THEREFORE TO CONVERT THE WORLD COORDINATES w_h OF A POINT INTO ITS COORDINATES IN THE IMAGE COORDINATE SYSTEM c_h

$$c_h = PCRG w_h$$

COLOUR IMAGES

→ COLOR IS PHENOMENON IN WHICH WE VISUALLY PERCEIVE SOME FUNCTION OF THE SPECTRAL CONTENT OF THE RADIANT ENERGY EMANATING FROM AN OBJECT.

→ THE PIGMENTS RESPONSIBLE FOR COLOR VISION ARE CONTAINED IN THE CONES.

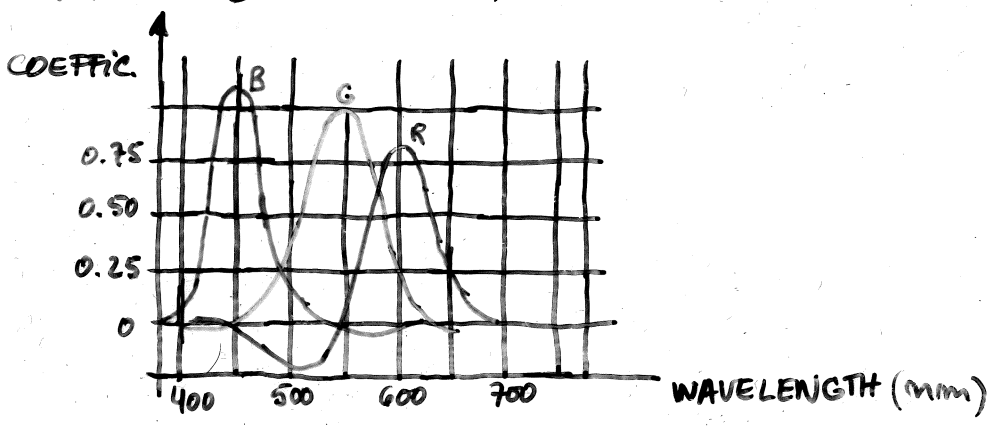
→ THE SENSATION OF COLOR IS EXPERIENCED BY MAN WHEN HIS EYE VIENS ENERGY SIGNALS CONTAINING WAVE-LENGTHS IN APPROXIMATELY THE RANGE BETWEEN 380 mm AND 780 mm.

→ OUTSIDE THIS BAND OF FREQUENCIES THE TRANSDUCERS IN THE RETINA ARE UNABLE TO DETECT A STIMULUS.

→ THE HUMAN EYE HAS THREE DIFFERENT KINDS OF CONES, EACH ONE WITH A DIFFERENT KIND OF PHOTOPIGMENT.

→THERE EXIST THREE PHOTOCHEMICALS, RESULTING IN WHAT ARE COMMONLY CALLED THE RED, GREEN, AND BLUE CHANNELS.

→THERE ARE THREE SENSITIVITY CURVES:



- IN SPITE OF THE FACT THAT COLOR PROCESSING IN THE HUMAN VISUAL SYSTEM IS NOT COMPLETELY UNDERSTOOD, THERE IS A PRACTICAL NEED TO DEAL WITH COLOR.

(ESPECIALLY WE KNOW VERY LITTLE ABOUT THE TRANSFORMATION OF THE TRICONE DATA INTO WHAT WE ACTUALLY PHYSICALLY PERCEIVE AS COLOR).

- IN 1931 THE C.I.E. (COMMISSION INTERNATIONALE DE L'ÉCLAIRAGE) ADOPTED A STANDARD BASED ON THE ASSUMPTION OF COLOR TRICHROMACY.

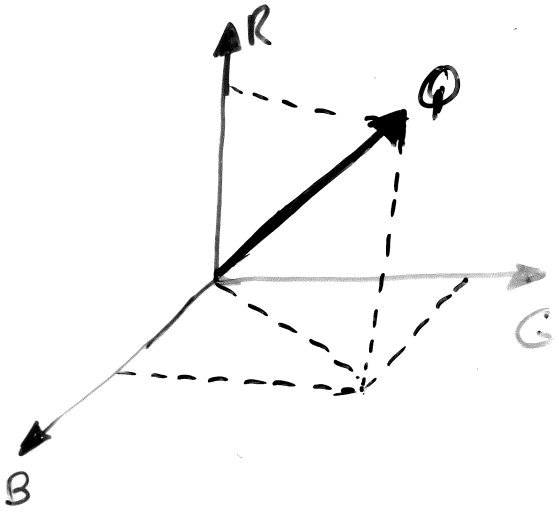
- TRICHROMACY HAS BEEN TAKEN TO IMPLY TWO BASIC ASSUMPTIONS:

1. ANY COLOR CAN BE MATCHED BY A VECTORIALLY ADDITIVE COMBINATION OF THREE PRIMARIES.

2. THE COLOR PROCESSING IS LINEAR.

- LET R, G AND B DENOTE VECTORS CORRESPONDING TO THREE PRINCIPAL COLORS;

- THEN EVERY COLOR IS REPRESENTED BY COMPONENTS OF THESE VECTORS R, G AND B (THESE ARE THE TRISTIMULUS VALUES).



- AN ARBITRARY VECTOR Q CAN BE SPECIFIED BY THE THREE TRISTIMULUS COORDINATES.

- THE CIE DEFINED TWO SYSTEMS: THE RGB AND THE XYZ.

- THE CIE RGB AND THE CIE XYZ ARE MATHEMATICALLY EQUIVALENT.

- THE XYZ SYSTEM IS BASED ON THE USE OF 3 UNREAL OR IMAGINARY PRIMARIES, SO THAT THE RESULTING COLOR MATCHING FUNCTIONS WILL BE POSITIVE FOR ALL WAVELENGTHS.

- WITH THESE 3 PRIMARY COLORS (X, Y, Z) ALL LIGHT SENSATIONS WE EXPERIENCE WITH OUR EYES CAN BE OBTAINED BY THE COMBINATION, WITH POSITIVE WEIGHTS, OF THESE 3 PRIMARIES.

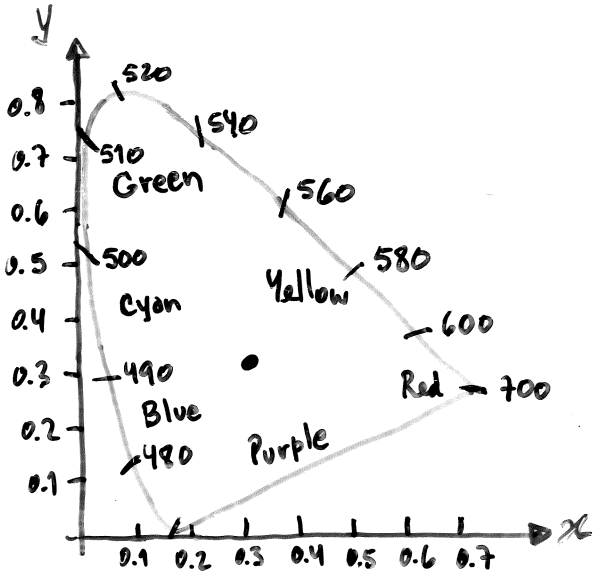
- LET X, Y, Z BE THE WEIGHTS APPLIED TO THE CIE PRIMARIES TO MATCH A COLOR;

  → THEN, WE CAN DEFINE CHROMATICITY VALUES, BY NORMALIZING AGAINST LUMINANCE (TOTAL AMOUNT OF LIGHT), SO THAT:

$$x = \frac{X}{X+Y+Z}, \quad y = \frac{Y}{X+Y+Z}, \quad z = \frac{Z}{X+Y+Z}$$

$$\Rightarrow x+y+z = 1$$

→ THE CIE CHROMATICITY DIAGRAM IS OBTAINED BY PLOTTING x AND y FOR ALL VISIBLE COLORS



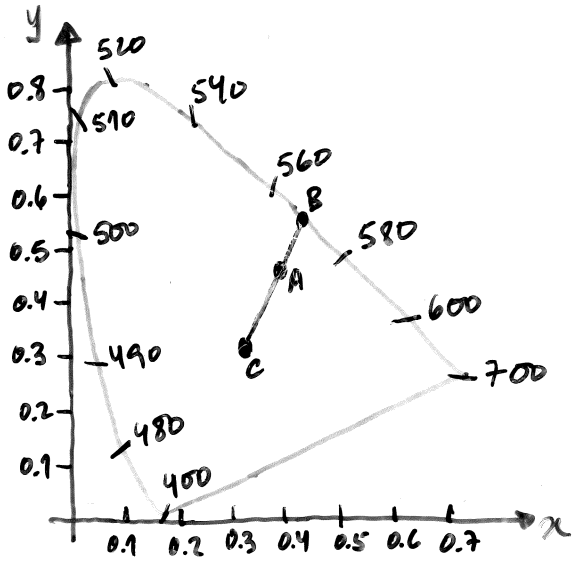
- THE HORSESHOE-SHAPED REGION AND ITS BOUNDARY REPRESENT ALL VISIBLE COLORS.

- STANDARD WHITE LIGHT (AN APPROXIMATION OF THE SUNLIGHT) IS MAPPED INTO THE CENTER DOT.
  (NEAR THE POINT $x = y = z = 1/3$)

  STANDARD WHITE LIGHT ⇒ DEFINED BY A STANDARD LIGHT SOURCE KNOWN AS ILLUMINANT C ⇒ BLACK-BODY RADIATOR AT 6504° KELVIN.

HOW USEFUL IS THE CIE CHROMATICITY DIAGRAM?

- ONE CAN MEASURE THE DOMINANT WAVELENGTH AND PURITY OF ANY COLOR;



- LET US CONSIDER THAT THE MATCHED COLOR IS AT POINT A;

- WHEN TWO COLORS ARE ADDED THE NEW COLOR LIES ON THE STRAIGHT LINE CONNECTING THE TWO COLORS BEING ADDED;

- COLOR A CAN BE THOUGHT OF AS A MIXTURE OF "STANDARD" WHITE LIGHT AND THE PURE SPECTRAL LIGHT AT POINT B.

→ PURITY OF A: $\frac{\overline{Ac}}{\overline{Bc}}$

A FEW MORE OBSERVATIONS ABOUT THE HUMAN VISUAL SYSTEM:

- THE TRI-STIMULUS APPROACH IS NOT THE ONLY THEORY USED TO EXPLAIN COLOR VISION;

- THE OPPONENT-COLOR THEORY AS WELL AS THE ~~ZONE~~ THEORY ARE ALSO USED;

- THE HUMAN EYE CAN DISTINGUISH ABOUT 350.000 DIFFERENT COLORS;

- EXCEPT AT SPECTRUM EXTREMES, MOST DISTINGUISHABLE COLORS ARE WITHIN 3 mm!

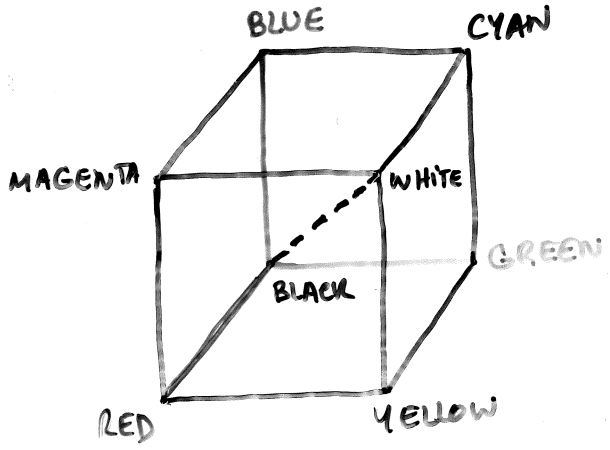
COLOUR MODELS:

- THE PURPOSE OF A COLOR MODEL IS TO ALLOW CONVENIENT SPECIFICATIONS OF COLORS WITHIN SOME COLOR GAMUT.

- THE 3 MOST COMMONLY USED HARDWARE-ORIENTED MODELS ARE:
  - THE RGB USED WITH COLOR TV CAMERAS AND WITH COLOR TV AND COMPUTER MONITORS;
  - THE YIQ, WHICH IS THE BROADCAST TV COLOR SYSTEM;
  - THE CMY (CYAN, MAGENTA, YELLOW) FOR COLOR PRINTING DEVICES;
- THESE COLOR MODELS DO NOT DIRECTLY RELATE TO OUR INTUITIVE COLOR NOTIONS OF HUE, SATURATION AND BRIGHTNESS.
- ANOTHER CLASS OF MODELS: HSV AND HLS.

THE RGB (RED, GREEN, BLUE) COLOR MODEL:

- USES A CARTESIAN COORDINATE SYSTEM;
- THE RGB PRIMARIES ARE ADDITIVE;



- MAIN DIAGONAL OF THE CUBE: GRAY LEVELS;

RED, GREEN, BLUE: ADDITIVE PRIMARIES;

THE CMY (CYAN, MAGENTA, YELLOW) COLOR MODEL

CYAN - COMPLEMENT OF RED
MAGENTA - COMPLEMENT OF GREEN
YELLOW - COMPLEMENT OF BLUE
} SUBTRACTIVE PRIMARIES

→ COLORS ARE SPECIFIED BY WHAT IS REMOVED OR SUBTRACTED FROM WHITE LIGHT RATHER THAN BY WHAT IS ADDED TO BLACKNESS;

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

THE YIQ COLOR MODEL

- THIS IS THE MODEL USED IN COMMERCIAL COLOR TV BROADCASTING;
- THIS IS A RECODING OF RGB FOR:
  - → TRANSMISSION EFFICIENCY;
  - → DOWNWARD COMPATIBILITY WITH B&W TV.

→ Y IS THE COMPONENT USED ON B&W TV.

→ RGB TO YIQ CONVERSION IS PERFORMED BY THE TRANSFORMATION:

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.30 & 0.59 & 0.11 \\ 0.60 & -0.28 & -0.32 \\ 0.21 & -0.52 & 0.31 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

→ THE YIQ MODEL IS ESPECIALLY USEFUL TO AVOID A TV PROBLEM:

→ THIS SYSTEM GUARANTEES THAT TWO COLORS THAT ARE MEANT TO BE DISTINGUISHED HAVE DIFFERENT LUMINANCES (VALUES OF Y), SO THEY ARE DISPLAYED AT DIFFERENT INTENSITIES.

THE HSV COLOR MODEL

H, S, V → HUE, SATURATION, VALUE

→ IF WE REFER TO THE CIE CHROMATICITY DIAGRAM, THE BORDER OF HORSESHOE-SHAPED REGION CORRESPONDS TO DOMINANT WAVELENGTHS. THE CORRESPONDING COLORS ARE MADE UP OF A MONO-WAVELENGTH RADIATION.

→ FOR ANY OTHER COLOR WE CAN DRAW A STRAIGHT LINE DEFINED BY THE CENTER POINT AND THE POINT CORRESPONDING TO THE COLOR.

→ THAT STRAIGHT LINE WILL INTERSECT THE BORDER AT A POINT CORRESPONDING TO THE DOMINANT WAVELENGHT.

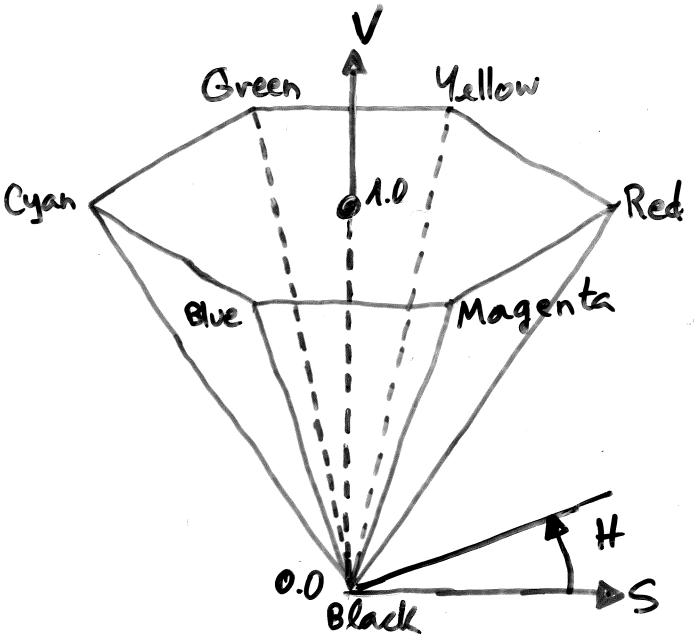
→ POINTS ALONG THE LINE ARE SEEN TO BE DEFINED IN TERMS OF THE PERCENTAGE OF THE TOTAL DISTANCE, THE SO-CALLED "EXCITATION PURITY" RATIO.

→ "HUE" CAN BE VIEWED AS THE PERCEPTUAL CORRELATE OF THE PHYSICAL VARIABLE "DOMINANT WAVELENGTH".

→ "SATURATION" CAN BE VIEWED AS THE PERCEPTUAL CORRELATE OF THE PHYSICAL VARIABLE "EXCITATION PURITY RATIO".

→ WE CAN ALSO SAY THAT SATURATION REFERS TO THE DEGREE OF WHITENESS IN THE COLOR.

→ THE SUBSPACE WITHIN WHICH THE HSV COLOR MODEL IS DEFINED IS A SIX-SIDED CONE, USUALLY DESIGNATED BY HEXCONE.



→ TOP OF THE HEXCONE ⇒ V=1 ⇒ CONTAINS MAXIMUM-VALUE COLORS.

→ COMPLEMENTARY COLORS ARE 180° OPPOSITE ONE ANOTHER.

→ THE VALUE OF S RANGES FROM 0 ON THE CENTER LINE (V-AXIS) TO 1 ON THE TRIANGULAR SIDES OF THE HEXCONE.

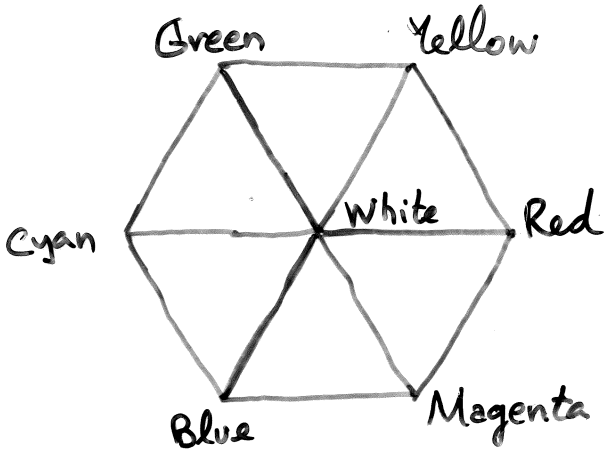
→ S=0 (CENTER-LINE) → GRAYS (H IS UNDEFINED)

HOW TO CONVERT FROM RGB TO HSV?

- GIVEN r, g, b EACH IN [0, 1]

$$\left\{\begin{array}{l} h \text{ IN } [0, 360] \\ s \text{ IN } [0, 1] \\ v \text{ IN } [0, 1] \end{array}\right. \Rightarrow \text{IF } s=0 \text{ THEN } \underline{h = \text{undefined}}$$

```
1) max := MAXIMUM(r, g, b);
   min := MINIMUM(r, g, b);

2) v := max;

3) if max <> 0 then s := (max - min)/max
                  else s := 0

4) if s = 0 then h := undefined
   else
   begin
      rc := (max - r)/(max - min);
                  {rc measures "distance" of
                   color from red}

      gc := (max - g)/(max - min);
      bc := (max - b)/(max - min);
      if r = max then h := bc - gc
      else if g = max then h := 2 + rc - bc
      else if b = max then h := 4 + gc - rc;

      h := h * 60;
      if h < 0 then h := h + 360
   end
```

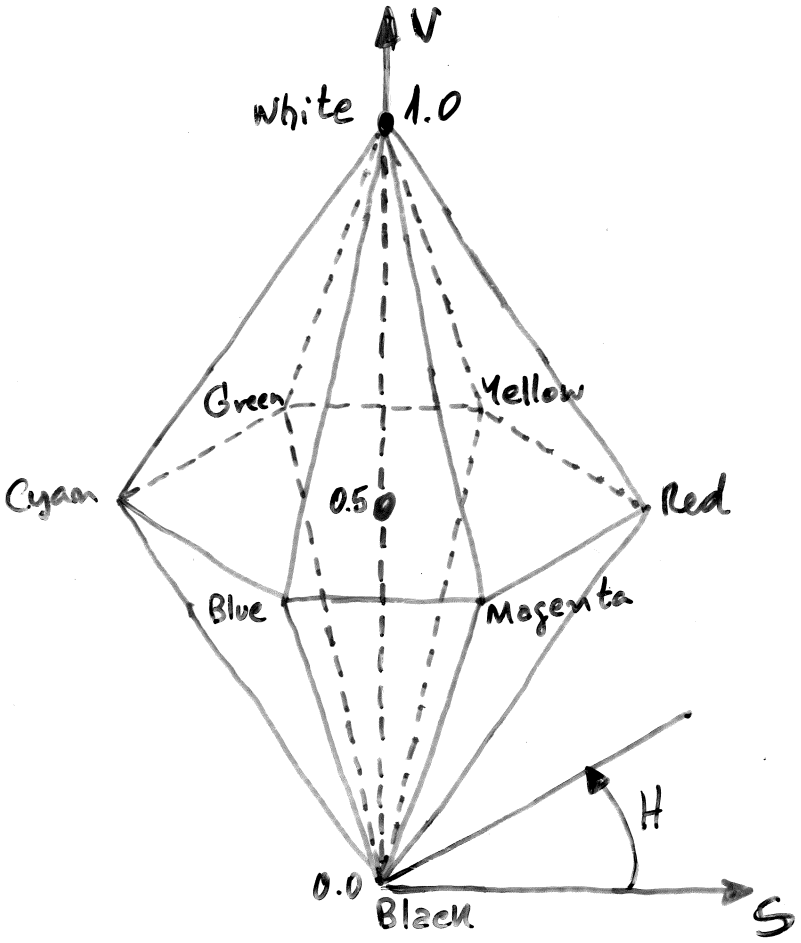


THE HLS COLOR MODEL

H, L, S → HUE, LIGHTNESS, SATURATION

→ THIS COLOR MODEL is USED BY TEKTRONIX

→ THE SUBSPACE WITHIN WHICH THE HLS COLOR MODEL IS DEFINED IS A DOUBLE HEXCONE.



- ONE CAN THINK OF HLS AS A DEFORMATION OF HSV, IN WHICH WHITE IS "PULLED" UPWARDS TO FORM THE UPPER HEXCONE FROM THE V=1 PLANE.

→ GRAYS ⇒ S=0

→ MAXIMALLY SATURATED HUES ⇒ (S=1, L=0.5);

→ NEITHER V IN HSV NOR L IN HLS CORRESPONDS TO LUMINANCE IN THE YIQ MODEL)

DIGITAL IMAGES

→ LET US USE $f(x,y)$ TO DENOTE THE TWO-DIMENSIONAL IMAGE OUT OF A TV CAMERA OR OTHER IMAGING DEVICE;

- x, y DENOTE SPATIAL COORDINATES (IN THE IMAGE PLANE);
- THE VALUE OF f AT ANY POINT (x,y) IS PROPORTIONAL TO THE BRIGHTNESS (INTENSITY) OF THE IMAGE AT THAT POINT;