Physics 1230: Light and Color

Exam extra credit assignment due at 5PM

Proto-letters: Look on CULearn

Lecture 15: Colors, additive and subtractive color mixing, color vision.

Reading: Summer reading!
Ch. 9 - Color

- Spectral and non-spectral colors
- Intensity distribution curve
- Intensity, hue, saturation
- Additive primaries: R, G, B.
- Subtractive primaries: C, M, Y
- Hair, skin, and eye color
- CIE diagram
- Lighting, painting and printing
Spectral colors: The Rainbow (again)
Spectral colors

Colors by special wavelength
- red 650 nm  Additive primary color
- orange
- yellow
- green 530 nm  Additive primary color
- blue 460 nm  Additive primary color
- (indigo)
- violet 400 nm

Mnemonic: Roy G. Biv
Additive primaries (more later)

- Red
- Green
- Blue

Red + Blue + Green = White
Most colors can be made by projecting these on a screen so that the light is added.
Colored light may originate several ways:

• A red light **emits** only red light.
• A red paint **reflects** only red light. Other wavelengths are absorbed.
• A red filter **transmits** only red light. Other wavelengths are absorbed.
Spectral curve shows the relative amount of each wavelength emitted
Transmission curve shows the relative amount of each wavelength transmitted

Transmission of a red filter

![Transmission of a red filter graph](image)
OK, so the colors of the spectrum… so is that all we perceive?

A) YES  B) NO

No, for TWO reasons:

We can see colors that are NOT in the rainbow (non-spectral colors)

We perceive some mixtures as spectral when they are NOT (metamers).
First: Non-spectral colors (mixtures)

- Brown = red + green
- Turquoise = blue + green
- Silver (shiny gray)
- Pink = blue + red + white
- Gold
- Plum
- Tan
- White (red + blue + green)

**NOTICE:** Not ‘redish green’, but BROWN, etc.
Spectral curves for nonspectral colors

Curves for cyan and magenta include multiple colors.
Cyan and magenta are most important nonspectral colors

Cyan = blue + green

Magenta = red + blue
Spectral curves for nonspectral colors

Curves for cyan and magenta include multiple colors.

How do we describe this type of spectrum?
How would you “text” someone a color, accurately

Tell them: **Intensity, hue, saturation**

**Intensity**
- lightness (a source) or brightness (a surface)

**Hue**: dominant wavelength
- red, or 650 nm

**Saturation**
- purity, is the spectral color narrow (pure color) or broad so that neighboring colors are included
Saturation

- A **saturated** red is a **narrow** band of wavelengths
- An **unsaturated** red is a **broad** band of wavelengths
Second issue: Metamers

Look the same but have different possible spectral curves.

Example: Yellow

Two ways to see yellow:
Metamers

Both of these, pure yellow OR a mix of red and green, appear YELLOW to us.

Newton discovered this effect. He felt that it implied an ‘imperfection’ in human vision and a way to probe it.

Two ways to see yellow.
Mixing light: The Eye does one of two things

1) The eye averages nearby colors to a central value of wavelength that appears to be a spectral color.
   Yellow + red = orange
   Or, it could be a nonspectral color:
   Blue + green = cyan, turquoise, teal

2) The eye averages “distant” colors to something nonspectral.
   Red + blue = magenta
   Red + green = brown
Artists’ primaries

Artists’ primaries are blue, yellow, and red. This is a different nomenclature from what is used in this course.
What color does this spectral curve look like?

Answer: Yellow, although there is no yellow light.
What color does this spectral curve look like?

Answer: White
What color does this spectral curve look like?

Answer: Gray
What color does this spectral curve look like?

gray + red = pink
**Definition**: Complementary colors

The complement is the color you would add to get white.

If $R + G + B = \text{White}$, then

Complement of Red $= G + B = \text{cyan}$

Complement of Green $= \ ?$

- A) MAGENTA
- B) RED
- C) BLUE
Complementary colors

Complement of Blue = R + G = Yellow

Yellow + Blue = White

The eye does this, but WHY??
More in a few minutes.
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Subtractive primaries are the complements of the additive primaries

All colors can be projected using 3 lights of additive primary color, OR 3 subtractive primary inks.

<table>
<thead>
<tr>
<th>Additive primary</th>
<th>Subtractive primary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>Cyan</td>
</tr>
<tr>
<td>Green</td>
<td>Magenta</td>
</tr>
<tr>
<td>Blue</td>
<td>Yellow</td>
</tr>
</tbody>
</table>
What are the colors shown on this package?
Ink transmission curves

Magenta = white – green
Ink transmission curves

Cyan = white – red
Ink transmission curves

Yellow ink (unsaturated) = white – blue
(contains green, yellow, orange and red)
How inks make all colors

No ink = paper = white = R + G + B

• Cyan ink + Magenta ink = ?
  (blocks red) + (blocks green) → blue

• Cyan ink + Yellow ink = ?
  (blocks red) + (blocks blue) → green

• Magenta ink + Yellow ink = ?
  (blocks green) + (blocks blue) → red
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Additive and subtractive color mixing

Why does one figure have a black background and the other is white?
Concept Question:

White is an equal mixture of red, green and blue. What is another metamer for white light?

A. Red and cyan;
B. Cyan, magenta and yellow;
C. Blue and yellow;
D. A, B, and C
Methods of adding colors

1. *Addition of illumination*:
   stage lighting and 3-color TV projector. Projected colors *overlap*.

2. *Partitive mixing*:
   closely spaced dots of colors. TV screens, laptop screens, pointillist paintings,
tight textile weaves, some printing

3. *Time mixing*:
   a rotating color wheel. It’s hard to find examples.

4. *Binocular mixing*:
   different color to each eye. The colors "blend" in the brain.
Partitive mixing is placing colors next to one another so that they are merged in the eye.

Examples:
Pointillist painting
LCD screens
Old TV screens (CRT)
Plasma TVs

Detail from *Circus Sideshow (or Parade de Cirque)* (1889) showing pointillism
*Georges Seurat*
Halftone printing

Halftones (black and white):
The printing plate is covered with dots of different size with the bigger dots putting more ink than the smaller dots.

Halftones (color)
There is a different halftone printing plate for each of the subtractive primaries.
High quality color printing (National Geographic, art books) use more than four inks.
Print resolution is measured in dots per inch. More dots/inch = more detail.
Typical inkjet: 600 dots per inch but 1200 to 4800 dots per inch (dpi) is possible
Halftone printing – black and white

Size of dots determines amount of black ink.

Newspapers have 85 lines of dots per inch.
Halftone printing - color

Where would I see this?
Sunday comics.
Halftone printing - color

Cyan = -red
Magenta = -green
Yellow = -blue

This is the final printed product of adding the 4 above images.
Ponder:

Are these colors the same?
Chapter 10: Color perception

- Trichromacy
- Metamers
- Psychological primaries
- Channels
- Color deficiency
- Animal vision
- Temporal processing
Trichromacy

- You have 3 kinds of color receptors (cones)
- Wavelengths: Short, Intermediate, Long

We know this because we can find the wavelengths absorbed by the cones.

Fig. 10.3 in textbook.
Metamers (again)

- Yellow (600) looks like red (650) + green (550)

- NOTE: No mixture will look like blue or red!!

Equal amounts of red and green do too.

Yellow stimulates the I and L receptors equally.
Why blue+yellow looks white

S+I+L stimulated the same amount as from white light!
How colors are perceived

- Blue excites S receptors
- Cyan excites S + I
- Green excites I mostly
- Yellow excites I + L
- Orange excites I + L
- Red excites L
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“Psychological primaries”

What is the minimum number of colors you need to describe any color verbally?

**Answer:**

Blue  Green  Yellow  Red

Yellow *cannot be described* as reddish green.
Psychological opponents

They are:

red – green
yellow – blue

We cannot imagine these being added.
There is no bluish yellow or reddish green.
Channels

Receptors are wired into three channels.

1. Yellow minus blue (y-b)
2. Red minus green (r-g)
3. White minus black (w-bk)
Channel wiring details

Example: red and green both turn up the yellow – blue channel
Channels (again)

Here is a review of the way the red minus green channel works.
High center signal = red. Low center signal = green. (No negative signals.)
Green surround turns up red at the center.

- Strongest signal (interpreted as red)
- Weakest signal (interpreted as green)
- No change in signal (color not noticed)
- No change in signal (color not noticed)

Note, you would still "see" red if the center were gray!
Note, you would still "see" green if the center were gray!
Channels (again)

Here is a review of the way the yellow minus blue channel works:
High center signal = yellow. Low center signal = blue. (No negative signals.)
Blue surround turns up yellow at the center.

Strongest signal (interpreted as yellow)

Note, you would still "see" yellow if the center were grey!

Weakest signal (interpreted as blue)

Note, you would still "see" blue if the center were grey!

No change in signal (color not noticed)

No change in signal (color not noticed)
Color constancy

Your visual perception system corrects for changes in lighting (red sunset, for example) so that colors remain relatively constant.

If the light is red, the visual system adds green.
If the light is yellow, it adds blue.
Are these colors the same?

Lateral inhibition works for color channels.
Simultaneous color contrast

Lateral inhibition applied to r-g or y-b channels.

Example:
Simultaneous color contrast (again)
Lateral inhibition (again)

What color is the wide line?
Lateral inhibition (again)
Chapter 10: Color perception

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Color deficiency  
(not color blindness)

Several kinds of color vision problems:
• Wavelength of one kind of cone is shifted
• One type of cone missing (S, I or L)
• Channel wiring is incorrect (r-g, y-b)

Some texts say S,M,L not S,I,L.
Color vision anomalies

A. Protanopes

B. Deuteranopes

C. Protanomalous

D. Deuteranomalous

Names for color deficiencies

- **Trichromats** ("three colors"): persons with one of the color channels shifted slightly from the usual band of wavelengths.
- **Dichromats** ("two colors"): persons missing one type of cone or one of the two color channels (r-g or y-b).
- **Deuteranomalous**: A kind of trichromat. About 5% of males. I channel is incorrect in wavelength nearer to red.

Missing cone types:
- **Protanope**: a person lacking an "L" (red) type cone. About 1% of males.
- **Deuteranope**: a person lacking an "I" (green) type cone. About 1% of males.
- **Tritanope**: a person lacking “S” (blue) cones
Why are males more likely to be color deficient?

- 8% of males and 0.5% of females have deficiency.
- Women have two x chromosomes, men one.
- In women, vision is ok if either one is good.
- In men, if the x is bad, that’s bad.
Chapter 10: Color perception

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Animal vision

Determined by survival needs

predator/prey relation,
predators: eyes in front (hawks, lions)
prey: eyes on the side (cows, frogs)

mate finding
finding food
Animal vision examples

Bees: 3 color receptors,
    shifted toward blue (matches flowers)
Squirrels: 2 colors
    blue (sky) and green (foliage)
Birds: good color vision
    color vision helps find mates: cardinals, robins
Fish: good color vision
    bright coloring helps blend with corals
    color vision helps find mates
Cats and owls:
    poor color vision, see movement well
    (mice are not brightly colored)
Animal night vision

Owls: larger eyes and pupils
  Fewer or no cones, mostly rods

Cats: Tapetum lucidum (“bright carpet”)
  Reflects light backward through retina

Extra sensitivity is a disadvantage in daytime:
  Hence slit-like pupils to reduce bright daylight
Animal underwater vision

- 510-540 nm (blue-green) goes furthest in water.
- Bulging eyes help correct for less refraction because cornea and water have similar indices of refraction.
Butterfly vision

Butterflies have color constancy. They go to yellow even if the illumination changes color. Butterflies may have 5 color channels, including UV.
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Temporal processing

Negative afterimage:
Look at a strong color, then white paper.
Fatigue of nerves causes a negative afterimage.
Example: Stare at red, then white,
You will see cyan (white – red)

Positive afterimage:
Strongly stimulated nerves keep firing
Happy 4th of July!
A good place to stop. Great to have you here!

Enjoy the rest of the summer.