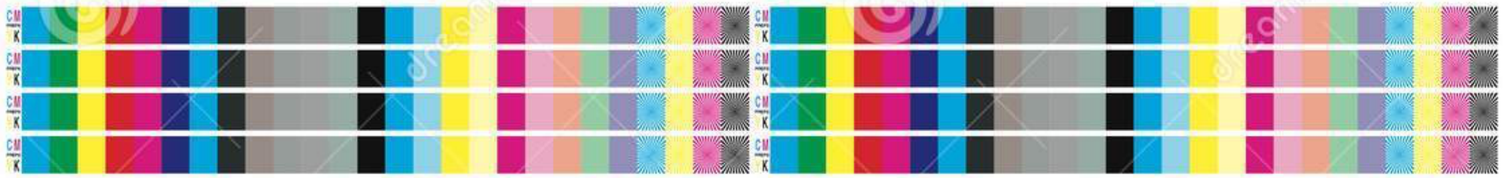
THE UNIVERSITY OF BRITISH COLUMBIA

# CPSC 425: Computer Vision



**Lecture 11:** Color

( unless otherwise stated slides are taken or adopted from **Bob Woodham, Jim Little** and **Fred Tung** )

# **Menu** for Today (**February 11, 2020**)

## Topics:

- Colour
- Colour Matching Experiments
- Trichromasity
- Colour Spaces

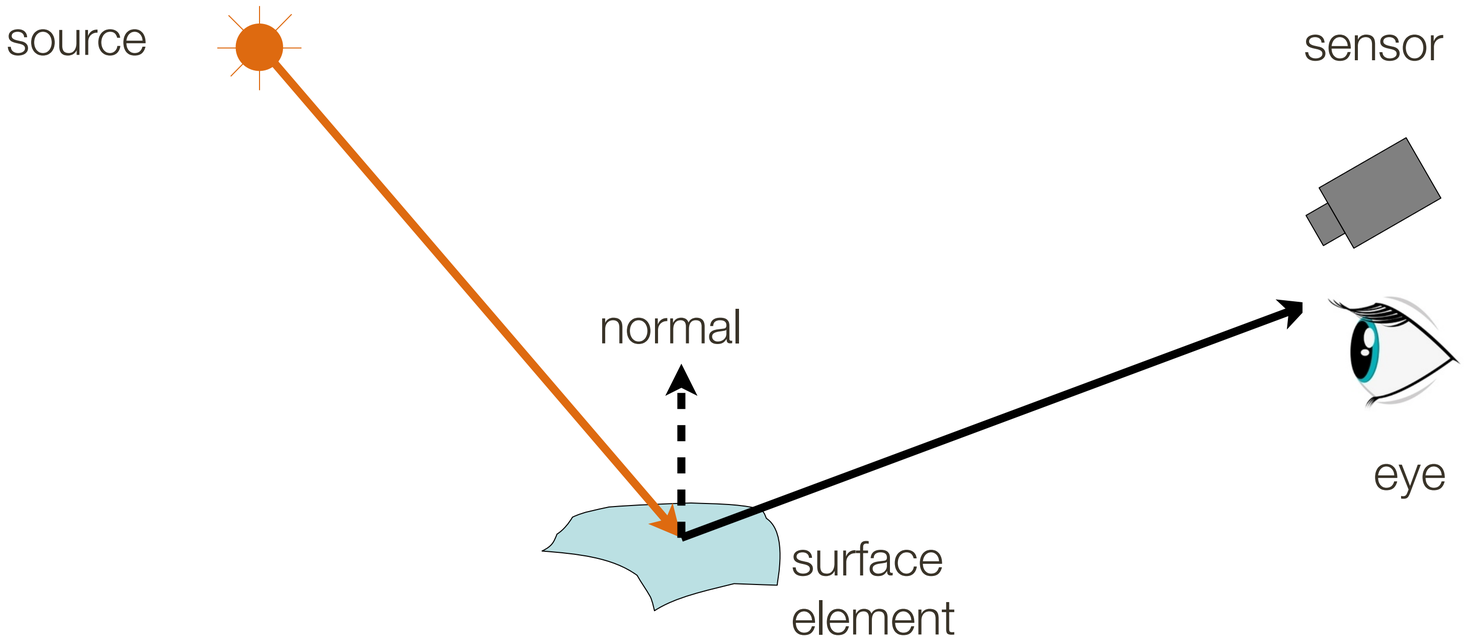
## Readings:

- **Today's** Lecture: Forsyth & Ponce (2nd ed.) 3.1-3.3
- **Next** Lecture: N/A

# **Overview**: Image Formation, Cameras and Lenses

The **image formation process** that produces a particular image depends on

- **Lightening** condition
- Scene **geometry**
- **Surface** properties
- Camera **optics**



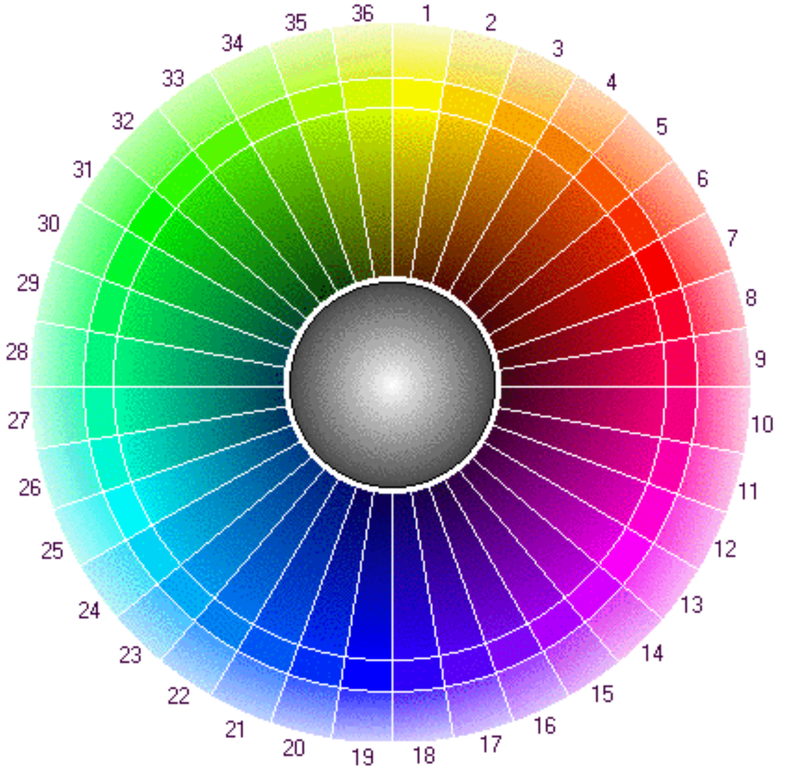

Sensor (or eye) **captures amount of light** reflected from the object

# Colour

— Light is produced in different amounts at different wavelengths by each light source

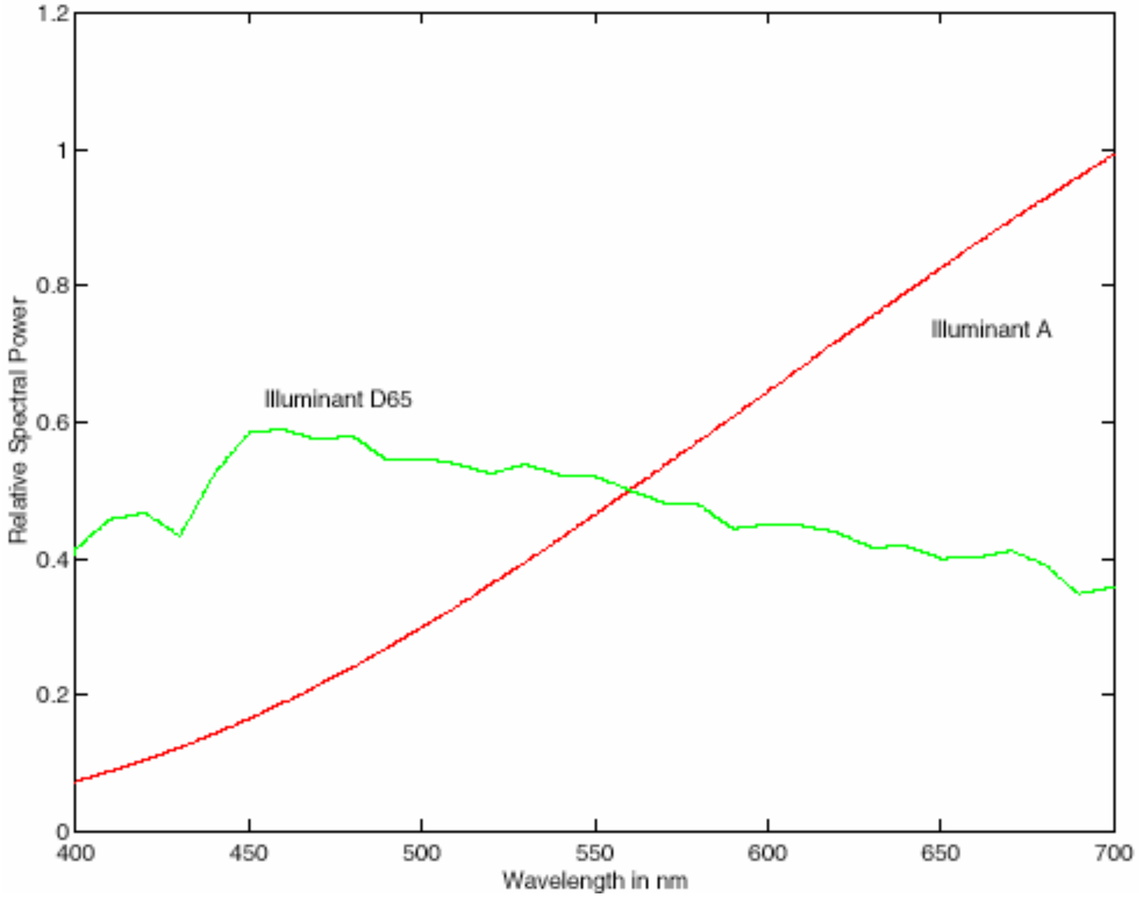
— Light is differentially reflected at each wavelength, which gives objects their natural colour (**surface albedo**)

— The sensation of colour is determined by the human visual system, based on the product of light and reflectance



# Relative **Spectral Power** of Two Illuminants

Relative spectral power plotted against wavelength in nm



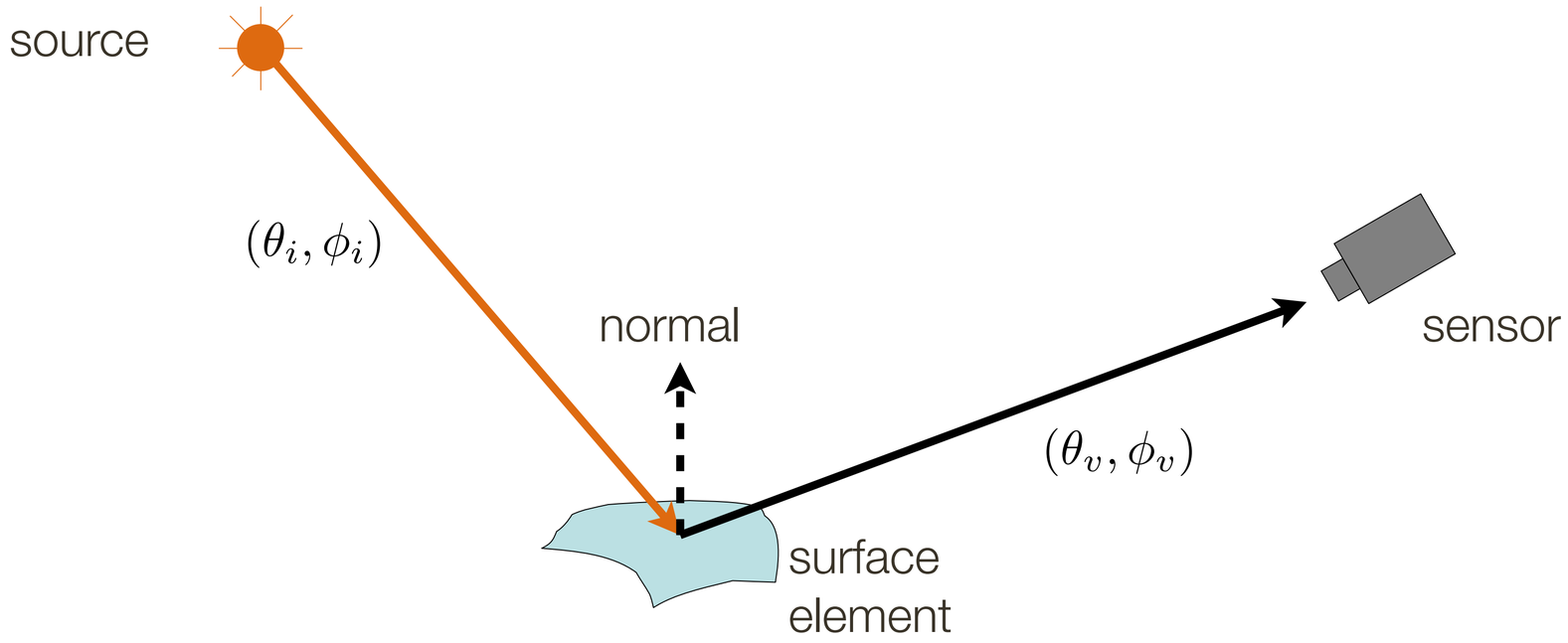

Incandescent Light Bulb

Sunlight

Forsyth & Ponce (2nd ed.) Figure 3.4

# (small) **Graphics** Review

Surface reflection depends on both the **viewing** $(\theta_v, \phi_v)$ and **illumination** $(\theta_i, \phi_i)$ direction, with Bidirectional Reflection Distribution Function: $\mathbf{BRDF}(\theta_i, \phi_i, \theta_v, \phi_v)$






**Slide adopted from**: Ioannis (Yannis) Gkioulekas (CMU)

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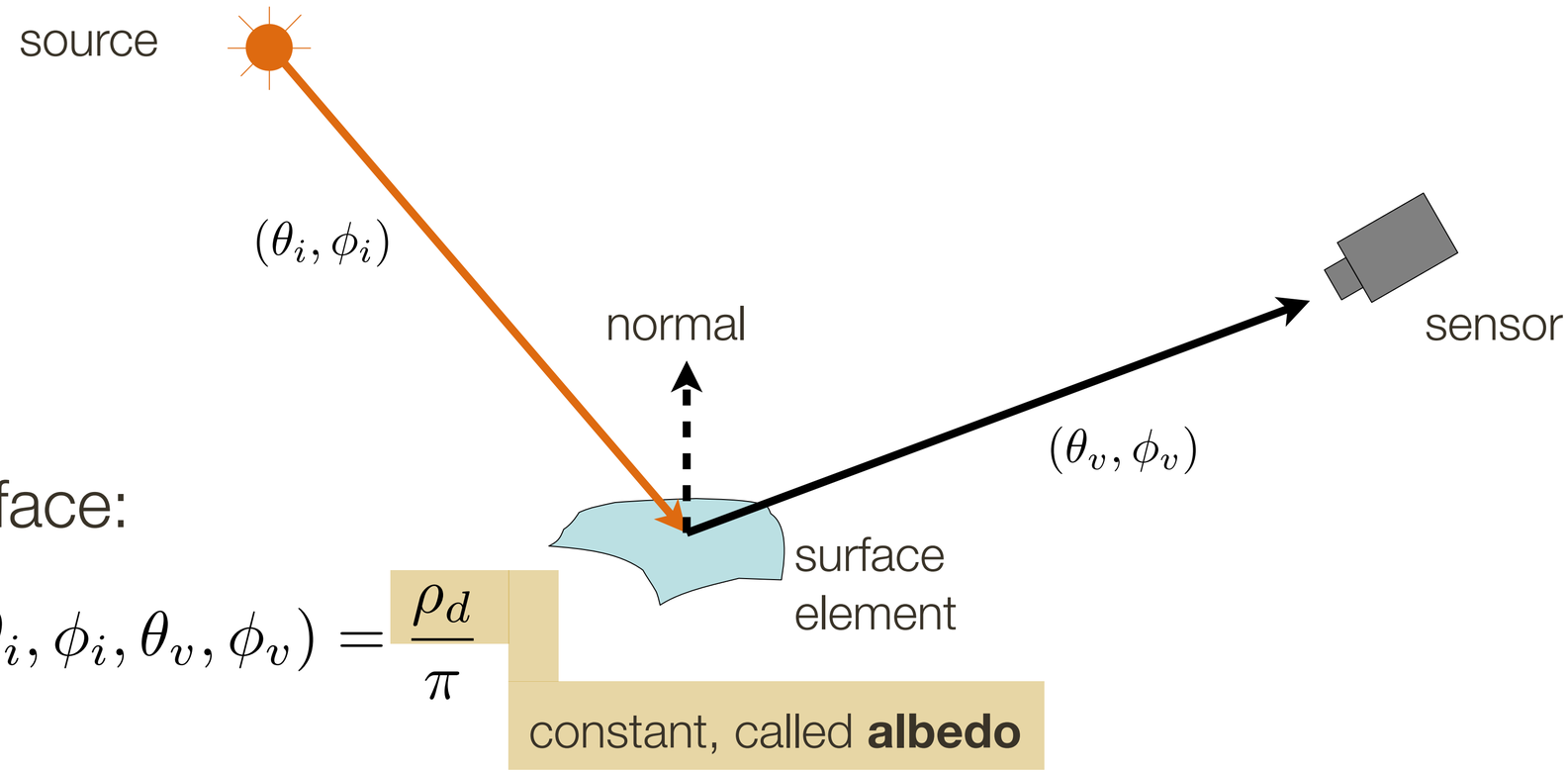



**Lambertian** surface:

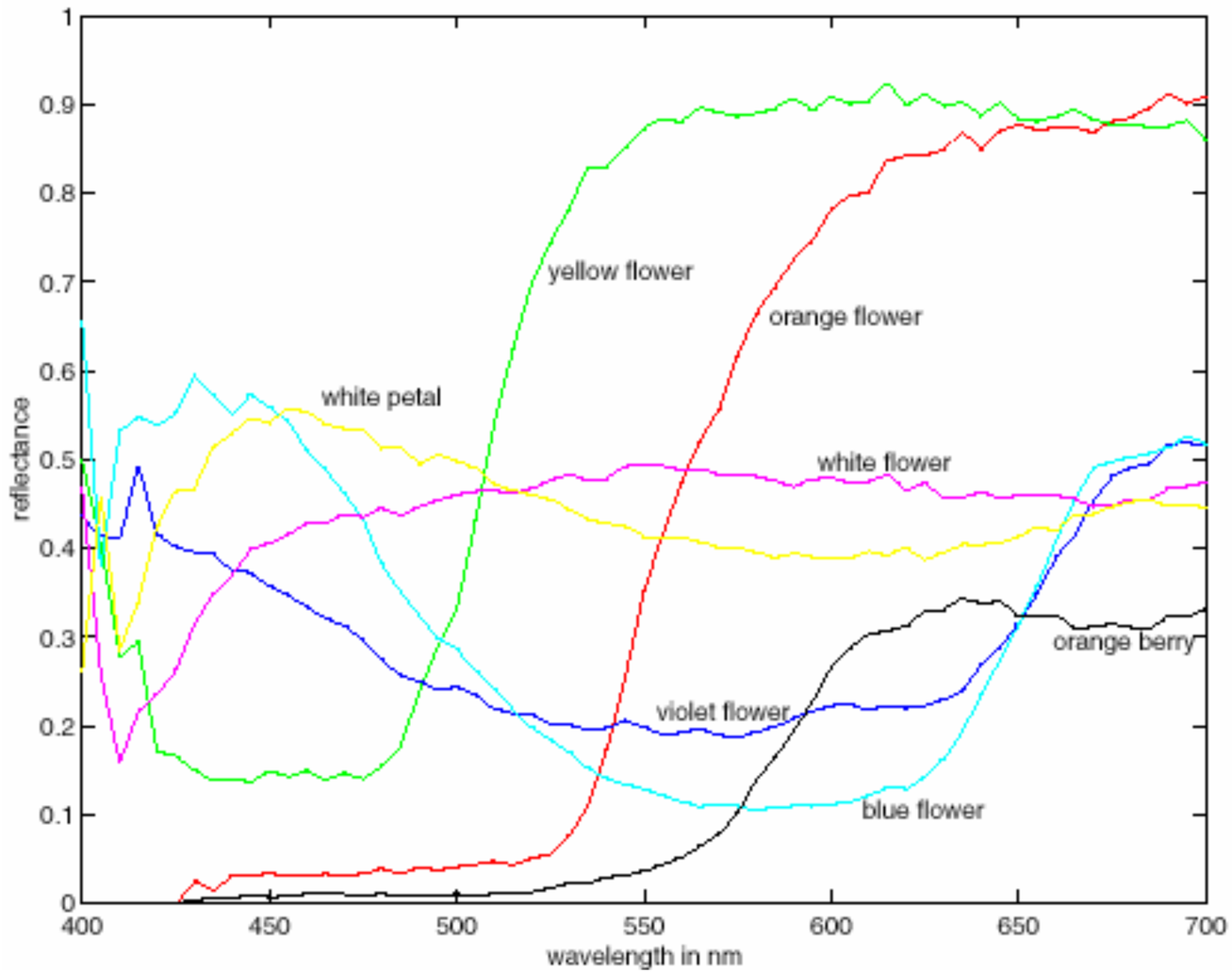
$$\mathbf{BRDF}(\theta_i, \phi_i, \theta_v, \phi_v) = \frac{\rho_d}{\pi}$$

constant, called **albedo**



**Slide adopted from**: Ioannis (Yannis) Gkioulekas (CMU)

# Spectral **Albedo** of Natural Surfaces




Forsyth & Ponce (2nd ed.) Figure 3.6

# **Colour** Appearance

Reflected light **at each wavelength** is the product of illumination and surface reflectance at that wavelength

Surface reflectance often is modeled as having two components:

— **Lambertian** reflectance: equal in all directions (diffuse)

— **Specular** reflectance: mirror reflectance (shiny spots)

# (small) **Graphics** Review

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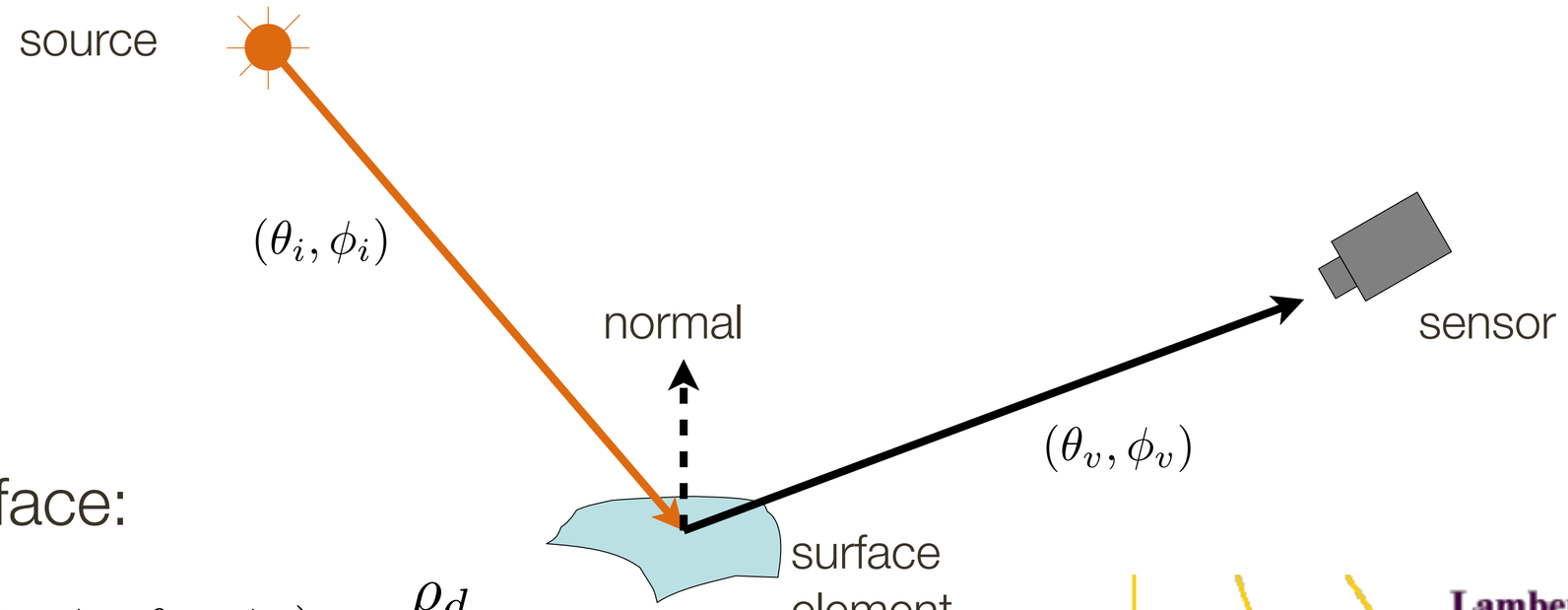
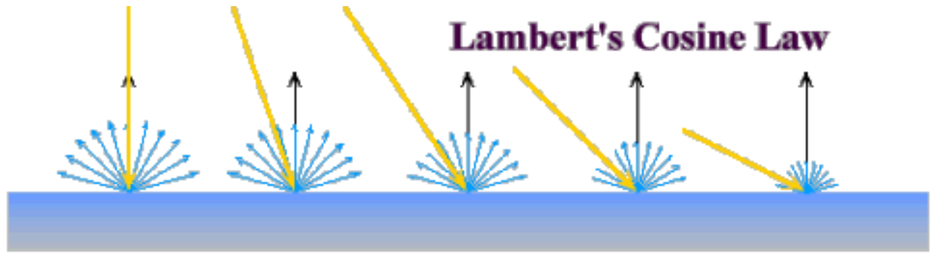



**Lambertian** surface:

$$\mathbf{BRDF}(\theta_i, \phi_i, \theta_v, \phi_v) = \frac{\rho_d}{\pi}$$

$$L = \frac{\rho_d}{\pi} I(\vec{i} \cdot \vec{n})$$



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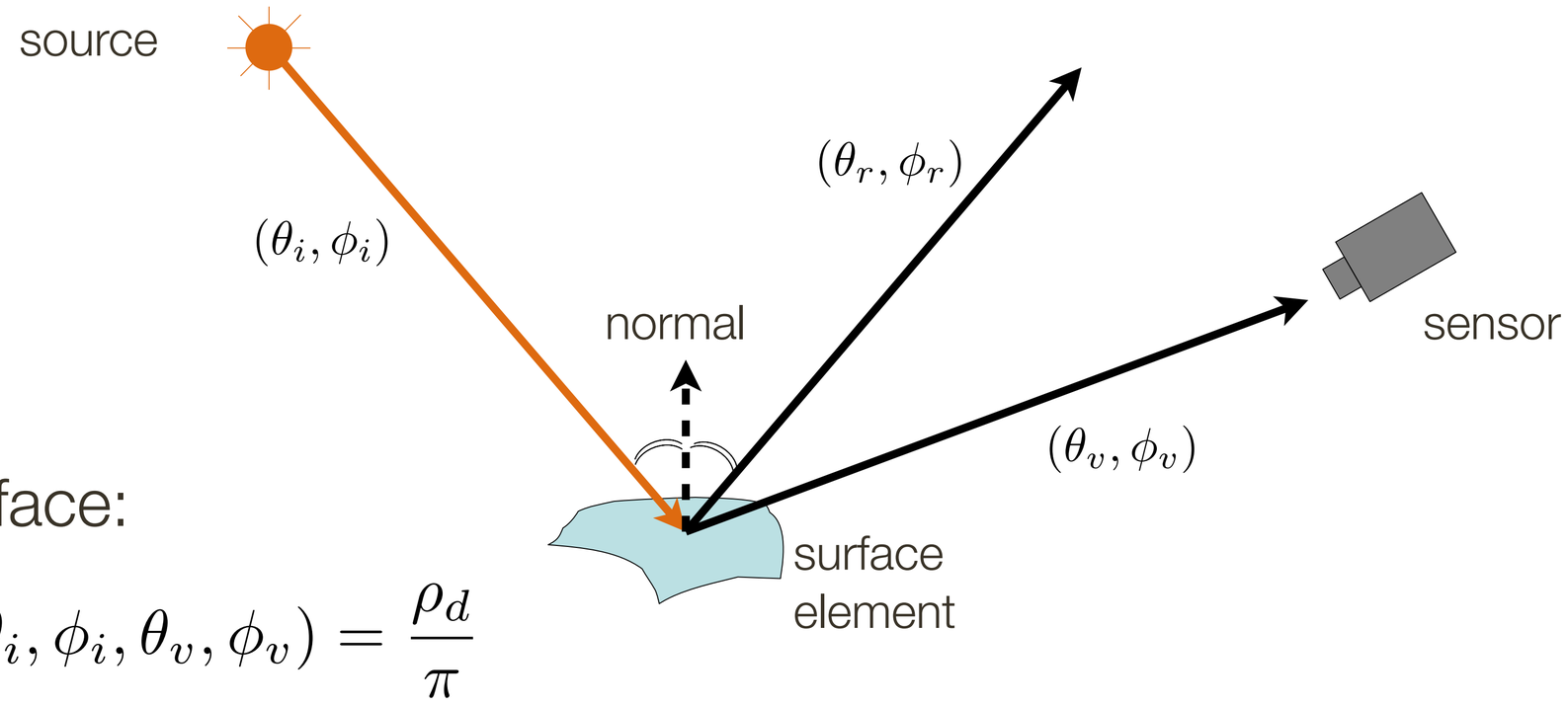



**Lambertian** surface:

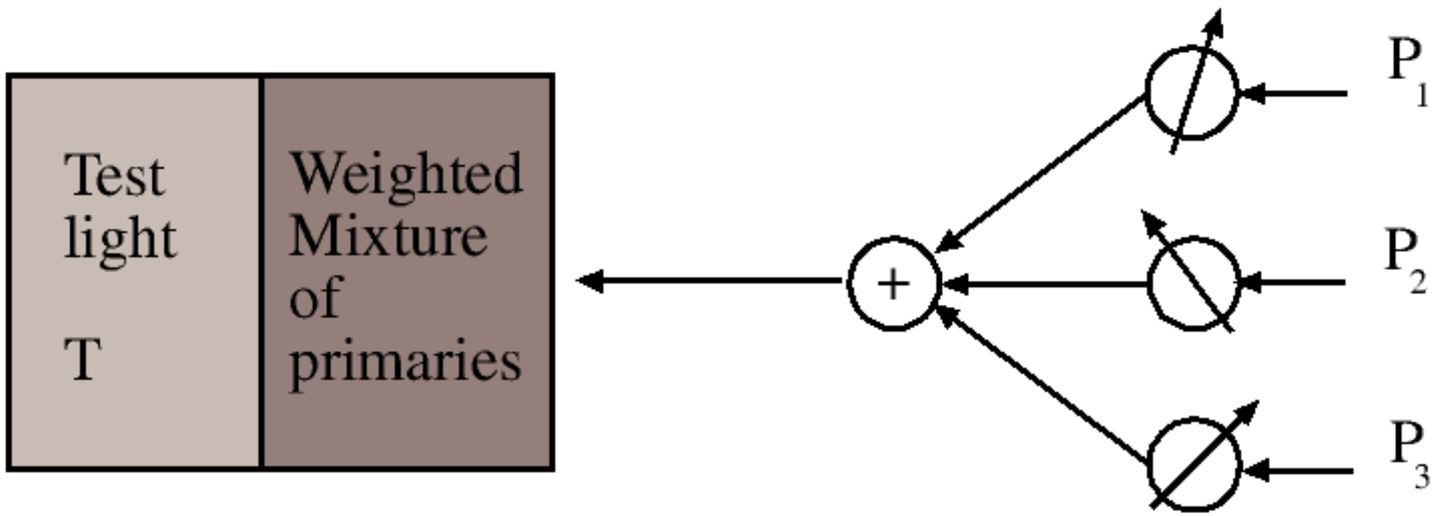
$$\mathbf{BRDF}(\theta_i, \phi_i, \theta_v, \phi_v) = \frac{\rho_d}{\pi}$$

**Mirror** surface: all incident light reflected in one directions $(\theta_v, \phi_v) = (\theta_r, \phi_r)$



**Slide adopted from**: Ioannis (Yannis) Gkioulekas (CMU)

# **Color** Matching Experiments



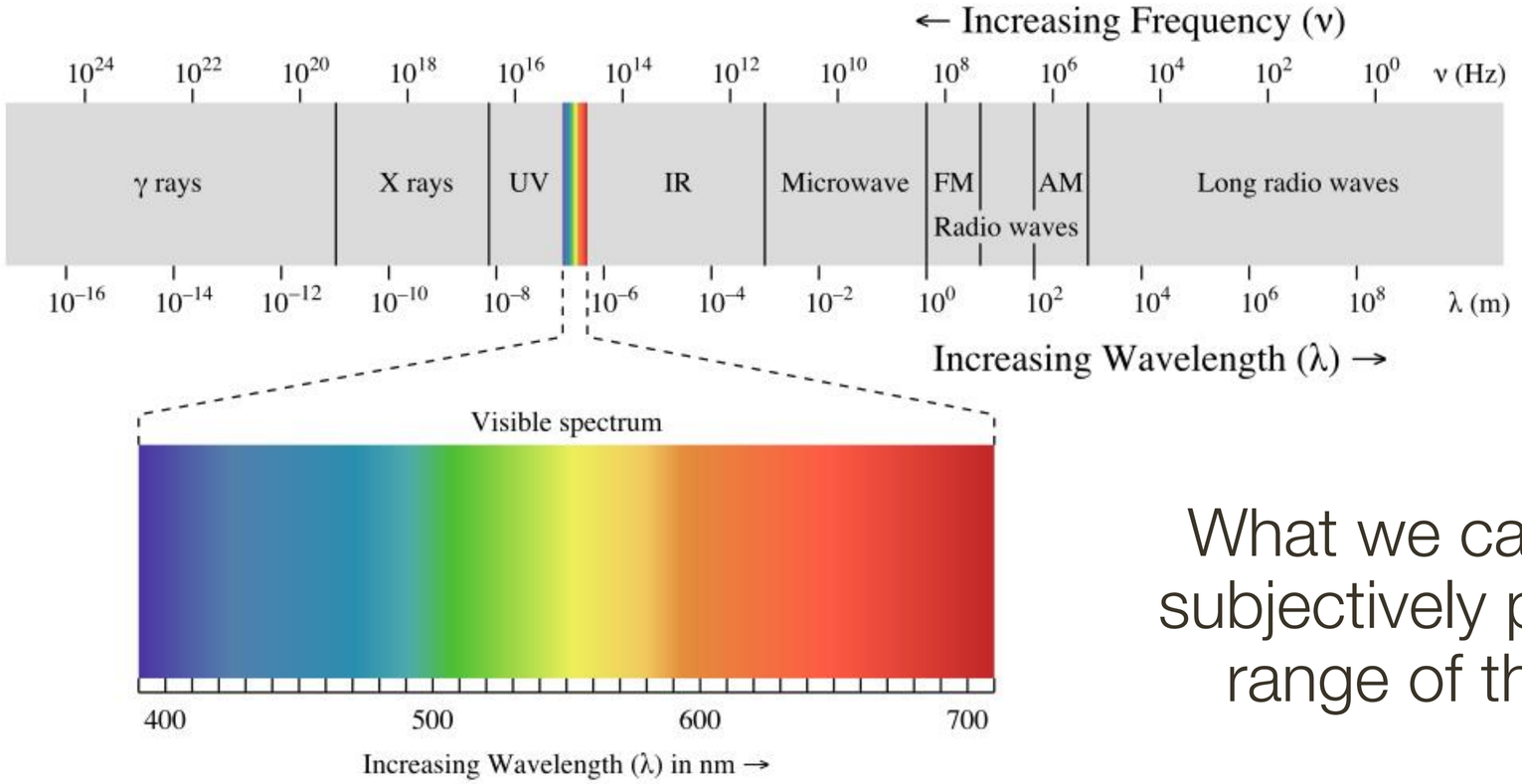

Forsyth & Ponce (2nd ed.) Figure 3.2

Show a split field to subjects. One side shows the light whose colour one wants to match. The other a weighted mixture of three primaries (fixed lights)

$$T = w_1 P_1 + w_2 P_2 + w_3 P_3$$

# **Recall**: Color is an Artifact of Human Perception

"Color" is **not** an objective physical property of light (electromagnetic radiation). Instead, light is characterized by its wavelength.



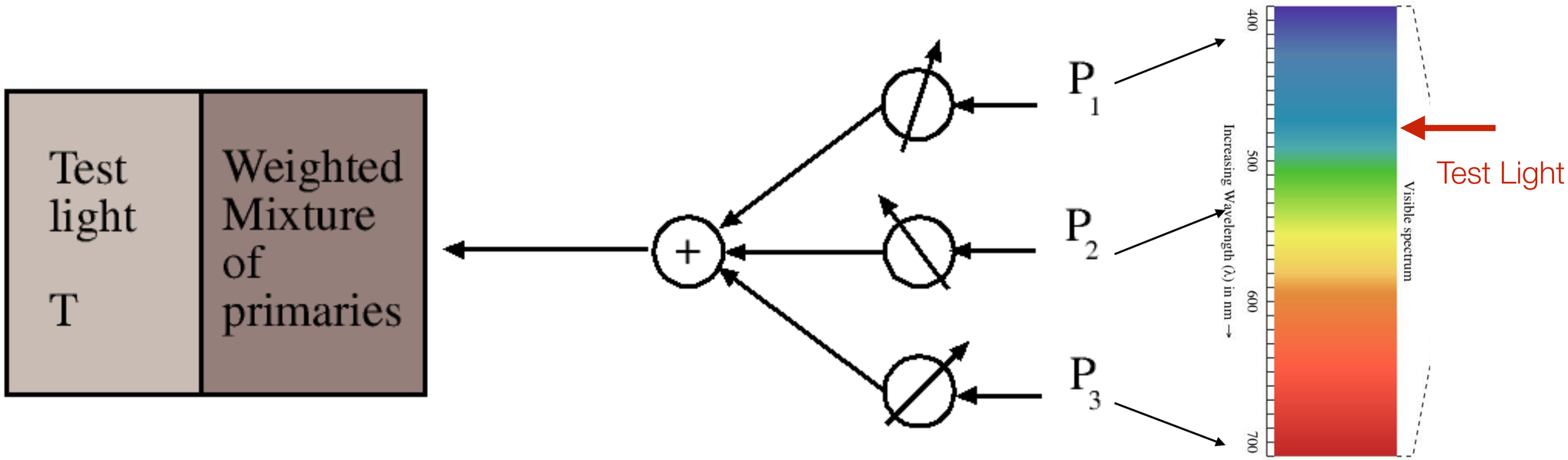

electromagnetic spectrum

What we call "color" is how we subjectively perceive a very small range of these wavelengths.



**Slide Credit**: Ioannis (Yannis) Gkioulekas (CMU)

# **Color** Matching Experiments

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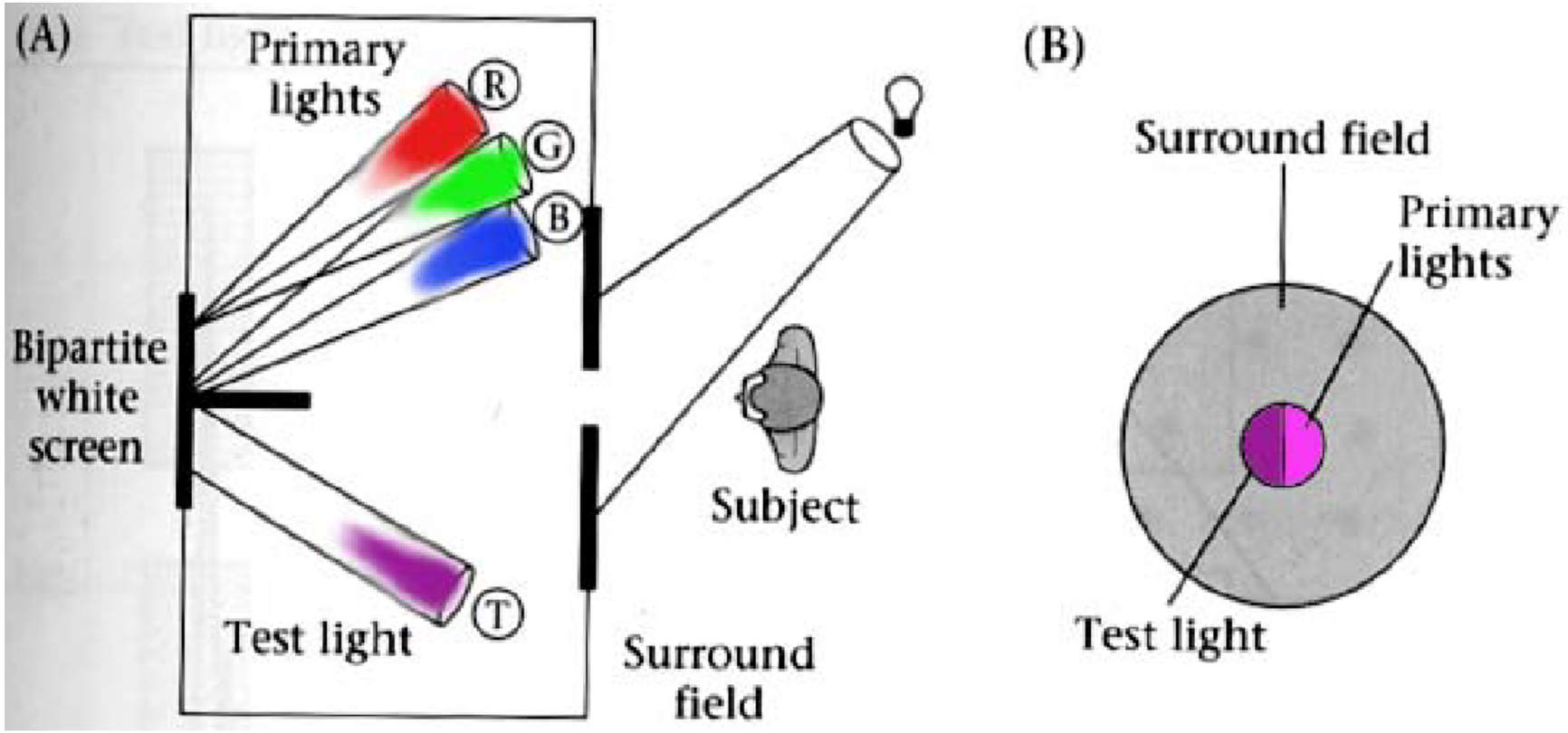
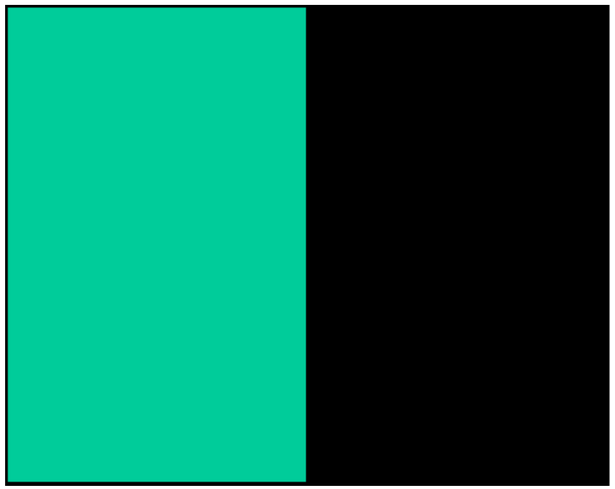



**Figure Credit**: Brian Wandell, Foundations of Vision, Sinauer Associates, 1995

# **Example** 1: Color Matching Experiment



**knobs** here

**Example Credit**: Bill Freeman

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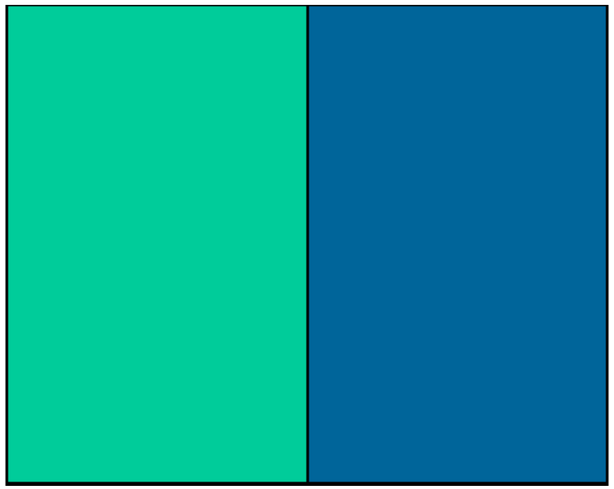

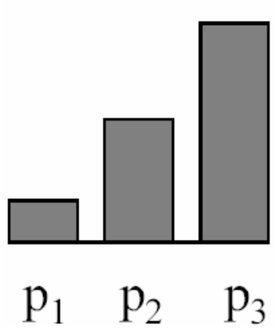


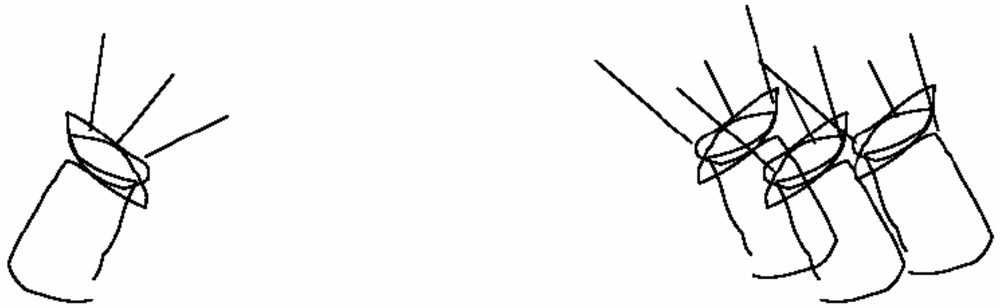

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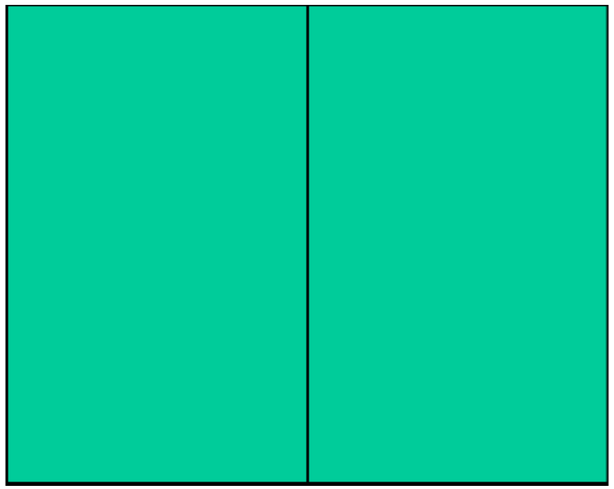

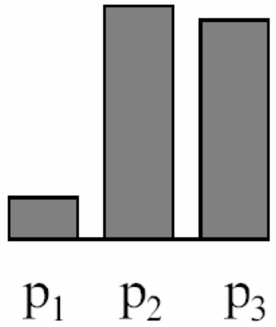


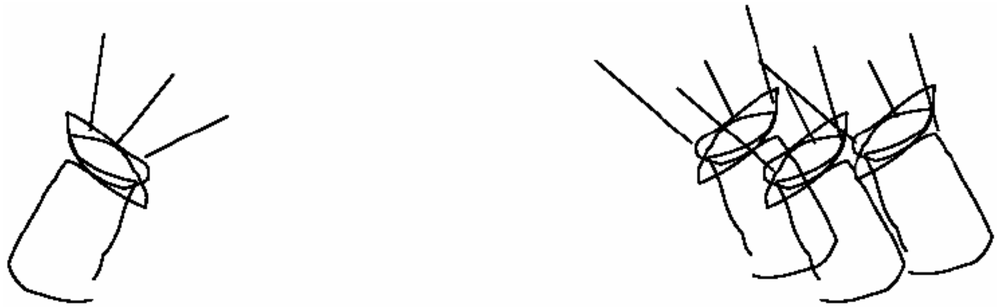

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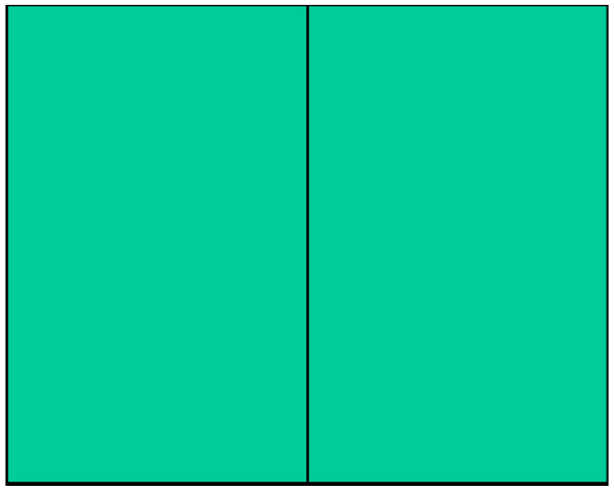

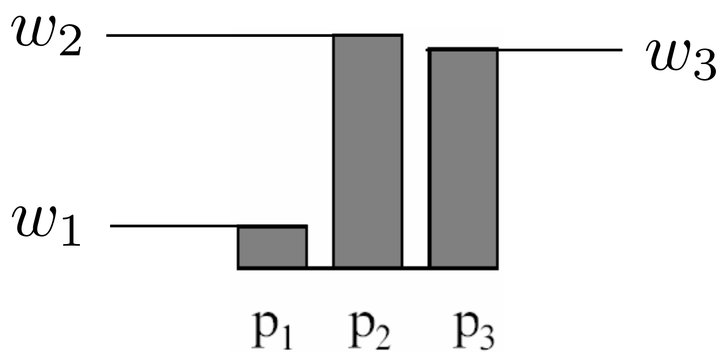


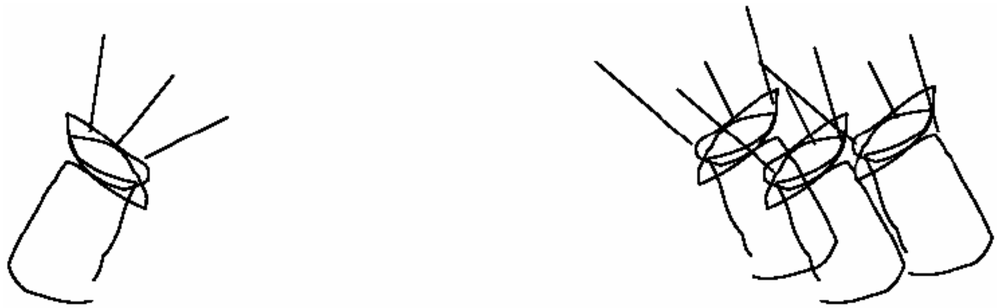

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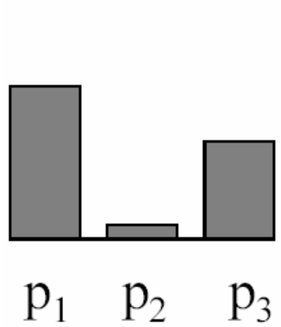


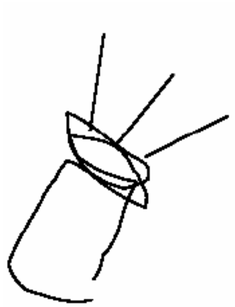

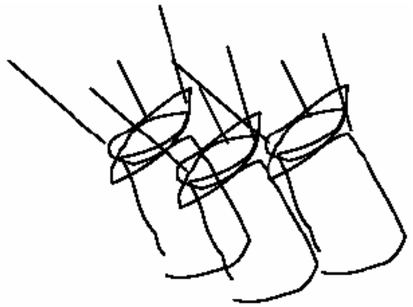

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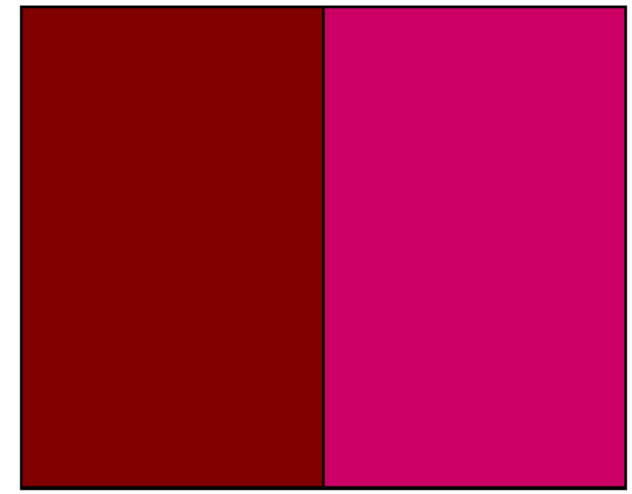

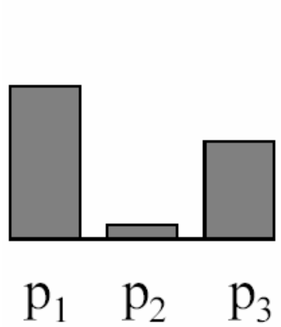


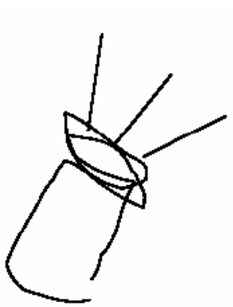

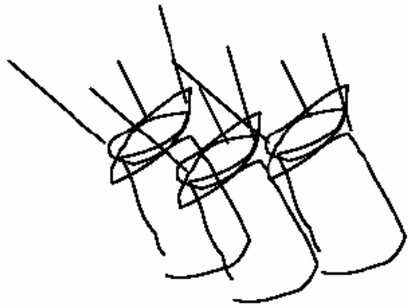

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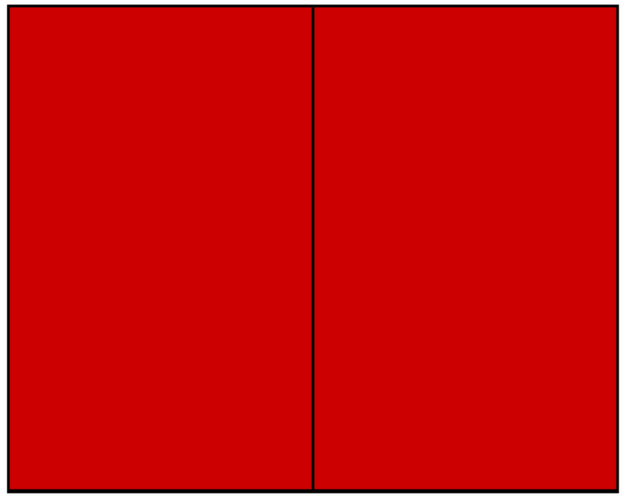
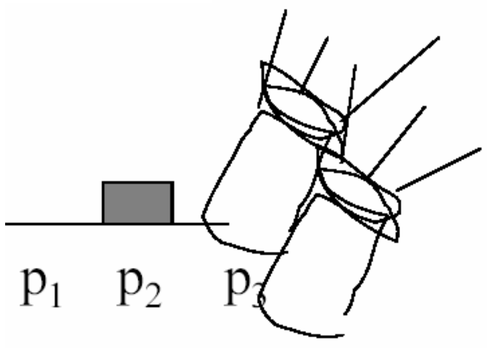
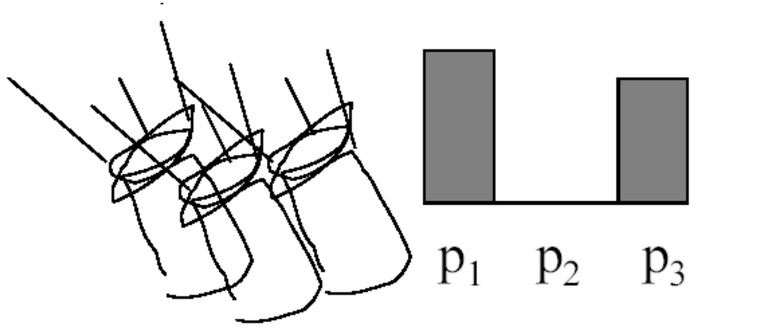


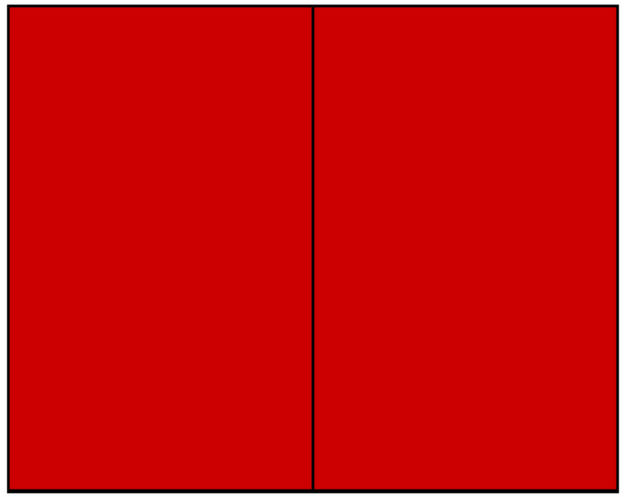


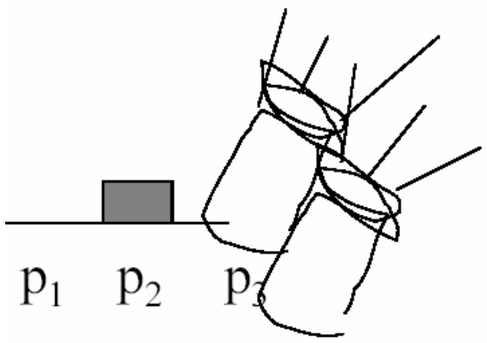



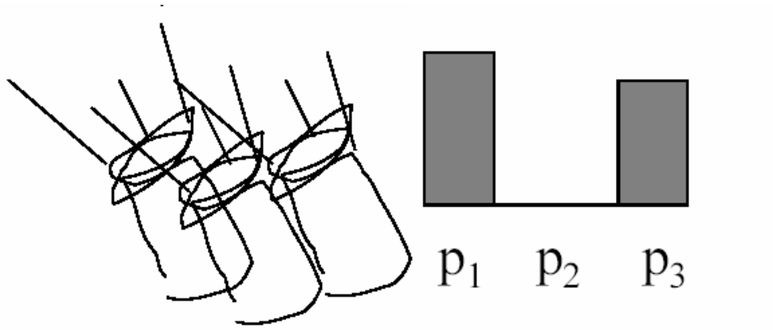

**Example Credit**: Bill Freeman

# **Example 2**: Color Matching Experiment

We say a “negative” amount of $P_2$ was needed to make a match , because we added it to the test color side



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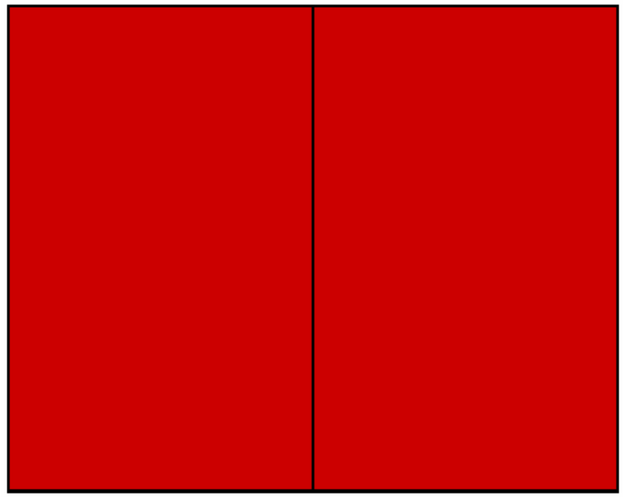
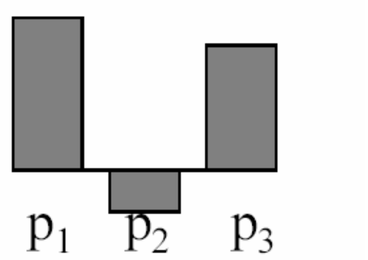
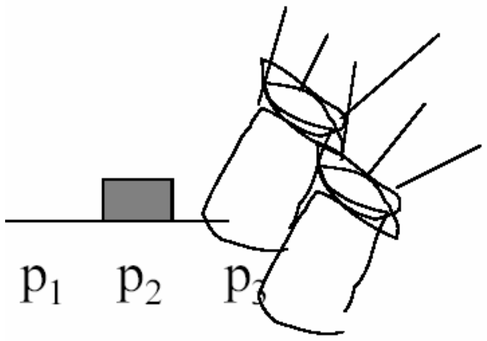
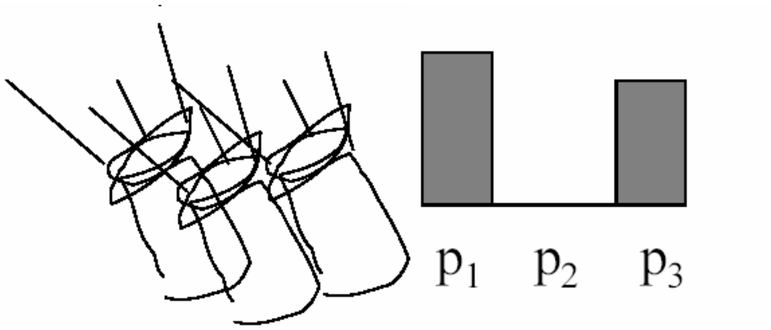


The primary color amount needed to match:




**Example Credit**: Bill Freeman

# **Color** Matching Experiments

— Many colours can be represented as a positive weighted sum of A, B, C

— Write

$$M = aA + bB + cC$$

where the = sign should be read as “matches”

— This is **additive** matching

— Defines a colour description system
  — two people who agree on A, B, C need only supply (a, b, c)

# **Color** Matching Experiments

— Some colours can’t be matched this way

— Instead, we must write

$$M + aA = bB + cC$$

where, again, the = sign should be read as “matches”

— This is **subtractive** matching

— Interpret this as (–a, b, c)

# **Color** Matching Experiments

— Some colours can’t be matched this way

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— Interpret this as (–a, b, c)

Problem for **designing displays**: Choose phosphors R, G, B so that **positive linear combinations** match a large set of colours

# Principles of **Trichromacy**

**Experimental** facts:

Three primaries work for most people, provided we allow subtractive matching

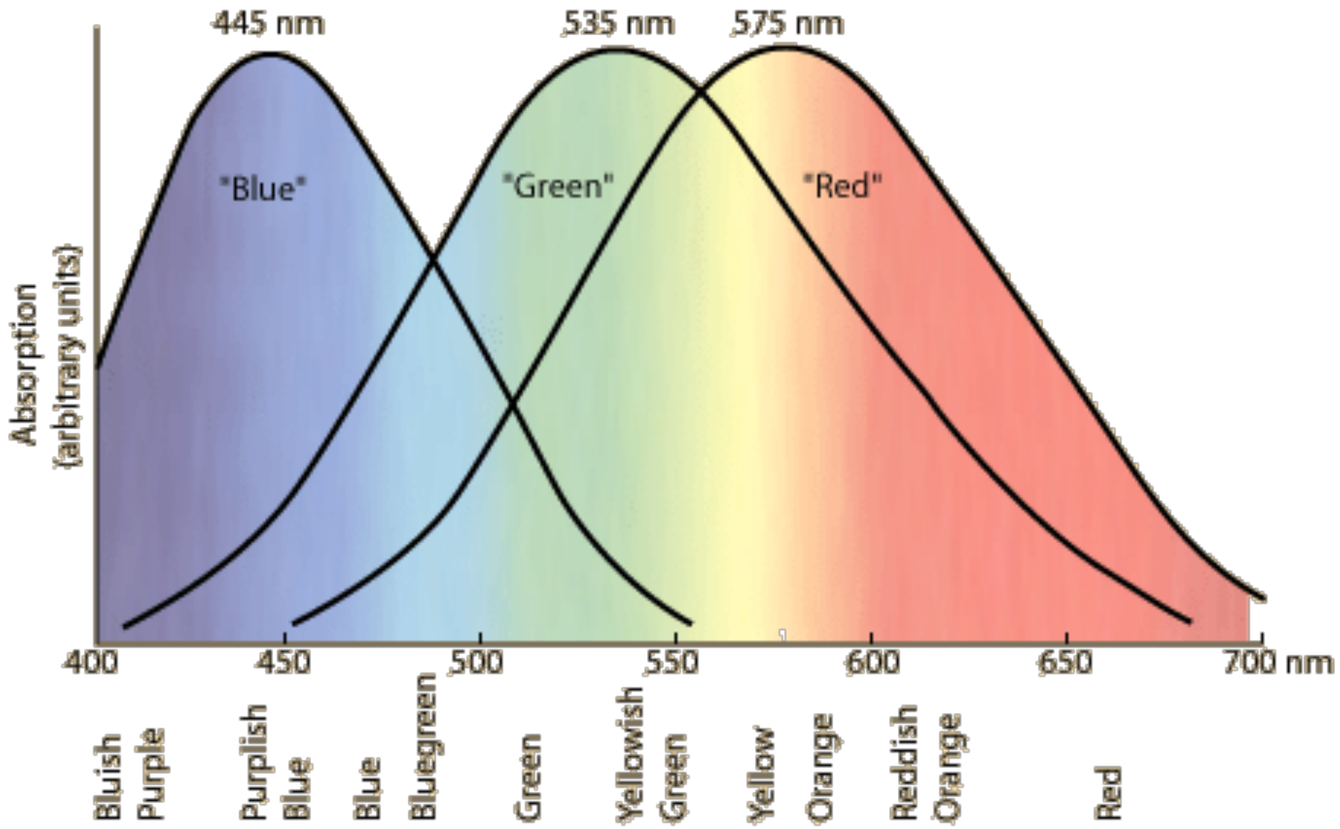
— Exceptional people can match with two or only one primary

— This likely is caused by biological deficiencies

Most people make the same matches

— There are some anomalous trichromats, who use three primaries but match with different combinations

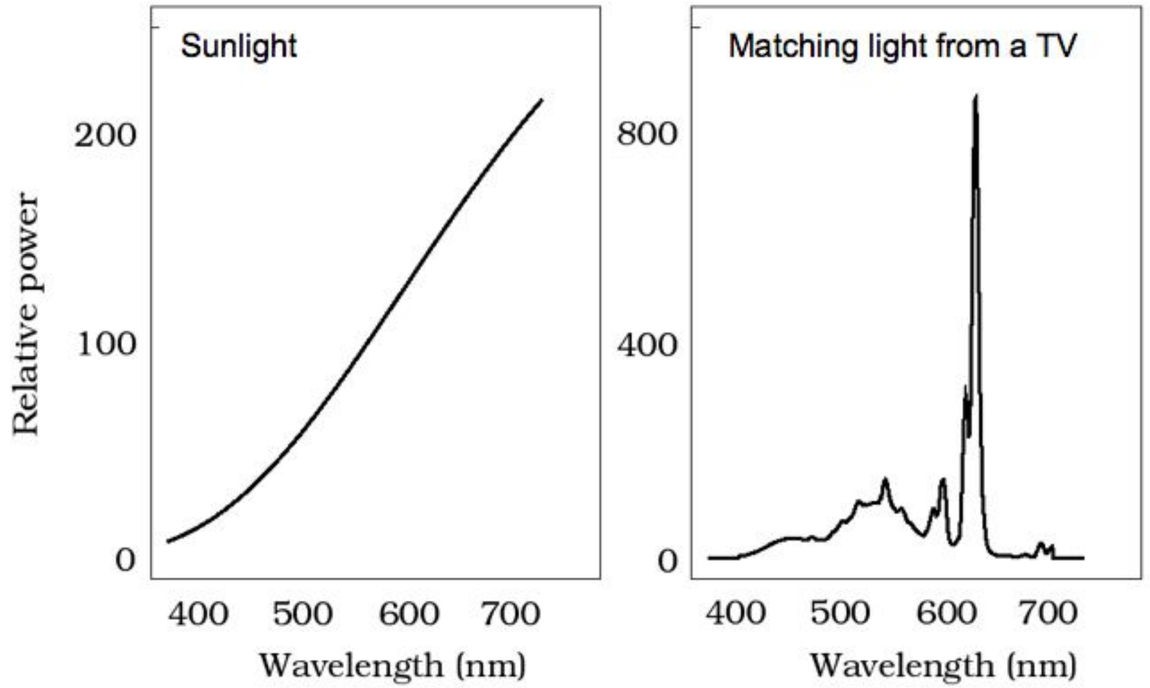
# Human **Cone** Sensitivity




http://hyperphysics.phy-astr.gsu.edu/hbase/vision/colcon.html

# **Metameric** Lights

Two lights whose spectral power distributions appear identical to most observers are called **metamers**.




(A) A tungsten bulb (B) TV monitor set to match (A)

**Figure credit**: Brian Wandell, Foundations of Vision, Sinauer Associates, 1995

# **Grassman**'s Laws

For colour matches:

— **symmetry**: $U = V \Leftrightarrow V = U$

— **transitivity**: $U = V \quad \text{and} \quad V = W \Rightarrow U = W$

— **proportionality**: $U = V \Leftrightarrow tU = tV$

— **additivity**: if any two of the statements are true, then so is the third

$$\begin{aligned} U &= V, \\ W &= X, \\ (U + W) &= (V + X) \end{aligned}$$

These statements mean that colour matching is, to an accurate approximation, linear.