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in this issue:

PBase Member

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Exclusive: The Official Whitehouse photographer

Eric Draper

LEARNING: # Camera less Photography

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Born and raised in New York City, Carol Pfeffer attended Walden, a small independent school on the upper west side of Manhattan. She earned her undergraduate degree in Physics as the only woman to graduate from the physics department of Boston University. Carol went on to law school and the practice of law and later pursued an associated degree in the visual arts.
Carol's love for composition, color and conceptual art led her directly to the darkroom. This is where the artist met the scientist. Her formal background in the science of light, chemicals and geometric optics came to bear on the making of art and brought this artist full circle, combining art and science, to her alternative medium of Camera less Photography

Introduction

I am often asked, "How do you make photographs without a camera?" As Ansel Adams once said, "I don't take a photograph, I make it."

In order to master camera less photography, I had to reach back to the history of photography and even further back to the history of Optics, the physics of light. The nature of how light is transferred to paper by emulsion is at the very heart of the medium of photography. It also is at the heart of the interaction of light with matter. This is still one of the most basics questions at the forefront of theoretical physics today.

Camera less photography is a printing techinique. The color darkroom printing process is chromogenic, producing what is commonly known as a C-Print. What do I mean by "*chromo*genic?" Do you know what "*photo*genic" means? "Photo" comes from the Greek *phos* or *photo* meaning "light." As in "photon" *photo* (light) + *on* (unit) a unit of electromagnetic radiation in the visible range. So, photogenic *photo (light)* + *genic (produced by)* means produced by light. Similarly *chroma*, coined in 1797 by the French chemist Nicolas-Louis Vauquelin when he discovered chromium, comes from the Greek word for color *khroma* or *khromatos.* So chromogenic means to produce color. In 1839, Sir John Herschel coined the term *photography* combining *photo* + *graph,* from the Greek *graphis* "stylus." He defined a photograph as a picture obtained by an instrument for recording light. Incidentally, he also invented fixer.

Today, we interchangably use chromogenic which refers to a process and C-print to describe the photographic print. The system for processing C-prints is called C-41. Do not mess around with C-41 chemistry! It is so much more toxic than any black and white chemicals you may have worked with.

Chemistry of the Chromogenic Process

A Chromogenic Print refers to the process of chromogenic developing. Between 1911 and 1914 Rudolph Fisher of Germany and Karl Schinzel of Austria invented a color film that had in it the color-forming ingredients known as color couplers. This was an advance over the dye inhibition processes that had currently been popular, whereby a dye image is transferrd from a gelatin relief image to the paper or film. This discovery, that color couplers could produce images by chromogenic development, basically laid the foundation for most color processors used today.

In this type of process, three layers of emulsion are stacked one on top of each other. Emulsion, the light (photo) sensitive coating, typically made of silver halide grains, is spread in a thin gelatin layer onto the paper or film. Actually, you can lay emulsion onto almost anything. Ever hear of Liquid Light? It is proprietary. It is emulsion that you can apply to almost any surface. Shop at B&H on 34th Street or here. During the chromogenic process the dye image is made at the same time that the silver halide image is developed in the emulsion. The silver is eventually bleached away, leaving only the dye which forms the final image. A dye is a colorant that is not water soluble.
In chromogenic paper or film there are three layers of emulsion. Each layer is sensitive to a different color, or wavelength, of light. Each layer of the emulsion is sensitive to either blue, green or red. The color couplers in each layer of the emulsion form a dye image in the complementary hue, the opposite of the color of the emulsion layer. I am getting to that.

Basically, here is how the film produces color: during the processing, each layer makes a different black and white image that corresponds to the amount of colored light that was recorded in each individual layer from your exposure. Think of this as adding the density. The developer oxidizes and combines with the color chemical couplers in the emulsion to create these dyes:
the Green-sensitive layer forms a Magenta dye;
the Blue-sensitive layer forms a Yellow dye; and
the Red-sensitive layer forms a Cyan dye.

During the remaining stages of processing, the silver is removed from each of the three layers. This leaves an image created solely from the dyes in each of the three layers. A mixture of these dyes will render the local color of your image. (By "local color" I mean the representational color of the object photographed.) Then basically it is fixed, washed and dried. This is referred to as Color Reversal Paper or Color Reversal Film because the dyes reverse in hue from the emulsion sensitive layers.

Why are the layers of emulsion specifically blue green and red? And why do blue green and red reverse to yellow, magenta and cyan? This is where color theory comes in.

NUGGETS:

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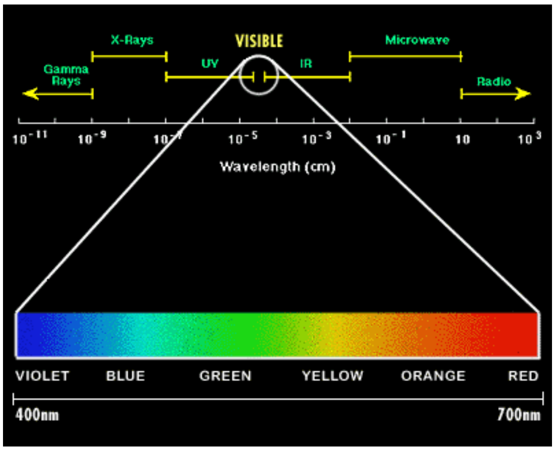
The Physics of Color

What does Color have to do with physics? Color begins with light. Light is energy. And physics is the study of energy and its interaction with matter.

To understand the nature of light and how we get color from light, requires a bit of physics history. No, don't worry! We are not going to go through the entire history of physics. We are going to start at the end, well almost the end. Because at the end, is where we find the basic principles of optics that are applied to chromogenic printing.

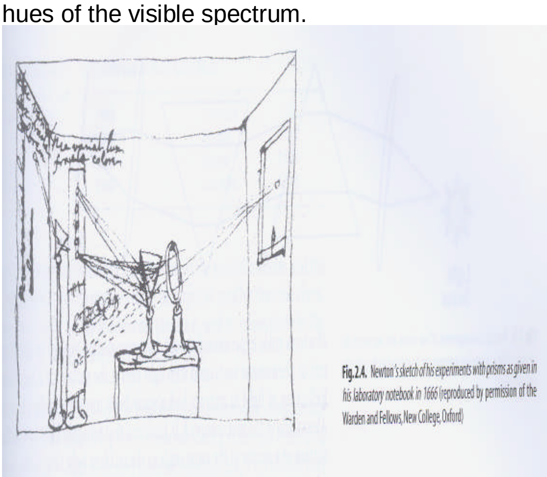
Light waves consist of electric/magnetic fields that interact with the charged particles of matter, especially the electrons. The energy that is transported in the form of light is contained in small, for lack of a better word, packets we call photons. These packets can exhibit both particle-like, as well as wave or string-like behavior. Most color that we see is the result of photons being emitted or absorbed by matter. Some wavelengths are absorbed and some are reflected. If all are absorbed and none are reflected the surface looks black. If all are reflected and none absorbed the surface will look white. We rely on the wave- like behavior of light to explain Color.



On an atomic level, the explanation for why a given surface absorbs only certain wavelengths is that the electrons are limited to particular energy levels. If a photon had just the right energy needed to raise an electron from its normal energy state to a higher one, then the photon could be absorbed. The sensation of color is perceived by the way our brain interprets different wavelengths. Color perception is a neurological function and is part of our object recognition system. Visual cues from the retina travel through the optic nerve for information processing, which takes place primarily in the occipital lobe.

Color is explained by a variety of principles of optics, the most common being Reflection. When we see a red barn, we perceive it as red because the pigment in the painted surface of the barn absorbs all of the incoming wavelengths of white light except red wavelengths. How do we know the incoming wavelengths of white light have all the other colors? That answer, proved by Isaac Newton, is based on the optical principle of Refraction.

Refraction means "to bend." It comes from the Latin *frangere,* meaning to break or to bend, like something that is fragile. When white light is refracted by a prism, it is deconstructed into the hues of the visible spectrum.



Now that we understand a bit about the physical nature of color we can make sense of the how chromatic relationships are at work in the chromogenic printing process.

Color Theory and Reversal Processes

When white light is refracted by a prism it spreads out in its spectral hues, vernacularly known as 'the colors of the rainbow.' The spectral hues are red, orange, yellow, green, blue and violet. "Hue" means the name of a color. The spectral hues are found in nature in a linear progression as in a rainbow. A color wheel is a color theory model that you get when you take the linear sequence of spectral hues and bend them around to form a circle.

The color wheel shows, among other things, the chromatic relationships. Complementary hues are colors that are directly opposite each other on the color wheel, for example red and green are complements. Complements, not Compliments.

The color wheel also tells us how to mix colors. The wheel shows us that the secondary hues (orange, green & violet) sit between the primaries (red, blue & yellow) and that they can be made by mixing two primaries, e.g. red + yellow = orange. This is called subtractive color mixing. Visit the Color Playground for color theory fun.

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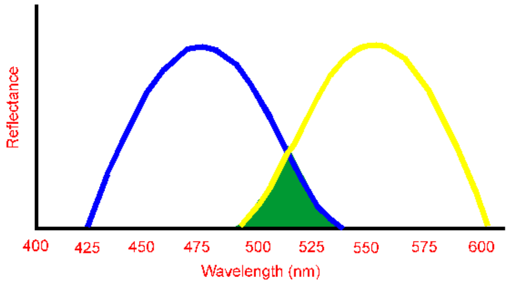
Blue paint reflects most light at the short wavelengths and absorbs light of long wavelengths. Yellow paint reflects most light at long wavelengths and absorbs light at short wavelengths. Because blue paint and yellow paint both reflect middle wavelengths, when blue and yellow paint are mixed together, the mixture appears green.



But, and this is a big but, this is not the color wheel we use for Chromogenic Printing.

What? There is another color wheel?

Yes. There is another color wheel: the color wheel for light. And with it comes its own set of chromatic relationships and color mixing system.

Color Arithmetic: Additive and Subtractive Color Mixing

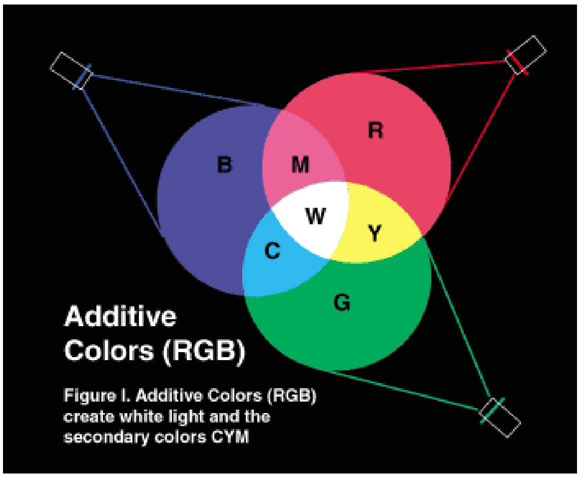
You can think of the color wheel we already discussed as the color wheel for paint. The primary hues were red, blue & yellow. It is subtractive because of the way color is produced. The color red is produced by the pigment in the paint absorbing all of the wavelengths of light except red. The physical explanation for the way it subtracts wavelengths is based on principles of destructive wave Interference (see here)

You may be wondering why it is called *subtractive* color mixing when it involves *adding* colors together? Any wavelengths of light that are not absorbed, are reflected. It is the addition of those wavelengths that perceive as the color. Goethe may have said this more poetically, " Thus if two opposite phenomena springing from the same source do not destroy each other when combined, but in their union present a third and pleasing appearance, this result at once indicates their harmonious relation." Johann Wolfgang von Goethe, *Theory of Colors*, 1840.

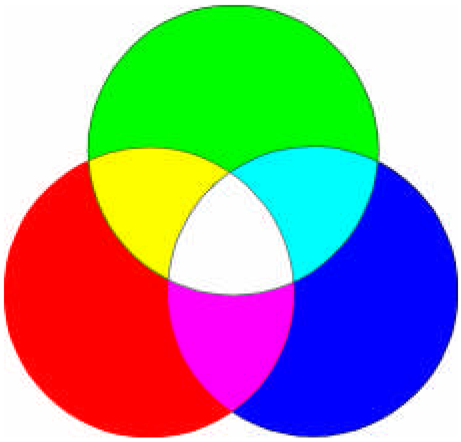
The language and vocabulary of color mixing is a minefield of linguistic problems much like the language of color theory itself. But this is a linguistics problem-not a color theory problem.

One set of descriptions is appropriate to describe light, or the results we get from additive color mixing. The other is appropriate to describe the perceived color of an object, the result of a surface subtracting light.

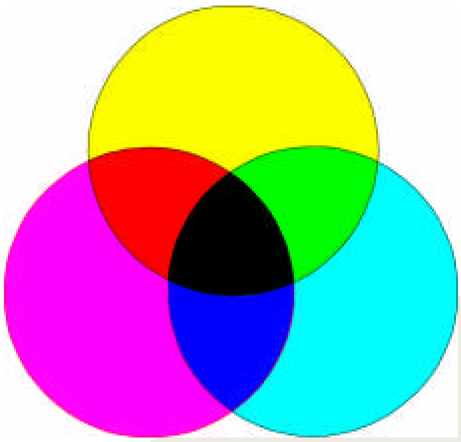
Color mixing with light is called additive color mixing. This three color mixing theory of color vision proposed in the 1800s by Thomas Young is the basis for all film, video and computer color systems today. Young propose that adding red, green and blue light together would make most of the colors of the spectrum. These he determined were the primary colors of light because they create a reasonable white. You can think of it as the opposite of Newton's famous prism experiment. Instead of decomposing white light with the prism, he added the spectral hues together to form white light (Newton had also proved this with a second prism.)



The primary colors of light are red, blue & green. The primary colors of paint are red, blue & yellow. Spend a few moments comparing these color wheels.



Additive Color Model



Subtractive Color Model

Can you see how they are related? Look at red, blue and green? Red, blue and green are the colors of the three layers of emulsion used to make C-Prints.
Just as with the color wheel for paint, adding any two primary colors of light creates secondary colors of light. But the hues are very different. Mixing red paint + green paint = muddy paint. Mixing red light + green light = yellow light; Green light + blue light = cyan light; and red right + blue light = magenta light.
Cyan, magenta & yellow (CMY, hereinafter) are the secondary additives or the primary subtractives. This is called an additive color mixing system because the process is additive in nature. Adding red light, blue light and green light (RBG, hereinafter) together make white light.
Try it here.

The primary colors of the *subtractive* system are RBY (the primary colors of the color wheel for paint.) But the printing industry calls CMY the subtractive primaries. Using the same language to describe primary colors in both the additive and subtractive mixing system causes a tremendous amount of confusion.

In order to see an object, it has to either emit light or reflect it. Objects that do not produce light are given their color by the subtractive process. The pigment in paint produces color this way. The confusion is caused by the fact that RBG are referred to as the primary colors in a subtractive mixing system. When you add RGB, the primary subtractives, you get CMY, or secondary colors of the additive system. So RGB are the primary additives in the subtractive system. They add together to make the light primaries, CMY (the secondary additives / primary subtractives) producing complements.

Cyan, magenta & yellow are the reversal colors of chromogenic printing. This explains why color film will show the complementary hues. A red barn will be green on the film. But when you print, the hues reverse again. The chromogenic printing process reverses the green barn on the film back to red.

Your enlarger head uses subtractive mixing as well. The dichromatic filters in the enlarger subtract their secondary additive complement. Remember we said that white light is made up of the three primary colors of light RBG. The three colors that result from mixing additive primaries are CMY, secondary additives/ primary subtractives. The subtractive primaries are the complements of the additive primaries. Cyan is the complement of red, magenta is the complement of green, and yellow is the complement of blue. To determine your 'filter pack' for printing think subtractive!

Blue=Magenta + Cyan; Green=Yellow+ Cyan; and Red= Yellow + Magenta. This is how you convert additive colors to their subtractive equivalents. The filter subtracts its complement. Here is how the magenta filter works: white light (RGB) passing through a magenta filter, subtracts its complement green, transmitting R+B. Red light + blue light = magenta.

Conclusion

Understanding the printing process, how color and light is transferred to paper, is fundamental to photography. In fact, it is photography. With an understanding of the color reversal process, I know that the hue of the object placed or projected onto photogenic paper will reverse to its complement. A color photogram of a kiwi will be magenta.

Knowing this, I work accordingly when I am going to transfer a painting in the darkroom. I have to paint in the subtractive. I know that my composition in green and cyan will print as magenta and red.

Informed use of color theory and printing materials helps you make intelligent choices in the darkroom. Enjoy!

Further Learning

- *Conceptual Physics*, Paul G. Hewitt
- *Exploring Color Photography* by Robert Hirsch
- *Color Photography*, by Henry Horenstein
- *Watercolor Mixing: The 12 Hue Method,* by Christopher Willard
- *Art Fundamentals Theory and Practice,* by Ocvirk, Stinson, Wigg, Bone & Cayton *Opticks*, Sir Isaac Newton
- *Interaction of Color*, Joseph Albers
- Vision and Art: The Biology of Seeing, by Margaret Livingstone
- *The Color Compendium,* by Hope and Walch
- The Essential Tension, by Thomas S. Kuhn

Photo credits

- Press portrait , © Andrew Epstein 2007
- "Magenta Kiwi" © Carol Pfeffer 2007 unique chromogenic projection print

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