The color of an object is determined by the light that is reflected from the object and then enters the human eye. The color that is perceived is the result of a light source, an object that absorbs, transmits, reflects, or scatters the light. The interpretation of the result of the reflected light by the observer (human visual system or other mechanical system). Therefore, the three basics are light, an object and the observer.

Light = first component of the color triplet
1. Form of visible energy
2. Took electromagnetic spectrum spread out over united states
   a. Visible spectrum = 1.5 inches of the whole spectrum
3. When daylight is made to pass through a crystal prism, it is bend and each wavelength changes direction by a diff amount (Isaac Newton)
4. This separates the various wavelengths and individuals colors of the visible spectrum are seen
5. *Red, green, blue = 3 main colors you see

Object
1. Light interacts, some reflected, some absorbed
2. Wavelength not
3. Rose, waves reflected, all others not
4. White = all light reflected
5. Dark object, all absorbed, hardly any reflected

Observer
1. When light enters eye strikes the retina
2. Fovea not the optic nerve is at center
3. Reaches rods and cones
   a. Chief component of retinal receptor complex
   b. Rods detect lightness and darkens (achromatic aspects (value)
   c. Cones = chromatic (hue and Chroma = color)
4. 3 types fo cones in human eye
   a. Photosensitive pigment (isidopsin) which perceives chromatic aspects
   b. Red, green, blue cones (mix that together to get the colors)
   c. If someone is color blind they miss one of these three cones
5. Many rods, dispersed everywhere
6. Cones are mainly concentrated in the fovea
7. Taking shades
   a. Squint eyes to eliminate color and look more at value
8. Distribution of rods and cones
   a. 25x more rods than cones, reason we see value as predominant factor in shade selection
   b. Value 14x more sensitive than Chroma
   c. Chroma 7x more sensitive than hue
9. Spectrophotometer
   a. Light = two light sources
10. Color mixing
    a. Light mixture primary colors (red, green and blue)
    b. Three large bands of color are observed in the visible light spectrum
    c. These are primary colors of the spectrum
    d. The mixing of two light mixture primary colors produces a secondary color
        i. Yellow = red and green
        ii. Cyan = green and blue
        iii. Magenta = red and blue
    e. This type of mixing = light mixture or additive color mixing and applies to only to combing lights or illuminants
11. Pigment mixture system or subtractive color mixing
    a. Primary colors in the subtractive = yellow, cyan and magenta
    b. These form the basis for the derivation of other colors in the pigment mixture system
    c. Where do we use this in every-day use?
       i. Printer cartridges

Order systems
1. A typical example of an order system is a map
2. With known longitude and latitude at any point can be found
3. 3D order system = box
   a. Length width and height are specified any given point in the room can be found
4. 3D order systems
Munsell Color system

1. Developed Munsell Color system
2. Coined 3 terms
3. Object can be described, height, width, length, and color (huge, value, chroma)

- **Hue** = quality by which we distinguish one family from another
- **Value** = light form dark (most important)
  - Designated as number and slash (4/)
  - First: Lightest is 10; darkest is 1
  - Second: High value = light (worse than too dark)
  - Third: Low value = darker
  - Fourth: When picking one shade and going between 2 shades, darker one is usually better off (one with less value)
  - Fifth: Too high of value if you don’t have second plane of reduction (spotlight...?)

- **Chroma** = weak color and intense color (amount of color)

2. Specrophotometric measurement so human teeth

1. Available shade guides did not provide proper range
2. Found huge, value, and Chroma ranges for normal shade guides
3. When he charted these, he found the shade guide was not in the same range as the teeth (not good for matching teeth)

Shade guides
1. RC Sproull used specrophotometric measurement so human teeth
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2. All these studies have shown there is a range of natural tooth shades inside the range of color

3. Shade guide designs
   a. Vitapan = empirical designs (what we use)
      i. Gold standard
      ii. 4 groups of tabs
         1) A = red
         2) B = yellow
         3) C = gray
         4) D = reddish-gray
         5) Higher numbers, 1-4 higher Chroma
         6) Can also be arranged by value, B1-C4
         7) Usually come organized by Chroma (As, Bs, Cs...)
   b. Vita 3D master (evidence based design)
      i. Toothguide
      ii. Linear guide
         1) Select value, then pick Chroma and hue
         2) It’s because we have more rods so see more value in teeth
      iii. Bleached guide
         1) Only shade guide for tooth whitening
         2) Causes decrease in Chroma
         3) More envelop of tooth color, more than the classic envelop of color
   c. Vita Lumin shade guide tabs in "envelop of natural teeth"

- **Value** = most important part for picking shade of a tooth

What’s wrong with the human color matching system
1. Elements effecting color
   a. Illumination
i. Proper lighting (5500 K), distance (6-8 inches), time (3-5 secs), proper environment (neutral, light blue or gray background), preoperative (dehydrated teeth are lighter)

ii. Kelvin color temperature is the color emitted when a standard black body is heated and reported in degrees K

1) 5500 K = white
2) As it gets hotter = blue
3) 2000K = yellow
4) 8000 K - blue

iii. Metamerism

1) Phenomenon occurring when the color of two objects appears to match under one lightening source but not under diff source
2) Occurs in dentistry because differences in optical properties of natural tooth and porcelain related to chemical and physical differences
   a) Porcelain and tooth may match in one environment and not in another
3) Examples
   a) Fluorescent lightening makes teeth appear blue
      i) Emission of light by a substance that has absorbed...(picking up UV?)
   b) We would like color corrected at 5500 K
   c) Too much light = too white

b. Contrast effects

i. Value
   1) Correlated to surrounding environment
   2) Same tooth against different backgrounds can appear as different values

ii. Hue
   1) When viewed against different background ts the teeth appear to take on the use of the backgrounds

iii. Chroma
   1) Highly chromatic tooth appears more vibrand against a background...

iv. Areal contrast
   1) Larger object = lighter

v. Spatial
   1) Object closer appears Larger and lighter
   2) Often seen with rotated teeth

vi. Successive contrast
   1) Rods and cones use up the neurotransmitters and then cause you to see the complimentary color (reason you cant stare at a shade)
   2) Reason 3-5 seconds to stare at a color

C. Simultaneous contrast

d. Viewer associated effects

i. Age
   1) Cornea and lens become yellow with age
   2) Begins at 30, noticeable at 50

ii. Fatigue
   1) Tired eyes do not perceive as well

iii. Emotions

iv. Medications

v. Binocular difference
   1) Should put the tooth edge to edge not next to the tooth

2. Easy shade compact = spectrophotometer

a. Measures shade
b. Build in memory that stores the last 25 measurements
c. Measures a single crown accuracy before seating
d. Get a more detailed shade analysis with a detailed map