Color.

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"COLOR"

A Dissertation
Submitted to the Faculty
Of the Graduate School of the College of Liberal Arts
In Partial Fulfillment of the
Requirements for the Degree
Of Master of Science

Department of Physics

By

BRUCE B. VANCE

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FOREWORD:

Leonardo in his treatise on painting says: "Those who become enamored of the practice of the arts without having previously applied themselves to the diligent study of the scientific part of it, may be compared to the mariner who put to sea in a ship without rudder or compass, and therefore, can not be certain of arriving at the wished for port. Practice must always be founded on good theory."

Page one.
INTRODUCTION:

Color, any attempt to apply the scientific principles of color vision in the making of a picture must surely fail if it be not granted at the outset that it is only to a limited degree that those principles can apply. Color appreciation is as much a psychical as a physiological, and indeed, it is psychical not only with regard to the objective impression itself, but also with regard to the subjective, the associational mental process. Previous knowledge and training, experience traditions, the association of color impressions with impressions previously received through other senses and stored away as memories, all play a part in
determining the effect which a color or a pattern of opposed colors has upon us. But even granting all this, there are many of the physical and physiological laws of color vision which must be adhered to before we can expect to produce these effects.

The first of these is a physical one:—It is the dissociation of white light into the spectral colors by means of diffraction. When we look at such a spectrum we are at once struck with the fact that the colors differ from one another not only in their hue, but in their brightness or lumniosity, the yellow and the immediately adjacent portions being much brighter than the others. At once, then, we recognize two physiological properties for each
spectral color, hue and brightness. There is, however, another property of color as seen in nature which is absent in the spectrum, namely, saturation. This refers to the degree of white light with which the color is mixed. It is more or less related to the artist's term "value" which expresses the transition of the color into gray; this may also mean the combination of two or more colors and their relation to each other.

Before we go into this latter phase it may be well to state some of the fundamental psychical, physiological and physical theories on color vision and color mixing. The Young-Helmholtz theory of the three color sensations, one of the most important, depends upon the
action of three independent physiological processes involving three substances or sets of nerves. This theory approaches the matter chiefly from the side of physics; that, the facts of color mixture are used in building up the theory. One of these principles of color mixture is called the subtractive method and the other the additive method.

The Subtractive Method: In a sense color, as we ordinarily encounter it, is produced primarily by subtraction. That is, a fabric appears colored as a rule because the chemicals used in staining it have the property of absorbing certain visible rays and of reflecting or transmitting the remaining rays. This subtraction of colored rays from white light results in the residual colored light.

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The integral of the light absorbed is said to be the complementary to the color of the light remaining if the total light in the beginning were white light.

The Additive Method: In the subtractive method of mixing color it is easily seen that if we pass white light through a filter which permitted only certain colors to pass then if the light was then passed through another filter and so on; in the end the result would be no light or black. With the additive method the arrangement is different and always tends toward the production of white light, or we may say that it is the reverse of the subtractive method of mixing color.

Ladd-Franklin: The theory that goes by this name is one that explains the
physiological operations by introducing two substances called rods and cones.

The Hering Theory: The principle foundation of this theory consists of facts such as those of contrast, and the apparent simplicity of black, white and yellow as well as red, green and blue. Hering assumed there were six fundamental sensations coupled in pairs, namely, white and black, red and green, yellow and blue. In order to account for these six fundamental sensations he assumed the presence somewhere in the retinocerebral apparatus of three distinct substances. Each substance is capable of building up (anabolism) or of breaking down (katabolism) under the influence of radiant energy or its effects.

Page seven.
Most of these theories give some general combinations of colors into complimentary pairs. They are general; so I have chosen as a problem the grouping into pairs narrow bands of the spectrum which when combined by the additive method of mixing color would give white or as near white light as possible.
APPARATUS:

The apparatus as finally used is shown in figure one.

$S_a$ and $S_b$ are two spectrometers. $S_a$ being adjustable by the observer at $T$. $C_1$ and $C_2$ are slits, $A_1$ and $A_2$ lenses. $L_1$ and $L_2$ are 150 watt Mazda lamps. $T$ is an observer telescope. $B$ is a plane surface piece of glass.

The light from $L_1$ and $L_2$ passing through the spectrometer $S_a$ and $S_b$ as refracted into band spectrum on the backs of the slits. $C_1$ and $C_2$ are so adjusted that the narrow band of light that passes through is as near monochromatic as possible. The lenses $A_1$ and $A_2$ are used to eliminate the defraction effect that is caused by the narrow slits. The band from
C passes through B and is observed at T, the band from C is reflected from B and the system of S is so adjusted that the two bands will coincide in the telescope T. In this manner the two bands of color are mixed.

After this calibration, which was made at the beginning and the end of each set of readings, 1 and set at a particular color, then B was adjusted so the band that appeared in the telescope was as near white as possible. This adjustment was arrived at by approaching the limit from both sides and then taking the average of a large number of readings. For example, suppose B is set so we have a blue band of color, then suppose with B we approach a mixture from the red and determine a white, then we pass through and approach the
PROCEDURE:

First both spectrometers were calibrated with a Cooper Hewitt Lab-Arc, (the calibration curves are shown in figures two and three).

After this calibration, which was made at the beginning and the end of each set of readings, $S_b$ was set at a particular color. Then $S$ was adjusted so the band that appeared in the telescope was as near white as possible. This adjustment was arrived at by approaching the limit from both sides and then taking the average of a large number of readings. For example; suppose $S_b$ is set so we have a blue band of color, then suppose with $S_a$ we approach a mixture from the red and determine a white, then we pass through and approach the
Dispersion Curve of $S_a$

Figure two
Dispersion Curve of $S_2$

Figure three
mixture from the blue side and obtain a white. By repeating this operation and taking the average we are able to obtain to a fair degree the mixture of two bands of color that would produce white light.

$S_b$ was set first at random starting on the red side of the spectrum and going to the blue. Later I started with a band of red as near that end of the visible spectrum as possible, then bands at intervals of 0.05 were observed. The results are tabulated in the tables.
\[ \begin{array}{cccc}
S_a & S_b & S_a & S_b \\
0.584\alpha & 0.415\alpha & 0.640\alpha & 0.556\alpha \\
0.563\alpha & 0.416\alpha & 0.655\alpha & 0.550\alpha \\
0.568\alpha & 0.416\alpha & 0.442\alpha & 0.550\alpha \\
0.576\alpha & 0.433\alpha & 0.583\alpha & 0.560\alpha \\
0.572\alpha & 0.436\alpha & 0.487\alpha & 0.581\alpha \\
0.577\alpha & 0.443\alpha & 0.582\alpha & 0.585\alpha \\
0.574\alpha & 0.450\alpha & 0.530\alpha & 0.600\alpha \\
0.572\alpha & 0.450\alpha & 0.502\alpha & 0.600\alpha \\
0.579\alpha & 0.459\alpha & 0.576\alpha & 0.607\alpha \\
0.656\alpha & 0.482\alpha & 0.534\alpha & 0.622\alpha \\
0.578\alpha & 0.485\alpha & 0.541\alpha & 0.650\alpha \\
0.571\alpha & 0.489\alpha & 0.515\alpha & 0.650\alpha \\
0.630\alpha & 0.500\alpha & 0.549\alpha & 0.656\alpha \\
0.657\alpha & 0.500\alpha \\
\end{array} \]

\( \alpha \) stands for \( \mu \)

Page sixteen.
CONCLUSION:

On the preceding page I have given a list of figures; the interpretation of these figures is another question.

In the Introduction I mentioned several theories on color vision and color mixture. The apparatus, that I have used, has mixed two bands of as near monochromatic light as could be obtained by the additive method of mixing color. By this I mean that the effect upon the retinocerebral apparatus is that of adding colors together. If a pair of colors are added and the result is white or near white then they are said to be complementary colors.

Then the several pairs that I have listed can be said to be complementary one to another.

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It has been a long disputed question between scientist and painter, whether blue and yellow were complementary colors.

If we take the region between 0.433\(\mu\) and 0.450\(\mu\) as blue, the table of results shows us that its complement will lie between 0.572\(\mu\) and 0.577\(\mu\) which happens to be about in the center of the yellow portion of the spectrum.

Now if we take the region between 0.482\(\mu\) and 0.500\(\mu\) which could be called greenish-blue, more blue than green, and its complement lies between 0.578\(\mu\) and 0.657\(\mu\), (with the exception of 0.571\(\mu\) which in all probability was an error), this region is yellow-orange.

The red-green combination worked out as usual, but not as well as it does with Page eighteen.
by the flicker method of mixing color. If we call the region from $0.600\lambda$ up, red, we find that its complement lies between $0.502\lambda$ and $0.549\lambda$, (with the exception of $0.607\lambda$ - $0.576\lambda$ which again we can take as an error). $0.546\lambda$ is our beautiful green Mercury line.

One other very interesting observation is that for the most part the reversal of the colors from $S$ to $S$ check in the results. a b
AIDENDUM:

Now at the end may I express my deep appreciation for the kind, sympathetic and inspirational assistance of Dr. Leo G. Raub, and Dr. Donald M. Bennett.