CPSC 4040/6040 Computer Graphics Images

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Lecture 04
Displays and Optics

Sept. 1, 2015

Slide Credits:
Kenny A. Hunt
Don House
Torsten Möller
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Agenda

- Open Help Session Issues:
    - Currently, T 6-8pm, 110B McAdams
        - Problem: 110B is a Windows lab, but we should be able to remote desktop into the linux machines
    - Alternate: move to a linux lab (110D / 110E):
        - Problem: only open time slots are either:
            A. 8-10pm on Thurs OR 6-8pm on Fri
            B. Morning slot (e.g. 8-10am, 9-11am, 10am-12pm on Wed.)
- Proposal #1: stay T 6-8pm and try out remote desktop
- Proposal #2: B slot
- Proposal #3: A slot

PA01

- Any clarifications needed?
- I have provided a sample makefile on the course homepage.
- Reminder: please make sure your code compiles on the lab machines before submission

Physics of Light

Light

- Is both: (1) particles known as **photons** that (2) act as **waves**.
- Two fundamental properties:
  - **Amplitude** (height of wave)
  - **Wavelength** (distance of which wave repeats)
    - Frequency is the inverse of wavelength
    - Relationship between wavelength (λ) and frequency (f):
      - $\lambda = c / f$
    - Where c = speed of light = 299,792,458 m / s

Light

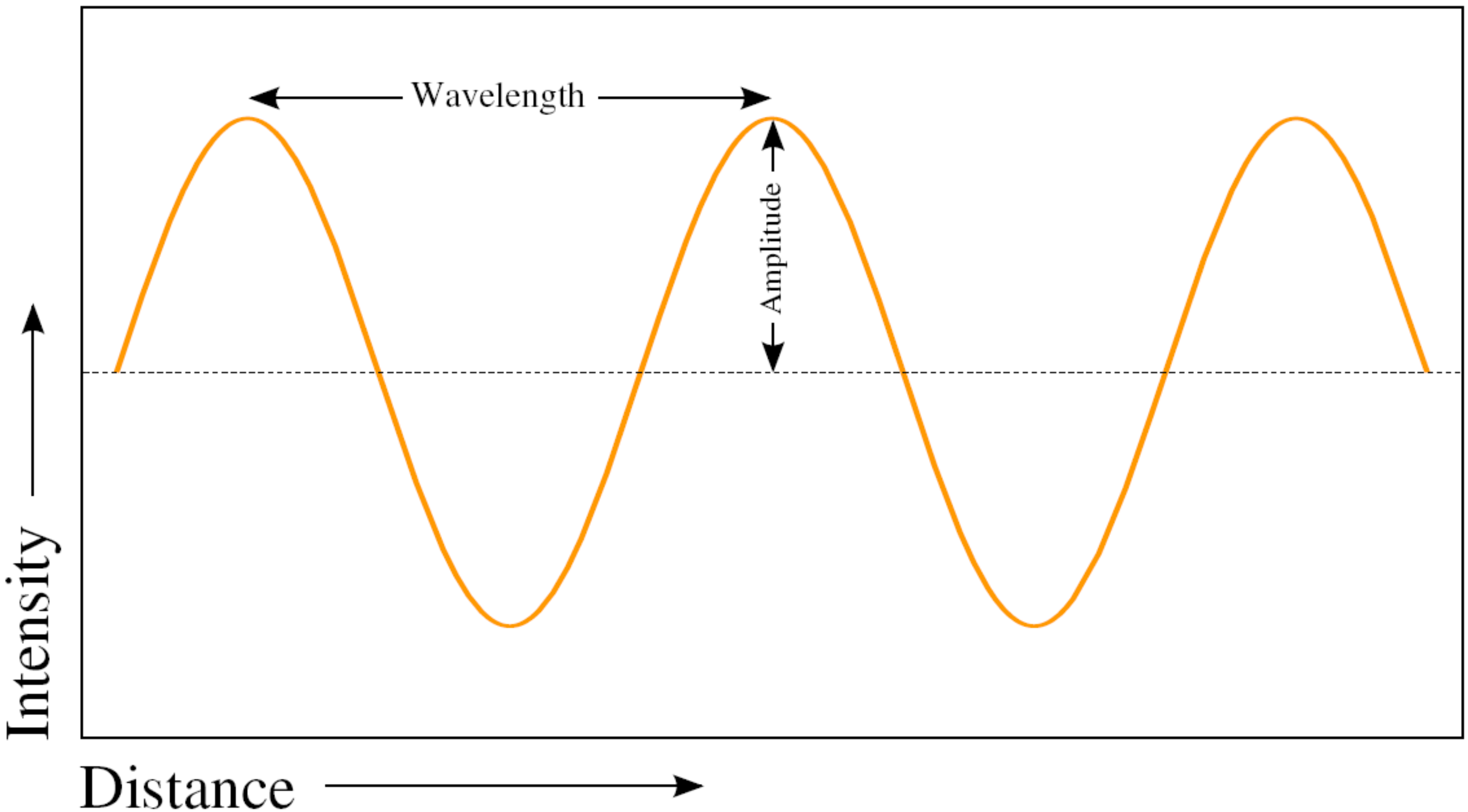
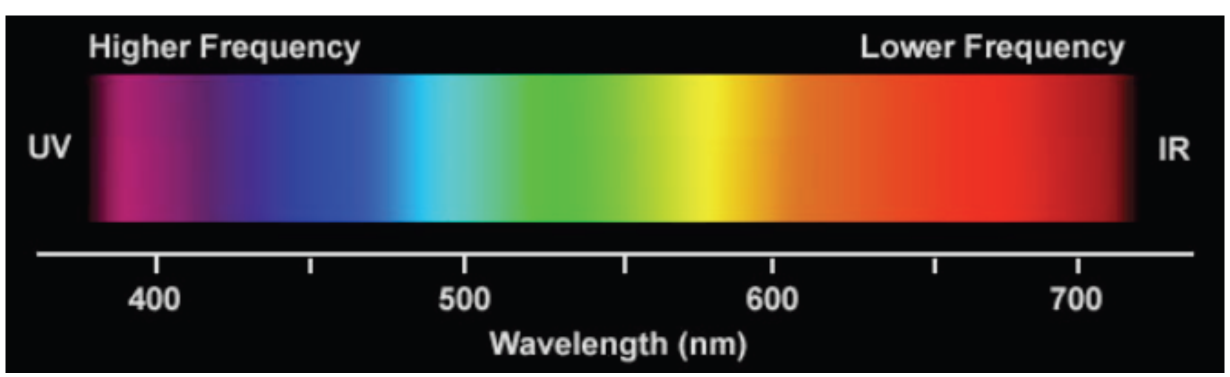
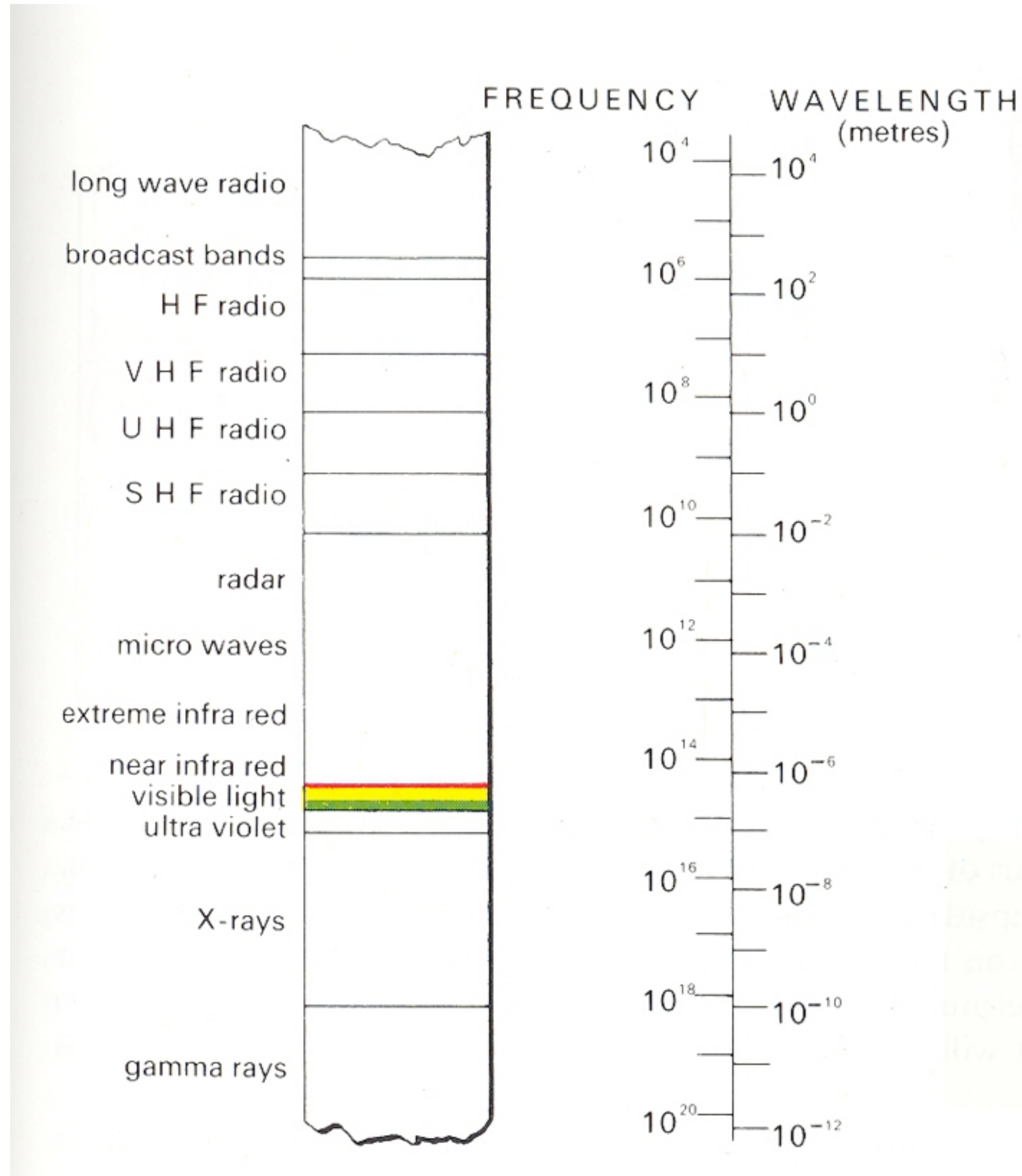


Diagram of a light wave.

Light is Electromagnetic Radiation

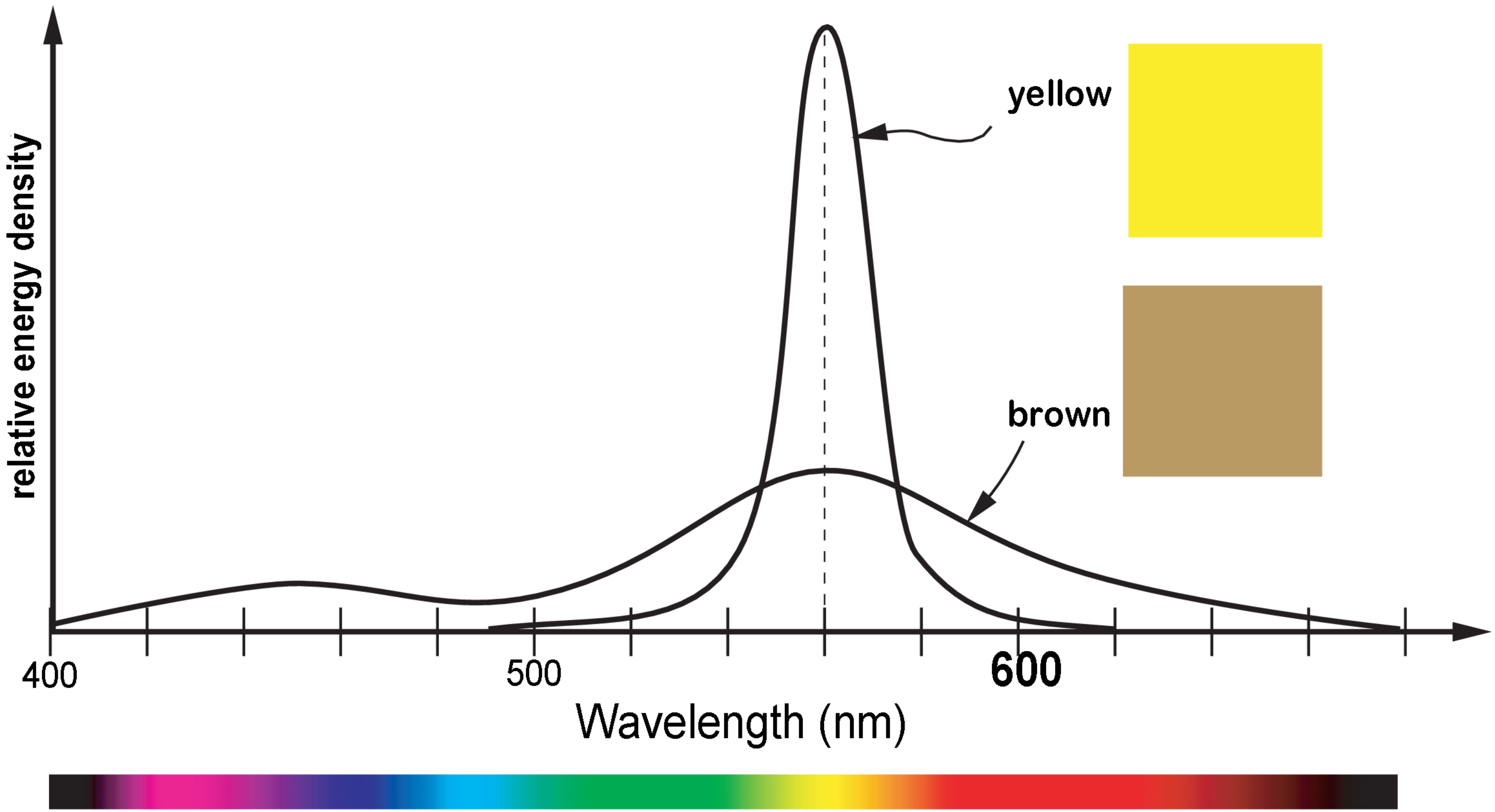
- Visible spectrum is "tiny"
- Wavelength range: 380-740 nm



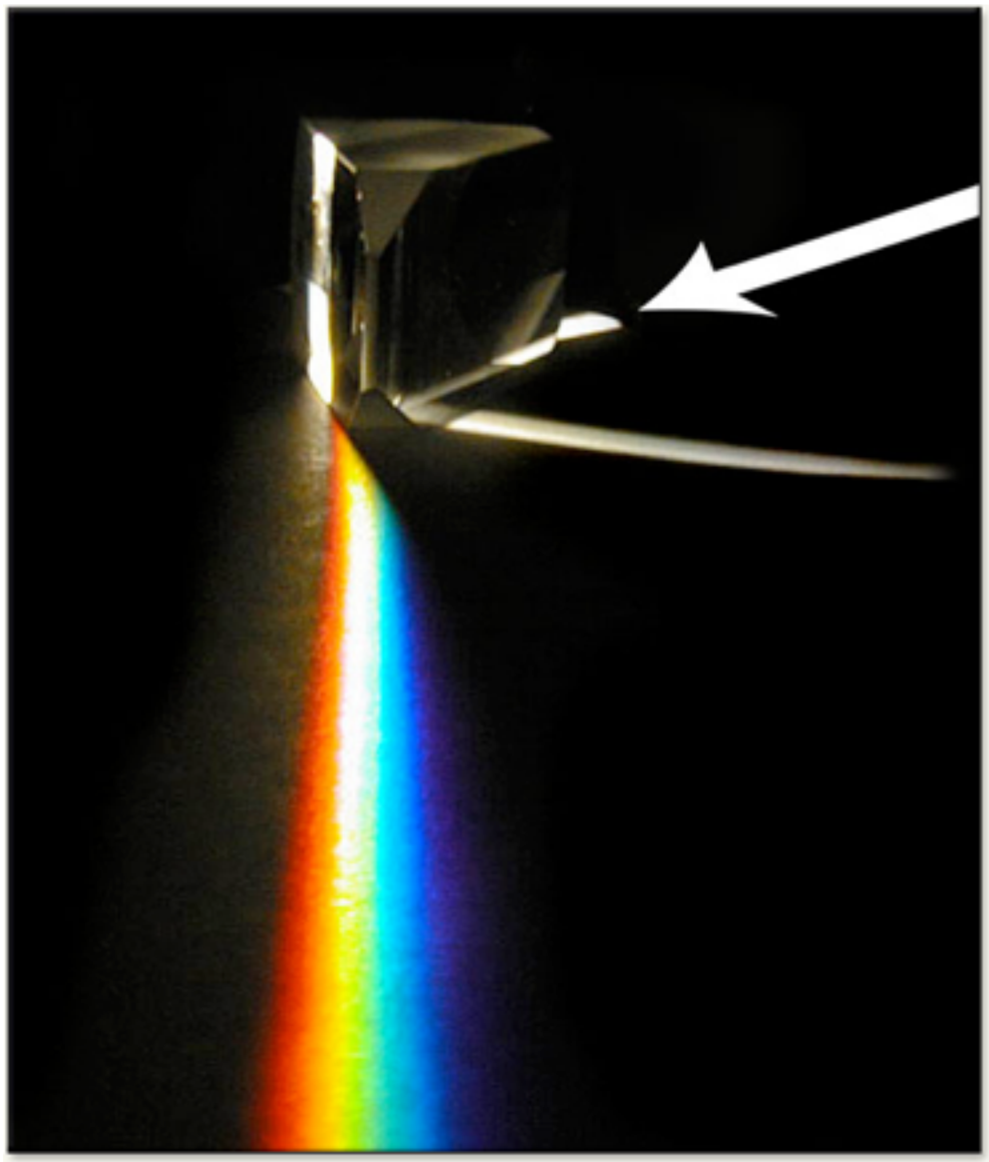


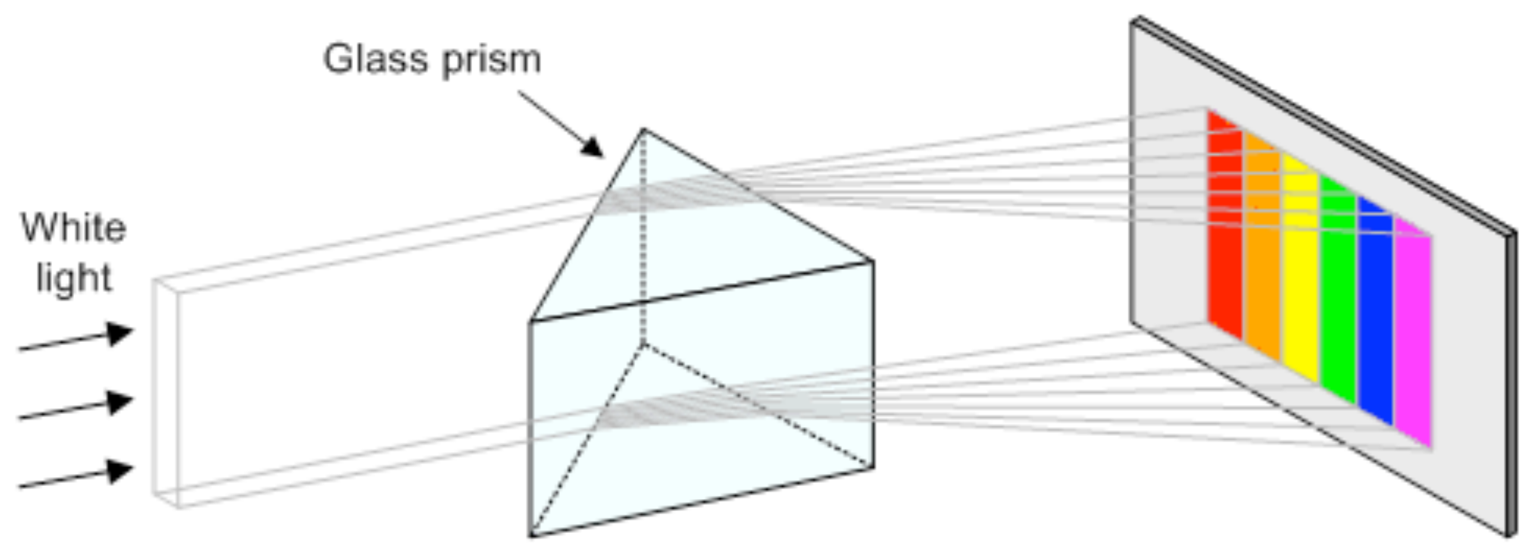
Color != Wavelength

But rather, a combination of wavelengths and energy



Isaac Newton, 1666





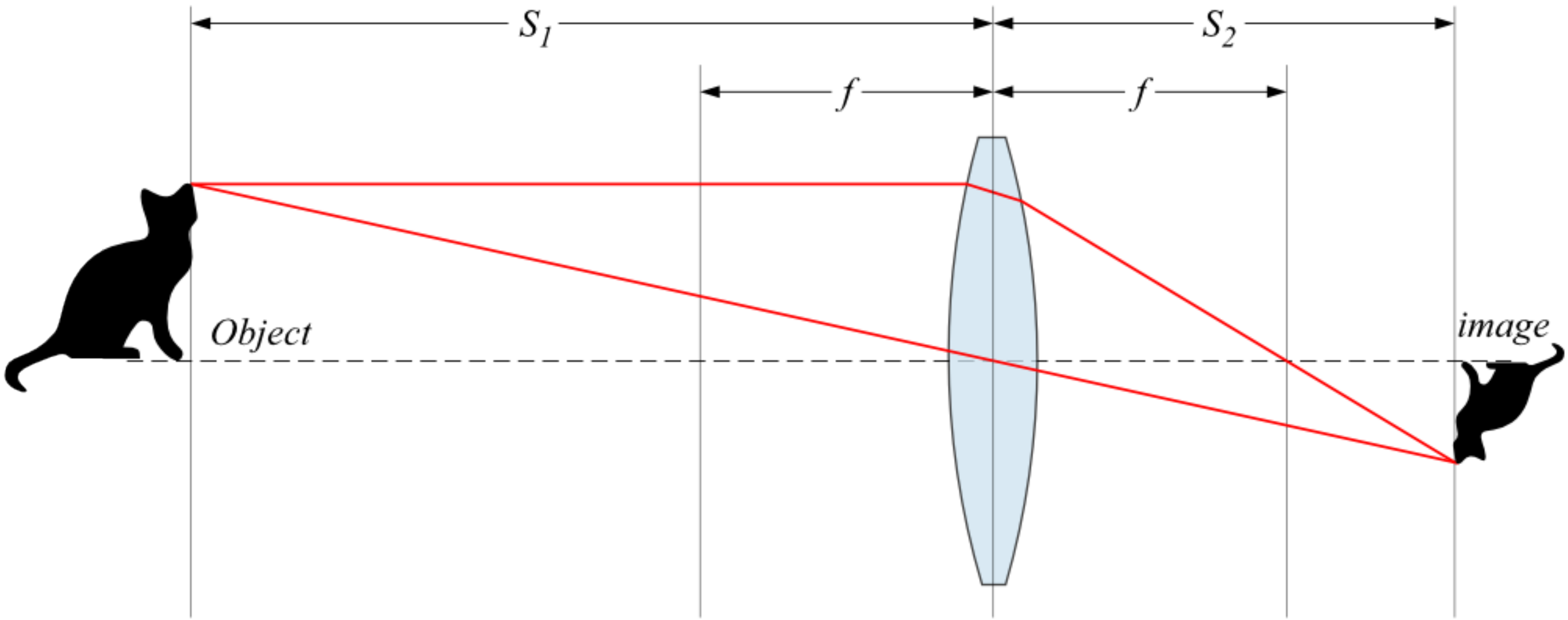
Newton's experiment for splitting white light into a spectrum

Optics

Thin Lens Equation

- A **lens** is a transparent device that allows light to pass through while causing it to either converge or diverge.
- Given a a camera, a target object, and a single converging lens:
  - Let S1 and S2 be the distance from the lens to the target and film
  - The **focal length**, f, is a measure of how strongly a lens converges light
  - The **magnification factor**, m = S2/S1, relates the two distances.
    - The optical zoom of a digital camera is usually larger than 1
    - The magnification factor of a single lens is usually less than 1

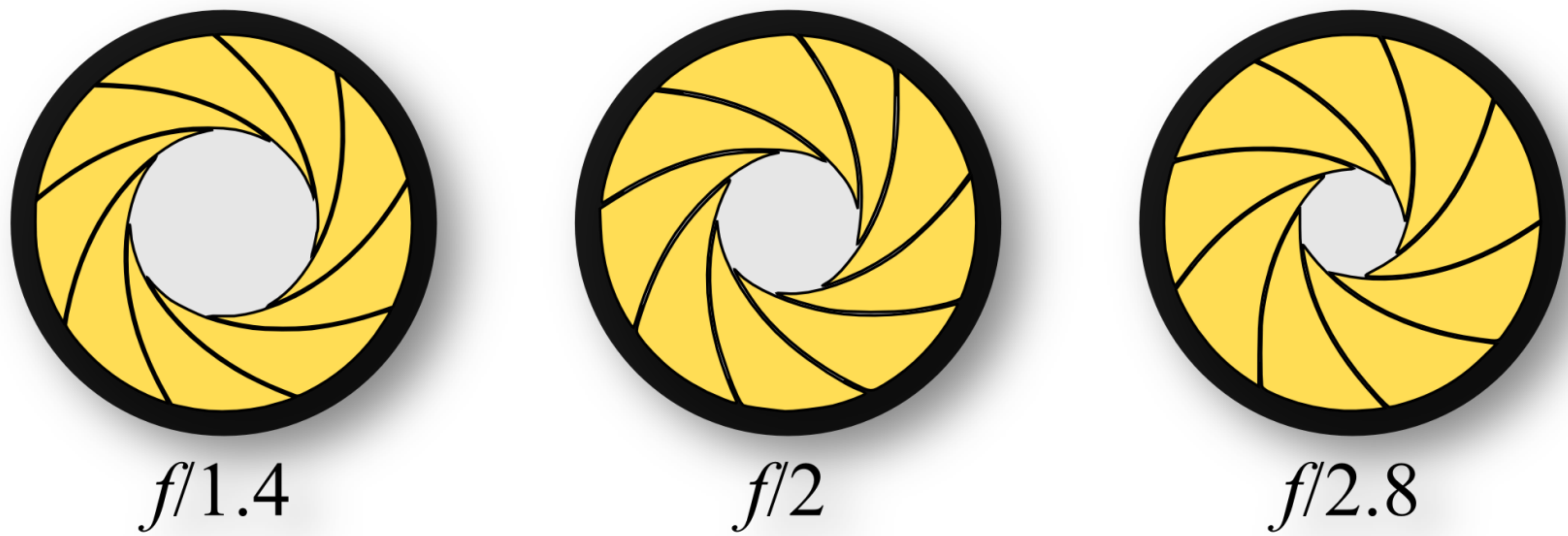
Thin Lens Equation



$$m = \frac{\text{image size}}{\text{object size}} = \frac{S_2}{S_1}$$

$$\frac{1}{S_1} + \frac{1}{S_2} = \frac{1}{f}$$

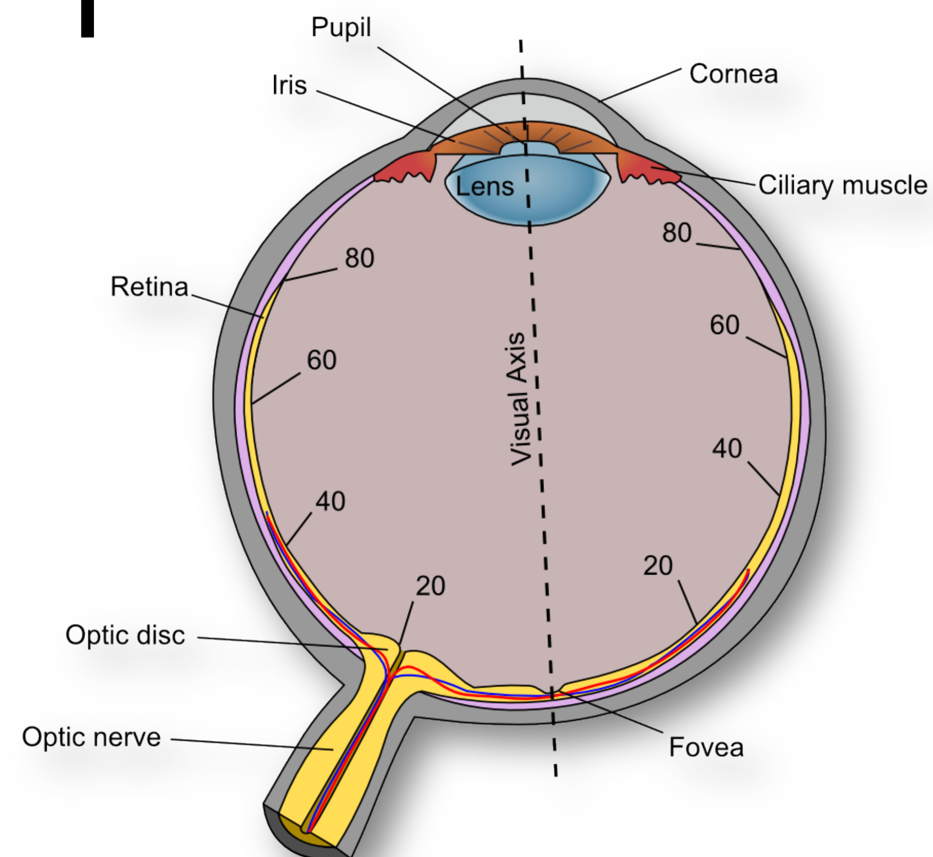
F-stops

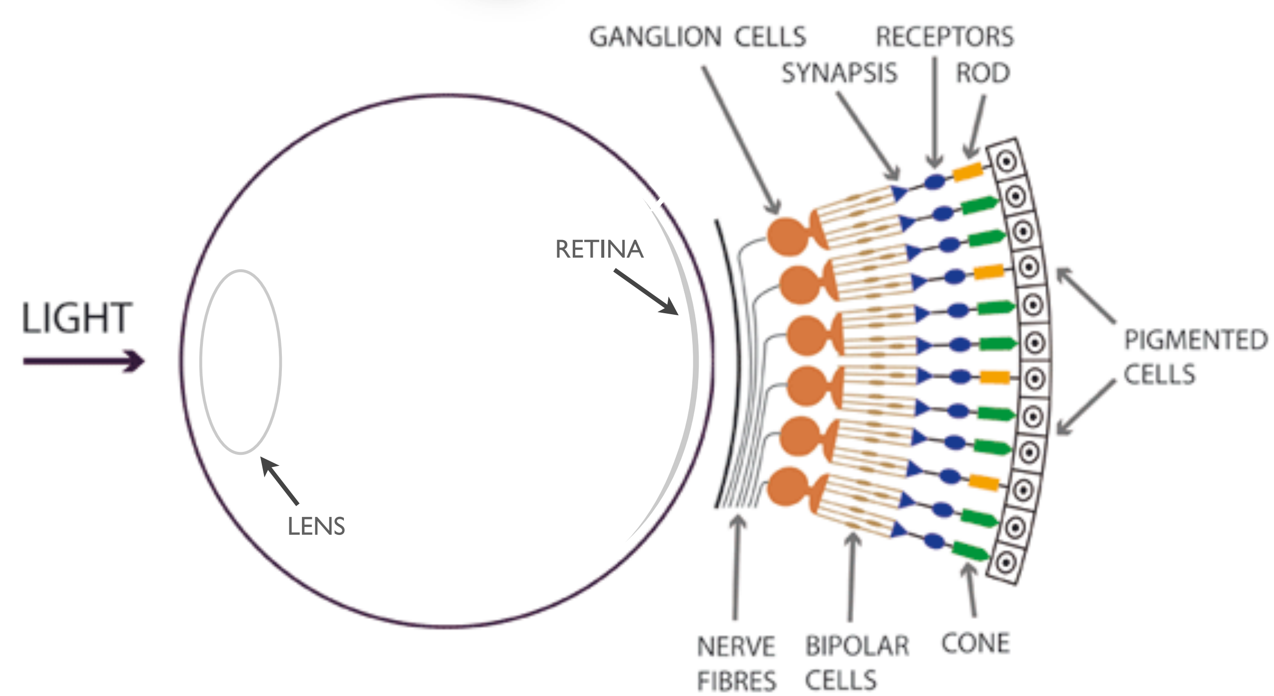


- F-number, N, is the ratio of focal length to the diameter of the aperture (lens opening). Written f/N, where higher N = smaller opening
  - Larger N's means darker images, or equivalently longer exposes to get the same brightness.
- F-stops are pre-defined aperture settings that are typically factors of 2 with respect to amount of light allowed into the camera.
  - Doubling "area" of a circle implies scaling the aperture diameter by $\sqrt{2} \approx 1.4$.
  - F-stops are geometric sequences involving powers of the $\sqrt{2}$.

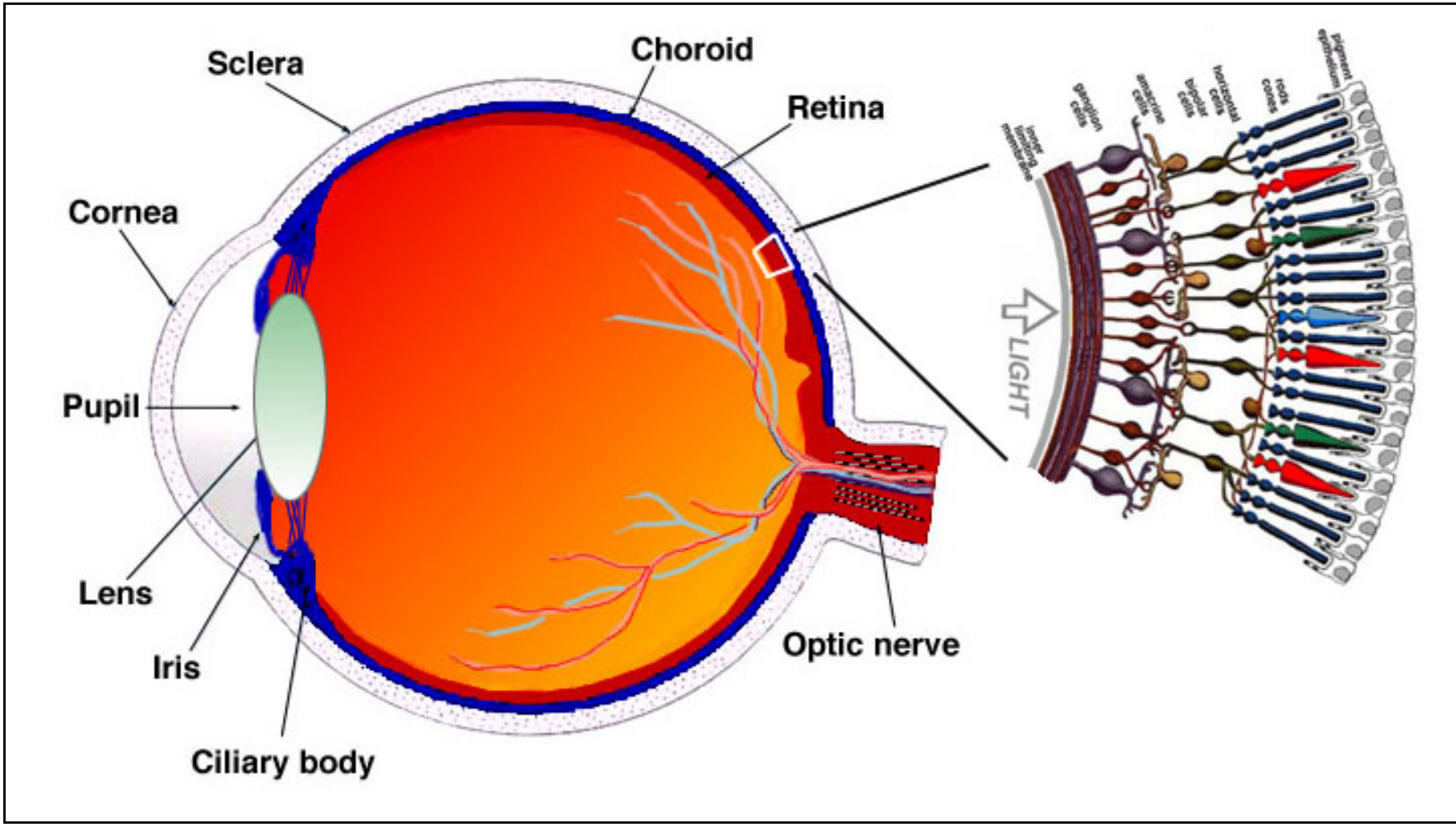
Human Optics

- In Human vision, **cornea** acts as a protective lens that roughly focuses incoming light
- Iris controls the amount of light that enters the eye
- The **lens** sharply focuses incoming light onto the retina
  - Absorbs both infrared and ultraviolet light which can damage the lens
- The **retina** is covered by **photoreceptors** (light sensors) which measure light





Physiology of the Eye



Source: http://webvision.med.utah.edu/

Photoreceptors

Rods

- Approximately 100-150 million rods.
- Non-uniform distribution across the retina
- Sensitive to low-light levels (scotopic vision)

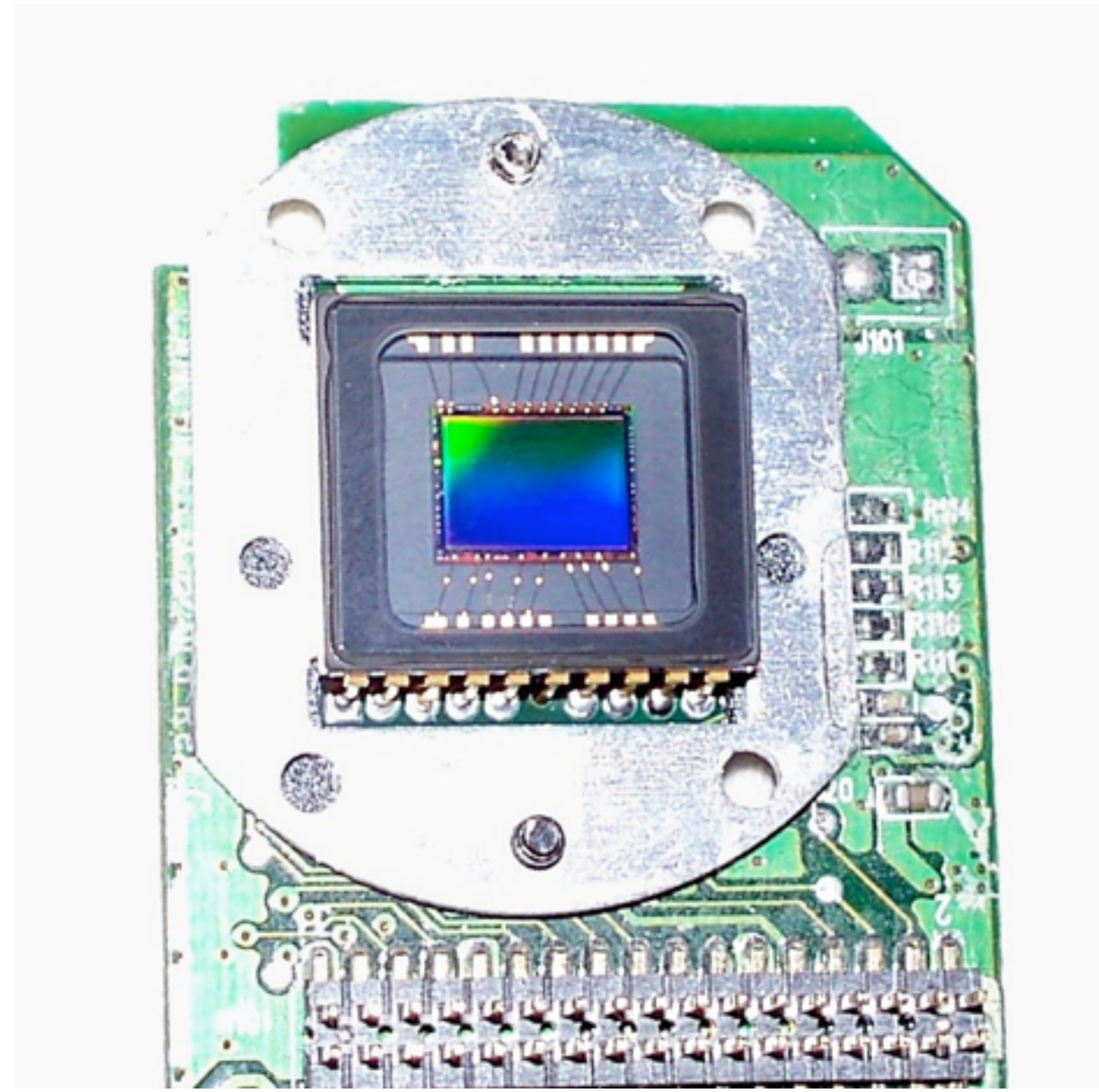
Cones

- Approximately 6-7 million cones.
- Sensitive to daytime-light levels (photopic vision)
- Detect color by the use of 3 different kinds:
  - Red (L cone) : 564-580nm wavelengths (65% of all cones)
  - Green (M cone) : 534-545nm (30% of all cones)
  - Blue (S cone) : 420-440nm (5% of all cones)

CCDs or “Electronic Eyes”

Charge-Coupled Devices (CCDs)

- A CCD is an electronic circuit with a grid of small rectangular photocells.
- The optical lens focuses a scene onto the sensors.
- Each photocell measures the amount of light that hits it.
- The collective data of the sensors represents an image when viewed from a distance.



http://en.wikipedia.org/wiki/Charge-coupled_device

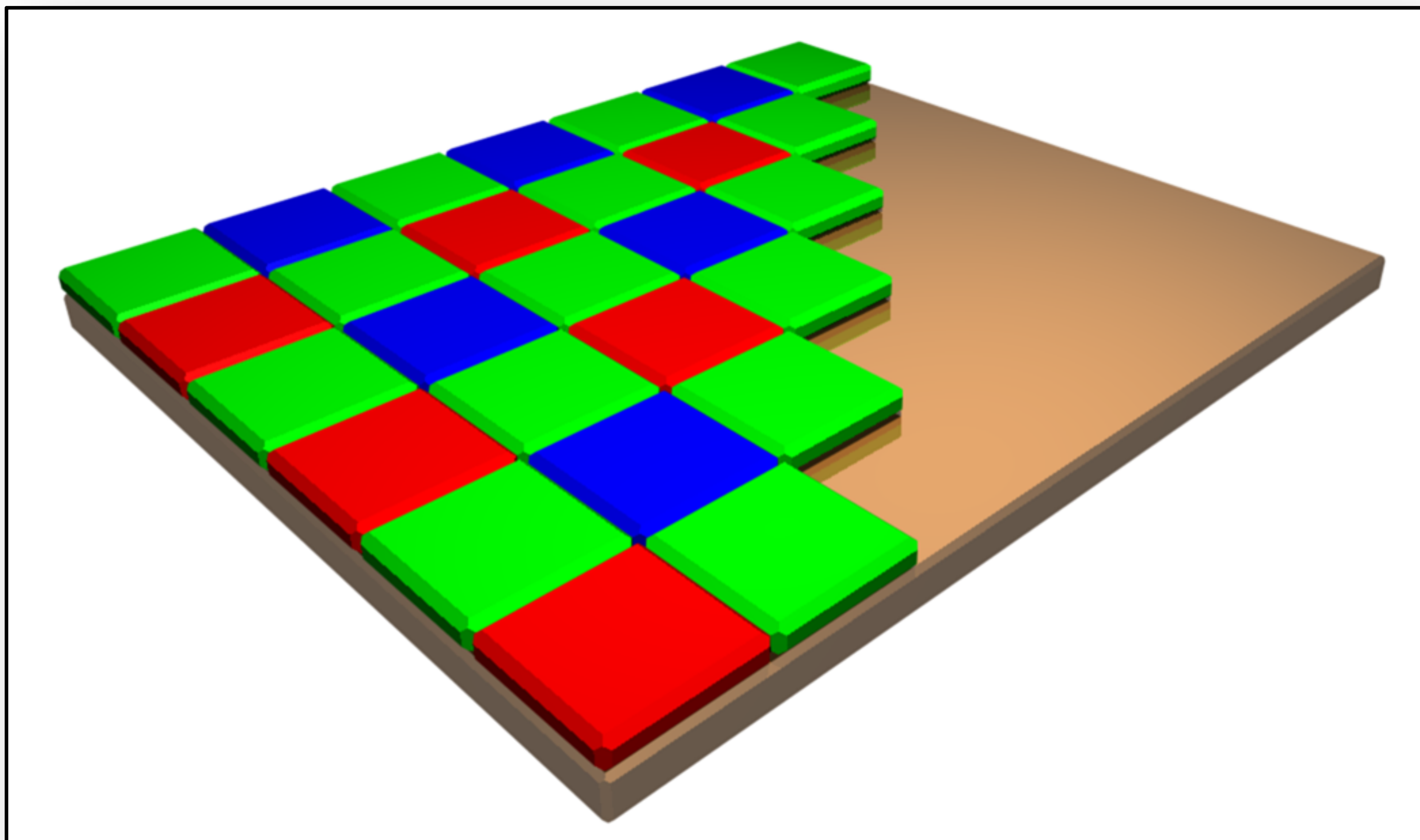
Color Image Acquisition

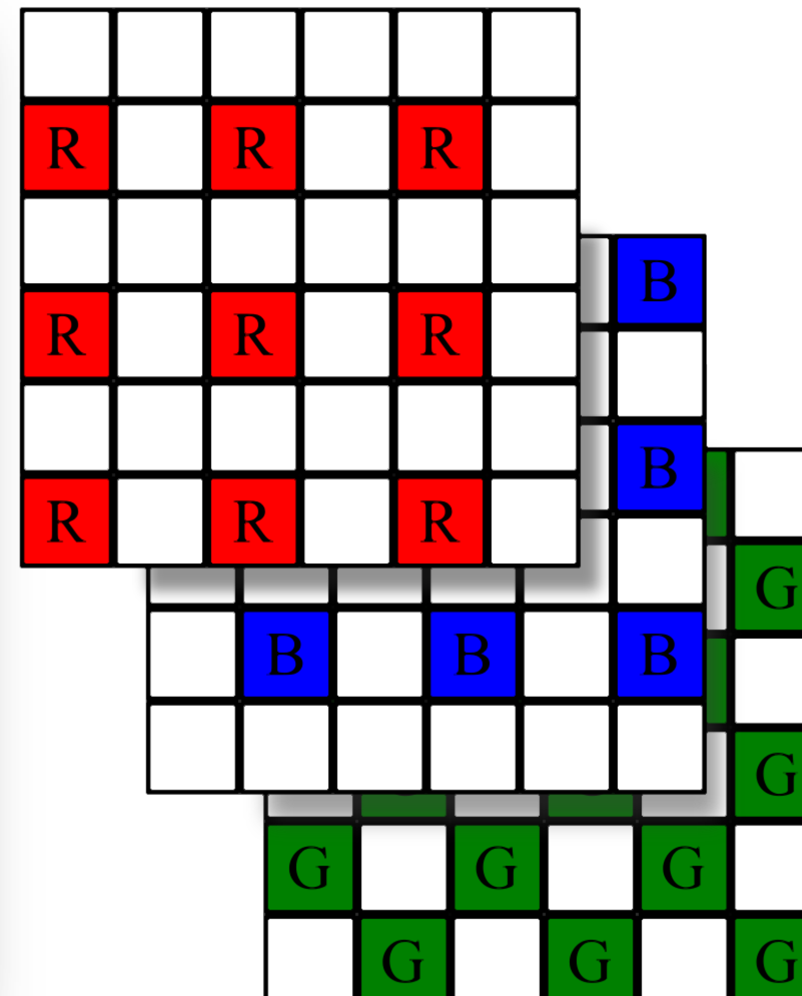
- A color camera must capture 3 samples for each pixel location. Somehow, each photosite must sense three different values.
- Color digital cameras work in various ways:
  - A single CCD where each photosite measures red, green, OR blue
  - A single CCD where each photosite measures red, green, AND blue
  - A three-CCD system such that each CCD captures one band

Color Image Acquisition

- Consider a single CCD color digital camera
  - Each individual photosite of the CCD is filtered to detect either red, green, OR blue light
  - Most filters mimic the cone density of the human eye
  - The Bayer filter uses 50% green and 25% red and blue sites.
    - If each green site is extracted – it forms a band with 50% gaps
    - If each red site is extracted – it forms a band with 75% gaps
    - If each blue site is extracted – it forms a band with 75% gaps
- The 'RAW' data must be **demosaiced** (fill in the gaps) to produce a true-color image. More on this in future lectures.

Bayer Filter



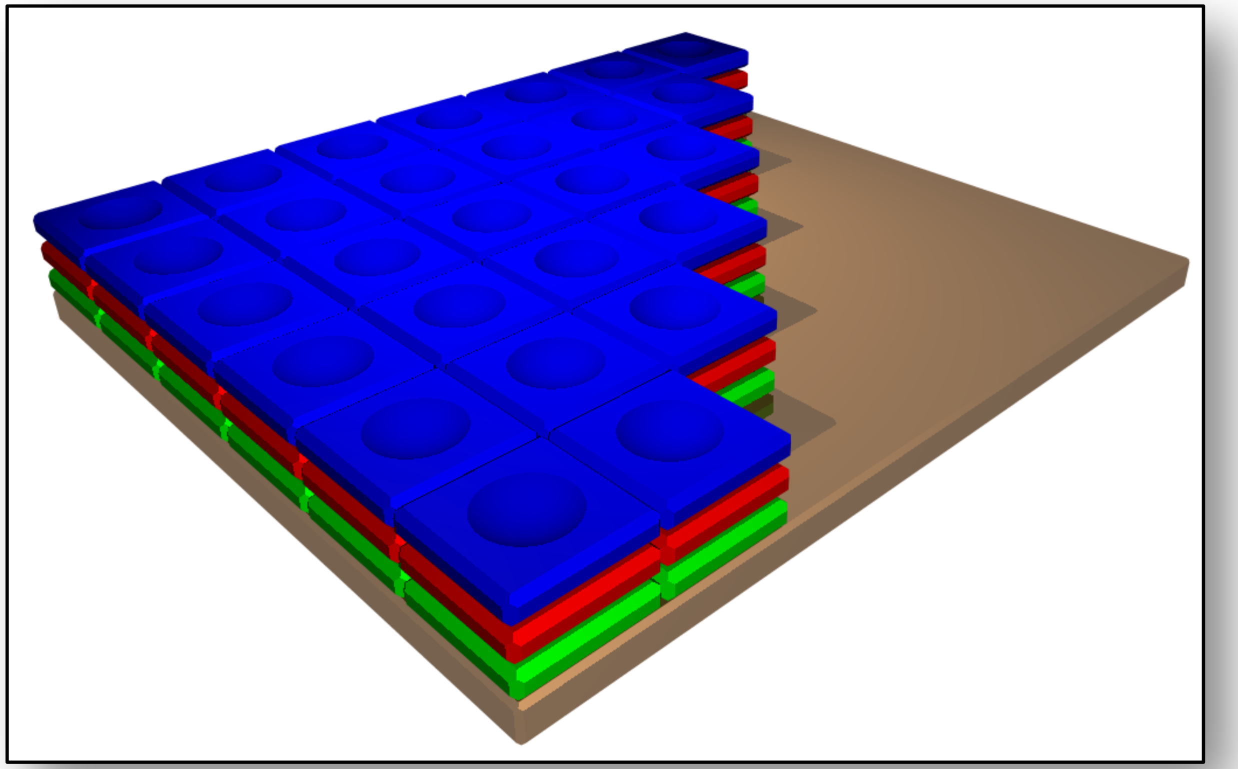


High-End Acquistion

- Other cameras contain a prism which divides the incoming light rays into their red, green and blue components.

- Newer technology allows each photosite is able to discriminate and measure red, green and blue light simultaneously.

- This technology does not require demosaicing.



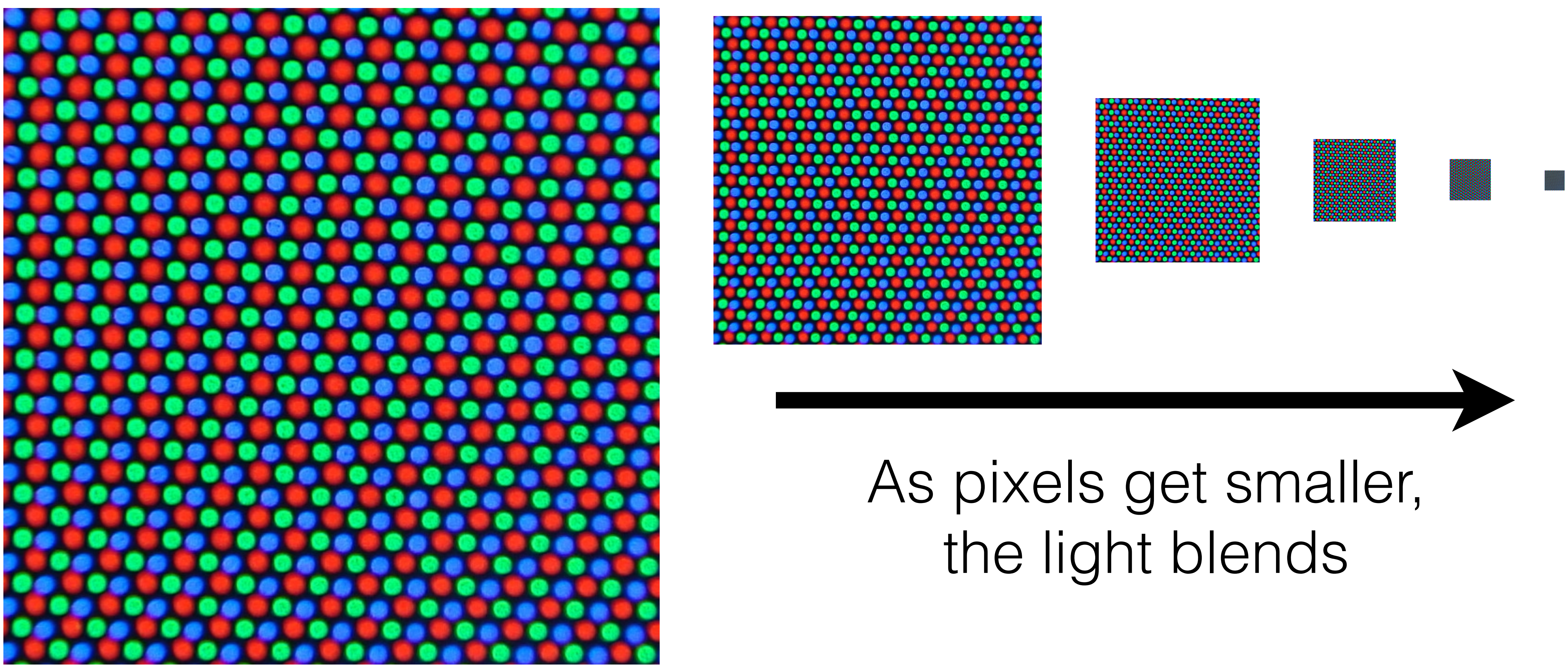
Displays

Display Challenges

- Problem: convert pixel data, stored in pixmaps, to images we see on screens.
    - This is a reconstruction problem (more on that in future lectures too)
- Goal: We have spatial data + color samples in some color space, and want to recreate some set of colors on screen

Optical Mixing

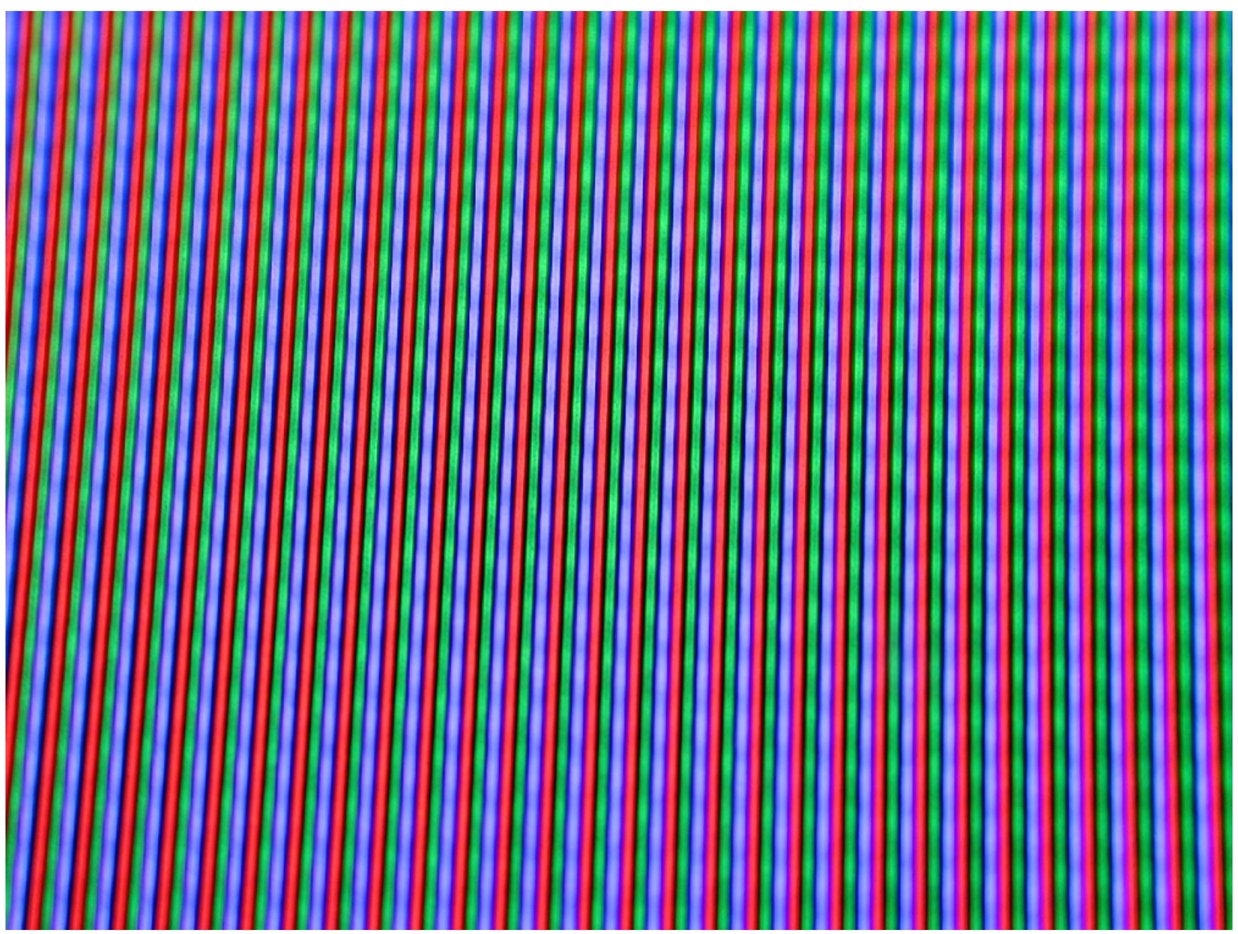
- To make any color, we combine light from three channels, Red, Green, Blue

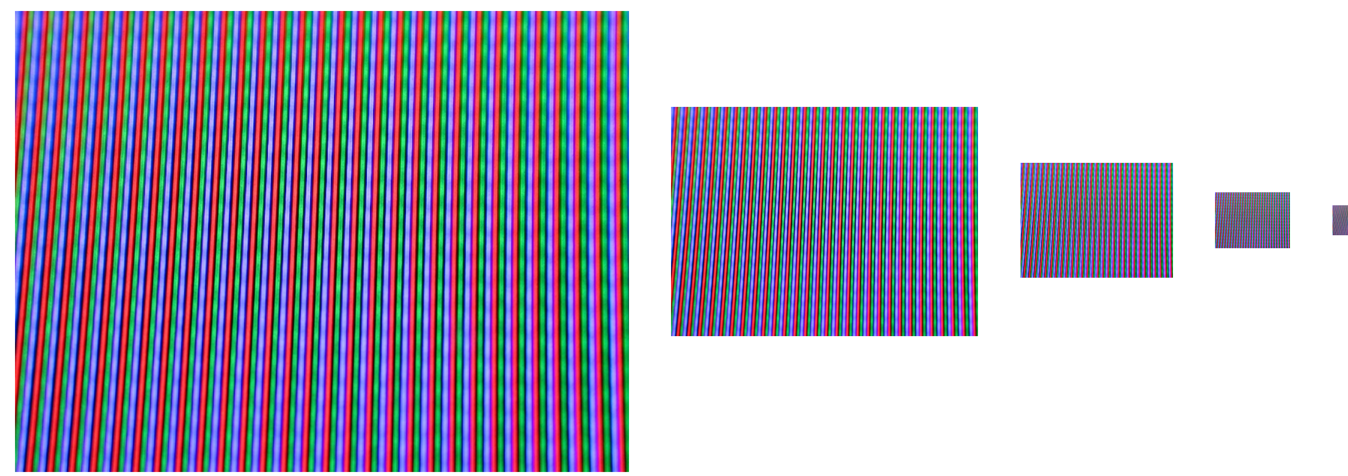


As pixels get smaller,
the light blends

Optical Mixing

- Sometimes color organized differently, same effect can be achieved

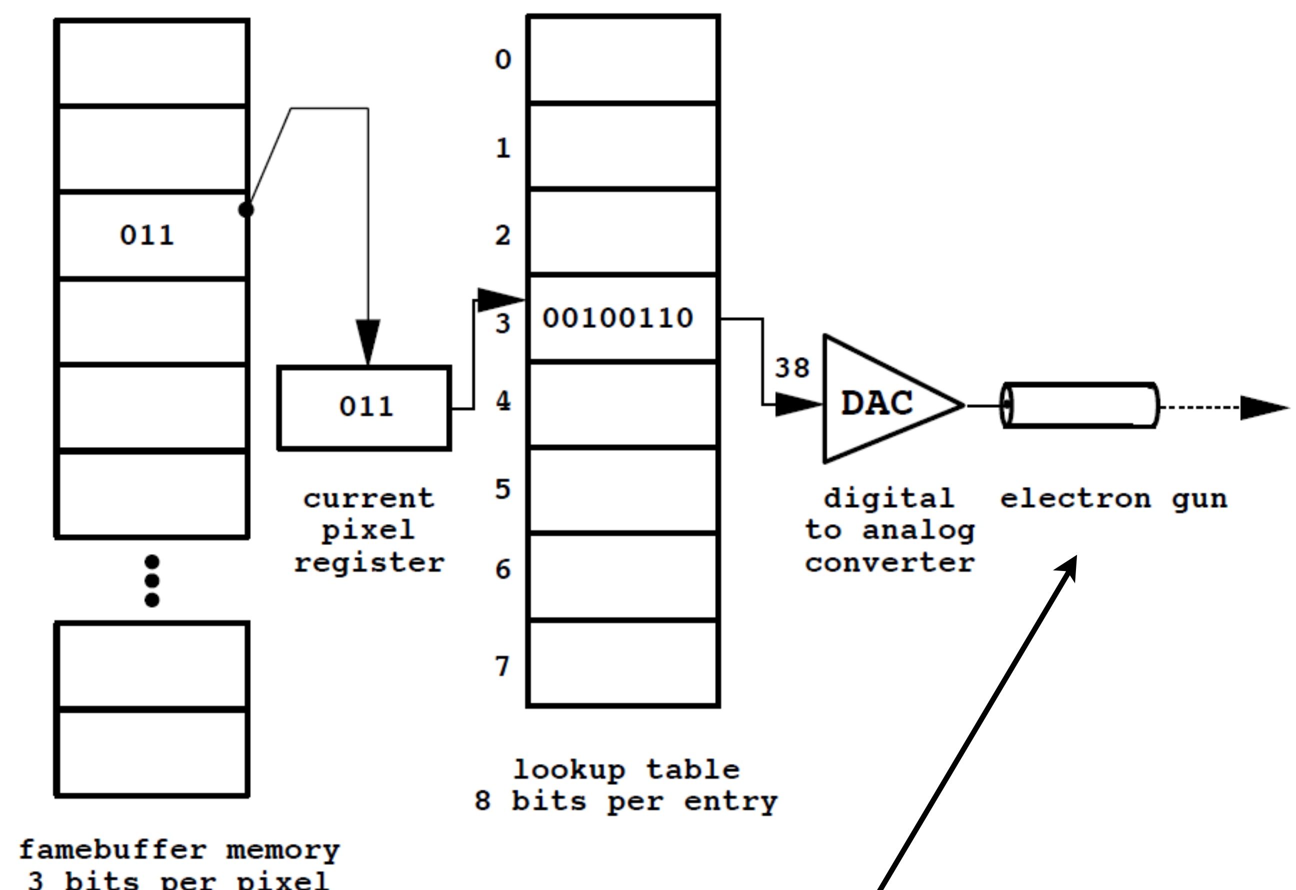




As pixels get smaller,
the light blends

Framebuffers: Preparing Image Data for the Screen

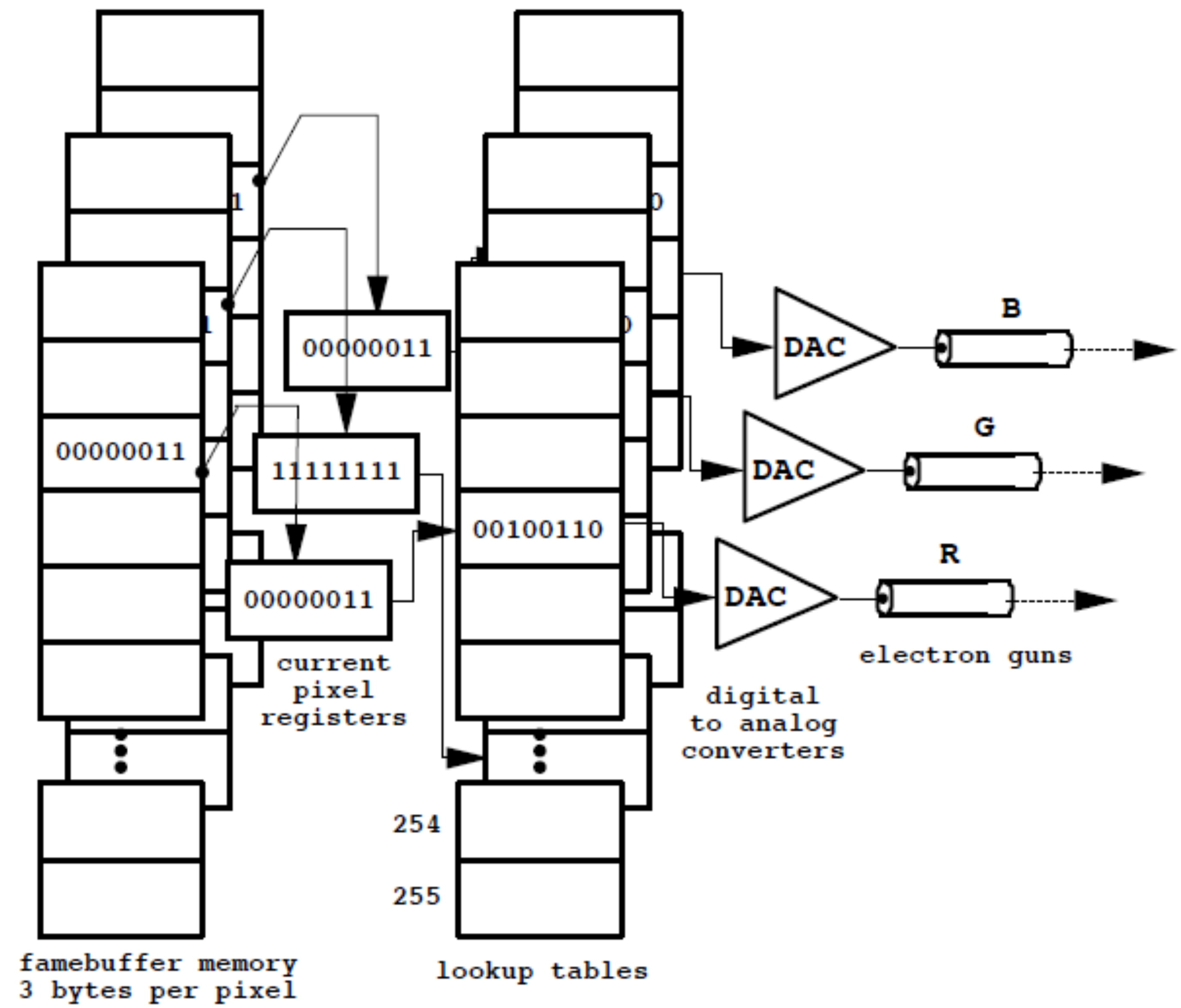
- A **framebuffer** is an array of memory, large enough to store an image on the screen.
- A **lookup table** or LUT converts information from memory to actual color responses on the display.



Note: Electron guns for CRTs, LCDs use something different

Framebuffers

- For color images, **CLUTs** (color lookup tables) are used.
- N = # of entries in the frame buffer limited by image data
- M = # of entries in the LUT limited by display's color capacity (usually greater than image)



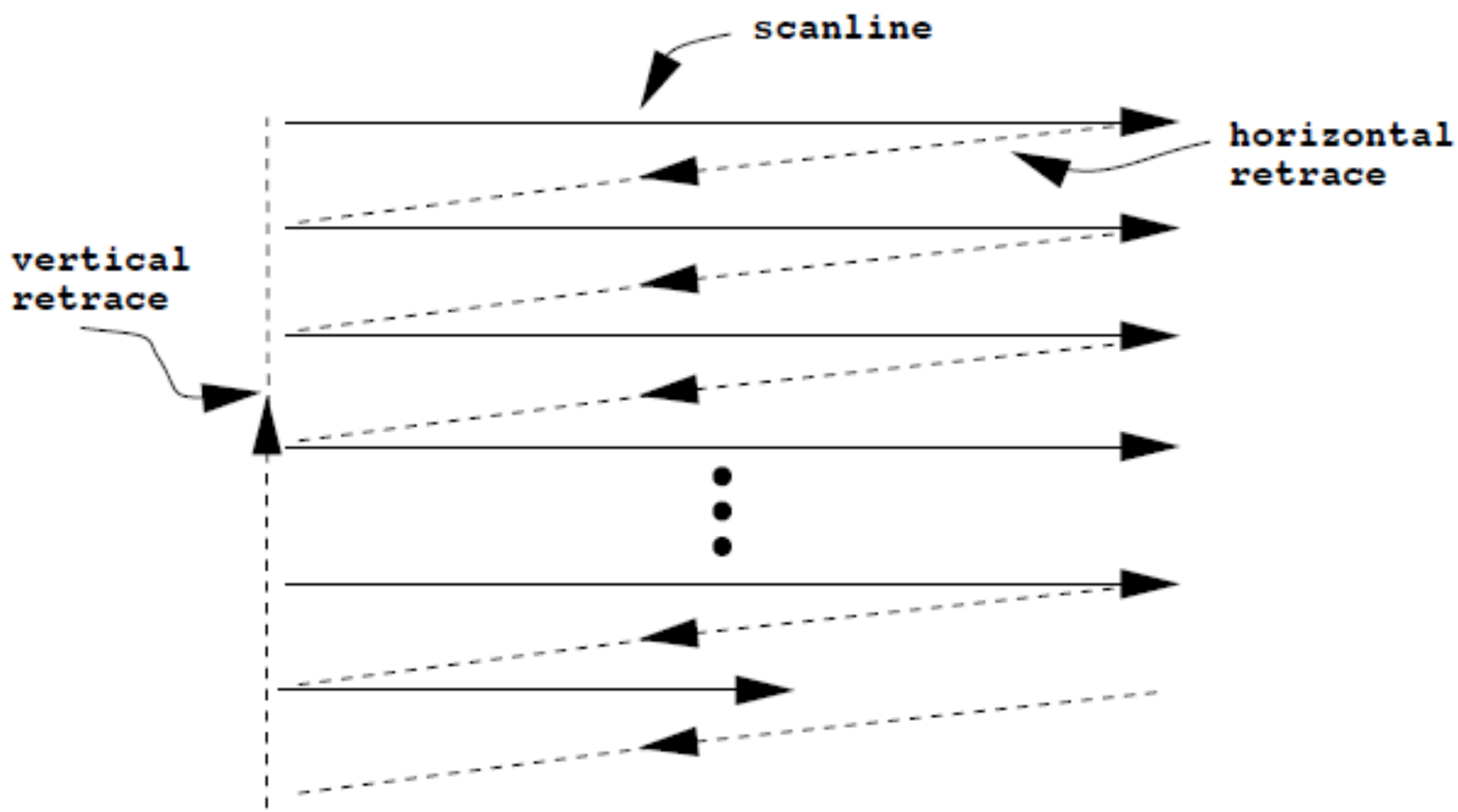
Truecolor displays have M = N

Uses of Framebuffers

- Color correction, since display may not respond at the same levels as how the data represents it.
- Simple example: Gamma corrections, brightness/contrast adjustment, etc.
- Your TV has these controls built into hardware, the image data does not change.
- More on this when we get to image processing topics.

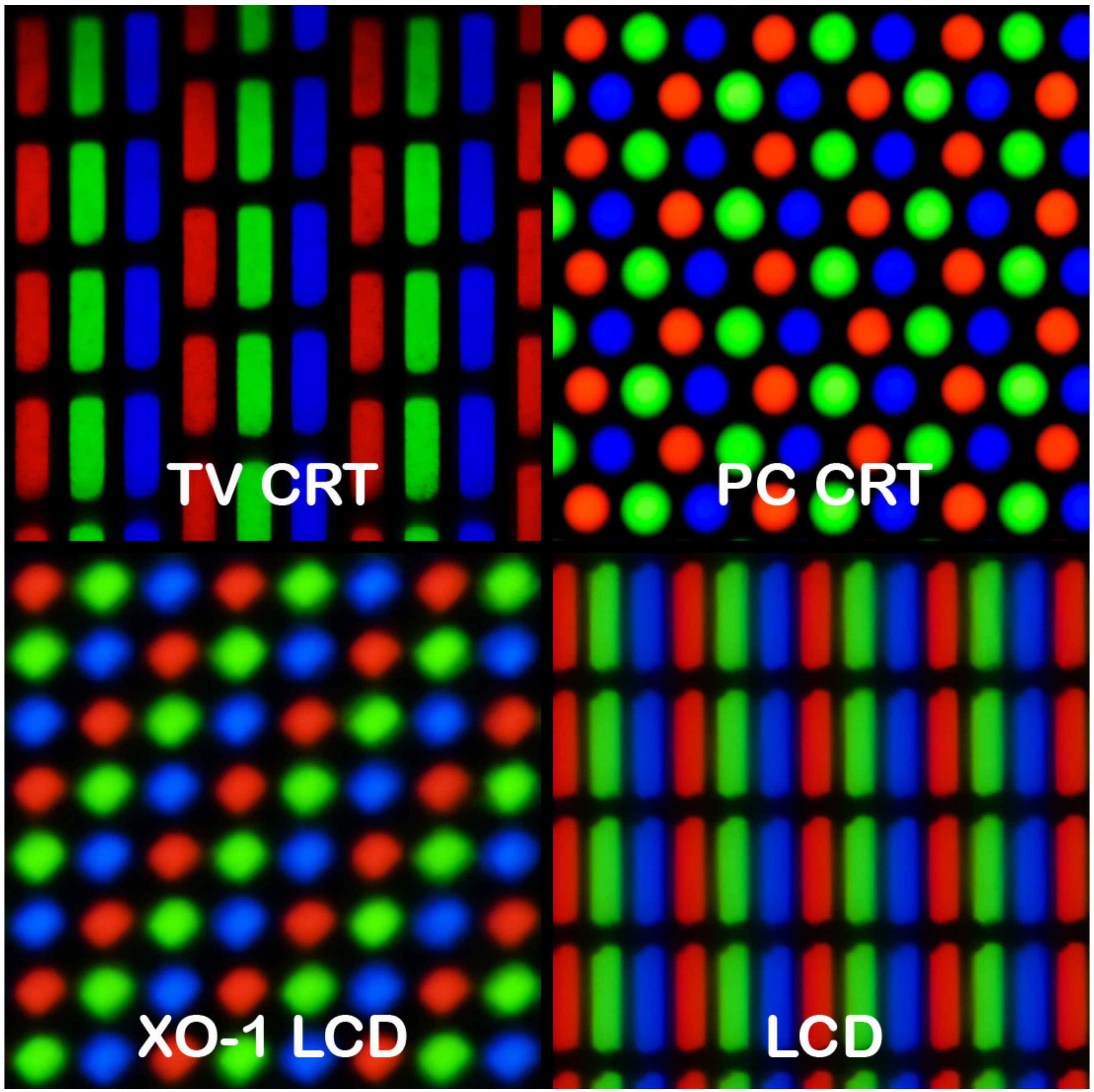
Drawing Image Data

- **Raster** scanning draws data across the screen row-by-row.
- We do not perceive this because it happens at 60hz or more.



LCDs

LCD Technology



- LCDs or **L**iquid **C**rystal **D**isplays produce color by selectively *blocking* light through different filters
- Pixels are organized in 3 side-by-side columns

Polarized Light

- Light oscillates as a wave in all directions perpendicular to its path. Polarizers selectively block certain oscillations

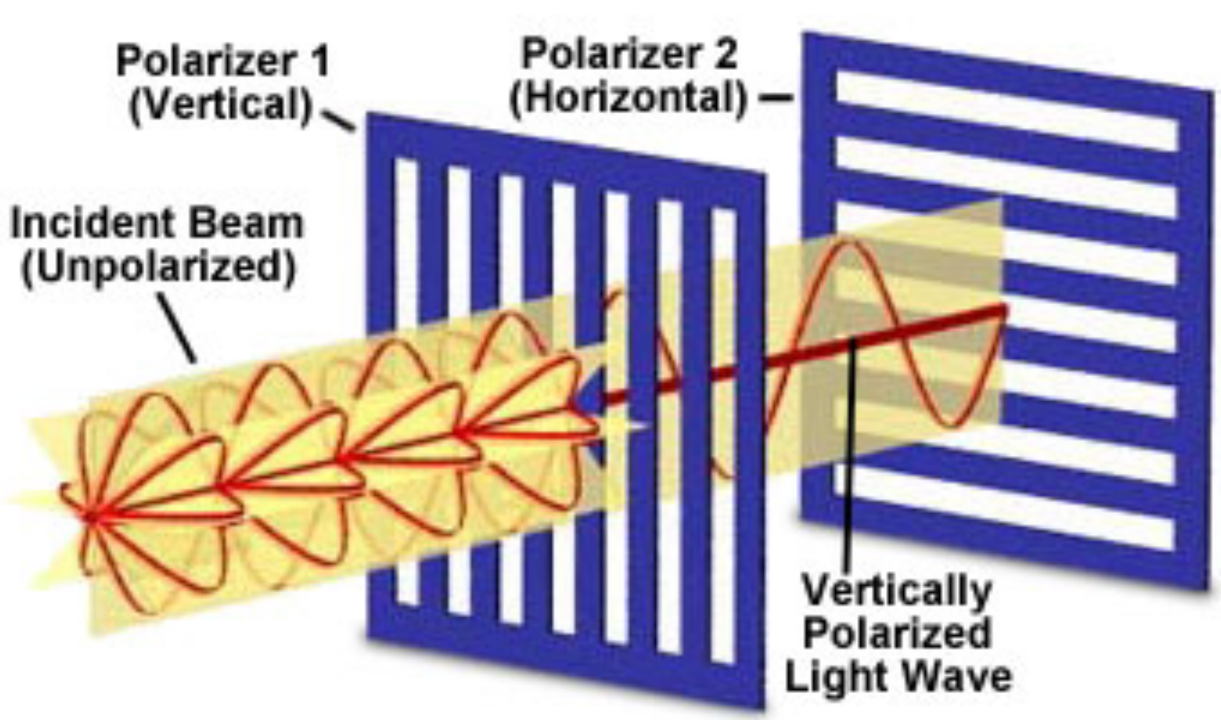


Figure 1

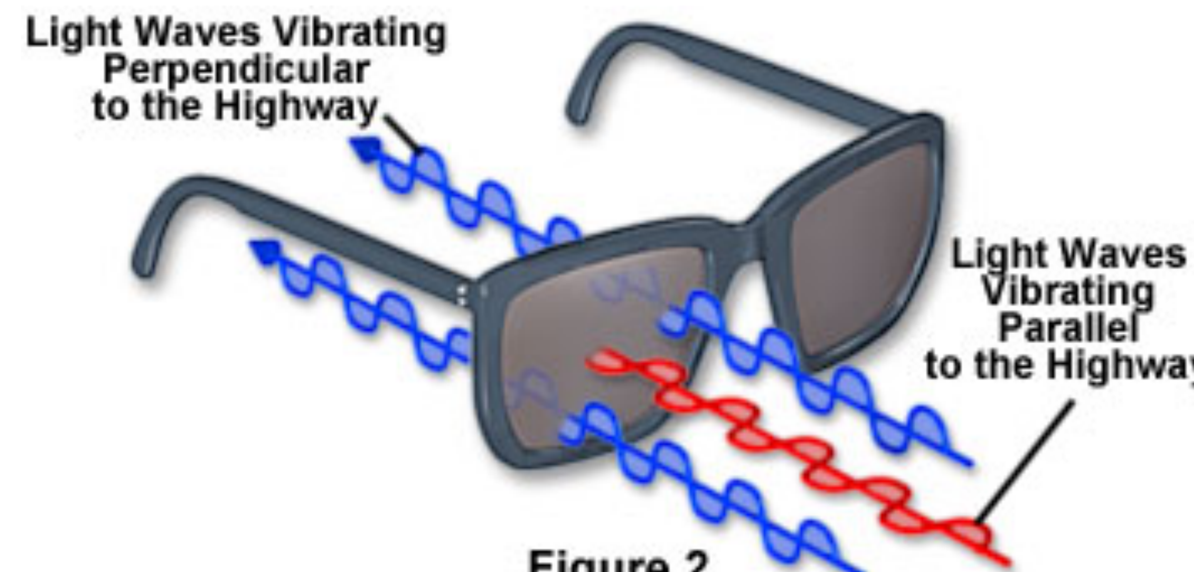
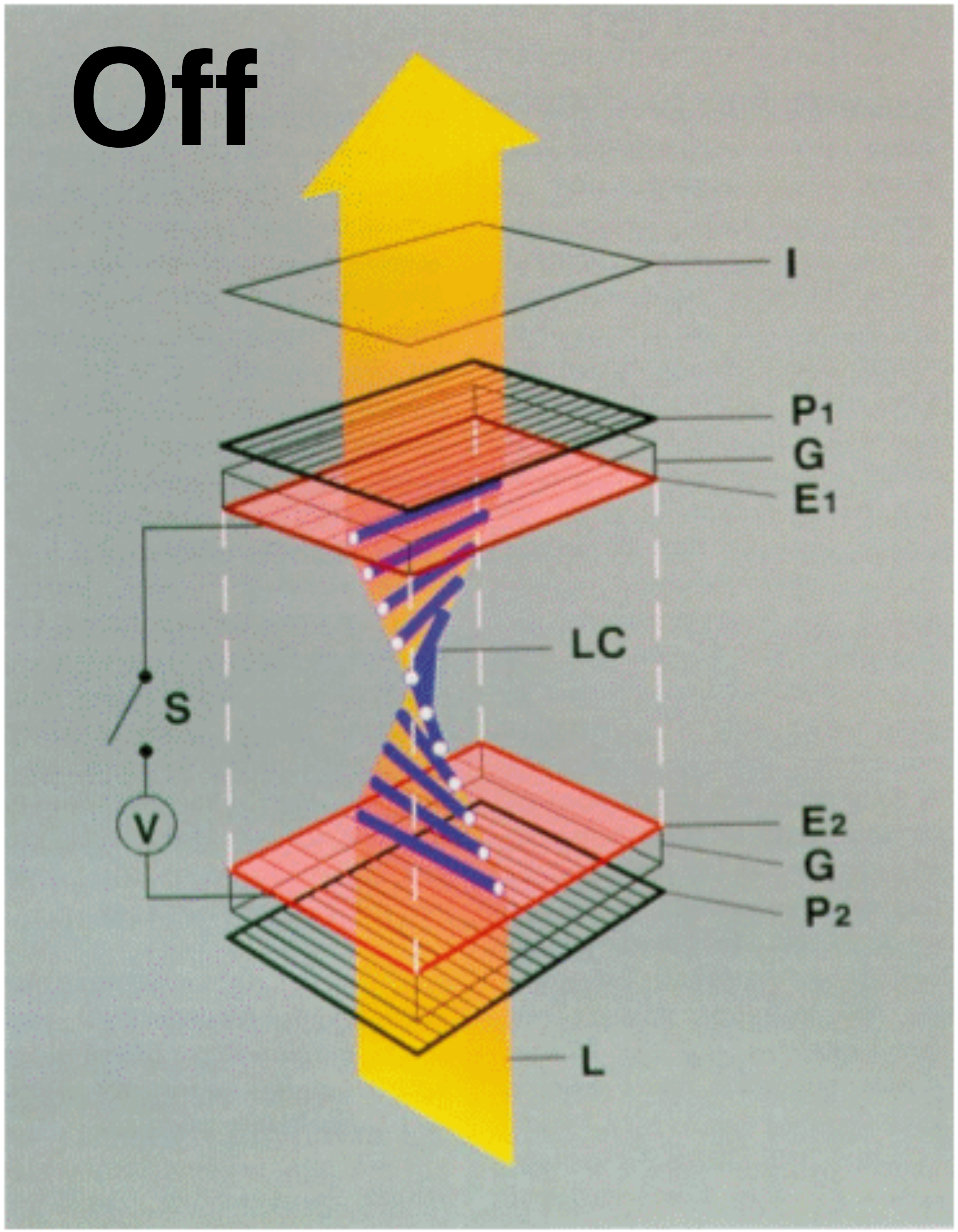
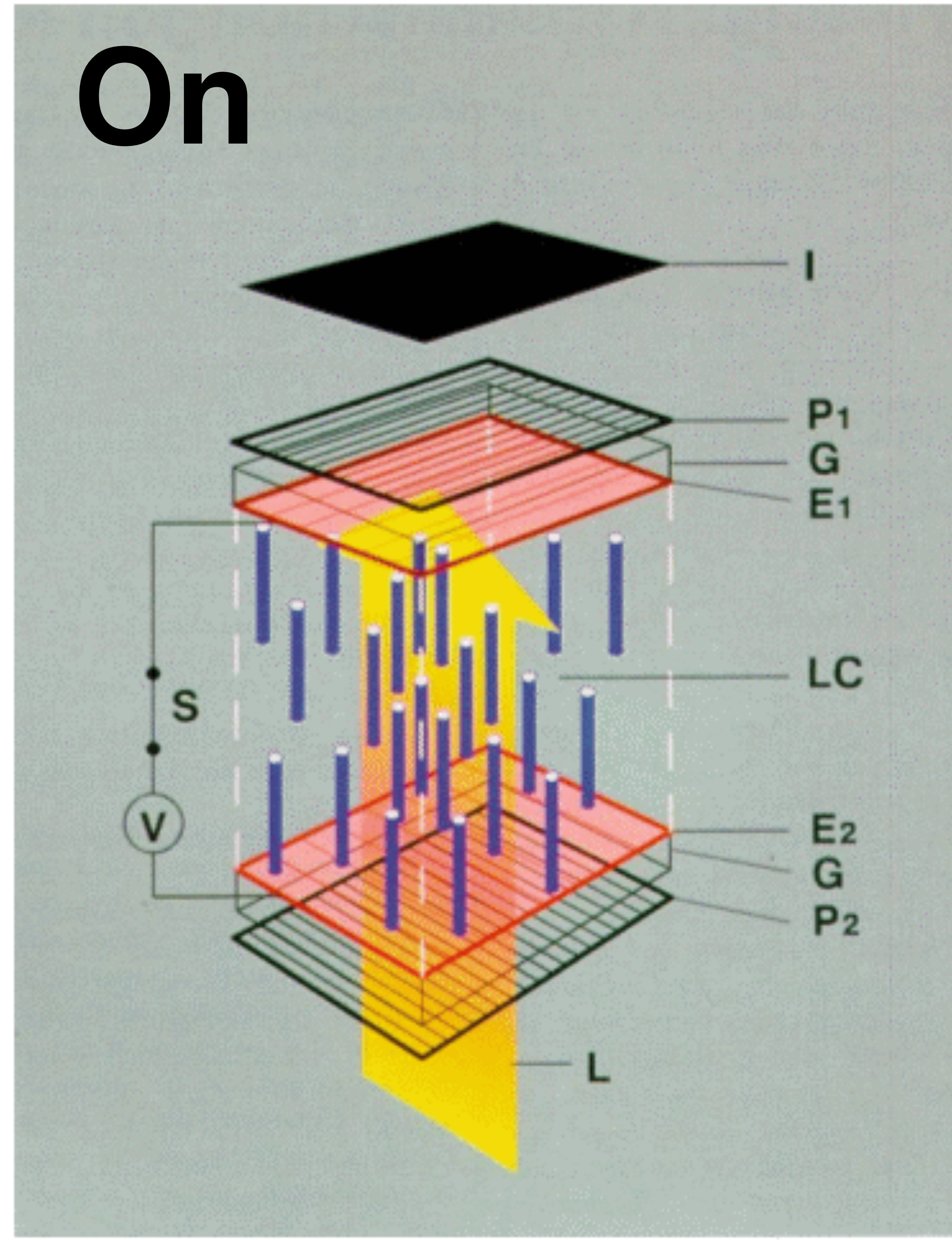


Figure 2

http://www.olympusmicro.com/primer/lightandcolor/polarization.html

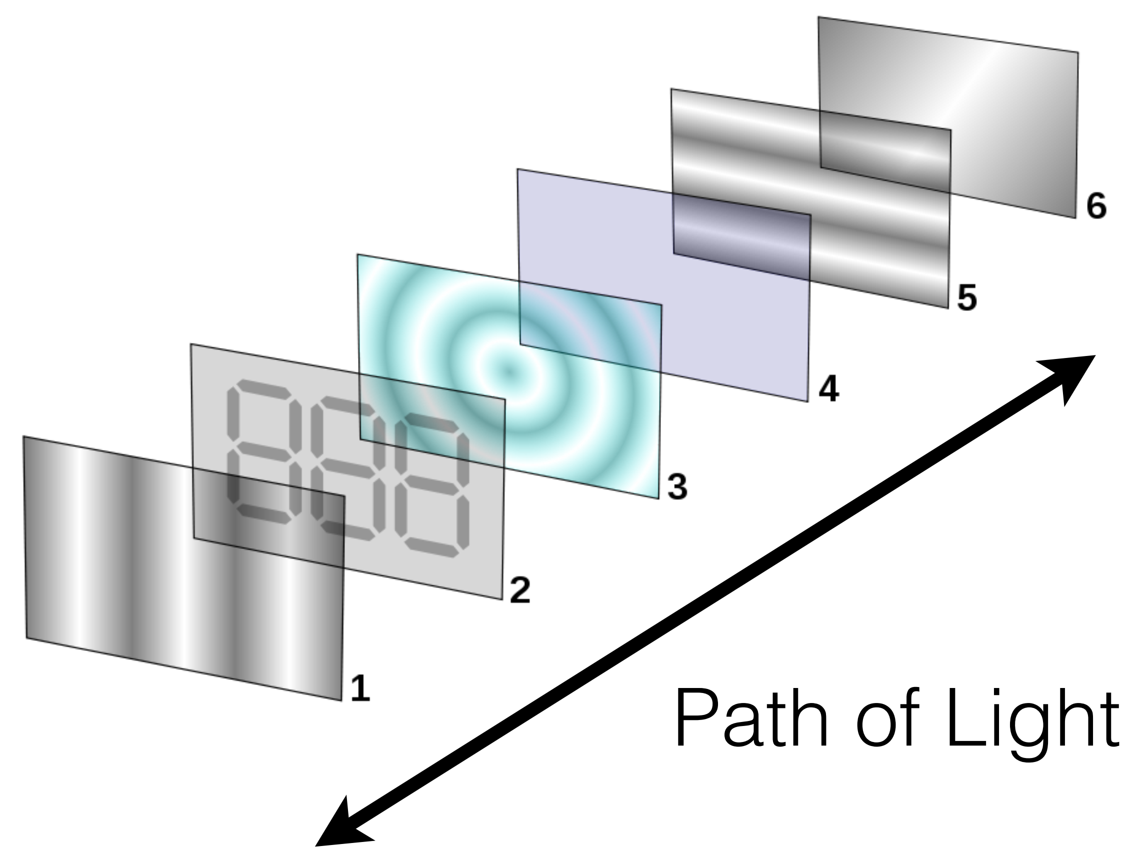
Twisted Nematics





LCD Technology

- Four basic layers (in **twisted nematics** displays):
- (1) Vertical filter film to polarize the light as it enters/exits.
- (2 – 4) Glass substrate sandwiched with electrodes. The activation of these electrodes will determine what light will penetrate via twisted nematic LCDS
- (5) Horizontal polarizer to filter light.
- (6) Reflective surface or light source to send light back to viewer.



http://en.wikipedia.org/wiki/Lcd

EngineerGuy.com

The engineering details of all the stuff you wanna know about

download video: mp4 or iPod friendly

LCD Monitor

Bill tears down an LCD monitor to show how it works. He describes how liquid crystals are used, the structure of the glass panes, and the thin film transistor (TFTs) that allow for active matrix addressing.

Learn more

- Learn more about liquid crystals from Case Western Reserve University.

Transcript This monitor uses liquid crystals to display images. How this thing works amazes me! Let me show you.

Let's start at the back of the screen. If you look here you'll see a row of LED lights at the bottom called the "backlight." These are the only lights in the monitor! Next I'll put in what's called the "optical system" which make the light even across the back of the screen.

The first sheet makes a nice even white background for the light. The next piece is called a "light-guide plate." You see its covered with dots. When light enters from the bottom edge it propagates down the plate by total internal reflection, unless it hits one of the dots. They make some of the light rays emerge out the front. Then engineers place a diffuser film; it helps eliminate the dot pattern from the light-guide plate. Then comes a "prism film."

When light from the backlight passes through the first polarizer and enters the sandwich it's rotated by the liquid crystals so as to allow it to pass through the second polarizer and emerge out the front of the screen. This is known as the normally white mode. Applying an electric field across the sandwich causes the crystals to line up lengthwise.

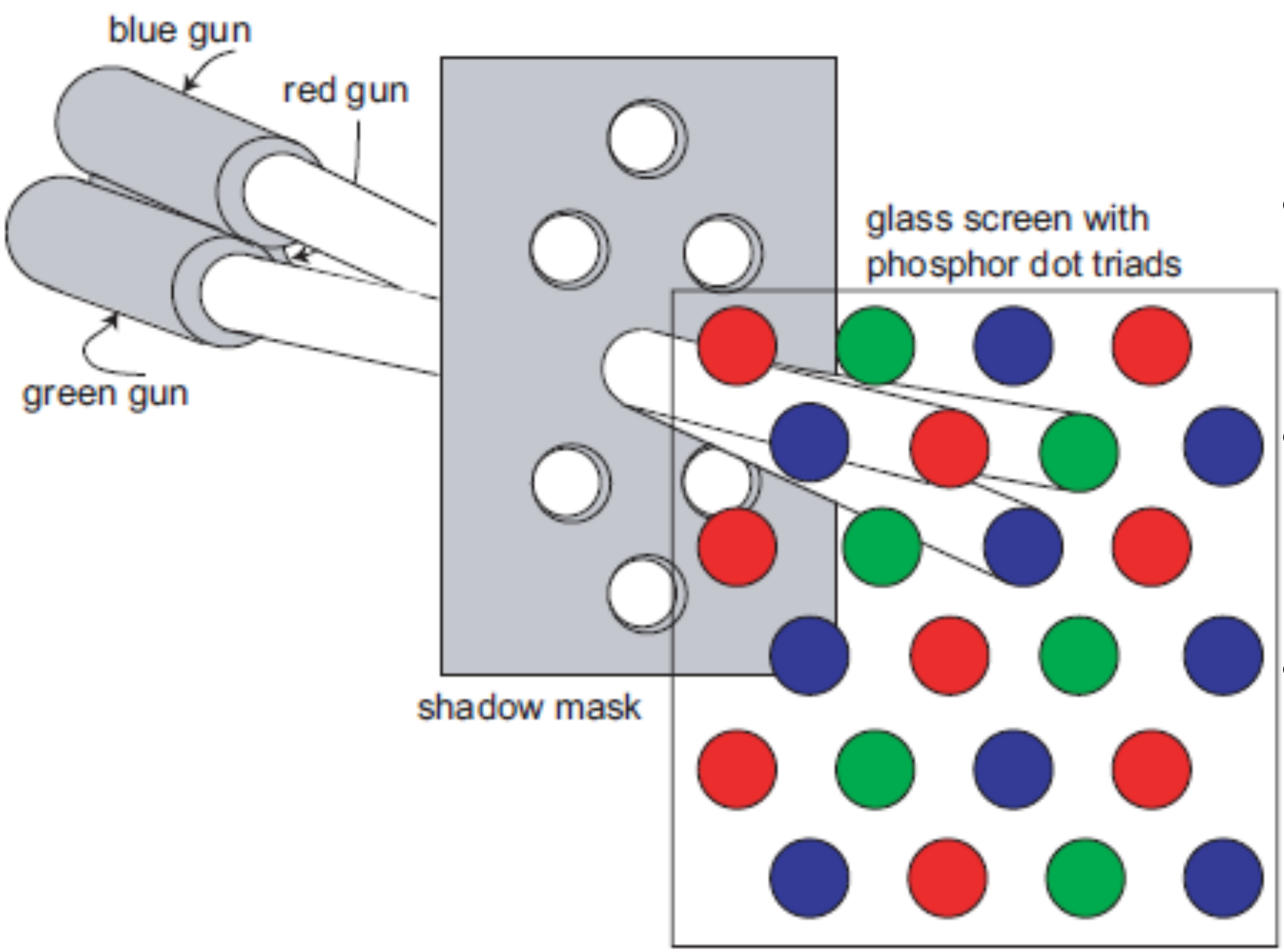
Now the light that passes through the first polarizer is not rotated by the crystals and can no longer pass through the front of the screen. We call this the normally black mode.

Now that we can control the light through the glass, who do we get color? Let's look in detail at the piece of glass.

By controlling the voltage between these transparent electrodes we can control the intensity of the light that passes through. Now, there's much more to the glass

CRTs (briefly)

Cathode Ray Tubes



- Electron guns fire at phosphor-coated glass
- Shadow mask filters and direct beams.
- Fire in a raster pattern, using 3 guns for each color
- Voltage applied to electron gun modulates the intensity of light (this is the cause of non-linear responses in CRTs)

Lec05 Required Reading

- Hunt, 3.2 (all), 3.3.2
- House, ch.4