Lec. 25, Tuesday, April 13
Chapter 13: Scattering and Polarization
Homework is due in room G2B90 “in boxes”

- Scattering:
  - Smoke, haze, fog, clouds, air, water,
  - Depends on wavelength, size of particle
- Polarization:
  - caused by reflection, scattering
- Applications
  - Sunglasses
  - Photographic filters
  - LCD displays

Extra stuff: digital images

Thursday: Chapter 14, Holography. Next week: Chap. 8, Binocular vision

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Small particles scatter light

Particles smaller than a wavelength of light scatter **blue** more than they scatter other colors. This is called **Rayleigh** scattering.

Examples of small particles (smaller than $\lambda$):
- Air molecules (blue sky)
- Water molecules (blue ocean)
- Some smoke particles (slightly blue)
- Particle in the iris of your eye (blue eyes)
Not-so-small particles scatter light

Particles larger than a wavelength of light scatter all colors about the same.

Examples of colorless particles which are larger than a wavelength of light:
- Rain clouds
- Dense smoke
- Smog
- Fat particles in milk

Bigger particles will reflect the color of the particle
Denver brown cloud (road grit, sand)

Red sunsets and blue sky are related?

The red sunset is because the blue is scattered out, leaving behind white minus blue.
Some thought questions

1. Why isn’t a glass of water blue?
2. Why isn’t the air in the room blue?
3. Why is the sun redder at sunset than at noon?
4. Why do some cars have yellow fog lights?

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Polarization

1. Polarized light has one direction for the electric force of the electromagnetic wave.
2. Polarizing filters pass one direction of polarization.

Light can have a polarization between vertical and horizontal, and in this case a fraction gets through a polarizing filter:

Polarizing filters

Demo with grill
Two crossed polarizers block all light

Reflection from a smooth surface is polarized

“Smooth” means glossy like metal, plastic, still water, not rough like paper or wood. Reflected light has the electric force (or electric field) parallel to the surface.
Reflection from a vertical wall or window?

- Is the electric field of the reflected light vertical or horizontal?

Polarization by scattering (1)

The electric field of scattered light is perpendicular to the plane with the light source, you and the scatterer.

Electric field $E$ is vertical
Polarization by scattering (2)

The electric field of scattered light is perpendicular to the plane with the light source, you and the scatterer.

Brewster’s angle is a cheap polarizer

• Light reflected (from glass or water for example) at this particular angle is 100% polarized.

For glass, Brewster’s angle is 56 degrees from the normal to the surface.
Natural birefringence

- A birefringent material has two indices of refraction. One each polarization (measured relative to a crystal axis.)
- Vertical and horizontal polarization are bent differently.

Stress birefringence

Clear substances that are stressed (bent, for example) will have birefringence that creates stress patterns when viewed through crossed polarizers.
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Applications (1)

Sunglasses:
Filter is oriented to block horizontal polarization. Why?
Applications (2)

Photographic filter:
Can be rotated for best looking picture.
   1. Enhance reflection in lake.
   2. Reject reflection in lake (see the fish).
   3. Darken sky, enhance clouds.
   4. Block light from haze.

Surface reflection is blocked.
E is vertical because the sun is at the left.
Notice the shadows.
Applications (3) : Liquid crystal display

Examples of liquid crystal displays (LCDs)

Black and white displays
   Digital watches
   Some calculators

Color displays
   Laptop computer screens
   Some digital projectors for classrooms

Textbook Ch. 13.7
How does an LCD panel work (1)

With **no voltage**, liquid crystals rotate polarization 90 degrees, light is passed through crossed polarizers.

How does an LCD panel work (2)

With **voltage**, polarization is not rotated, light is blocked by the crossed polarizers.
What are liquid crystals?

They are a liquid.
The molecules can line up, like the atoms in a crystal.
The lined up molecules can rotate the polarization.
Apply a voltage to liquid crystals with electrodes on either side, and they line up differently.
An array of wires (in rows and columns) goes to the pixels and voltages tell which one to be “on” or “off” or in-between.
Color displays: have rows of red, green and blue filters over the pixels.

Liquid crystals are not colored.
Extra stuff: What is a digital image?

First: What is a matrix?
The matrix $M$ is rows and columns of numbers.

\[
\begin{array}{ccc}
M_{1,1} & M_{1,2} & M_{1,3} \\
M_{2,1} & M_{2,2} & M_{2,3} \\
M_{3,1} & M_{3,2} & M_{3,3}
\end{array}
\]

Dot matrix printer

The numbers in the matrix are 0 for OFF and 1 for ON. The 0 or 1 is a bit. The matrix is a bit map. One dot is a pixel.

Example

boy
Why do I want more pixels?

1. To make an enlargement
2. To read the fine print

How many pixels does my display have?

640 x 480  
800 x 600  
1024 x 768  
1280 x 1024  
1600 x 1200  

VGA used in 14 in. displays  
SVGA  
XGA  
SXGA  
UXGA used in 20 inch displays

Pixels in digital cameras:
2240 x 1680 (4 megapixels)  
4064 x 2704 (11 megapixels)

In color images, there are 3 subpixels, one for each color.

Two designs for color pixels. [Wikipedia](https://en.wikipedia.org/wiki/Pixel)
How many shades of gray?

Instead of 0 for black and 1 for white:

0 to 255 for shades of gray (256 values)

How many possible colors on your screen?

256 shades of red x 256 shades of blue x 256 shades of green

= 16.7 million colors