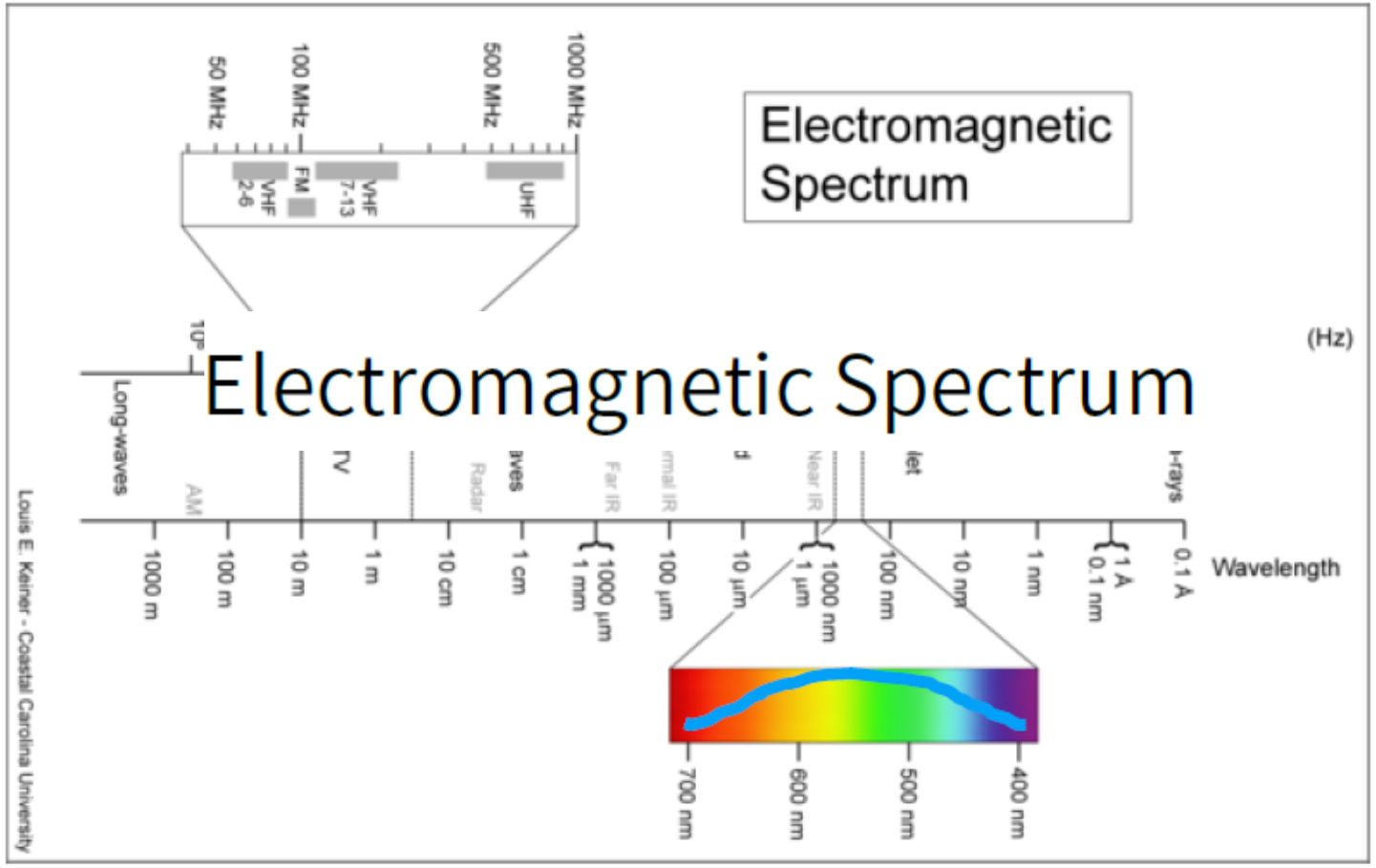
Camera and Its defect Introduction

Alex Lin

Outline

- ***What is color?***
- ***CCD & CMOS camera***
- **Camera Defects**

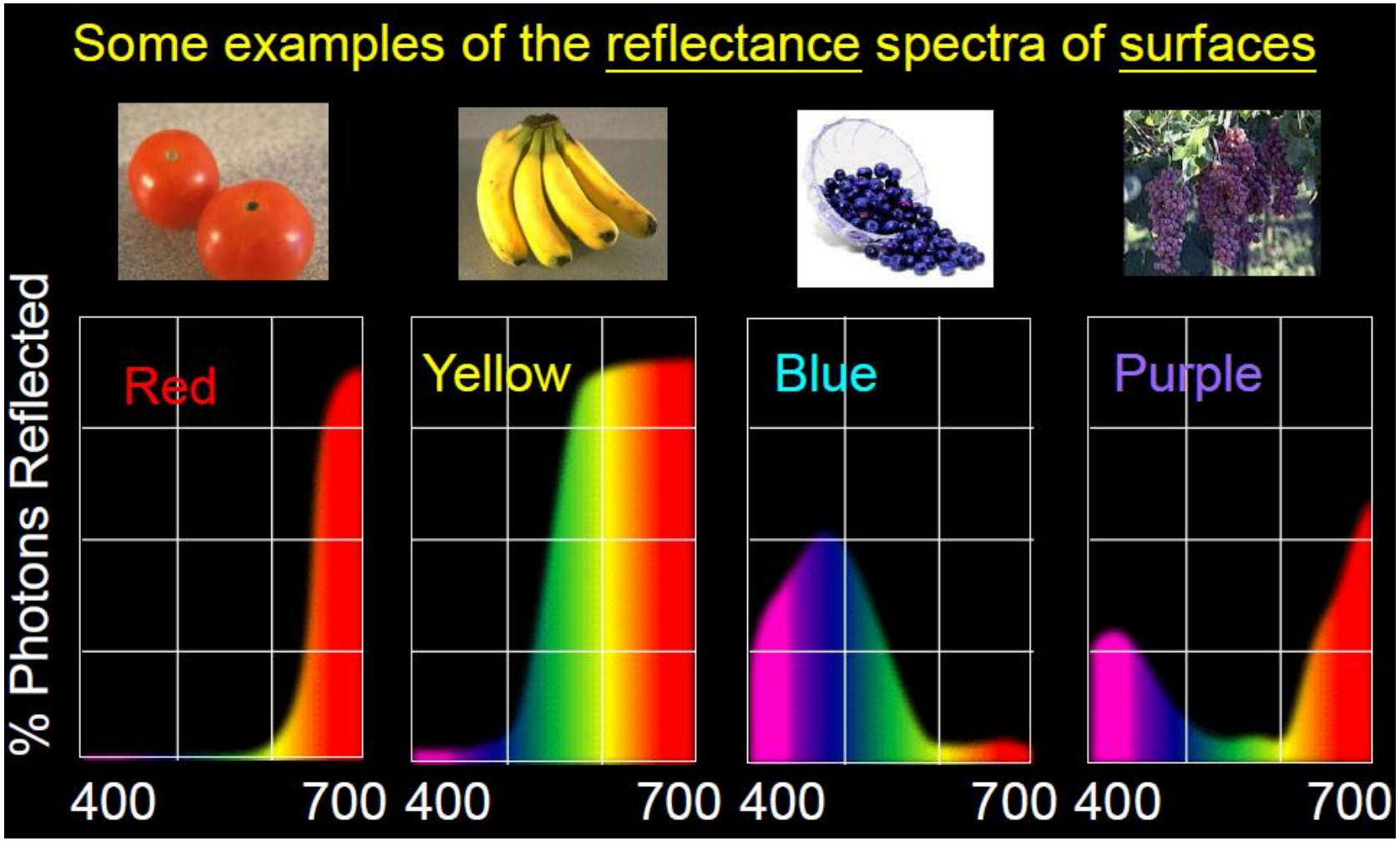
Electromagnetic Spectrum



Human Luminance Sensitivity Function

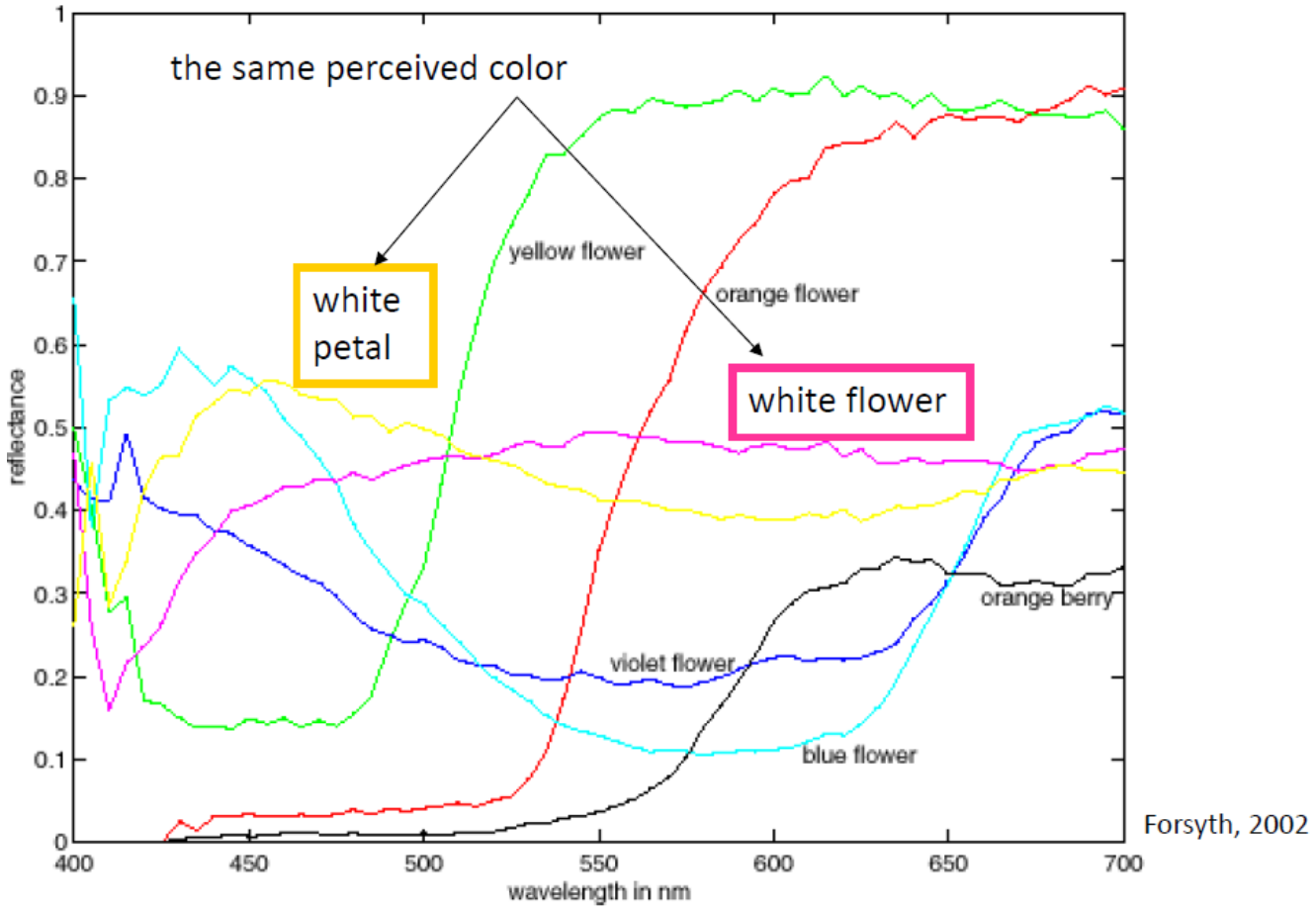
[Wikipedia]

Thy Physics of light



What is the same color?

- Different colors normally have different spectral reflectance, but different spectral reflectance may cause the same perceived color.



Forsyth, 2002

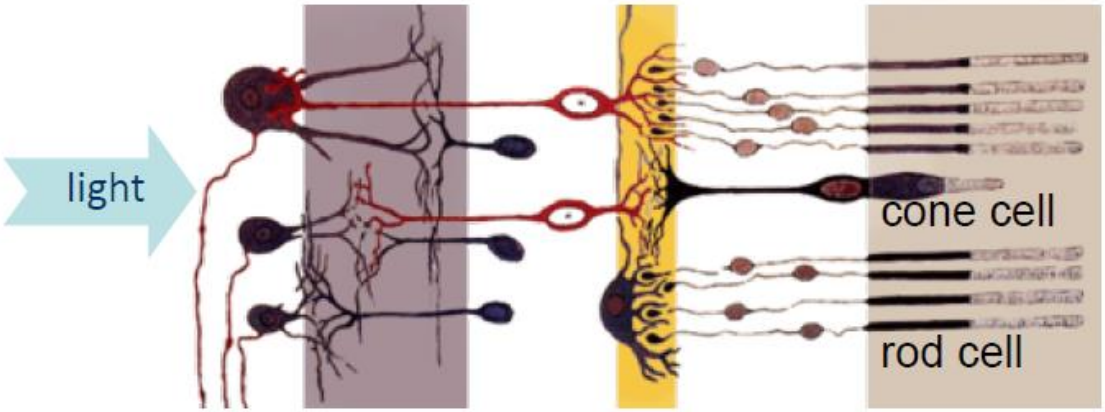
Human eye perception

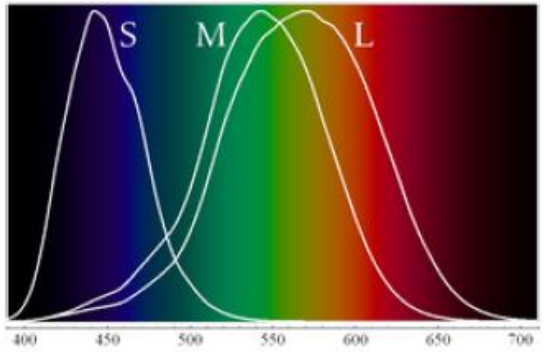
Cone cells function in relatively bright light.

There are three types of cones responding to different wavelengths of light.

Rod cells can function in less intense light than cone cells.

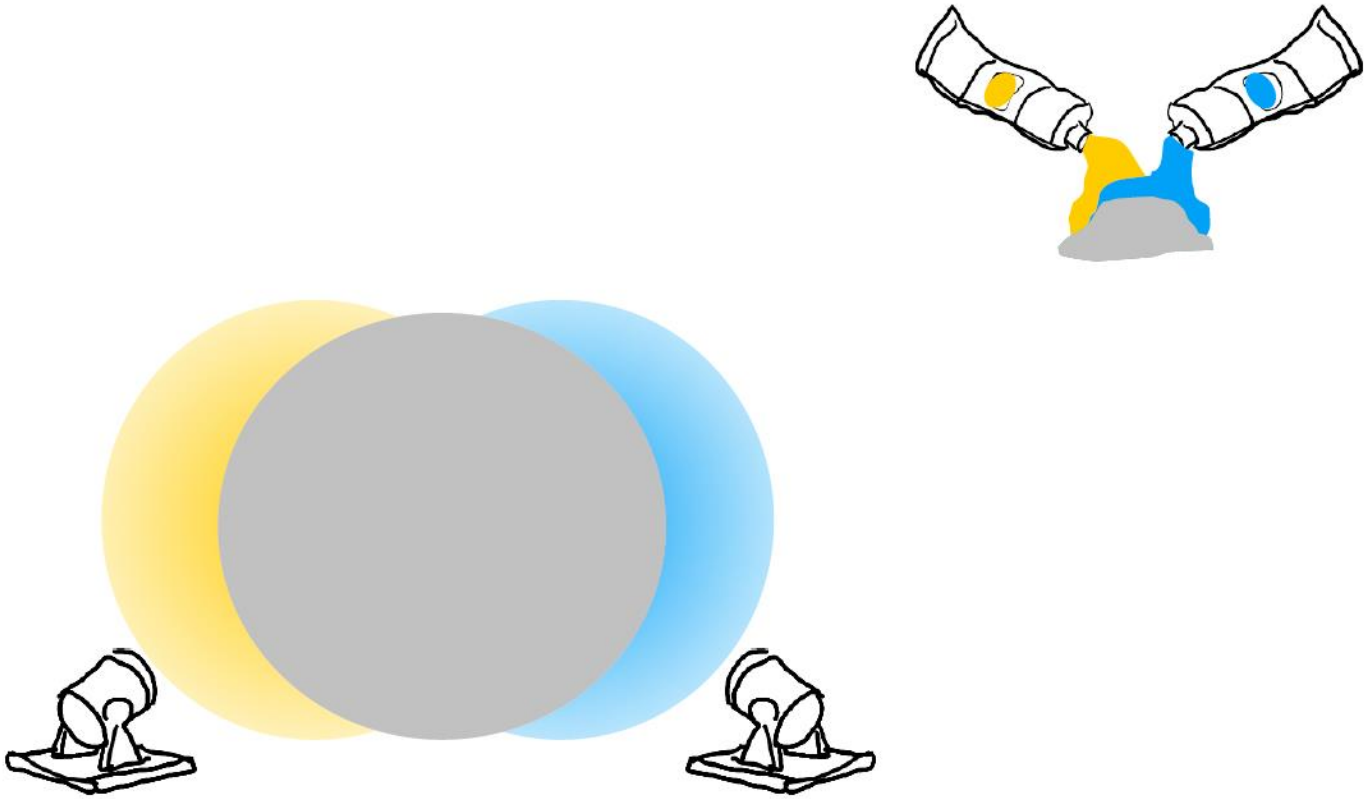
Rod cells are more light-sensitive, thus responsible for night vision.



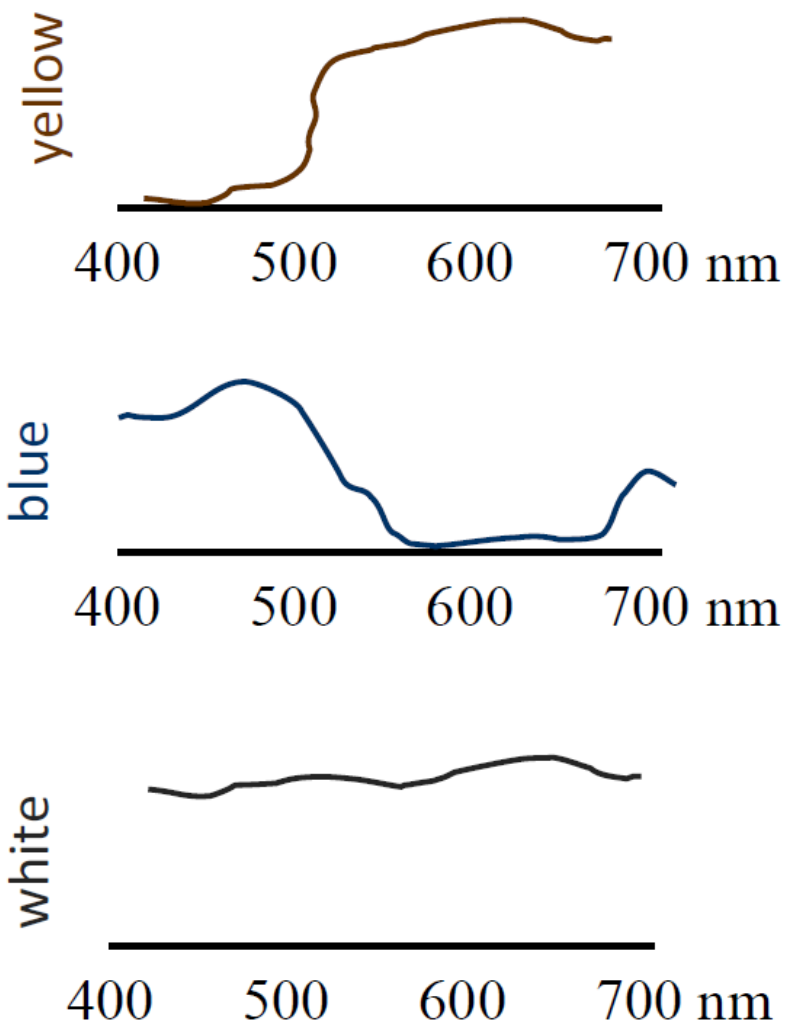


[Wikipedia]

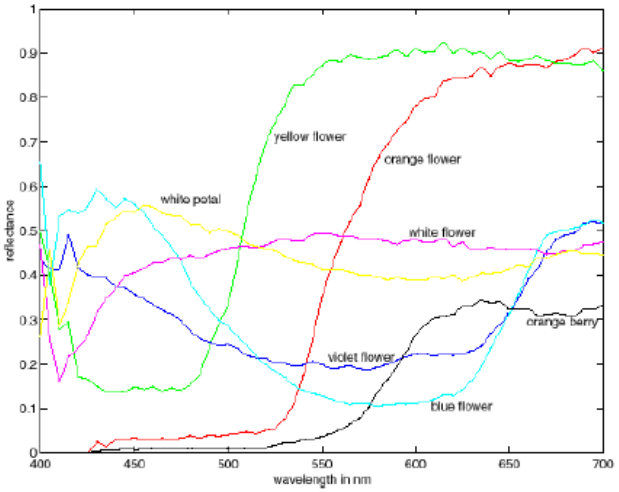
Additive and Subtractive Color Mixing



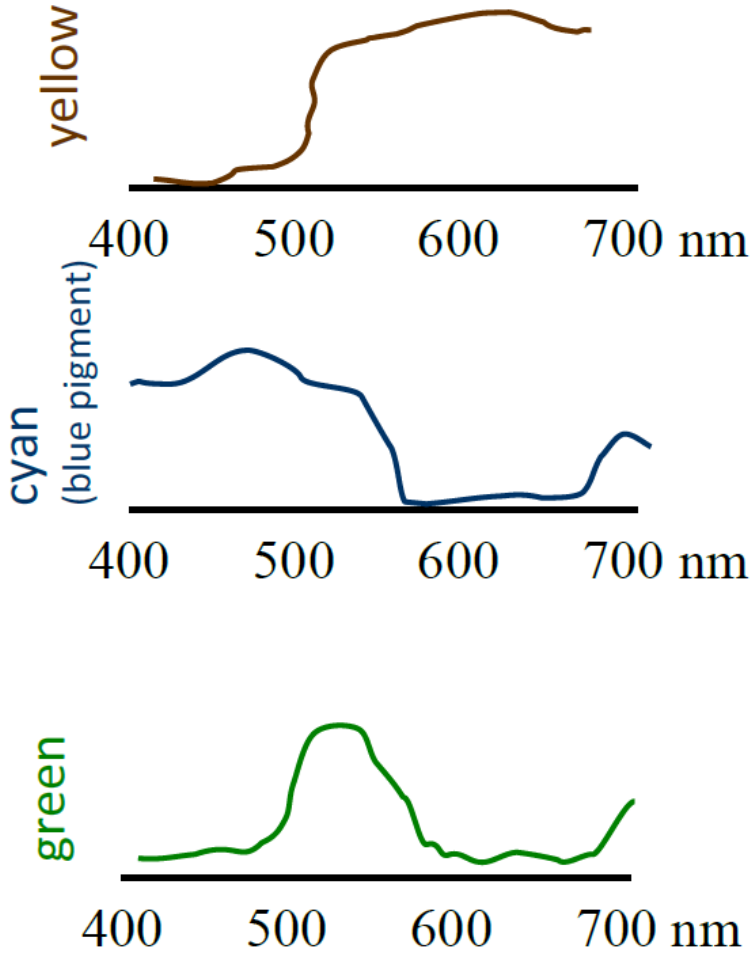
Additive Color Mixing



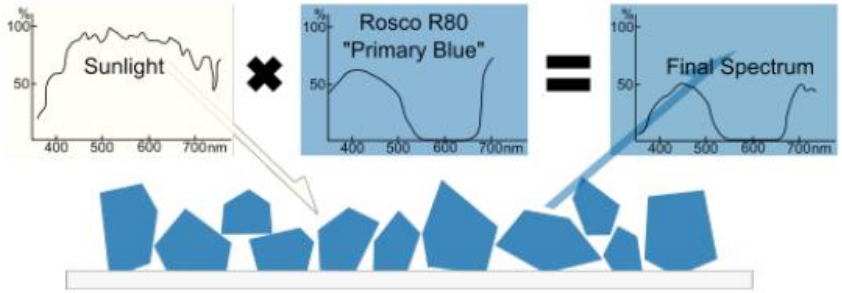
When colors are combined by *adding* the color spectra, e.g., three-color projectors.



Subtractive Color Mixing

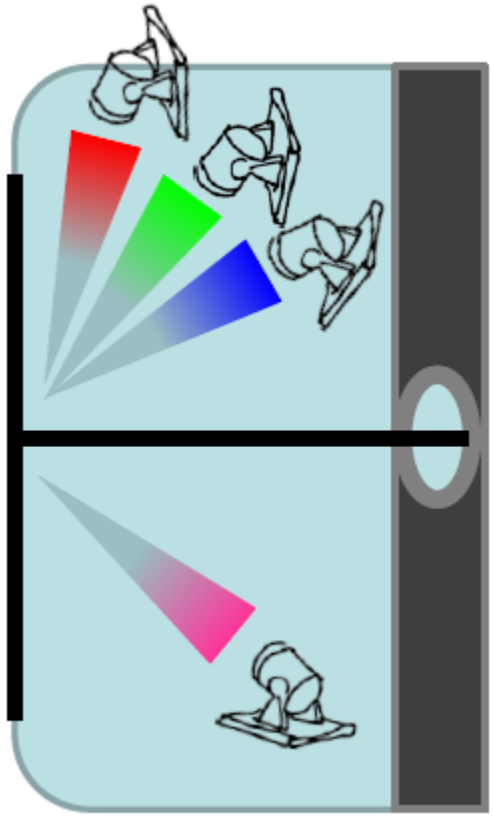


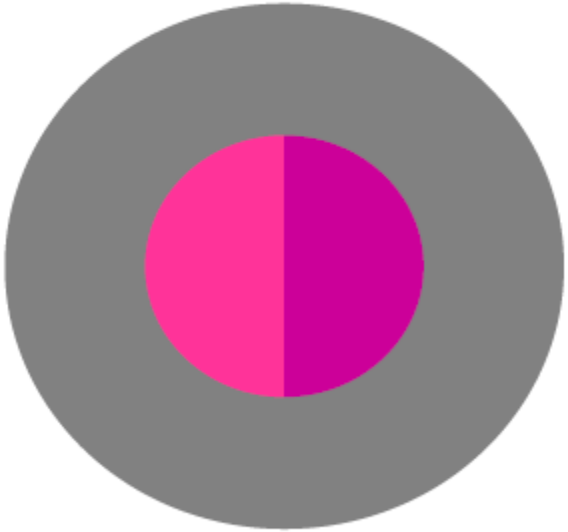
When colors are combined by *multiplying* the color spectra, e.g., pigments.



[Wikipedia]

Color Matching Experiment





Principle of 3-colour reproduction

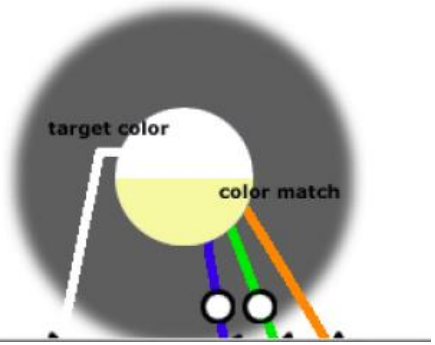
- From experiments:
  - For most people, any color could be reproduced by 3 colors if “negative color” is allowed.
  - The 3-colour coefficients of a specific color perceived by different people are the same.

Maxwell's Trichromatic Measurements

Maxwell's Trichromatic Measurements. The Young-Helmholtz primaries were used in the first precise, quantitative **color matching experiments**, conducted in the 1850's by both Helmholtz and the brilliant Scottish physicist **James Clerk Maxwell** (1831-1879, right). Maxwell created **additive color mixtures** in two ways: by mixing colored lights through a system of prisms, mirrors and neutral filters enclosed in a long, flat box (a *Maxwell box,* the first modern colorimeter), or — the method he found more practical and accurate — by visually mixing circular wedges of colored papers on a rapidly spinning disk (a **color top** or *Maxwell disk,* shown at right). He demonstrated that any color of light could be matched by a specific combination of just three primaries, which he represented on his color top with the pigments vermilion (scarlet, **PR106**), emerald green (bluish green, **PR21**), and ultramarine blue (blue violet, **PB29**), and in his prism box by the wavelengths 650 nm ("scarlet"), 510 nm ("green") and 480 nm ("blue"). His colorimeter became the most widely used apparatus in modern color research.

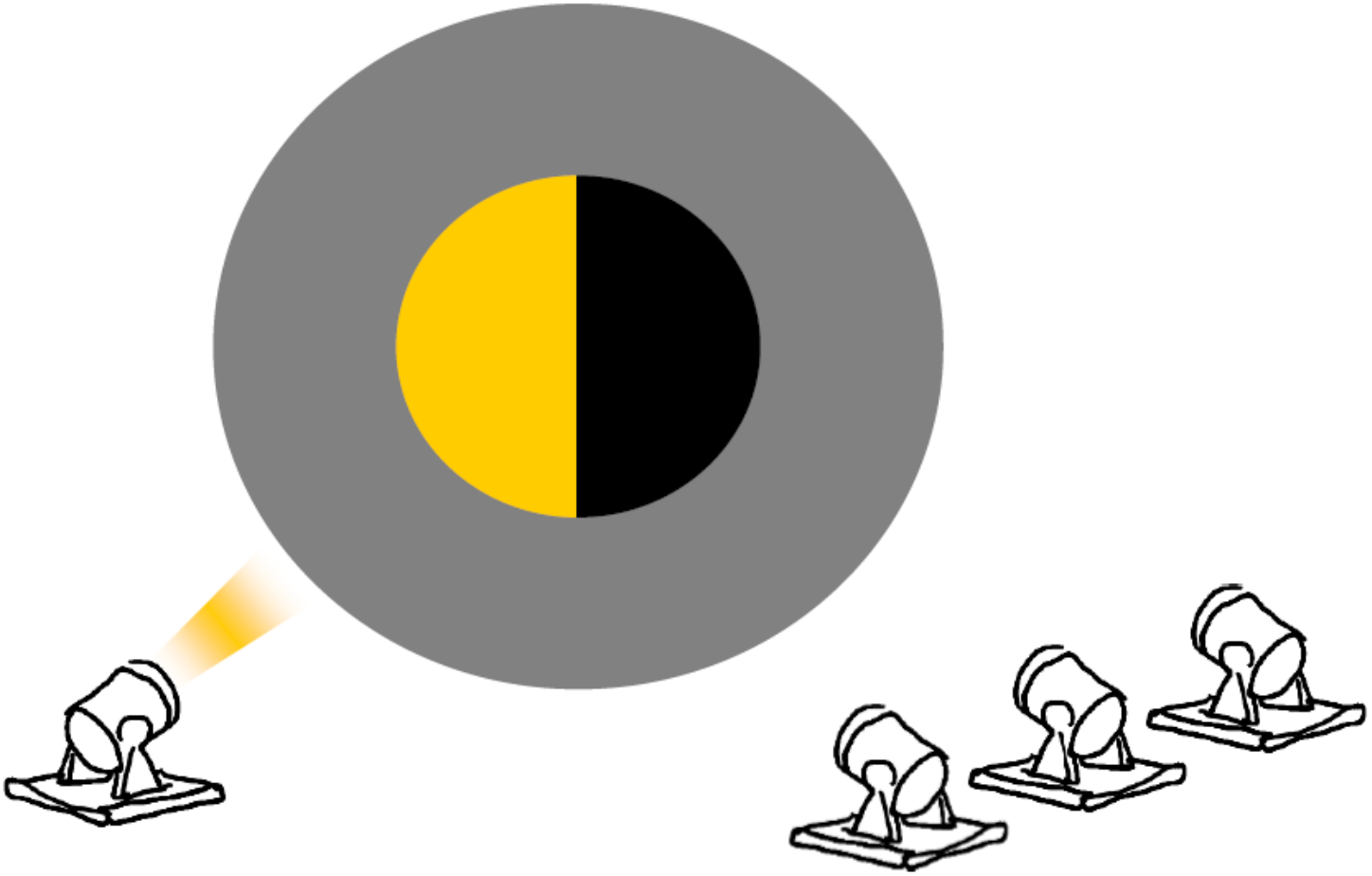
In the original version of Maxwell's color matching experiments, the viewer looked through a small lens or eyepiece to see a

the young James Clerk Maxwell holding his color top (c.1860)

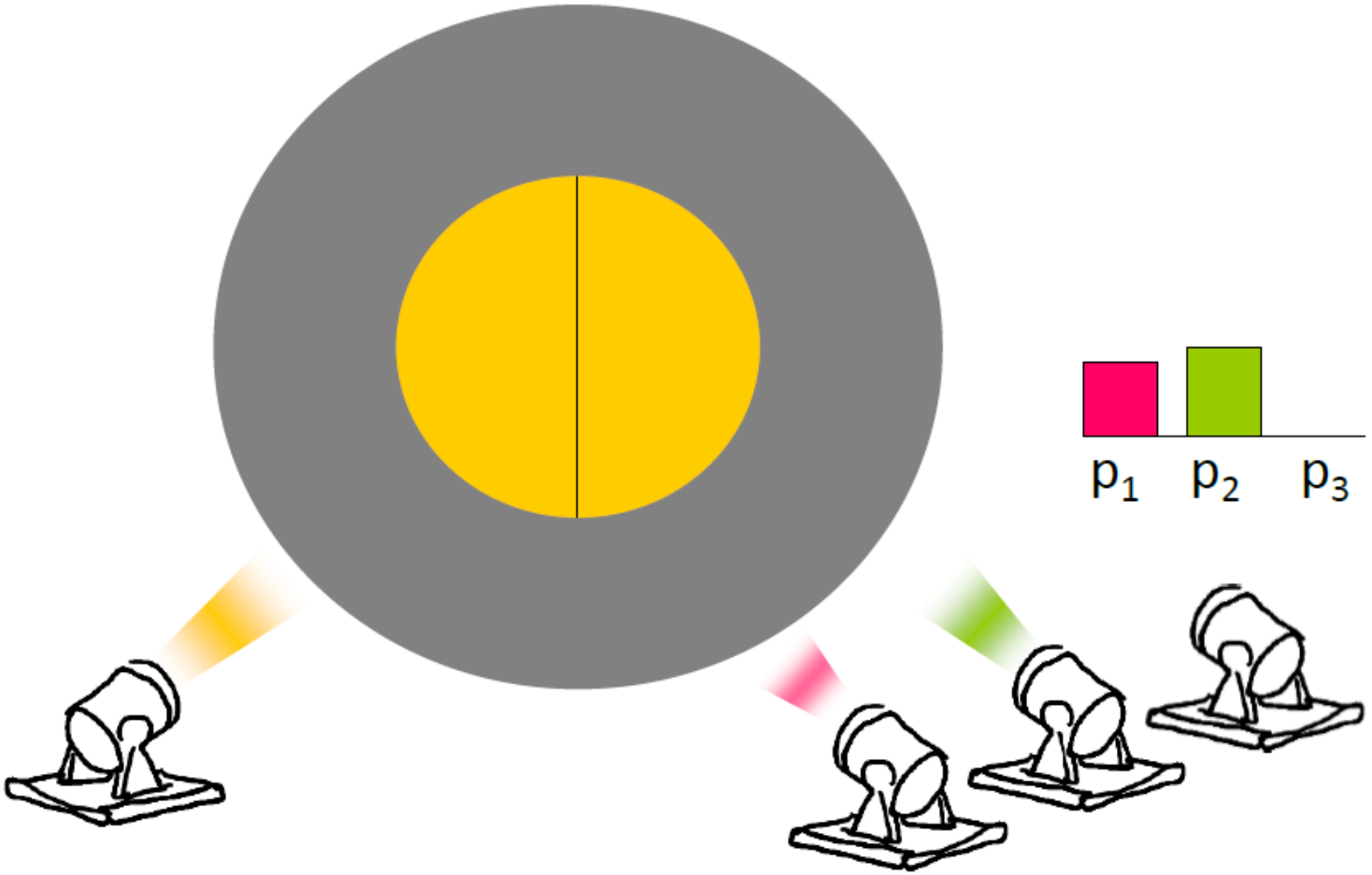


Ref: www.handprint.com/HP/WCL/color6.html

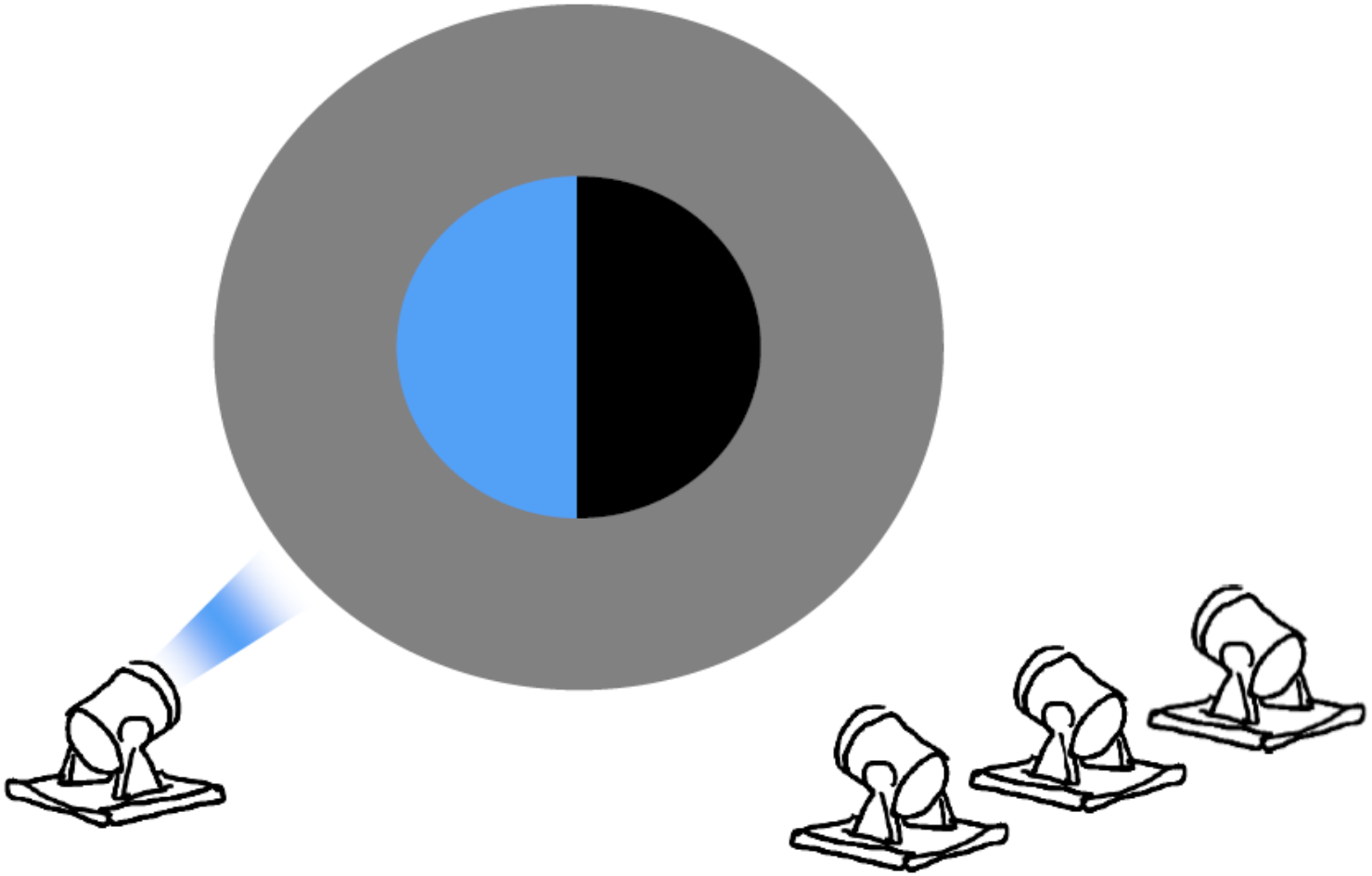
Color Matching Experiment 1



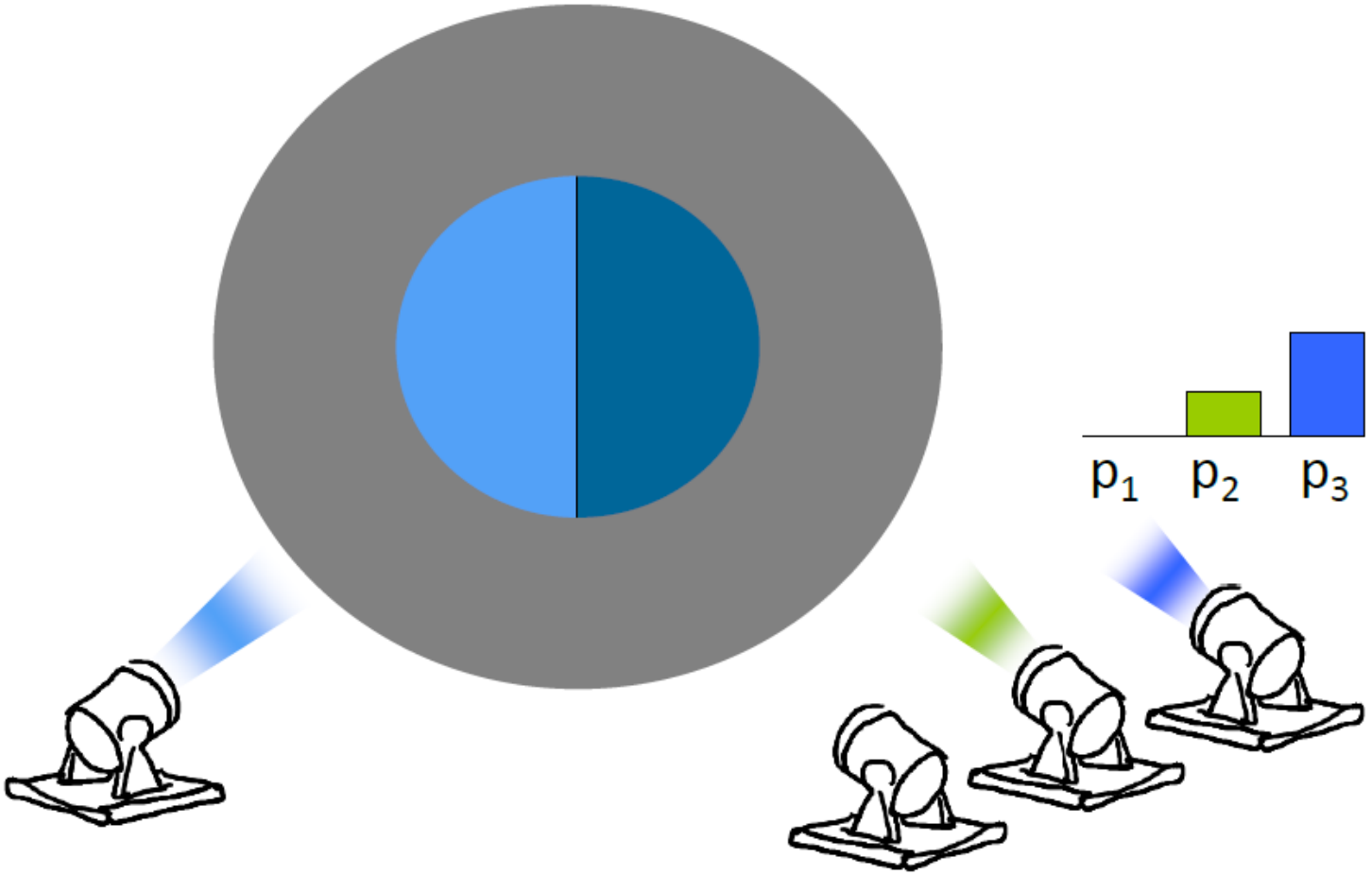
Color Matching Experiment 1



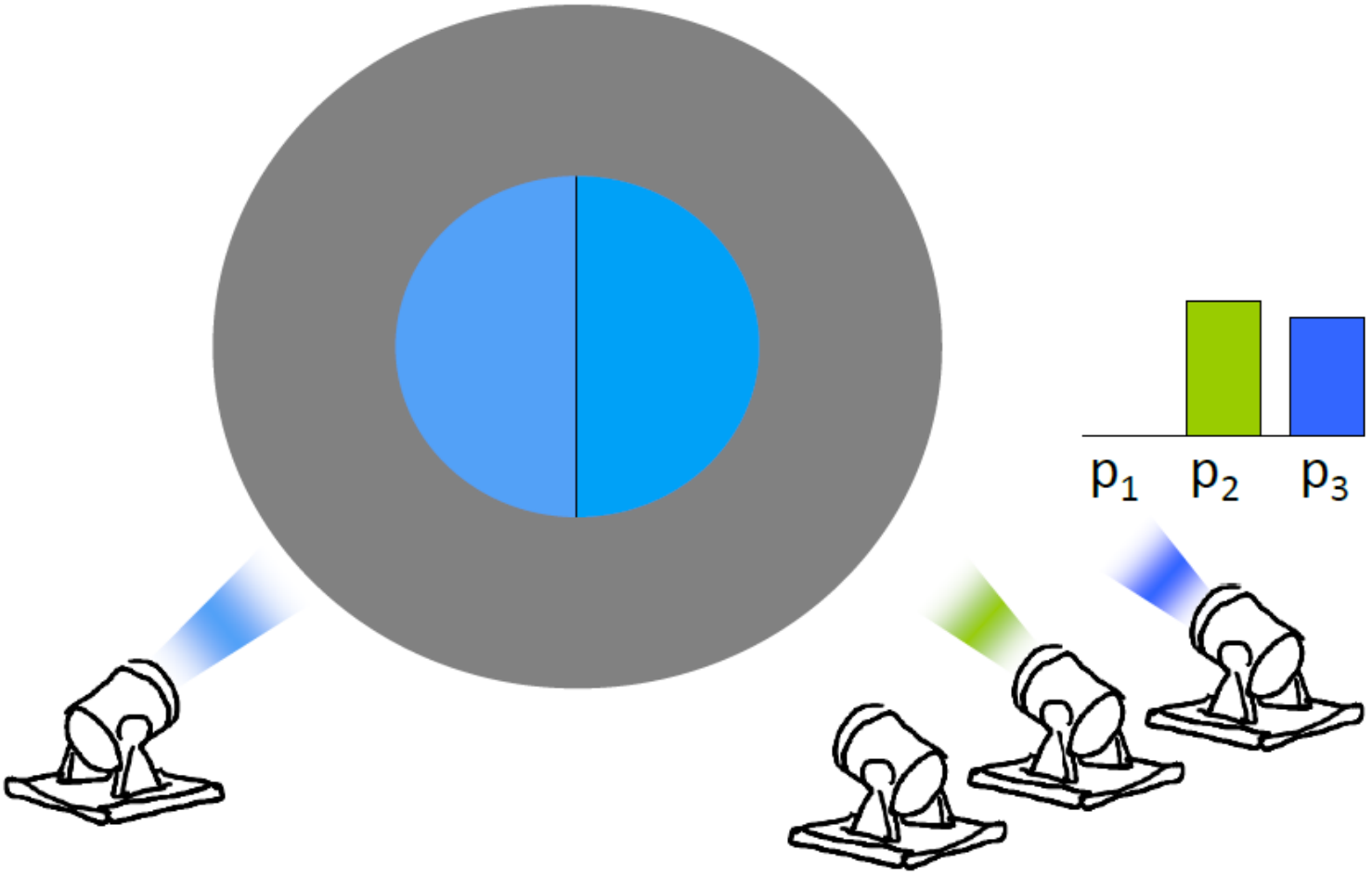
Color Matching Experiment 2



Color Matching Experiment 2

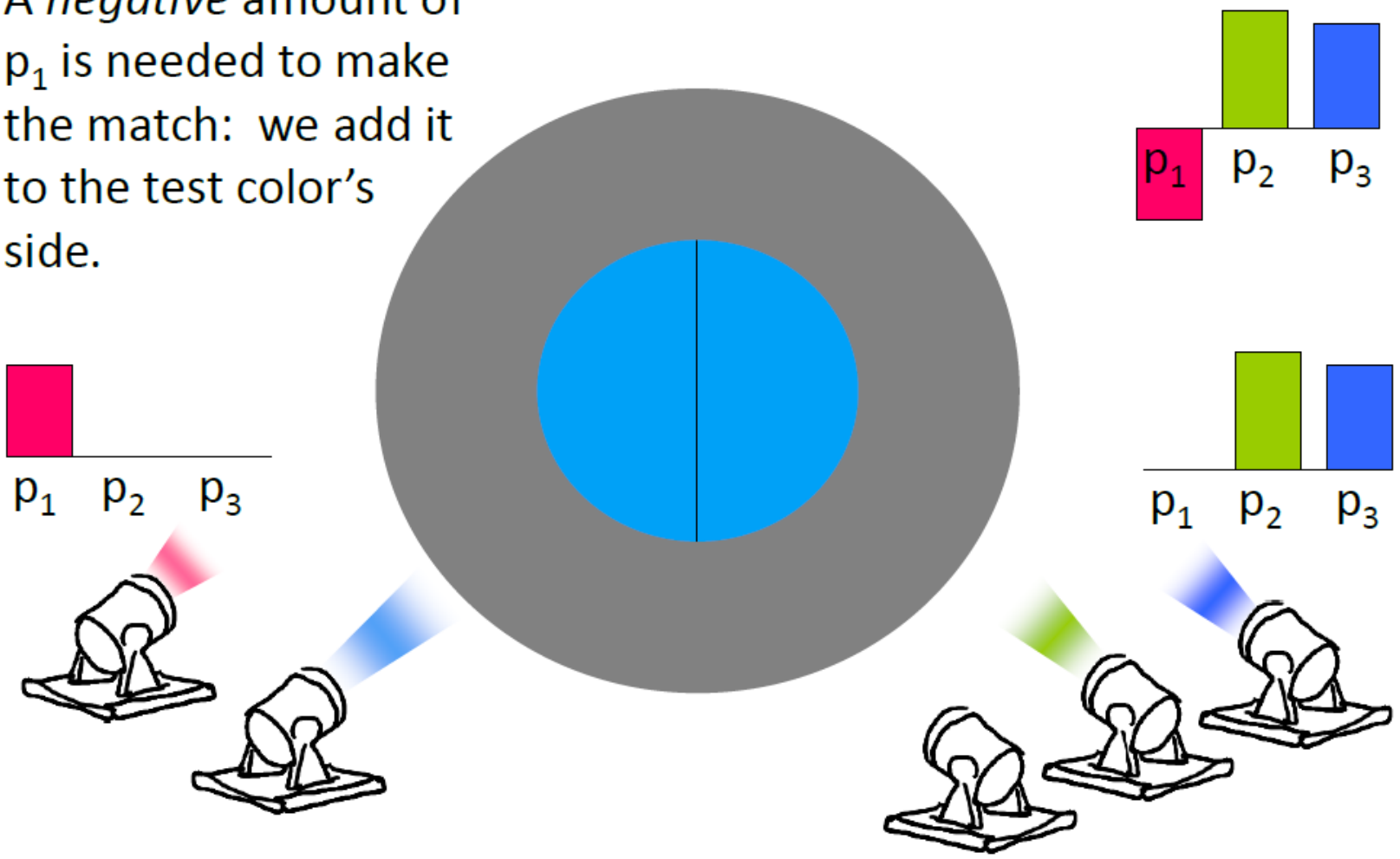


Color Matching Experiment 2

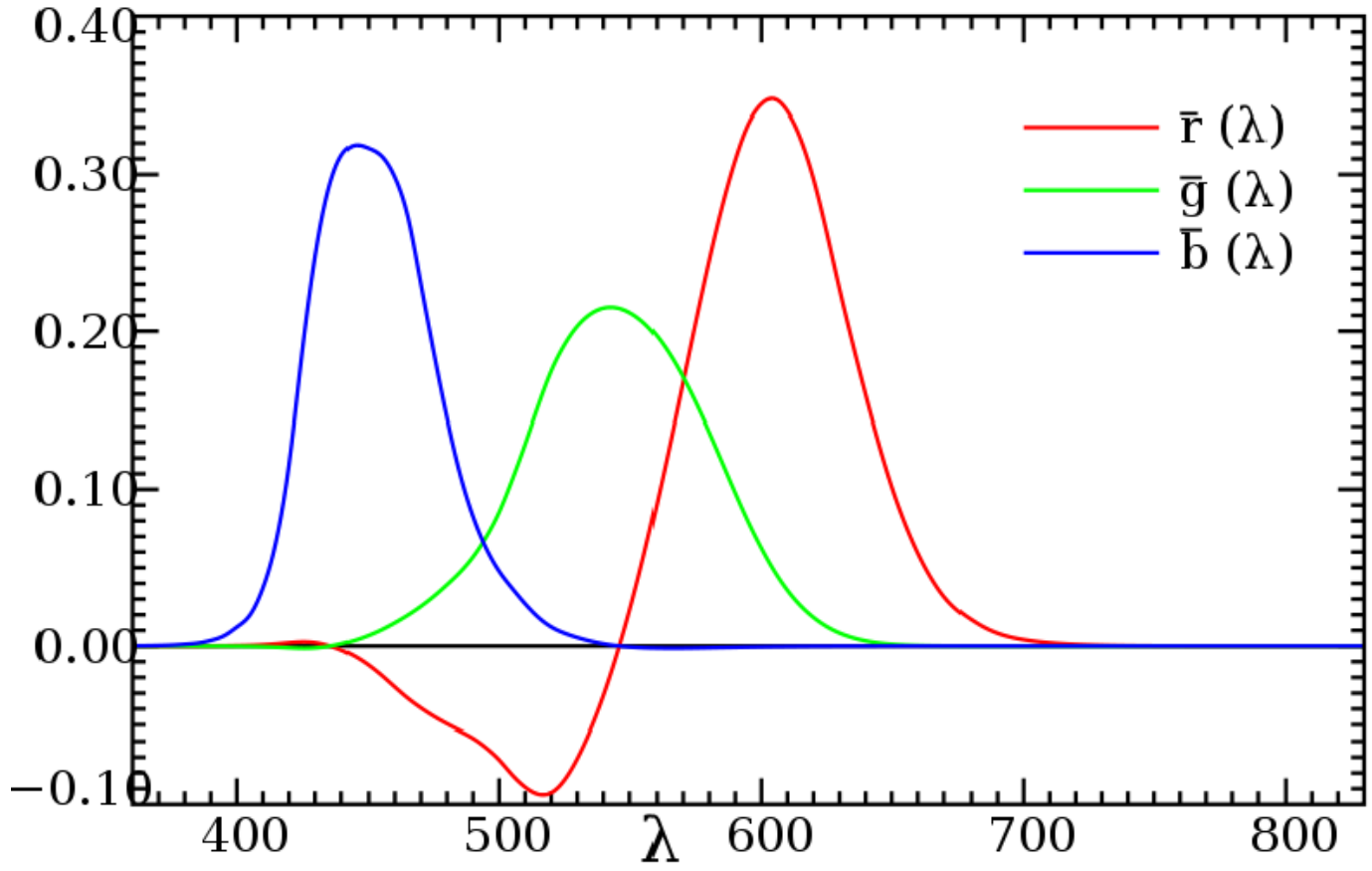


Color Matching Experiment 2

A *negative* amount of p_1 is needed to make the match: we add it to the test color's side.



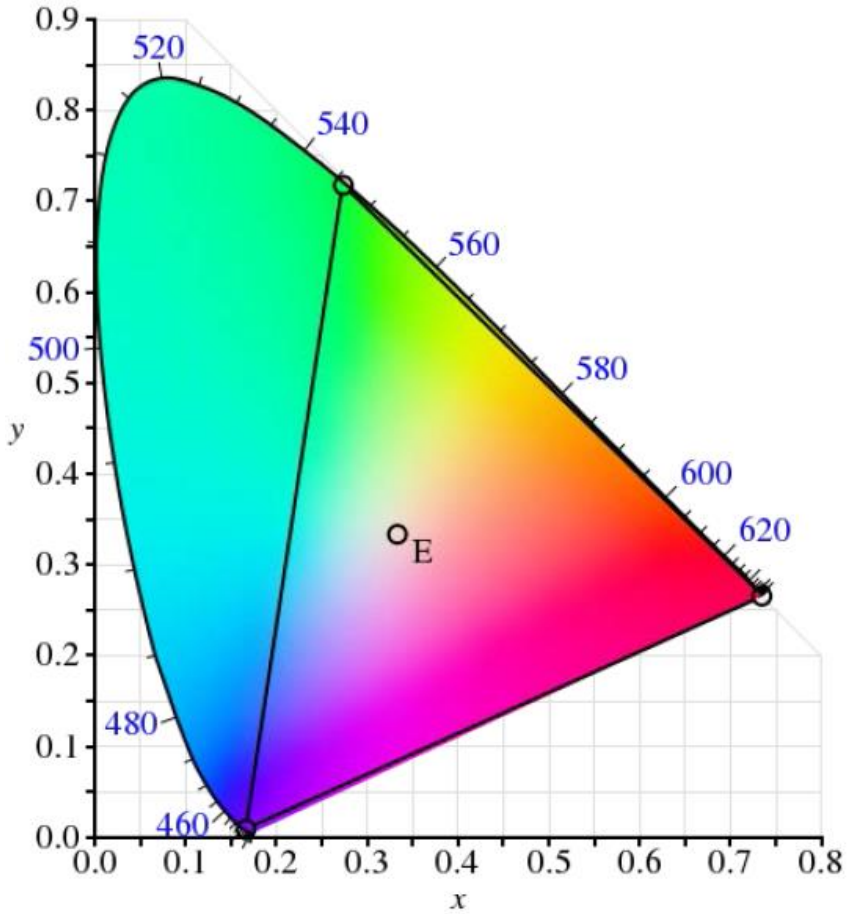
CIE 1931 RGB Color Matching Functions



700 .0nm
546.1 nm
435.8 nm

[Wikipedia]

The CIE 1931 xy Chromaticity Diagram with CIE RGB

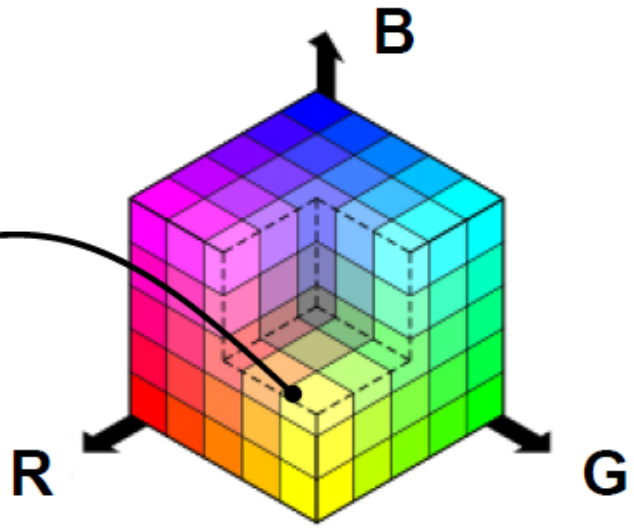


[Wikipedia]

RGB

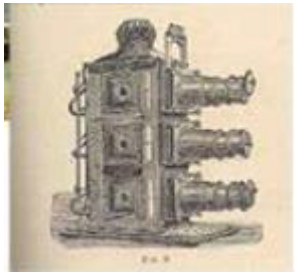
- 32-bit mode
  - Only 24 bits are used
  - 8 bits each channel

(c_1, c_2, c_3)



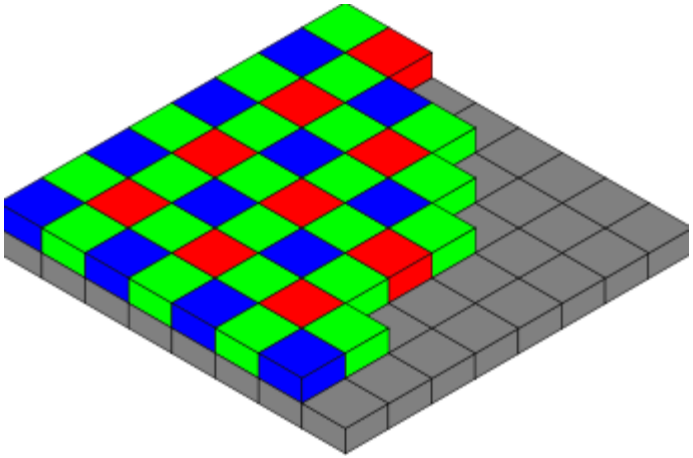
Early Color Photography

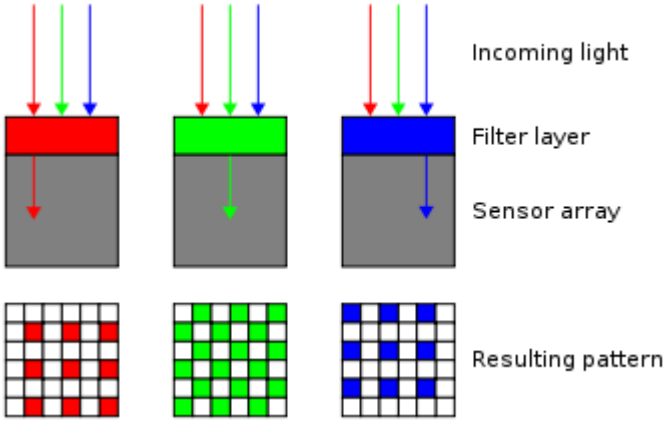
- Sergey Prokudin-Gorsky
- Optical color projections (1905)



Color sensing in Digital Camera (RGB) Bayer Filter and Demosaicing

- Bayer filter is the most popular color filter array where green photosensors are luminance-sensitive elements, red and blue ones are chrominance-sensitive elements.
- Demosaicing is an algorithm of digital image processing used to reconstruct a full color image from the incomplete color samples output from an image sensor overlaid with a color filter array.





CCD vs CMOS

- CCD:
  - More power
  - Higher pixel quality
  - Good low light response
  - Expensive
  - Greater Dynamic Range
  - Linear response
  - Smear & blooming defects
  - Global Shutter

CMOS:

- Less power
- Less Image quality
- Poor low light response
- Cheaper
- Poor dynamic range
- Logarithmic response
- Rolling Shutter

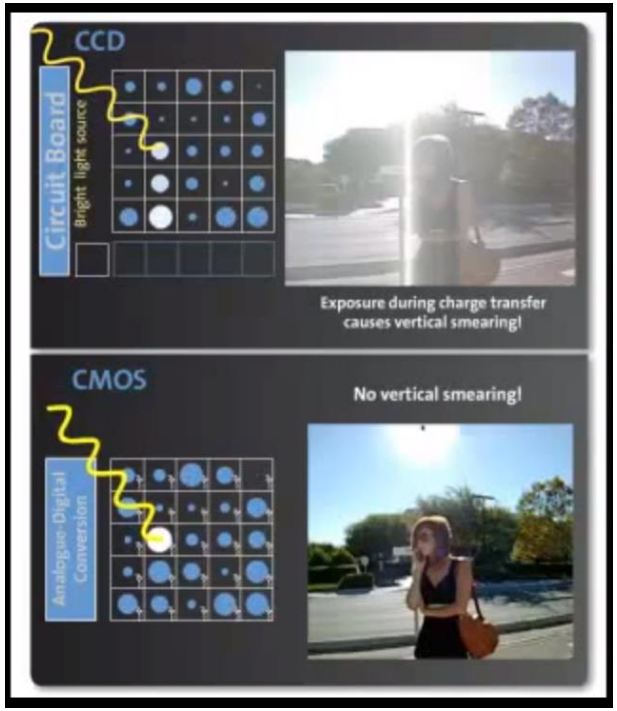
Blooming

- Blooming:
  - an effect where the charge developed on a pixel leaks into adjacent pixels and corrupts the scene
  - typically occurs when there are very bright spots in the scene
  - diminishes the accuracy of the pixel data as information from one pixel is then present in adjacent pixels.

Ref: https://www.youtube.com/watch?v=-DoTgQbALU0

Smear

- Smear:
  - Stray electrons generated under the photodiode area diffuse into the vertical shift registers
  - typically occurs when there are very bright spots in the scene
  - Image pixels are shifted vertical ly downward, row by row.
  - If there is any leakage of charge into an area of the vertical trans fer register, it will be picked up and shifted downward



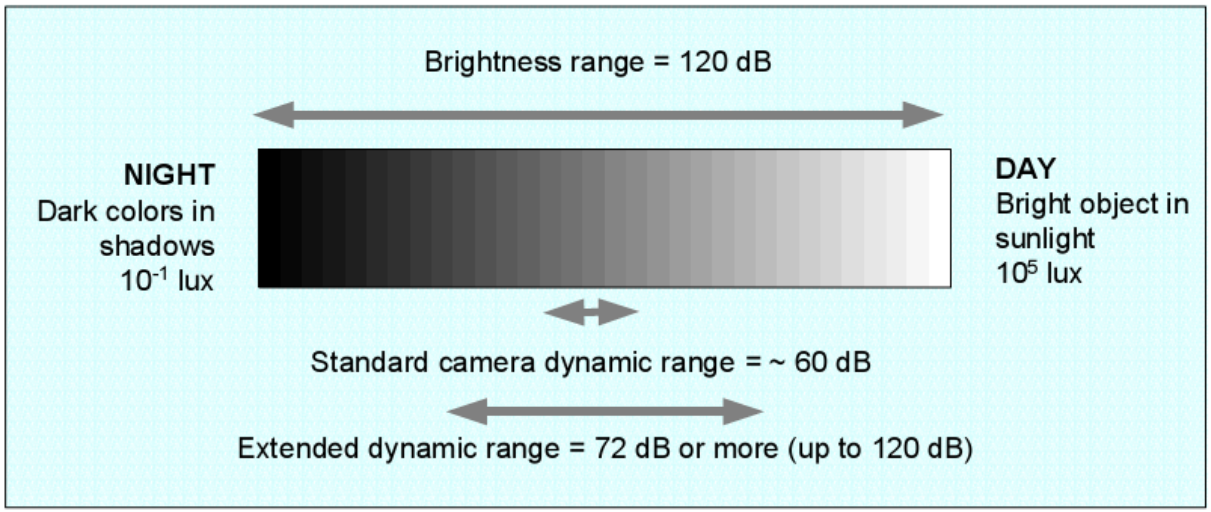
Ref: https://www.youtube.com/watch?v=Dw9wBcVYQzA

Dynamic Range

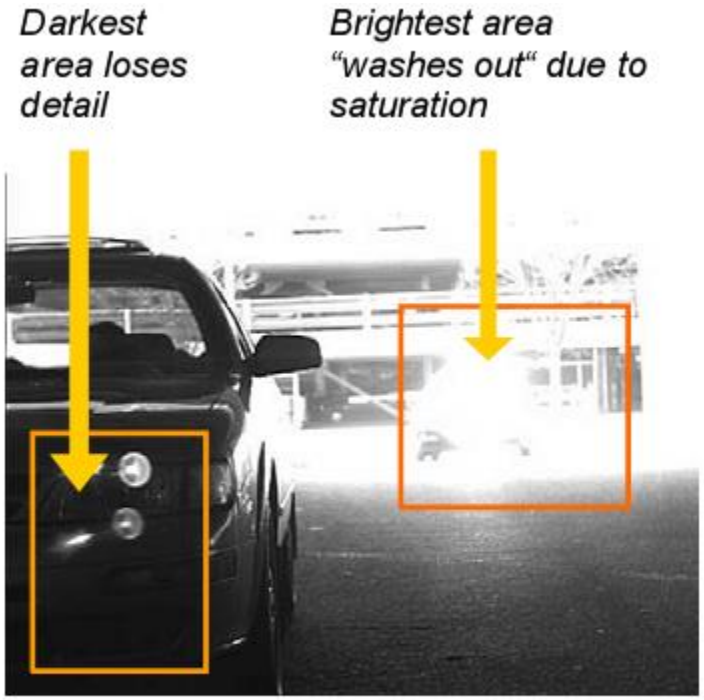
- The best solution of blooming and Smear phenomenons: High dynamic range camera
- The definition of Dynamic range

Expressed in decibel units (dB), dynamic range is a logarithmic ratio of light units measured in lux or candelas per square meter (cd/m2) according to the equation:

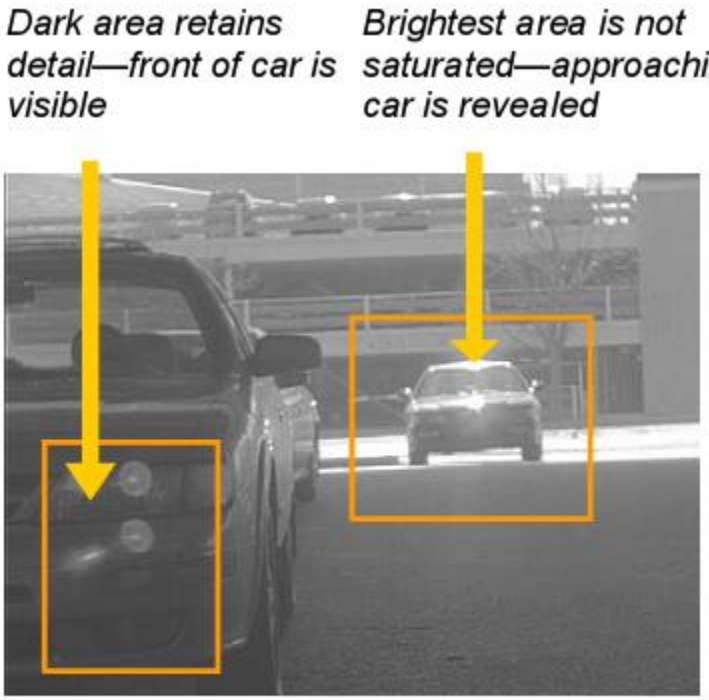
$$Dynamic\,Range = 20\,Log\,\frac{Signal\,(saturation)}{Signal\,(noise)}$$



Why is HDR important in obstacle detection?



Standard CCD or CMOS camera



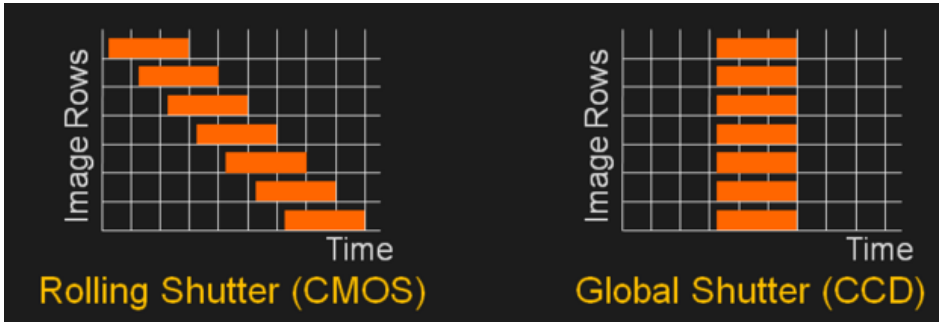
Extended wide dynamic range with Autobrite-enabled camera

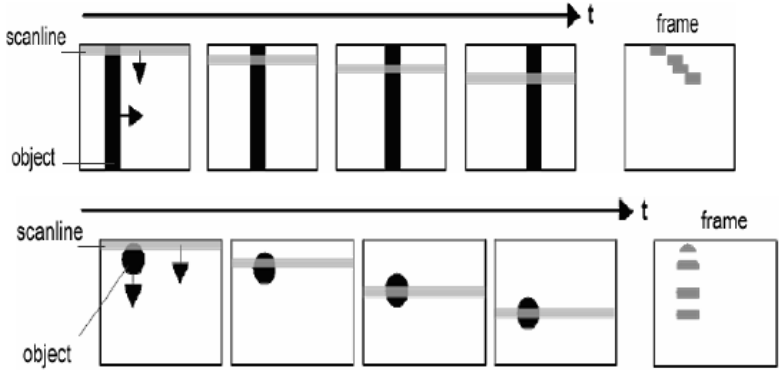
Global Shutter and Rolling Shutter

- Shuttering is the process of exposing an imaging sensor to light at a rate.
- A global shutter controls incoming light to all photosites simultaneously.
- Rolling shutter is where a line or a group of lines is read out while all other lines on the sensor continue to be exposed.

Global Shutter

Rollingl Shutter





Chromatic Aberration

- Chromatic aberration:
  - also called "color fringing"
  - is caused by the camera lens not focusing different wavelengths of light onto the exact same focal plane (the focal length for different wavelengths is different)
  - May be also caused from the lens magnifying different wavelengths differently.