How We See

- The inner surfaces of your eyes contain photoreceptors (retina) – specialized cells that are sensitive to light and relay messages to your brain.
- There are two types of photoreceptors: cones (which are sensitive to color) and rods (which are more sensitive to intensity).
- We are able to see an object when light from the object enters your eyes and strikes these photoreceptors.

How We See

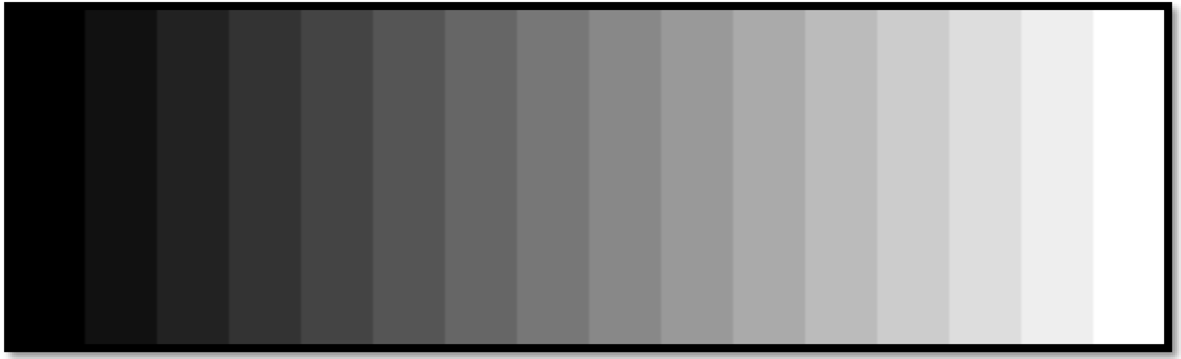
- Some objects are luminous and give off their own light; all other objects can only be seen if they reflect light into our eyes.
- However, humans can only see visible light, a narrow band of the electromagnetic spectrum.
- This spectrum includes non-visible radio waves (AM, FM, microwave), infrared light, ultraviolet light, X-rays, and alpha, beta, gamma rays, etc.
- In terms of wavelengths, visible light ranges from about 400 nm to 700 nm. (always, freq. $\times$ wavelength $= 3\times10^7$m/sec)

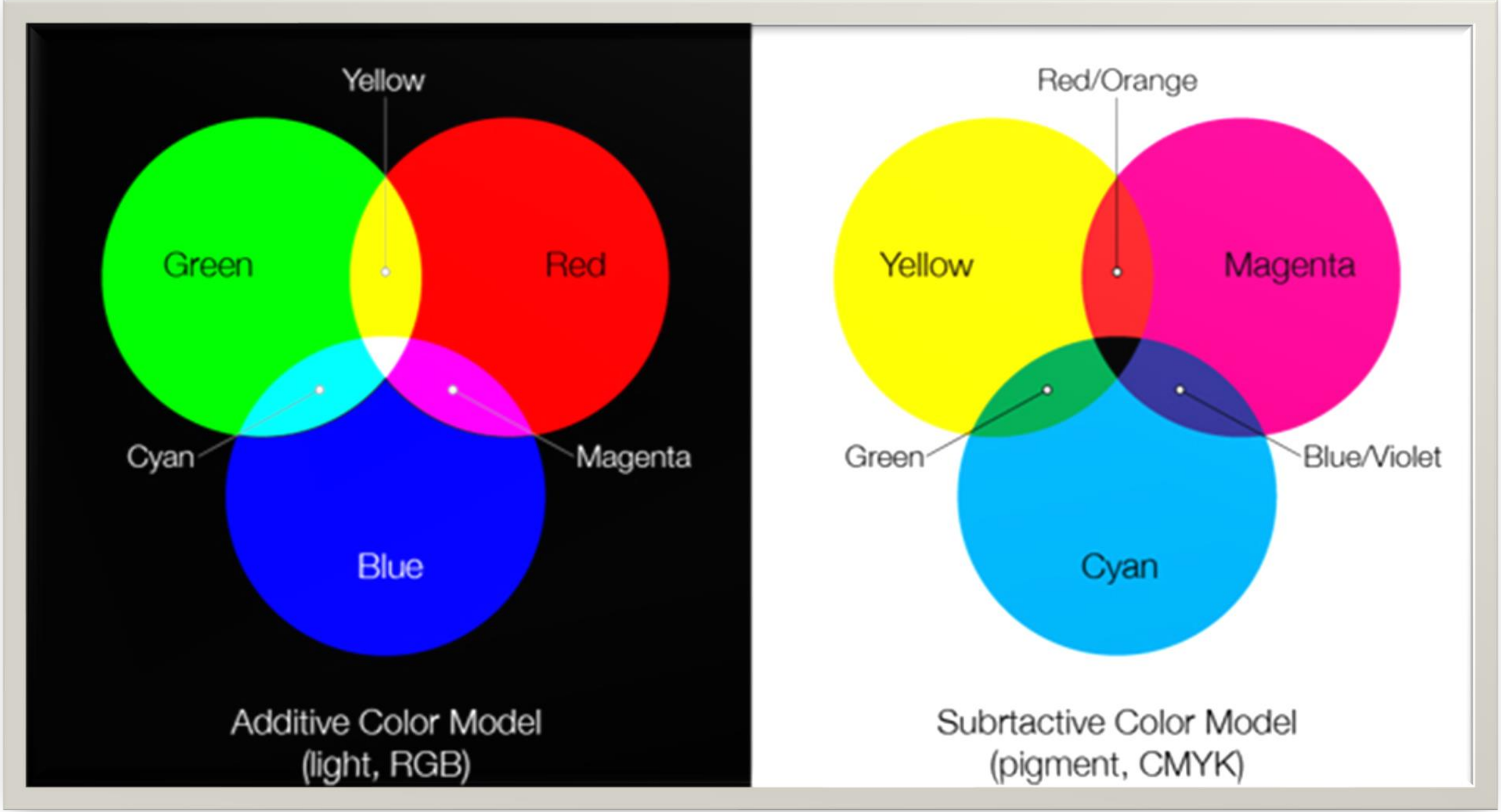
Color Model of Light

- There are two basic color models that art and design students need to learn in order to have an expert command over color, whether doing print publications in graphic design or combining pigment for printing.
- These two color models are:
  - Additive Color Model or Light Color Primaries (Red, Green, Blue) or RGB/RGBA.
  - Subtractive Color Model or Pigment Color Primaries (Cyan, Magenta, Yellow) or CMY/CMYK

Achromatic Light

- Achromatic Light: "without color," quantity of light only
  - Called intensity, luminance, or measure of light's energy/brightness
    - The psychophysical sense of perceived intensity
  - Gray levels (e.g., from 0.0 to 1.0)
    - We can distinguish approximately 128 gray levels
  - Seen on black and white displays
  - Monochrome Light: Only two levels




Yellow
Green
Red
Cyan
Magenta
Blue
Additive Color Model
(light, RGB)
Red/Orange
Yellow
Magenta
Green
Blue/Violet
Cyan
Subrtactive Color Model
(pigment, CMYK)

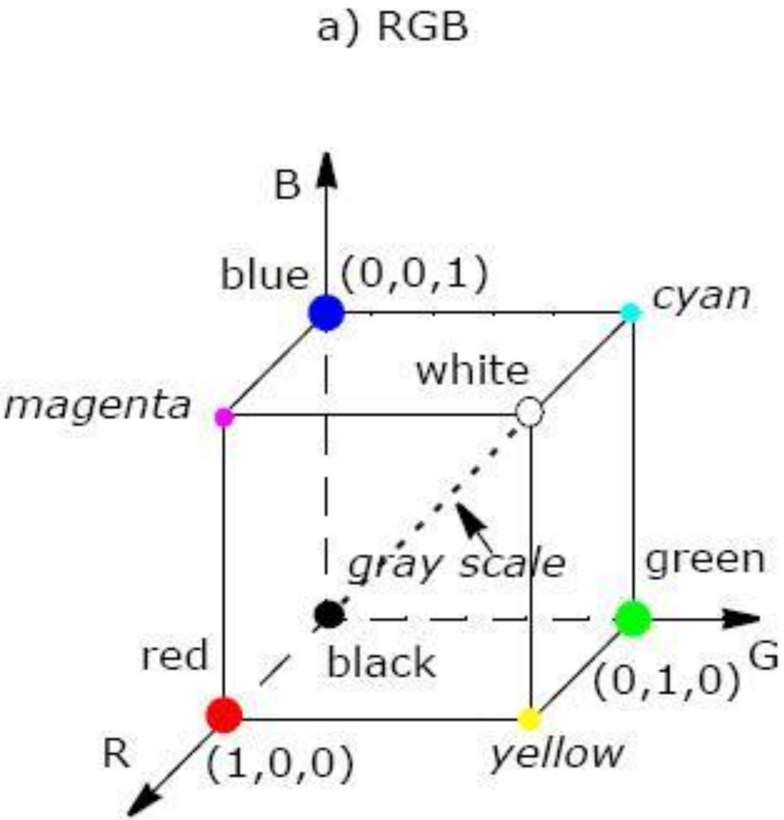
Additive (Light) Color Primaries

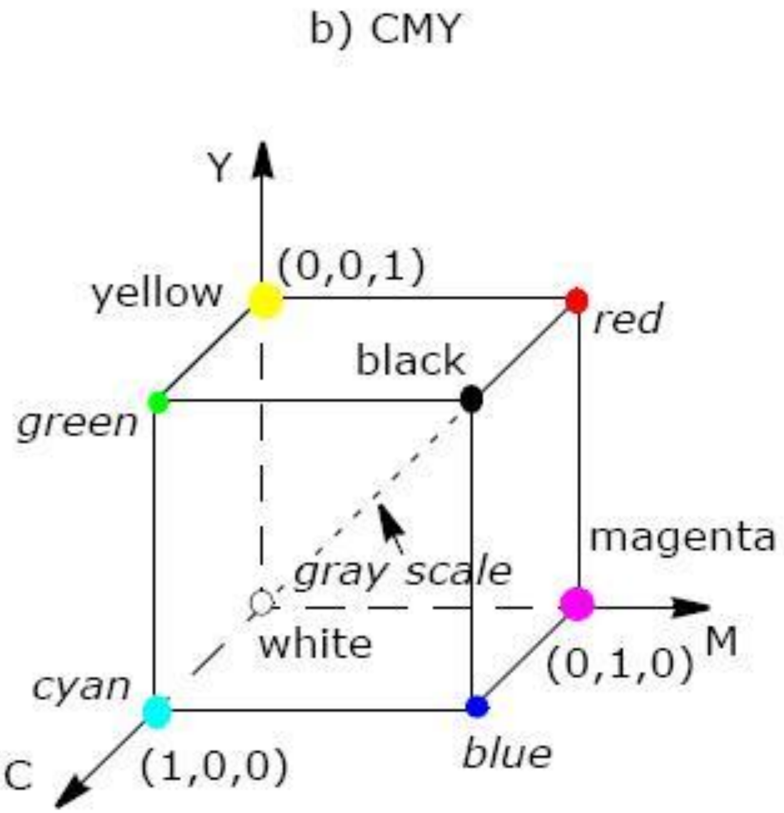
- Red, green, and blue are the primary colors of light—they can be combined in different proportions to make all other colors.
- For example, red light and green light added together are seen as yellow light. (The brightness of yellow is greater than red or green)
- This additive color system is used by light sources, such as televisions and computer monitors, to create a wide range of colors.
- When different proportions of red, green, and blue light enter your eye, your brain is able to interpret the different combinations as different colors.

Subtractive (Pigment) Color Primaries

- However, there is another set of primary colors with which you may be more familiar. The primary colors of pigment (also known as subtractive primaries) are used when producing colors from reflected light; for example, when mixing paint or using a color printer. The primary colors of pigment are magenta, yellow, and cyan (commonly simplified as red, yellow, and blue).
- Pigments are chemicals that absorb selective wavelengths—they prevent certain wavelengths of light from being transmitted or reflected. Because paints contain pigments, when white light (which is composed of red, green, and blue light) shines on colored paint, only some of the wavelengths of light are reflected. For example, cyan paint absorbs red light but reflects blue and green light; yellow paint absorbs blue light but reflects red and green light.

Additive vs Subtractive color





Key Differences Between RGB and CMY

1. RGB color model is known as the additive model because these colors produce a brighter outcome when added with light. Conversely, CMY is a subtractive model where we begin with the white sheet of paper, and for getting the dark result, you need to add more ink to it.
2. The RGB model is mainly implemented in the display monitors for generating various colors. In contrast, CMY is utilized in printing material majorly.
3. In the RGB model, the light is used for changing the produced color intensity. On the contrary, in CMY model uses ink for altering the color intensity.
4. By adding the RGB colors, the white color is generated while the addition of CMY colors produces a black color.
5. There is a straightforward relationship between the additive and the subtractive color. To represent this in an additive system we can consider the creation of the colors by mixing them such as the yellow color is produced by combining red and green light. As against, in the subtractive system, the yellow color is generated due to the subtraction of blue color from the white light.
6. The RGB model helps in operating the tasks at a higher speed and consumes less memory space (file size is smaller) as compared to the CMY model.

HSV Color Model

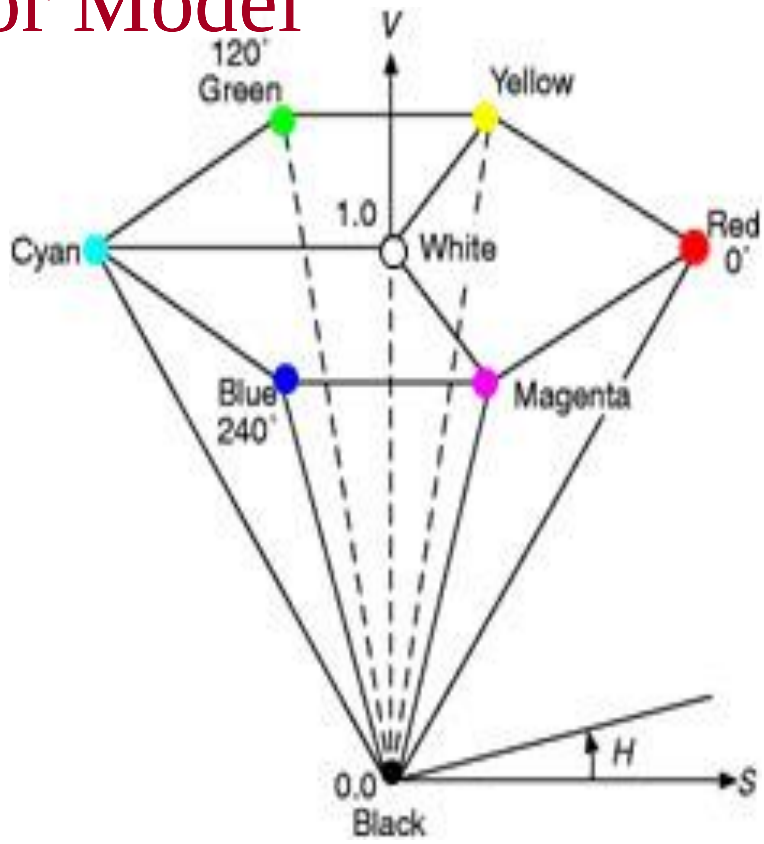
- Unlike RGB and CMY, which use primary colors, HSV is closer to how humans perceive color, utilizes RGB hardware.
- It has three components: hue, saturation, and value (driven from RGB).
- This color space describes colors (hue or tint) in terms of their colorness (saturation of color) and their brightness value.
- Some color pickers, like the one in Adobe Photoshop, use the acronym HSB, which substitutes the term "brightness" for "value," but HSV and HSB refer to the same color model.

How to Use the HSV Color Model

- The HSV color wheel sometimes appears as a cone, but always with these three components:
- Hue: Hue is the color portion of the model, expressed as a number from 0 to 360 degrees:
- **Red** falls between 0 and 60 degrees., **Yellow** falls between 61 and 120 degrees, **Green** falls between 121 and 180 degrees, **Cyan** falls between 181 and 240 degrees, **Blue** falls between 241 and 300 degrees, **Magenta** falls between 301 and 360 degrees.
- Saturation: Saturation describes the amount of gray in a particular color, from 0 to 100 percent.
- Reducing this component toward zero introduces more gray and produces a faded effect. Sometimes, saturation appears as a range from 0 to 1, where 0 is gray, and 1 is a primary color.
- Value (or Brightness): Value works in conjunction with saturation and describes the brightness or intensity of the color, from 0 to 100 percent, where 0 is completely black, and 100 is the brightest and reveals the most color.

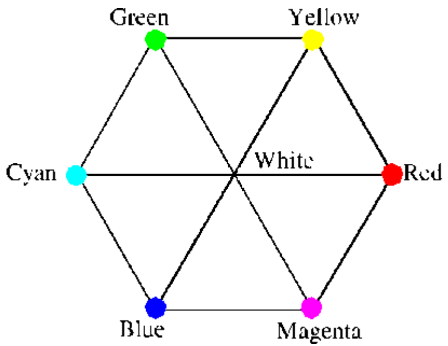
The HSV Color Model

- Hue, Saturation, Value (Brightness)
- HSV-space invented by Alvy Ray Smith—described in his 1978 SIGGRAPH paper, *Color Gamut Transformation Pairs.*
- Hexcone subset of cylindrical (polar) coordinate system
- Single hexcone HSV color model. The cross-section at V = 1 contains the RGB model's R =1, G = 1, B = 1

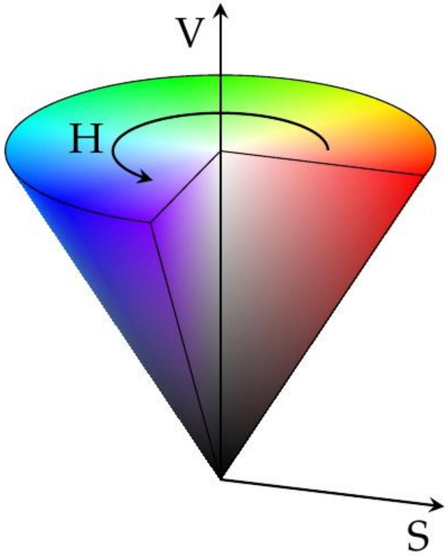


The HSV Color Model

- Colors on V = 1 plane are not equally bright perceptually
- Complementary colors 180° opposite (Hue = 0 to 360^0)
- Saturation measured relative to color gamut represented by mathematical HSV model which is subset of the perceptually-based chromaticity diagram for a given value (Color Button in TV):
- Top of HSV hexcone is projection seen by looking along principal diagonal of RGB color
- RGB subcubes are plane of constant V
- Note: linear path RGB ≠ linear path in HSV! (has consequences for interpolation/animation)



RGB color cube viewed along the principal diagonal



RGB to HSV conversion

$\Delta = max(R,G,B) - min(R,G,B);$

$\boxed{V = max(R,G,B);}$

if (V == 0){

S = 0;

}

else {

$\boxed{S = \Delta / max(R,G,B);}$

}

if (S == 0){

H = undefined;

}

else {

if (max(R,G,B)== R){

$\boxed{H = \left(\frac{G-B}{\Delta} \times 60\right);}$

if(H<0) H+=360;

}

else if (max(R,G,B)== G){

$\boxed{H = \left(\frac{B-R}{\Delta} \times 60\right) + 120;}$

}

else {

$\boxed{H = \left(\frac{R-G}{\Delta} \times 60\right) + 240;}$

}

}

RGB to HSV

$$H = \left(\frac{B-R}{\Delta} \times 60\right) + 120; \quad V = max(R,G,B);$$

R	G	B	H	S	V
0.31	0.97	0.67			
0.58	0.42	0.15			

$$S = \Delta / max(R,G,B);$$