Course Updates

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

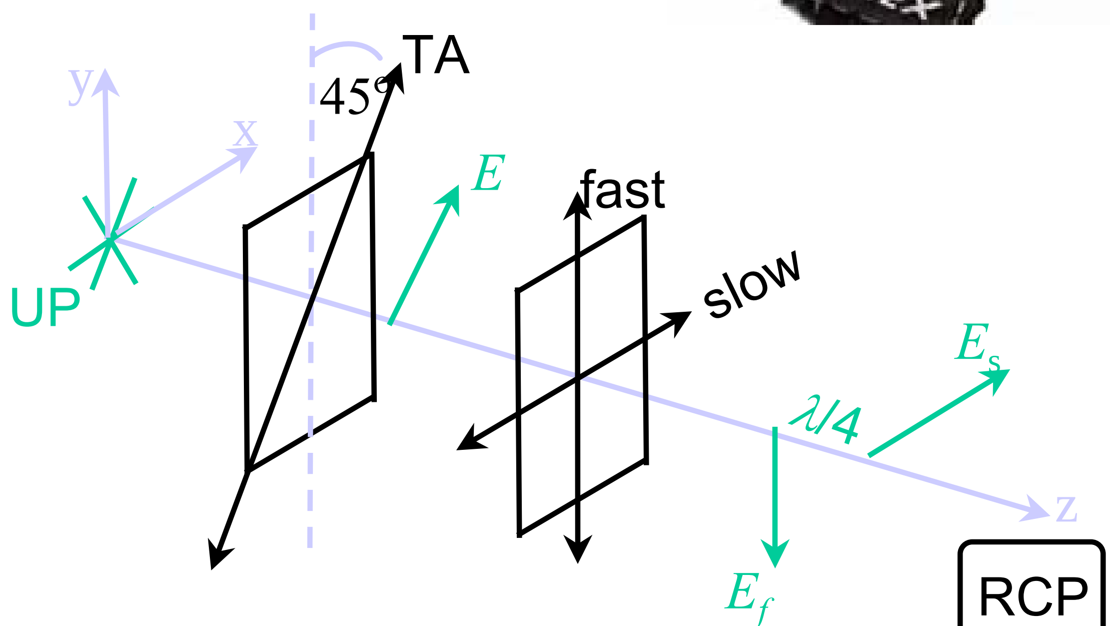
Reminders:

1) Assignment #13 → due Monday

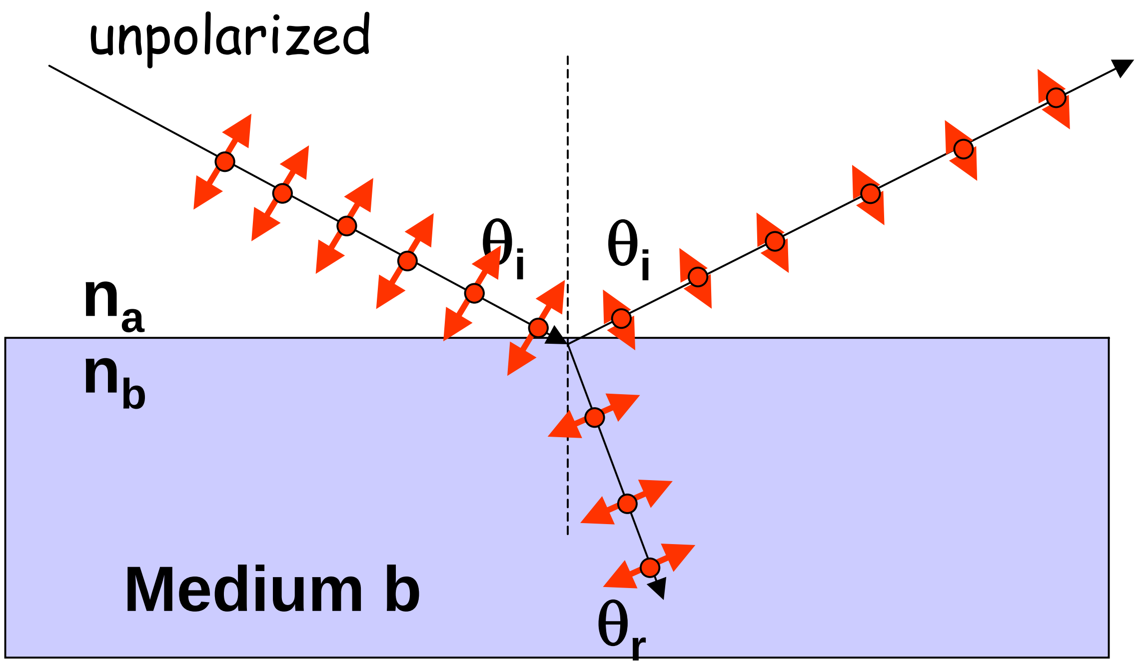
2) Polarization, scattering (why the sky is blue)

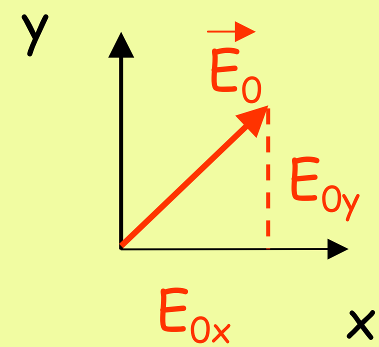
3) Last HW (#13 posted) → due Monday, May 3rd

Polarization



Polarization by reflection

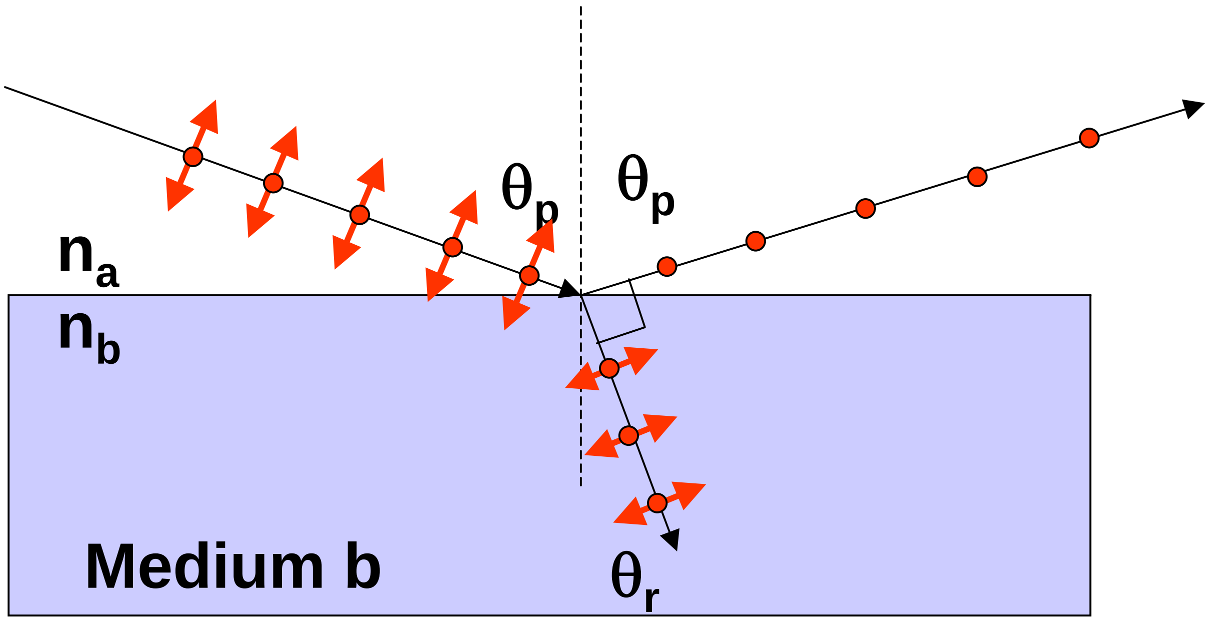




Can always describe E in terms of components in two arbitrary directions. The components are equal for unpolarized light.

The reflected rays are partially polarized in the horizontal plane. The transmitted rays are also partially polarized.

Polarization by reflection

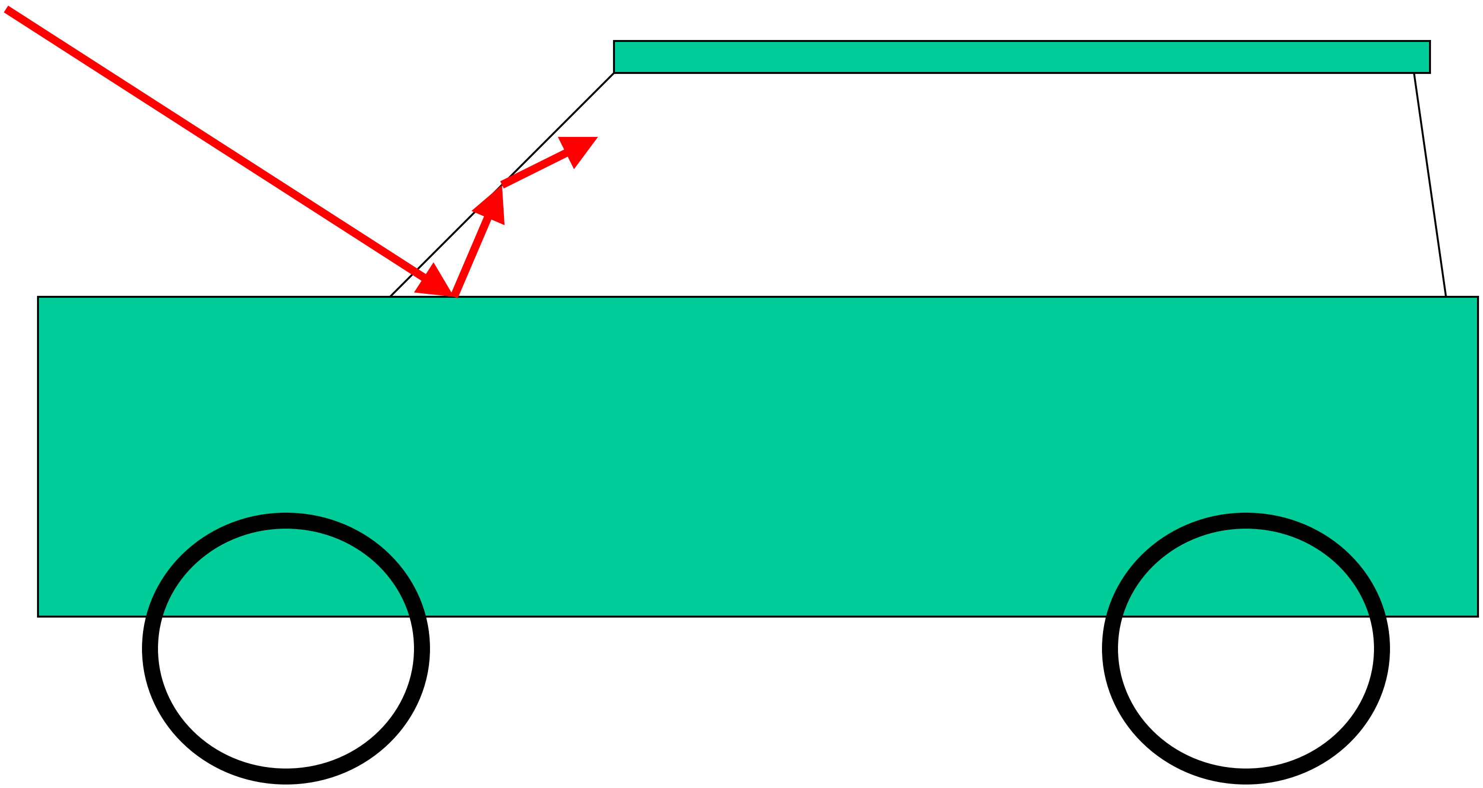


For a certain angle, the Brewster angle, the reflected light is completely polarized in the horizontal plane. This occurs when the angle between the refl. and refr. rays is 90°.

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

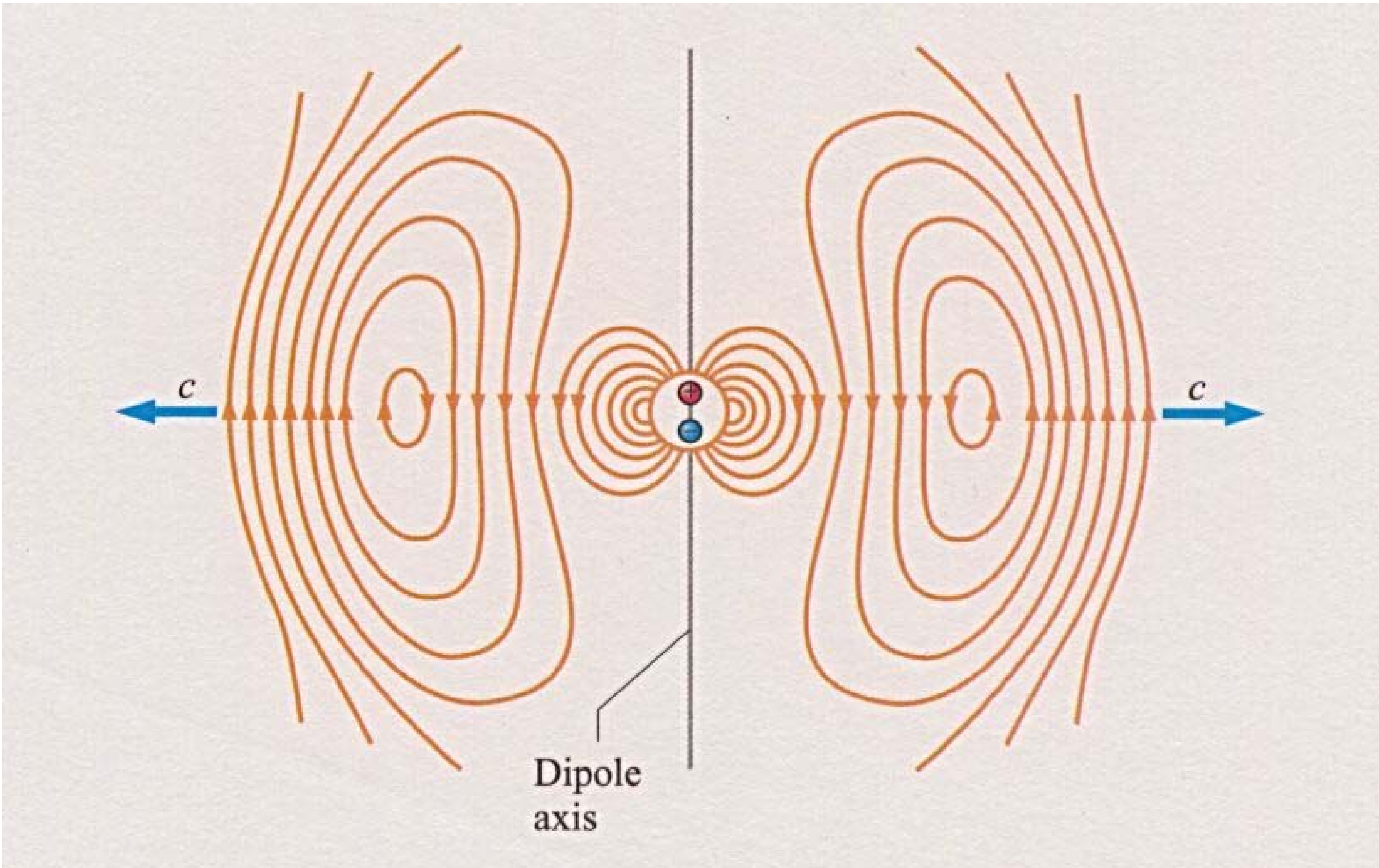
$$\tan \theta_p = \frac{n_b}{n_a}$$

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



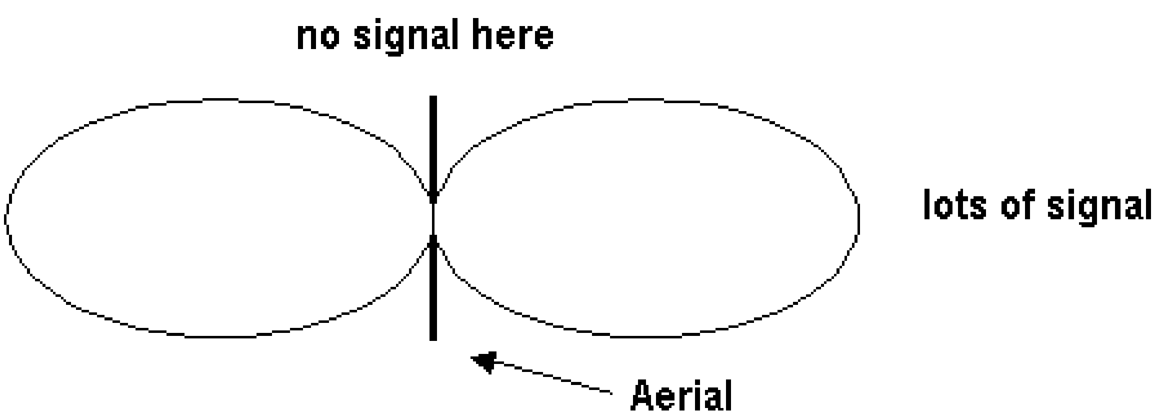
Electric field lines from oscillating dipole

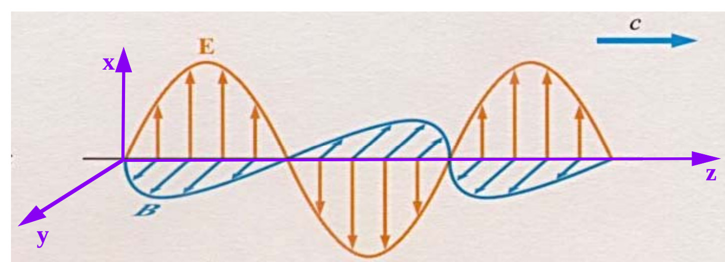
full computer simulation - a snapshot in time



Dipole radiation pattern

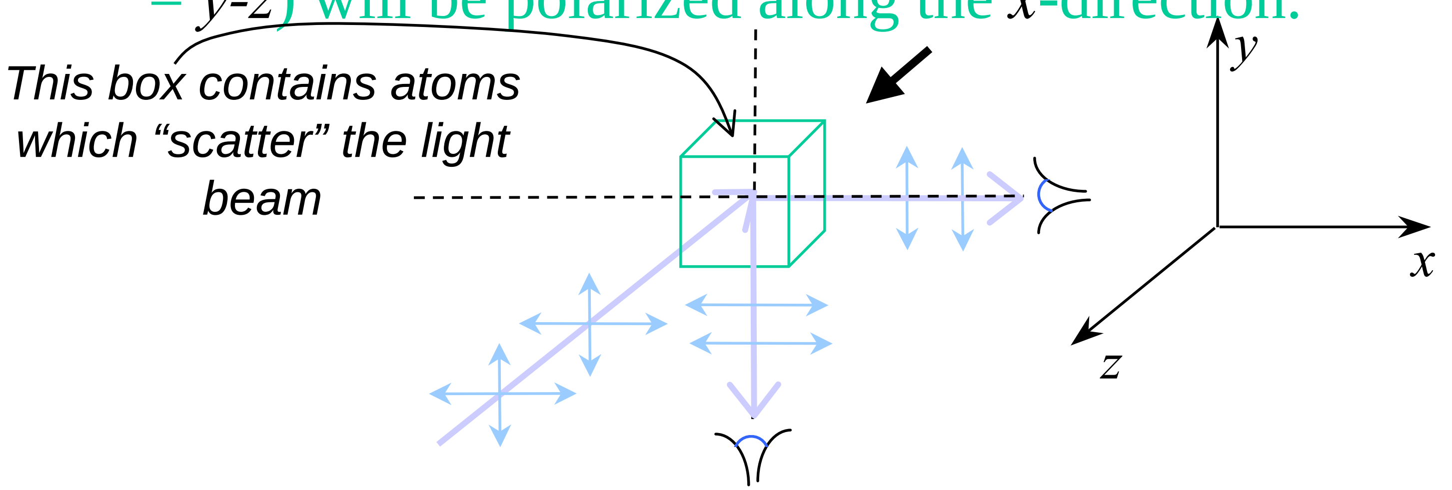
- Oscillating electric dipole generates e-m radiation that is **linearly polarized** in the direction of the dipole
- Radiation pattern is doughnut shaped & outward traveling
  - zero amplitude above and below dipole





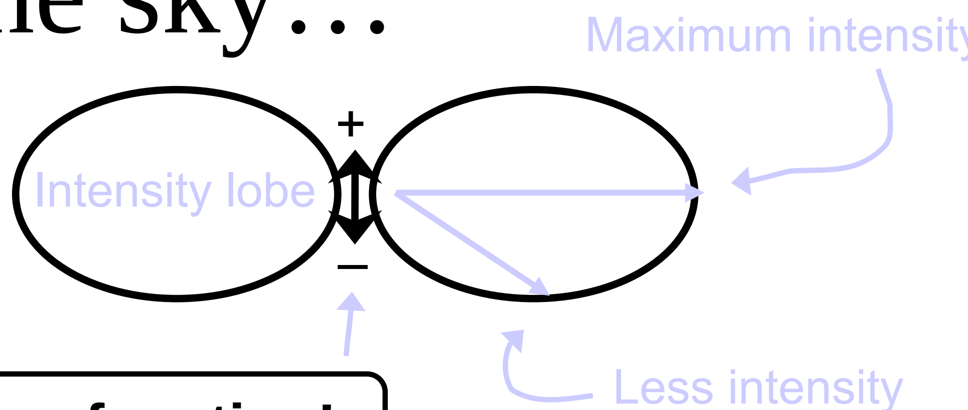
Polarization by Scattering

- Suppose unpolarized light encounters an atom and scatters (energy absorbed & reradiated).
  - What happens to the polarization of the scattered light?
  - The scattered light is preferentially polarized perpendicular to the plane of the scattering.
    - For example, assume the incident unpolarized light is moving in the *z*-direction.
    - Scattered light observed along the *x*-direction (scattering plane = *x*-*z*) will be polarized along the *y*-direction.
    - Scattered light observed along the *y*-direction (scattering plane = *y*-*z*) will be polarized along the *x*-direction.



Polarization of the sky…

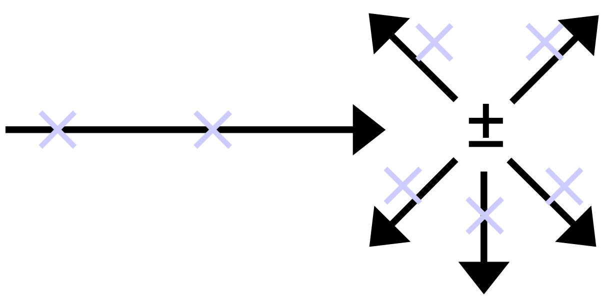
In the atmosphere light is radiated/scattered by atoms – oscillating electric dipoles.



***No* radiation along direction of motion!**

Start with sunlight with all polarizations & randomly oriented dipoles.

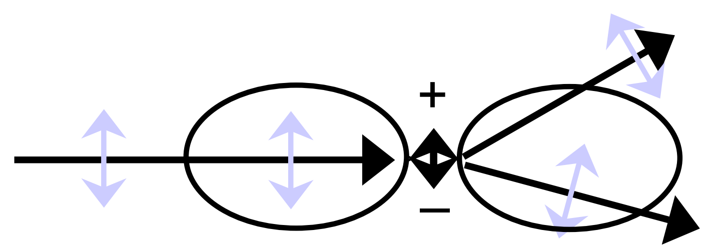
<u>2 cases</u>:



Dipole oscillates *into* the paper.

Horizontal dipoles reradiate H-polarized light downward.

(Do not respond to incident V-light.)



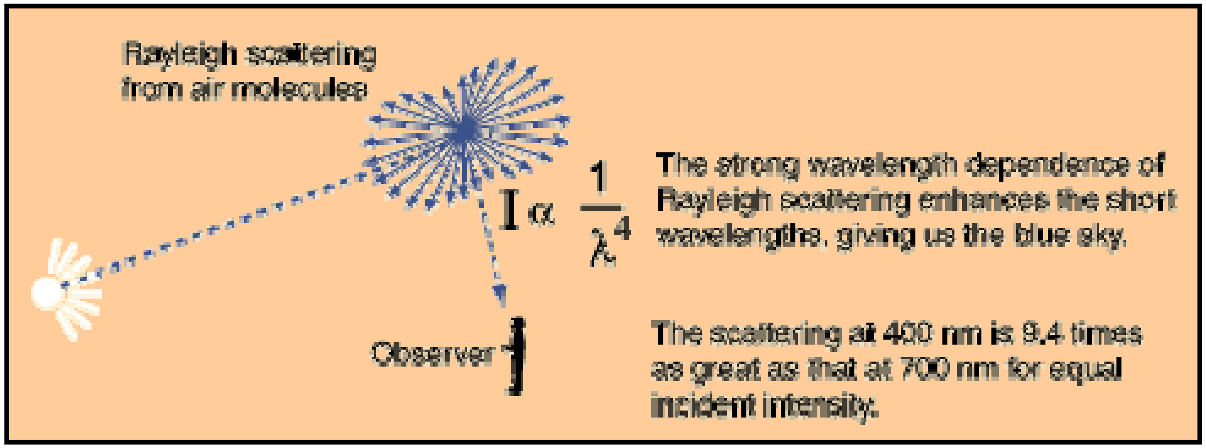
Dipole oscillates vertically.

Vertical dipoles reradiate V-polarized light to the sides (*not* downward).

(Do not respond to incident H-light.)

Why is the sky blue?

- Light from Sun scatters off of air particles–"Rayleigh scattering"
  - Rayleigh scattering is wavelength-dependent.
  - Shorter wavelengths (blue end of the visible spectrum) scatter more.

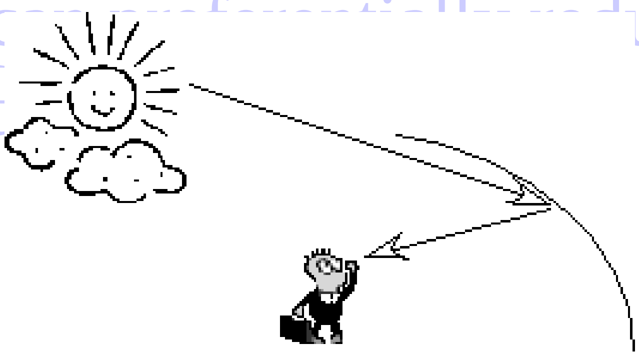


- This is also why sunsets are red!
  - At sunset, the light has to travel through more of the atmosphere.
  - If longer wavelengths (red and orange) scatter *less*…
  - The more air sunlight travels through, the redder it will appear!
  - This effect is more pronounced if there are more particles in the atmosphere (e.g., sulfur aerosols from industrial pollution).

Applications

- Sunglasses
  - The reflection off a horizontal surface (e.g., water, the hood of a car, etc.) is strongly polarized. Which way?

- Polarized sky
  - A perpendicular polarizer can preferentially reduce t
  - The same argument applies to the sky:



Polarizing filters important in photography!

More Polarizations

General linear polarization state: $\vec{E} = \underbrace{(\cos\theta\,\hat{x} + \sin\theta\,\hat{y})E_0}_{\equiv \vec{E}_0}\ \sin(kz - \omega t)$

if $\theta = 45°$ $\quad \vec{E}_0 = \frac{\hat{x}+\hat{y}}{\sqrt{2}}\ E_0$

What if instead we had $\vec{E}_0 = \frac{\hat{x}-\hat{y}}{\sqrt{2}}\ E_0$ **?** ⇨ **Polarized at** $-45°$**.**

Another way to write these:

$$\vec{E}_{45} = E_0\,\hat{x}\sin(kz - \omega t) + E_0\,\hat{y}\sin(kz - \omega t)$$

$$\vec{E}_{-45} = E_0\,\hat{x}\sin(kz - \omega t) + E_0\,\hat{y}\sin(kz - \omega t + \pi)$$

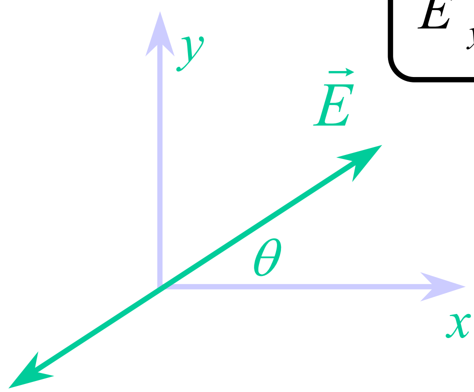
So the only difference is a phase shift between E_{0x} **and** E_{0y} **.**

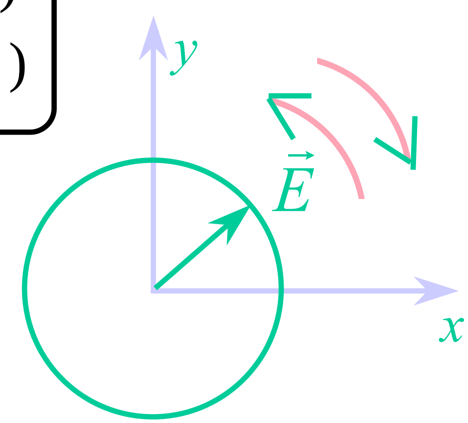
In general, this phase shift can take other values!

Other Polarization States?

- Are there polarizations other than linear?
  - Sure!!
  - The general harmonic solution for a plane wave traveling in the +z-direction is:

$$
\begin{aligned}
E_x &= E_{x0} \sin(kz - \omega t + \phi_x) \\
E_y &= E_{y0} \sin(kz - \omega t + \phi_y)
\end{aligned}
$$





Linear Polarization ⇨

$$\phi \equiv \phi_x - \phi_y = 0$$

$$\frac{E_{yo}}{E_{xo}} = \tan\theta$$

Circular Polarization ⇨

$$\phi \equiv \phi_x - \phi_y = \pm\frac{\pi}{2}$$

$$E_{yo} = E_{xo}$$

(E_{0x} and E_{0y} are ±90° out of phase.)

Question 1

- What is the polarization of an electromagnetic wave whose *E* vector is described as:

$$E_x = -E_0 \cos(kz - \omega t)$$

$$E_y = E_0 \sin(kz - \omega t)$$

(a) **linear** (b) **circular** (c) **elliptical**

Question 1

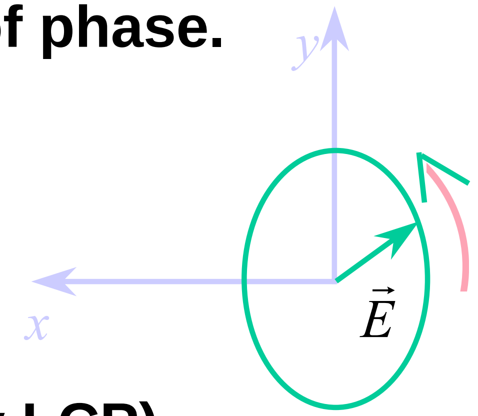
- What is the polarization of an electromagnetic wave whose E vector is described as: $E_x = -E_0 \cos(kz - \omega t)$

$$E_y = E_0 \sin(kz - \omega t)$$

(a) linear **(b) circular** **(c) elliptical**

Not linear because E_x and E_y are out of phase.

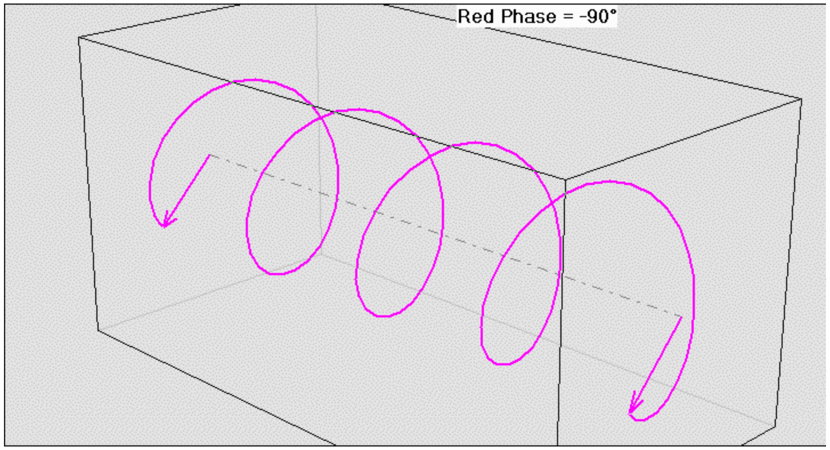
It would be "elliptical" if $|E_x| \neq |E_y|$.



The correct answer is circular (actually LCP).

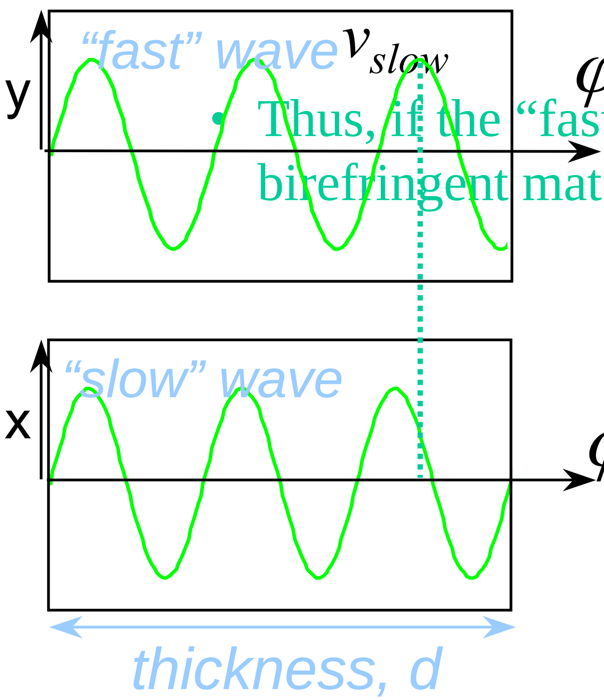
Visualization

- **Why do we call this circular polarization?**



Birefringence

- How can we make polarizations other than linear, e.g., circular?
  - Birefringence!
    - Birefringent materials (e.g., crystals or stressed plastics) have the property that the speed of light is different for light polarized in the two transverse dimensions (polarization-dependent speed), i.e.,
      - light polarized along the “fast axis” propagates at speed v_{fast}
      - light polarized along the “slow axis” propagates at speed v_{slow}
    - Thus, if the “fast” and “slow” polarizations start out in phase, inside the birefringent material the “fast” polarization will ‘pull ahead’:



$$\varphi_{fast} = \omega\, t_{fast} = \omega\, d / v_{fast}$$

$$\varphi_{slow} = \omega\, t_{slow} = \omega\, d / v_{slow}$$

$$\varphi_{fast} - \varphi_{slow} = \omega\, d \left(\frac{1}{v_{fast}} - \frac{1}{v_{slow}} \right)$$

For a given birefringent material, the relative phase is determined by the thickness d, and frequency ω.

Example: Wave Plates

- Birefringent crystals with precise thicknesses

Ex.: Crystal which produces a phase change of $\pi/2$ → "quarter wave plate" (a "full wave plate" produces a relative shift of $4 \times \frac{\pi}{2} = 2\pi$ → no effect).

Light polarized along the fast or slow axis merely travels through at the appropriate speed → polarization is unchanged.

Light linearly polarized at 45° to the fast or slow axis will acquire a relative phase shift between these two components → alter the state of polarization.

The phase of the component along the fast axis is $\pi/2$ out of phase with the component along the slow axis. E.g.,

Before QWP ⇨

$$E_x = E_0 \sin(kz - \omega t)$$
$$E_y = E_0 \sin(kz - \omega t)$$

After QWP ⇨

$$E_x = E_0 \sin(kz - \omega t)$$
$$E_y = E_0 \sin(kz - \omega t - \frac{\pi}{2})$$

Quarter Wave Plate summary:
- linear along fast axis → linear
- linear at 45° to fast axis → circular
- circular → linear at 45° to fast axis

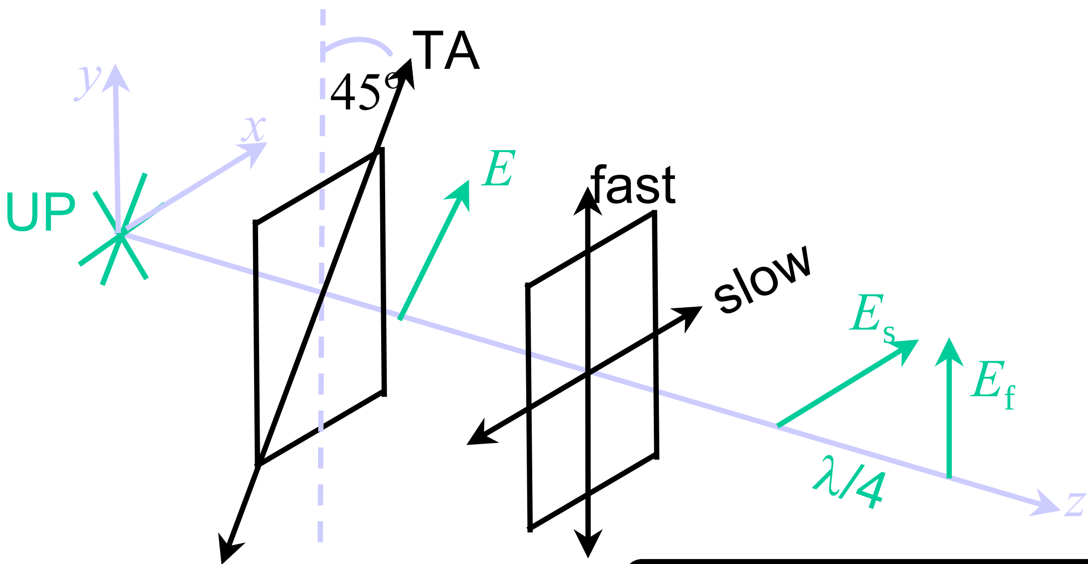
Quarter Wave Plates

- Light linearly polarized at 45° incident on a quarter wave plate produces the following wave after the quarter wave plate:

Fast axis: $E_y = E_0 \cos(kz - \omega t)$

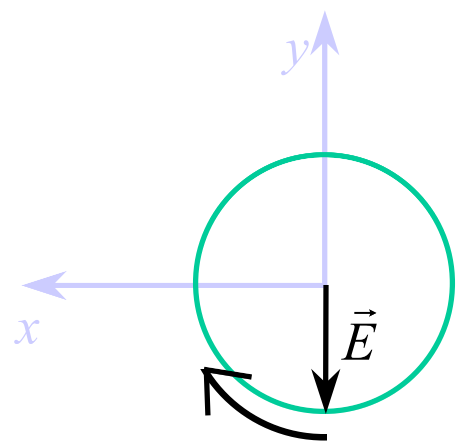
Slow axis: $E_x = E_0 \sin(kz - \omega t)$

RCP



Max vectors at t=0:

Rotation at t = 0:



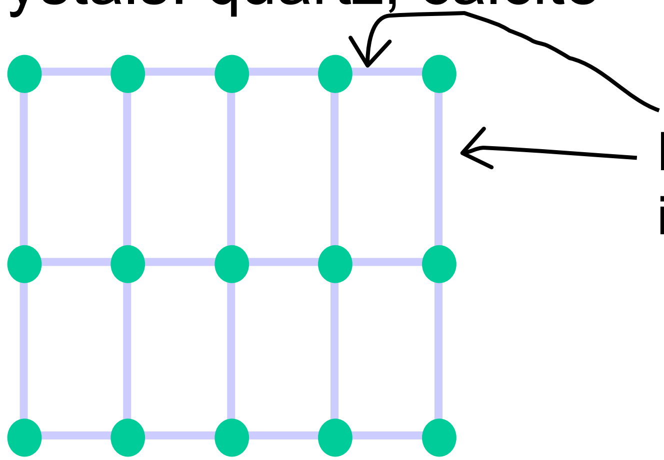
RCP = CW

QWP: fast ahead of slow by λ/4)

What Causes Birefringence?

Birefringence can occur in any material that possesses some asymmetry in its structure, so that the material is more “springy” in one direction than another.

<u>Examples</u>: Crystals: quartz, calcite

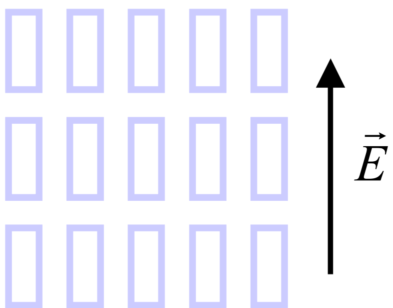


Different atom spacings in $\hat{x}$ and $\hat{y}$.

Long stretched molecular chains: saran wrap, cellophane tape

Birefringence, cont.

Oblong molecules: “liquid crystals”

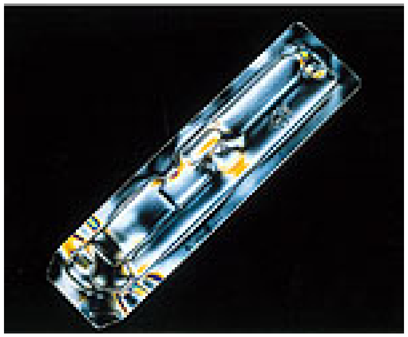


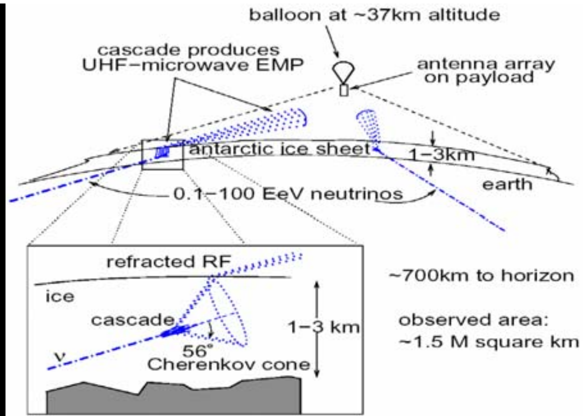
Dipoles of the molecules orient along an externally applied electric field. Change the field → change the birefringence → change the polarization of transmitted light → pass through polarization analyzer to change the intensity

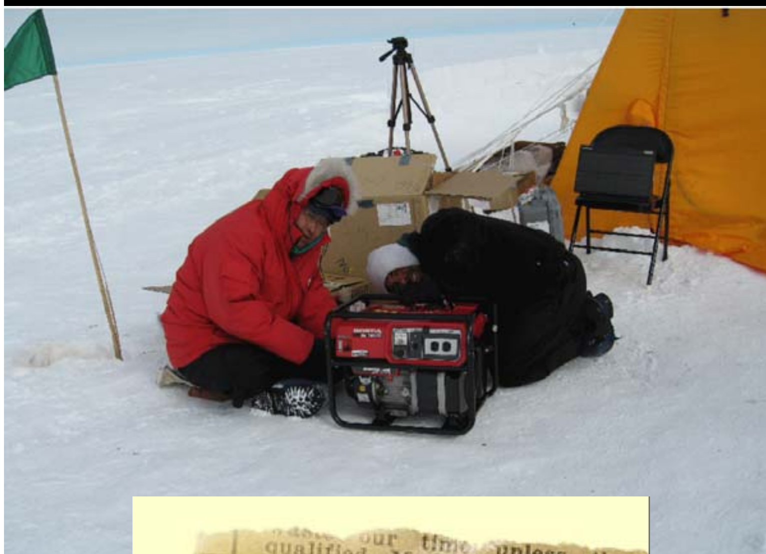
→ Digital displays, LCD monitors, etc.

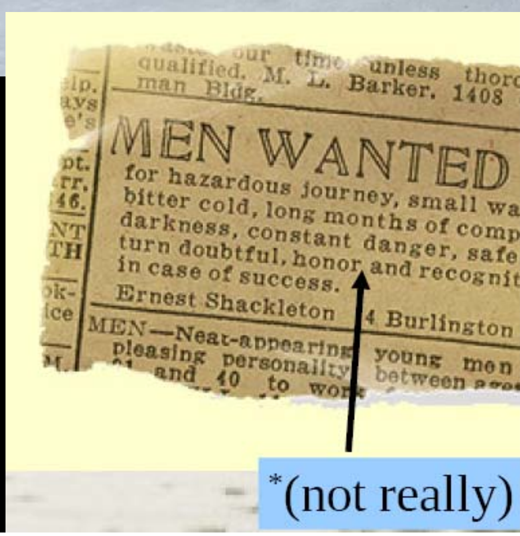
Stress-induced birefringence:

Applying a mechanical stress to a material will often produce an asymmetry → birefringence. This is commonly used to measure stress.





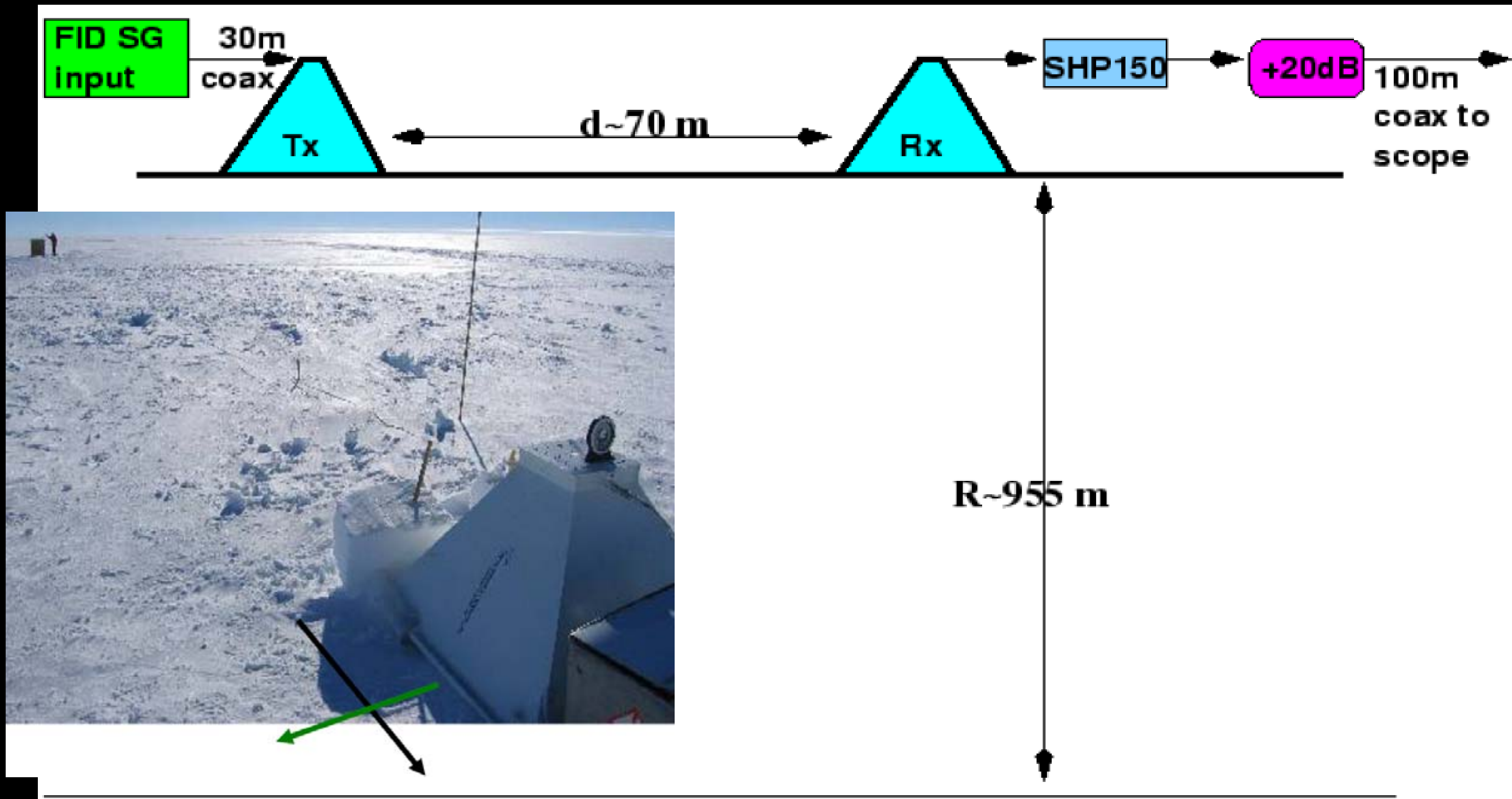



qualified. M. L. Barker. 1408
man Bldg.

MEN WANTED
for hazardous journey, small wa
bitter cold, long months of comp
darkness, constant danger, safe
turn doubtful, honor and recognit
in case of success.
Ernest Shackleton 4 Burlington

MEN—Neat-appearing young men
pleasing personality between ages
21 and 40 to work

Taylor Dome Calibration Basecamp



Time difference between
Pink & Green/Red is birefringence
(measureable!)
What causes it?