d) direction of propagation.

Question 1
Question 2

• Which of the following ray diagrams could represent the passage of light from air through glass and back to air? \( (n_{\text{air}} = 1 \text{ and } n_{\text{glass}} = 1.5) \)

(a) \hspace{1cm} (b) \hspace{1cm} (c)
Question 2

• Which of the following ray diagrams could represent the passage of light from air through glass and back to air? \((n_{\text{air}}=1 \text{ and } n_{\text{glass}}=1.5)\)

(a) (b) (c)

• Since \(n(\text{glass}) > n(\text{air})\), \(\sin \theta(\text{glass}) < \sin \theta(\text{air})\).

• Therefore, moving from air to glass, ray will bend toward normal.
  • this eliminates (a).

• Moving from glass to air, ray will bend away from normal.
  • this eliminates (c).

• As a matter of fact, the final angle in air must be equal to the initial angle in air!!
EXAMPLE, from air into glass;

Suppose we have light in air (n=1) incidence on glass (n=1.55) at an angle $\theta_a = 45$ deg. What is the angle of the refracted light, $\theta_b$?

$$n_{air} \sin \theta_a = n_{glass} \sin \theta_b$$

$$(1) \sin(45^\circ) = (1.55) \sin \theta_b$$

$$\sin \theta_b = \frac{(1) \sin(45^\circ)}{1.55} = \frac{1}{1.55\sqrt{2}}$$

$$\theta_b = 27^\circ$$
EXAMPLE, from glass into air; Suppose we have light in glass (n=1.55) incident into air at an angle $\theta_a = 30$ deg. What is the angle of the refracted light, $\theta_b$?

$$n_{\text{glass}} \sin \theta_a = n_{\text{air}} \sin \theta_b$$

$$(1.55) \sin(30^\circ) = (1) \sin \theta_b$$

$$\sin \theta_b = (1.55) \sin(45^\circ) = \frac{1.55}{2}$$

$$\theta_b = 51^\circ$$
The ANITA Concept

~4km deep ice!

Typical balloon field of regard

balloon at ~37km altitude

cascade produces UHF-microwave EMP

antenna array on payload

antarctic ice sheet 1-3km

earth

0.1-100 EeV neutrinos

refracted RF

ice cascade 1-3 km

56° Cherenkov cone

~700km to horizon

observed area: ~1.5 M square km

~4km deep ice!
Refraction limits ANITA!

- ANITA at float (123Kft)
  - Seen through amateur telescope from the South Pole
  - Size of the Rose Bowl!
  - (thanks to James Roth)
“Mini-Antarctica” at Stanford Linear Accelerator
SLAC T486

- 2 mile long accelerator
- 28 Billion electron Volts
- If you’ve driven I-280 between San Francisco and San Jose
Problem!!!

\[ n_{\text{ice}} \sin \theta_a = n_{\text{air}} \sin \theta_b \]
\[ (1.8) \sin(34^\circ) = (1) \sin \theta_b \]
\[ \sin \theta_b = (1.8) \sin(34^\circ) = 1.0 \]
\[ \theta_b = 90^\circ \]

There is no escape!!!
. Problem

\[ n_{\text{ice}} \sin \theta_a = n_{\text{air}} \sin \theta_b \]
\[ (1.8) \sin(34^\circ) = (1) \sin \theta_b \]
\[ \sin \theta_b = (1.8) \sin(34^\circ) = 1.0 \]
\[ \theta_b = 90^\circ \]

. Solution = cut!

\[ n_{\text{ice}} \sin \theta_a = n_{\text{air}} \sin \theta_b \]
\[ (1.8) \sin(27^\circ) = (1) \sin \theta_b \]
\[ \sin \theta_b = (1.8) \sin(27^\circ) = 0.82 \]
\[ \theta_b = 54.8^\circ \]
Mini-Antarctica at Stanford Linear Accelerator

Cut ~7 degrees! (jackhammers, chainsaws, mauls not shown)
Let there be light! (OK, radio)
Suppose you are stranded on an island with no food. You see a fish in the water. Where should you aim your spear to hit the fish?

**ANSWER:** do not aim directly at the apparent position of the fish. Aim at the inside of the fish.
Suppose in the previous question instead of a spear you had a high power laser to simultaneously kill and cook the fish (in the water). Where should you aim the laser?

**ANSWER:** aim directly at apparent fish position as the laser beam will refract to the correct fish position.
For next time

• Homework #12 posted → due Monday

• The home stretch: optics/optical phenomenon
Key Instrument pieces

- CSBF
- CIP
- Battery box
- Instrument box
Launch: December 15, 2007
(after almost 2 agonizing weeks of waiting)

• A flawless launch
  – CSBF truly professional
  – After day after day after day of false starts, we were really ready to go

Courtesy Kim Palladino