Course Updates

http://www.phys.hawaii.edu/~varner/PHYS272-Spr10/physics272.html

Reminders:

1) Assignment #12 → due today

2) Polarization, dispersion

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

– Consider light moving from glass \((n_1=1.5)\) to air \((n_2=1.0)\).

\[\sin \theta_2 = \frac{n_1}{n_2} > 1 \quad \Rightarrow \quad \theta_2 > \theta_1\]

I.e., light is bent away from the normal. as \(\theta_1\) gets bigger, \(\theta_2\) gets bigger, but \(\theta_2\) can never get bigger than 90° !!

In general, if \(\sin \theta_1 > \left(\frac{n_2}{n_1}\right)\), we have NO refracted ray; we have TOTAL INTERNAL REFLECTION.

For example, light in water which is incident on an air surface with angle \(\theta_1 > \theta_c = \sin^{-1}(1.0/1.33) = 48.8^\circ\) will be totally reflected. This property is the basis for the optical fiber communication.
“Mini-Antarctica” at Stanford Linear Accelerator
Problem!

\[ \theta_a \quad \theta_b \quad \text{air} \]

There is no escape!!!

Not always a bad thing
Question 1
The path of light is bent as it passes from medium 1 to medium 2. Compare the indexes of refraction in the two mediums.

a) \( n_1 > n_2 \)

b) \( n_1 = n_2 \)

c) \( n_1 < n_2 \)
Question 1
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(c) $n_1 < n_2$

Snell's Law: $n_1 \sin \theta_1 = n_2 \sin \theta_2$
Here, $\theta_2 > \theta_1$ implies $n_2 < n_1$
A light ray travels in a medium with $n_1$ and completely reflects from the surface of a medium with $n_2$. The critical angle depends on:

- $a)$ $n_1$ only
- $b)$ $n_2$ only
- $c)$ $n_1$ and $n_2$
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Critical angle occurs when $\theta_2 = 90^\circ$

Therefore, $\sin \theta_{\text{critical}} = \frac{n_2}{n_1}$
An optical fiber is surrounded by another dielectric. In case I this is water, with an index of refraction of 1.33, while in case II this is air with an index of refraction of 1.00.

Compare the critical angles for total internal reflection in these two cases

a) $\theta_{cI} > \theta_{cII}$

b) $\theta_{cI} = \theta_{cII}$

c) $\theta_{cI} < \theta_{cII}$
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Since $n_1 > n_2$ TIR will occur for $\theta > \text{critical angle}$. Snell’s law says $\sin \theta = \frac{n_2}{n_1}$.

If $n_2 = 1.0$, then $\theta_c$ is as small as it can be.

So $\theta_{c1} > \theta_{cII}$. 
Total Internal Reflection

Total internal reflection occurs when $\theta > \theta_c$ and provides 100% reflection. This has better efficiency than silvered mirror.

Examples of devices using Critical Angle

- Prism Binoculars

- Fiber Optics

Fiber optics is extremely important for high speed Internet and digital data transfer at long distances. Many companies (Lucent) have laid fiber over long Distances to provide internet service.
I2 (academic) network of fiber connections

10 gigabit/sec connections
Mt. Tsukuba
KEK
Tsukuba, Japan

~2mi circ. ring

World’s highest Luminosity collider

8 GeV e⁻
SCC RF(HER)

ARES
(LER)

3.5 GeV e⁺

Ares RF cavity
e⁺ source
μ/Κₜ detection
14/15 lyr. RPC

Tracking + dE/dx
small cell + He/C₂H₅

Aerogel Cherenkov cnt.
n=1.015~1.030

SC solenoid
1.5T

Csl(Tl) 16X₀

TOF counter

8GeV e⁻

3.5GeV e⁺

Si vtx. det.
3 lyr. DSSD

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Belle Detector
Belle Upgrade (Run stops June 2010)

- SC solenoid 1.5T
-μ/\(K_L\) detection 14/15 lyr. RPC+Fe → tile scintillator
- Csl(Tl) 16\(X_0\) → pure CsI (endcap)
- Aerogel Cherenkov counter + TOF counter → "TOP"/F-DIRC
- Si vtx. det. 4 lyr. DSSD → 2 pixel/striplet lys. + 4 lyr. DSSD
- Tracking + \(dE/dx\) small cell + He/C\(_2\)H\(_5\) → remove inner lys. Use fast gas
- New readout and computing systems
imaging TOP (iTOP)

Total internally reflected Photons used for “Particle ID”

Side view of crystal

Linear-array type photon detector

Quartz radiator

400mm

20mm
TOP counter principle

- Measure Position+Time
  - Compact detector!
  - Linear-array type photon detector
  - Quartz radiator
  - Linear array PMT (~5mm)
  - Time resolution $\sigma \sim 40$ps

Different opening angle for the same momentum
$\Rightarrow$ Different propagation length (= propagation time)

$+$ TOF from IP works additively.
Dispersion: \( n = n(\omega) \)

The index of refraction depends on frequency, due to the presence of resonant transition lines. For example, ultraviolet absorption bands in glass cause a rising index of refraction in the visible, i.e.,

\[ n(\text{higher } \omega) > n(\text{lower } \omega) \]:

\[ n_{\text{red}} = 1.52 \quad n_{\text{blue}} = 1.54 \]
Chromatic dispersion

Variation of propagation velocity depending on the wavelength of Cherenkov photons

- Due to wavelength spread of detected photons
- \( \Rightarrow \) propagation time dispersion

- Longer propagation length
  \( \Rightarrow \) Improves ring image difference
  But, decreases time resolution.
Consider our EM plane wave. The E field is polarized in the Y-direction. We say this is “linearly Polarized light”.

\[ E_y = E_0 \sin( kx - \omega t) \]

\[ B_z = \frac{E_0}{c} \sin( kx - \omega t) \]

Most light sources are not polarized in a particular direction. This is called unpolarized light or radiation.

polaroid (sunglasses)

Long molecules absorb E-field parallel to molecule.
LP Intensity Reduction

- This set of two linear polarizers produces LP light. What is the final intensity?
  - First LP transmits 1/2 of the unpolarized light: \( I_1 = \frac{1}{2} I_0 \)
  - Second LP projects out the E-field component parallel to the TA:
    \[
    E_2 = E_1 \cos \theta \quad \Rightarrow \quad I_2 = I_1 \cos^2 \theta
    \]

\[
E \frac{I}{\propto E^2} \]

Law of Malus
An EM wave is passed through a linear polarizer. Which component of the $E$-field is absorbed? The component of the $E$-field which is absorbed is ____________.

a) perpendicular to the transmission axis

b) parallel to the transmission axis

c) both components are absorbed
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An EM wave polarized along the $y$-axis, is incident on two orthogonal polarizers.

What percentage of the intensity gets through both polarizers?

a) 50%

b) 25%

c) 0%
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Question 6

An EM wave polarized along the \( y \)-axis, is incident on two orthogonal polarizers.

Is it possible to increase this percentage by inserting another polarizer between the original two? (Explain.)

a) Yes  
b) No
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Is it possible to increase this percentage by inserting another polarizer between the original two? (Explain.)

a) Yes

b) No
What you said ??

• ZERO: the component that is passed by the first is blocked by the second.
• BUT, adding an intermediate polarizer will restore some light !!!

Right:
• Yes, a polarizer at an intermediate angle can change the direction of polarization so that some light is able to get through the last filter.

Wrong:
• No. One polarizer will get rid of all of the field that is perpendicular to the axis and the other will get rid of all that is parallel. No other filter will add more signal in any direction.
Question 7

- Light of intensity $I_0$, polarized along the $x$ direction is incident on a set of 2 linear polarizers as shown.

  - Assuming $\theta = 45^\circ$, what is $I_{45}$, the intensity at the exit of the 2 polarizers, in terms of $I_0$?

(a) $I_{45} = \frac{1}{2} I_0$
(b) $I_{45} = \frac{1}{4} I_0$
(c) $I_{45} = 0$
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- We proceed through each polarizer in turn.
  - The intensity after the first polarizer is:
    $$I_1 = I_0 \cos^2 (45 - 0) = \frac{I_0}{2}$$
  - The electric field after the first polarizer is LP at $\theta_1 = 45$.
  - The intensity after the second polarizer is:
    $$I_{45} = I_1 \cos^2 (90 - 45) = \frac{I_1}{2} \quad \Rightarrow \quad I_{45} = \frac{1}{4} I_0$$
Question 8

• Light of intensity $I_0$, polarized along the $x$ direction is incident on a set of 2 linear polarizers as shown.

• What is the relation between $I_{45}$ and $I_{30}$, the final intensities in the situation above when the angle $\theta = 45^\circ$ and $30^\circ$, respectively?

(a) $I_{45} < I_{30}$  
(b) $I_{45} = I_{30}$  
(c) $I_{45} > I_{30}$
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• In general, the first polarizer reduces the intensity by $\cos^2 \theta$, while the second polarizer reduces it by an additional factor of $\cos^2(90 - \theta)$.

• Thus, the final output intensity is given by:

$$I_{out} = I_0 \cos^2(\theta) \cos^2(90 - \theta) = I_0 \cos^2(\theta) \sin^2(\theta) \propto \sin^2(2\theta)$$

This has a maximum when $\theta = 45^\circ$. 
The reflected rays are partially polarized in the horizontal plane. The transmitted rays are also partially polarized.
For a certain angle, the Brewster angle, the reflected light is completely polarized in the horizontal plane. This occurs when the angle between the refl. and refr. rays is $90^\circ$.

From Maxwell’s eqn. it can be shown that Brewster’s angle is given by

$$\tan \theta_p = \frac{n_b}{n_a}$$
Light reflected on dashboard to the windshield will be polarized in the horizontal plane. Using polaroid dark glasses with a vertical axis will remove most of reflected light.
Electric field lines from oscillating dipole computer simulation - a snapshot in time
Dipole radiation pattern

- Oscillating electric dipole generates e-m radiation that is linearly polarized in the direction of the dipole
- Radiation pattern is doughnut shaped & outward traveling
  - zero amplitude above and below dipole

![Dipole radiation pattern diagram](image)

- Aerial
- no signal here
- lots of signal
- E
- c
For next time

• Homework #12 posted ➔ due today

• The home stretch: optics/optical phenomenon

• Quiz #6 on Friday (E&M waves, refraction [Snell’s Law])