

Primary Colors

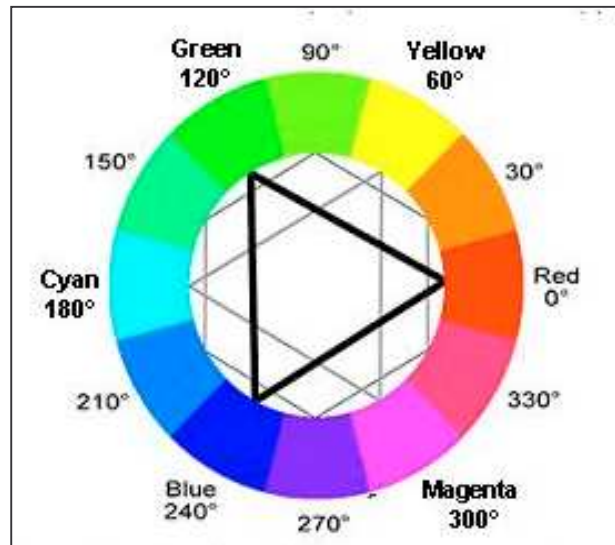
Part 2 of 3

Neal McLain

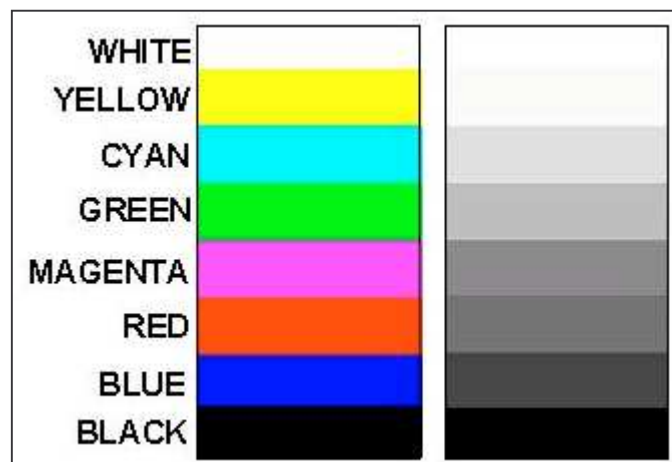
Last month, I noted that the RGB (red-green-blue) color model is an *additive* model: it describes how *light* beams interact. These primaries *add* to produce other colors of light. In this color model:

- The *primary colors* are red, green, and blue.
- Combining two RGB primary colors, *at the intensity ("brightness") levels that match the color sensitivity of the human eye*, produces a *secondary color* (the *complement* of the third primary). Thus, for example, mixing red light and green light produces yellow light. Similarly, red+blue produces magenta and blue+green yields cyan.
- Mixing all three, *again at the intensity levels that match the eye*, produces white light.

We can represent these colors with a traditional "color wheel":



But the color wheel doesn't tell us anything about what those intensity levels are. To illustrate intensity levels, we can represent colors as a series of bars, similar to the "color bar" test pattern used in the television industry, as shown below. Also shown is the underlying grayscale, representing the intensity levels that match the color sensitivity of the eye.



Note that the colors in this series of bars are not arranged in order by wavelength; they are ordered, from bottom to top, in order of *increasing* intensity *as perceived by the human eye*.

Starting at the bottom and working up, we also note:

- **Black** appears to be identical in both sets of bars. This, of course, simply means that black is the absence of any light of any color.
- **Blue** (primary) is the "darkest" of all colors.
- **Red** (primary) is slightly brighter than blue.
- **Magenta** (red + blue secondary) is *brighter than* either red or blue.
- **Green** (primary) is the brightest primary.
- **Cyan** (green + blue secondary) is *brighter than* either green or blue.
- **Yellow** (red + green secondary) is *brighter than* either red or green.
- **White** appears to be identical in both sets of bars. This confirms the fact that white is the additive sum of all three primary colors as perceived by the human eye.

Stated more generally:

■ ■ ■ **THE LAW OF ADDITIVE PRIMARIES** ■ ■ ■
 In the RGB *additive* color model, each RGB secondary is *brighter* than either of its constituent RGB primaries.

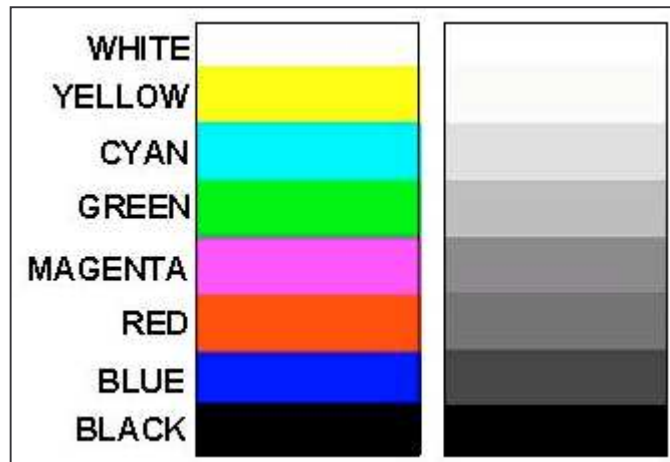
This, of course, makes intuitive sense: if we add any two (or all three) light sources, the result is brighter than either light alone.

The YCM Color Model

The YCM (yellow-cyan-magenta) color model is a *subtractive* model: it describes how *pigments* (paints, dyes, inks) reflect white light. When illuminated by white light, pigments *reflect* some colors and *absorb* others. In this color model:

- The *primary colors* are yellow, cyan, and magenta (YCM). In this article, I refer to them as "YCM primaries" to avoid confusion with red-green-blue primaries of the RGB color model.
- Combining two YCM primaries, *at the intensity ("brightness") levels that match the color sensitivity of the human eye*, produces a *secondary color* (the *complement* of the third YCM primary) — which is, of course, one of the RGB primaries. Thus, for example, mixing yellow pigment with magenta pigment produces red pigment.
- Mixing all three, *again at the intensity levels that match the eye*, produces black pigment.

As before, we can represent colors as a series of bars accompanied by the underlying grayscale.



Again, we note that the colors in this series of bars is not arranged in order by wavelength; they are ordered, from bottom to top, in order of *increasing* intensity as perceived by the human eye.

Starting at the bottom and working up, we also note:

- **Black** appears to be identical in both sets of bars. This, of course, simply means that black pigment absorbs all light, and reflects none.
- **Blue** (cyan + magenta secondary) *reflects less light* than either cyan or magenta.
- **Red** (yellow + magenta secondary) *reflects less light* than either yellow or magenta.
- **Magenta** (primary) is the darkest of the YCM primaries.
- **Green** (cyan + yellow secondary) *reflects less light* than either cyan or yellow.
- **Cyan** (primary) is slightly darker than yellow.
- **Yellow** (primary) the brightest of the YCM primaries.
- **White** appears to be identical in both sets of bars. This simply means that white pigment reflects all colors equally.

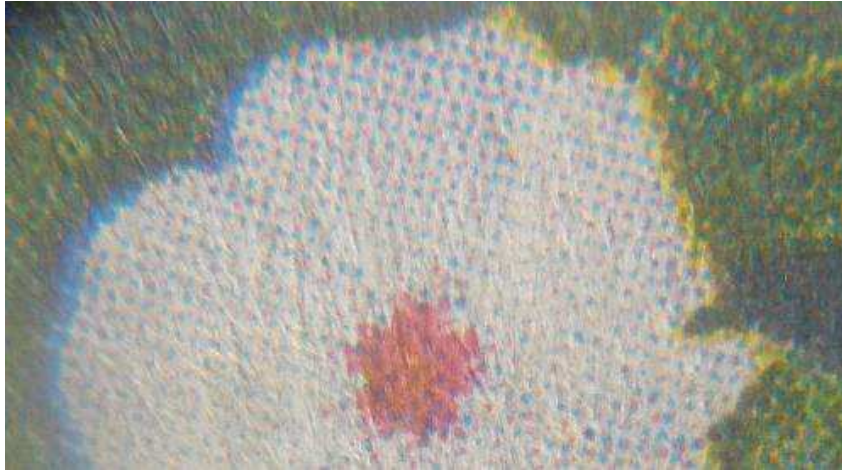
Stated more generally:

■ ■ ■ **THE LAW OF SUBTRACTIVE PRIMARIES** ■ ■ ■
 In the YCM *subtractive* color model, each YCM secondary color is darker (*reflects less light*) than either of its constituent YCM primary colors.

In other words, if we mix two (or all three) primary pigments together, the mixture is darker than either of the original pigments alone.

The YCM color model underlies many printing processes. In these processes, YCM primaries are indeed "mixed" — not by physically mixing the pigments before printing, but by printing "dots" of different YCM primaries in close proximity. Thus, for example, closely-spaced yellow and magenta dots are perceived as red. Different shades of red can be obtained by varying the relative sizes of the dots.

Here is an example, a greatly enlarged image of a photograph taken from a newspaper:



The Four-Color Printing Process

The term "printing" generally applies to a variety of processes for reproducing text and images on paper, although the physical medium may be fabric, plastic, glass, leather, metal, wood, wallpaper, vinyl flooring, circuit boards, or other materials.

Printing processes can be divided into three categories:

- **Monocolor processes:** processes in which the *process itself* determines the color of the copy. This category includes *cyanotypes* (blueprints, brownprints), *diazotypes* (whiteprints, sepias), *hectographs* (purple dye on paper), *mimeographs* (black ink on paper), *photostats* (negative photographic images on paper), *thermal transfer prints* (black text on heat-sensitive paper), and *xerographs* ("Xerox copies").
- **Multicolor processes:** processes in which creators are free to select from among a variety of pigments (paints, inks, or dyes) in just about any desired color, or to mix new pigment colors if desired. This category includes *single-copy hand reproductions* (drawings, paintings, illuminated manuscripts, hand-colored black-and-white photographs) and low-volume limited-edition *printmaking* processes (screenprints, engravings, intaglio prints, etchings, and similar processes).
- **Four-color processes:** processes in which only four colors are used: yellow, cyan, magenta, and black. This category includes *high volume mass-production printing* (offset lithography, rotogravure), and *single-copy digital printing* (color laser prints, color inkjet prints, color xerographs).

For the purpose of this article, I will restrict this discussion to the four-color processes.

The colors of the four-color printing process are the colors of the YCM color model, plus black. But in the commercial printing business, black is called "key," and the color model is called the "CMYK Color Model." So we have to keep in mind that YCM and CMYK are different names for the same three primary colors.

So why add black to the YCM color model?

In theory, mixing yellow, cyan, and magenta in the appropriate ratios will produce black. But there are compelling reasons for adding black as a separate color:

- **Cost:** black ink is cheaper than color inks. This is obvious to anyone who has ever purchased ink cartridges for a home computer; it's equally true for high-volume commercial printing processes.
- **Registration:** When printing two or more colors, the printing equipment must properly align ("register") all colors in precisely the same physical position on the paper. Misregistration can cause some colors to be offset from others (the "comic book" effect). But black is the dominant visual element in most images; as such, it tends to mask misregistration of other colors.
- **Intensity variations:** When printing two or more colors to produce other colors, all printed colors must be printed at precise, predetermined intensity ("brightness") levels. Any variation will be perceived as a slight change in color. In most cases, such variations are not visible to the average reader, but "black" text that isn't black will be obvious.

And why do we use the YCM/CMYK color model for printing, while we use the RGB color model for television and computer screens?

Because:

- **The Law of Additive Primaries** tells us that the RGB primaries — red, green, and blue — are *darker* than the RGB secondaries (or, for that matter, any mixture of the three RGB primaries). In the case of a television or computer screen, we start with a *dark* (ideally black) screen and *add light* to build the image. We start with the *darkest colors* as primaries, and mix them together to produce *brighter* colors.
- **The Law of Subtractive Primaries** tells us that the YCM primaries — yellow, cyan, and magenta — are *brighter* than the YCM secondaries (or, for that matter, any mixture of the three YCM primaries). In the case of a printed image, we start with a *bright* (ideally white) surface (paper, fabric, whatever), and apply pigments to *subtract light* to build the image. We start with the *brightest colors* as primaries, and mix them together (as colored dots on the surface) to produce *darker* colors.

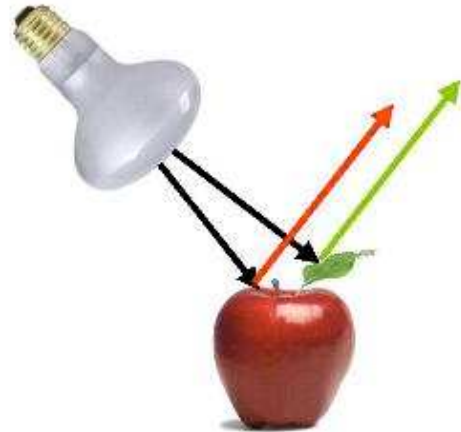
But:

Keep in mind that The Law of Subtractive Primaries is relevant only in the case of printed images produced by the four-color printing process. Creators using multicolor processes can utilize a full range of pigment colors.

To illustrate this point, following are three cases:

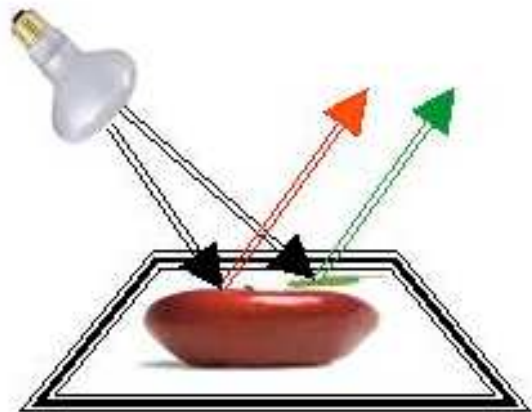
If we illuminate a red apple and a green leaf with white light, a viewer would see:

- *Red* light reflected from the apple.
- *Green* light reflected from the leaf.
- *White* light reflected from the background.



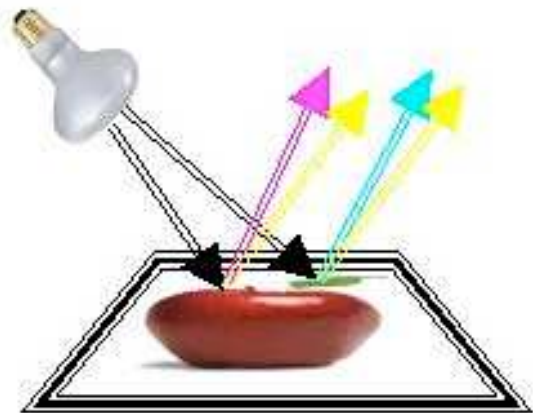
If we illuminate a *painting* of the apple (assuming the painter has painted the colors realistically), a viewer would see:

- *Red* light reflected from *pigment* that represents the apple.
- *Green* light reflected from *pigment* that represents the leaf.
- *White* light reflected from the *pigment* that represents the background.
- No light reflected from the black frame (which the eye would interpret as black).



If we illuminate a *printed image* (say, a photograph in a magazine), a viewer would see:

- *Yellow* and *magenta* light reflected from the *pigments* that represent the apple (which the eye would interpret as red).
- *Yellow* and *cyan* light reflected from the *pigments* that represent the leaf (which the eye would interpret as green).
- *White* light reflected from the *pigments* (or, more precisely, the lack of pigments) that represents the white background.
- No light reflected from the black frame (which the eye would interpret as black).



Next month I will conclude this series of articles with discussion of the YCM color model as it applies to photographic processes.

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