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ON THE UNAMBIGUITY OF BASICS IN THE COLOR REPRODUCTION THEORY

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Abstract. *When studying the subject of «Color Theory,» we encounter confusion regarding certain issues related to the fundamental principles of color reproduction theory. In other words, the theories of obtaining various color shades by mixing different color components are based on different initial assumptions in different books, which do not allow students to construct a unified color model for practical use. The purpose of this study was to address this problem. Open data from the Internet was used as a source of information.*

Keywords: *color, color circle, newton's color circle, goethe's color circle, itten's color circle, oswald's color circle, primary colors.*

Introduction

The study of color begins with its historical foundations. The foremost among the founders, who is always mentioned when studying color theory, is Isaac Newton (1643-1727) (Figs. 1-2).

If you read textbooks on color theory and color reproduction carefully, you may unexpectedly discover a surprising contradiction. The entire theory – from high school physics to the science of chromatics – follows Newton, accepting Red-Orange-Yellow-Green-Blue-Violet as the primary colors (Fig. 3).

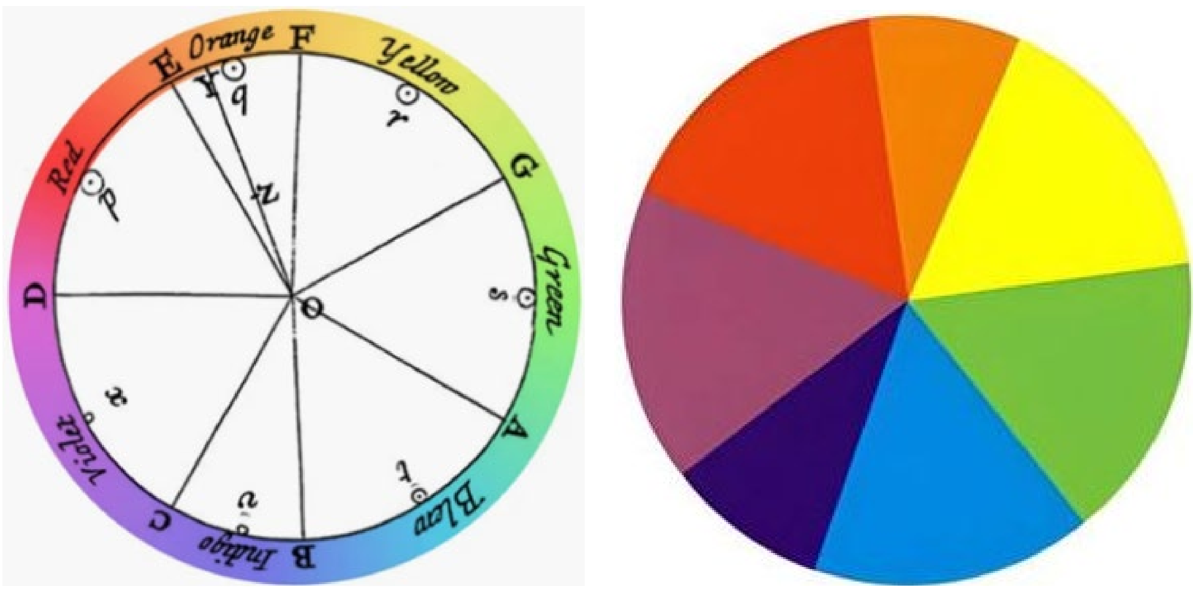

Figure 1 – Newton's historical color circle

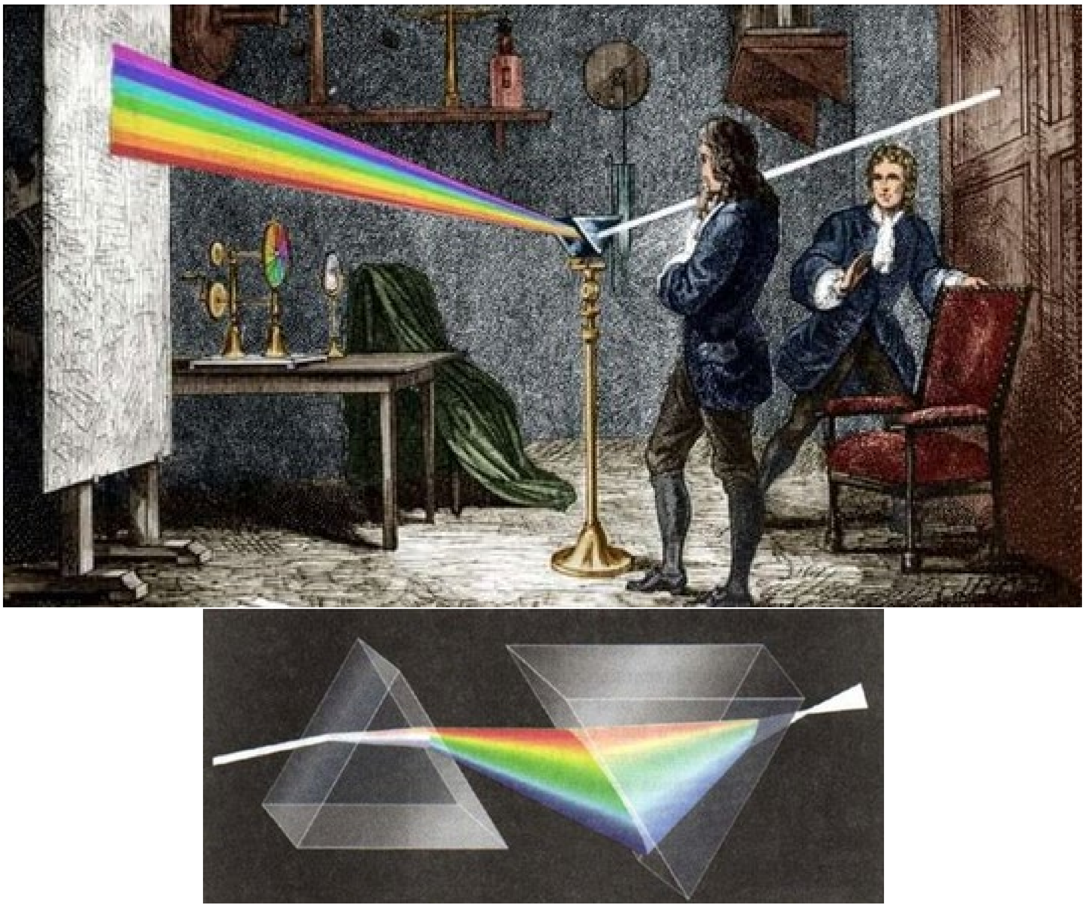

Figure 2 – Isaac Newton's experiments in 1666

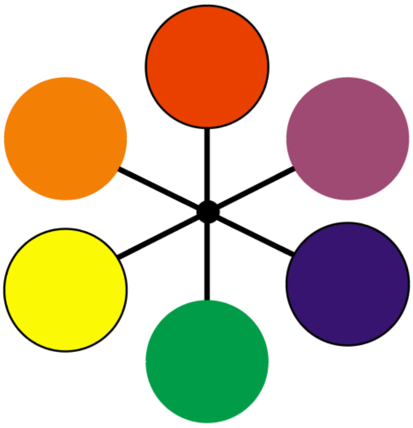

Figure 3 – The basic color model of chromatics, adopted in color theory based on Newton's teachings

Moreover it is claimed that Red, Yellow, and Blue are primary colors in this model because they cannot be produced by mixing any other colors and cannot be broken down into their components. Orange, Green, and Violet, on the other hand, are secondary colors because they are formed by mixing pairs of colors from the primary triad.

Modern practice, however, which is directly related to design and digital technologies, uses the RGB and CMY color models (Fig. 4), where the key colors are Magenta (M) – Red (R) – Yellow (Y) – Green (G) – Cyan (C) – Blue (B). Full-color images in printing are reproduced using all possible combinations of the three primary (completely different «primary»!) colors: C (cyan = blue), M (magenta = purple), Y (yellow), to which K (blacK) is added. If you try to «charge» an offset press with red, yellow, and blue, the colors in advertisements, brochures, books, etc., will turn out dirty and dull.

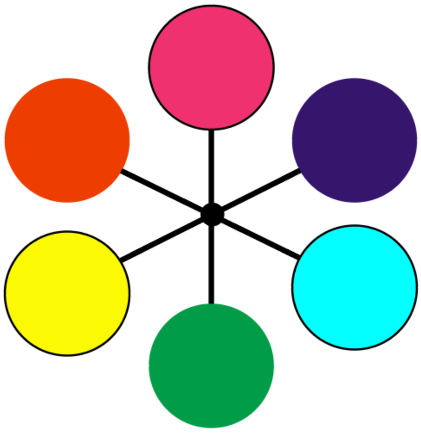

Figure 4 – The RGB-CMY model used in practice

Isn't it strange that magenta and cyan are completely absent from the model accepted by science? And if we try to generate red and blue in any graphic design software, we'll find that these colors are created by mixing:

red = 100% magenta + 100% yellow;
blue = 100% magenta+ 100% cyan.

And it is no longer possible to claim that they cannot be broken down into their components. Despite the fact that computer technologies have long been used by designers, architects, and publishers as a primary tool, the contradiction that has arisen between theory and practice remains unresolved. Designers are still being offered models from 300-200 years ago to study, which in no way align with today's realities.

Let's summarize the questions for Newton:

1. *It is unclear on what basis Newton accepted the initial five colors as primary, especially since he himself noted that a range of colors could be obtained by mixing adjacent ones (for example, green from yellow and blue).*
2. *Which colors did Newton ultimately accept as primary?*
3. *The seven colors of the rainbow are not the result of a scientific experiment, a scientific theory, or any physical law. They are merely the result of Newton's arbitrariness and his desire to artificially reduce color and sound harmony to a common denominator. Why did he not attempt to provide evidence for his claim?*
4. *Does color not exist without our eyes?*
5. *Despite the objections of scientists today, Newton's theory of color became established in classical physics and, for 300 years, was not subject to serious revision or further rethinking. Why?*

Were there attempts during Newton's time and afterward to create a different color model that differed significantly from Newton's theory? Yes, there were. But by no means were all of them successful. Of greatest interest to us are the experiments and conclusions of Johann Wolfgang von Goethe (1749-1832).

Experiments with the direct and reverse spectra allowed Goethe to assert that Newton's theory was flawed, as it considered only half of color phenomena.

Goethe believed that color is the result of the interaction of light and darkness. Yellow, as the minimal dimming of light, and blue, as the maximal illumination of darkness, are the fundamental, primary colors that cannot be broken down into any others. Goethe regarded red as an intensification of yellow, and violet as an intensification of blue. In addition, between red and violet, Goethe discovered a color not found in Newton's spectrum – magenta.

The sciences dealing with color did not immediately accept Goethe's views on color, although Goethe himself considered his research in this field more important than all his other works. Yet Goethe's theory, which so strikingly foreshadowed modern achievements in the field of color, has found virtually no practical application for a long time. Only a few authors mention it in their works, and even then, as a rule, in an extremely fragmentary manner and almost always in a distorted form.

The question arises: why? After all, if we look closely, it was Goethe who correctly constructed the color circle in the RGB-CMY system [1] that we use today (Fig. 5).

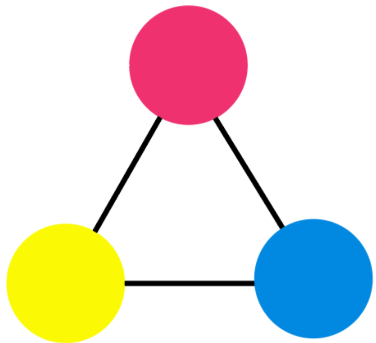

Figure 5 – The primary colors of Goethe's color circle

Purpose and Objectives of the Study

The relevance of this study lies in the existence of ambiguous interpretations of the fundamental principles of color theory in educational and scientific literature.

The purpose of this study is to investigate and explain this ambiguity.

The objective of this study is to answer the question: why has this ambiguity in the theory not yet been resolved?

The primary research methodology is the analysis of published sources on color theory.

Main Part

An absurd situation arises: *we study according Newton's color circle, yet we use Goethe's unrecognized color circle*. The question arises: why? And how can we resolve this situation?

All official sources still rely on Newton's research in the field of color. Newton's achievements eventually became practically an indisputable truth. The six-part circle, constructed based on Newton's theory, formed the foundation of all subsequent concepts regarding color patterns and color harmony and became the primary tool in Chromatics. As mentioned earlier, the primary colors in the circle are yellow, red, and blue, while the intermediate (secondary) colors – orange, magenta, and green – are obtained by mixing two adjacent colors. When comparing Newton's seven-part color circle with the six-part circle used in chromatics, we note that the latter lacks the color blue, which occupies a significant sector in Newton's model.

And immediately a big **BUT** arises. Recall: the intermediate (secondary) colors – orange, violet, and green – are obtained by mixing two adjacent colors. **But blue and yellow do not produce green when mixed** (Fig. 3). *Yellow can be obtained by mixing **blue** and green.* Blue and yellow produce gray. Another **BUT**. Gray and black result from mixing primary colors. And green is not a primary color.

And it is unclear who lost the blue and how?

In fact, understanding the nature of the color yellow is the main point of contention among proponents of various color theories. Is the perception of yellow the result of the combined activity of the red and green receptor systems, or is it primary – a view supported by the simplicity of the sensation it evokes?

Thomas Young (1773-1829) hypothesized (Fig. 6) that we always see yellow when red and green are mixed in certain proportions, and that there is no special type of receptor sensitive to yellow light rays, but rather two types of receptors, sensitive to red and green rays respectively, whose joint activity produces the sensation of yellow.

Young settled on three «primary» colors for a very simple reason.

He discovered that any color visible in the spectrum (including white) can be created by mixing three – but no fewer than three – light rays, selecting the appropriate light intensity.

As we can see, Young could not definitively identify the three primary colors that would be capable of mixing to produce all the other colors in the world. Young's theory was later developed by the German naturalist, doctor, physiologist, and psychologist Hermann Ludwig Ferdinand Helmholtz (1821-1894):

According to the Young–Helmholtz theory, there are three types of color-sensitive receptors (flasks) that respond to red, green, and blue (or magenta) colors, respectively, and the perception of all other colors in the spectrum arises from the mixing of signals from these three receptor systems.

Based on Young's theory, the English physicist James Maxwell developed a color model that is fully consistent with modern concepts of color mixing and is based on the RGB-CMY color systems familiar to designers (Fig. 7).

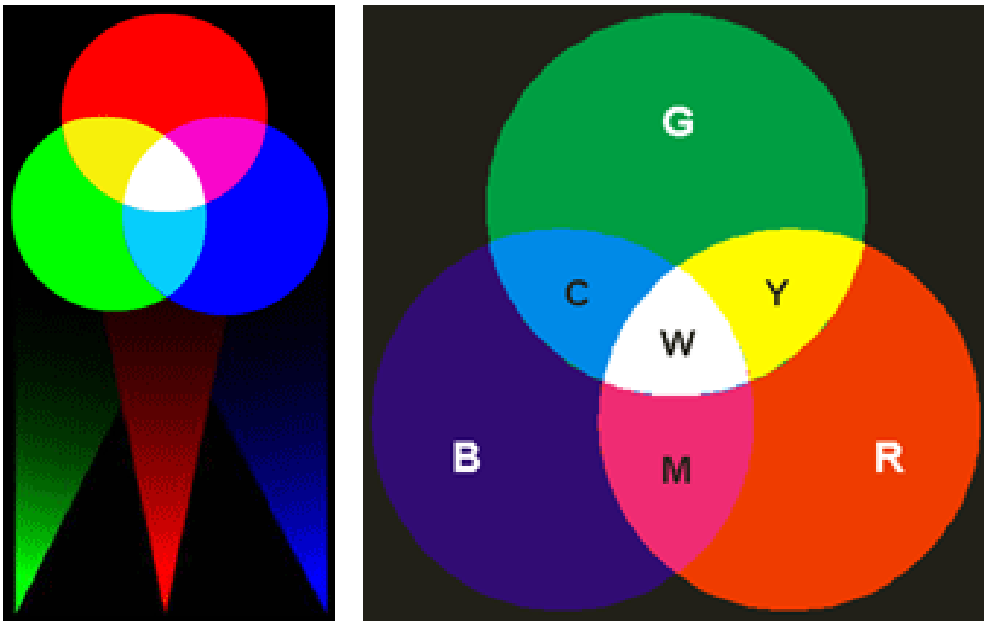

Figure 6 – Young's experiment on color mixing.
By mixing three light beams (rather than colors – MM) that are quite far apart from one another in the spectrum, Young demonstrated that any color in the spectrum can be produced by adjusting the intensities accordingly

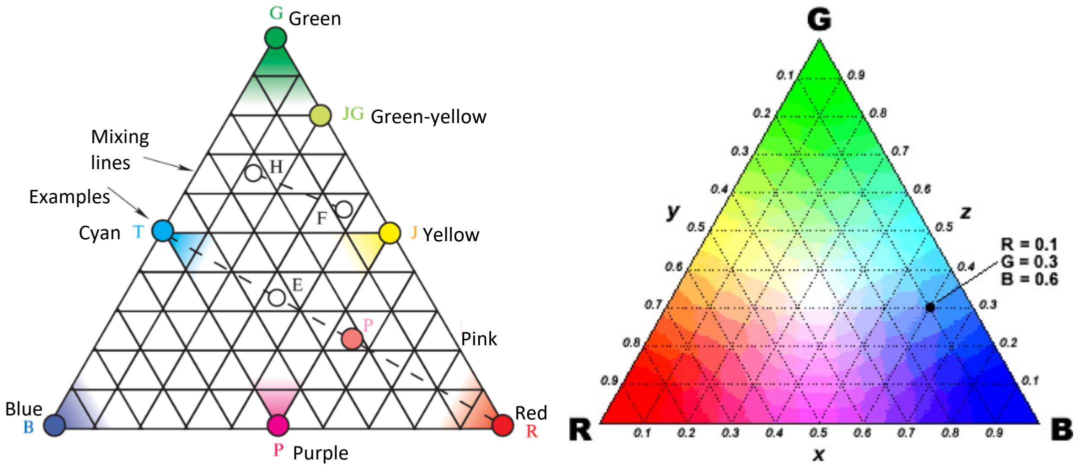

Figure 7 – Maxwell's model. 1857

Maxwell pointed out the possibility of applying the principles of the tri theory of vision to the reproduction of color images, and in 1861 he demonstrated for the first time a color photograph produced using the three-colored method.

It seems that from this point on, certain parts of the official theory of color have developed along two divergent paths:

– the development of photography, followed by color television, computer color models, and principles of image reproduction in printing – based on the Young-Maxwell model, where RGB (red-green-blue) and CMY (cyan-magenta-yellow) are adopted as the primary colors ,

– everything else (chromatics) – based on Newtonian optics with the main colors red-blue-yellow.

To be more accurate: color theories in physics and painting have remained rooted in Newton's principles; they were studied and developed for nearly three centuries, and in our time they have been automatically transferred to the realm of design. Contemporary design, however, is concerned only with practical results – achieved, incidentally, through computer technology. And it turns out that classical theory does not align with practice. Despite the obvious paradox, few people are trying to bring them into common agreement. Even if such attempts are made, the pressure from authorities established over centuries prevents any serious breakthroughs in this field for the time being.

The ideas established by Newton have become so deeply «ingrained» in color theory over the past three hundred years that virtually none of the subsequent researchers in this field have been able to avoid Newton's various contradictions and inconsistencies. The nature of color and the principles of color formation, as well as its effect on humans, are interpreted by specialists from various fields of knowledge – physicists, physiologists, psychologists, artists, and designers. Each perspective is, to some extent, unique. One might think that a multifaceted examination of color phenomena would result in a unified whole that fully reflects the nature of color. However, this does not happen. Psychologists and artists, who are quite distant from delving into the laws of physics due to their focus on the humanities, take these laws as a basis in the form in which they are presented in physics textbooks and build their research upon them. If, for some reason, the pieces do not fit together, there is no choice but to artificially force one phenomenon to fit another, using unfounded assumptions.

Unfortunately, even Johannes Itten (1888-1967), an undisputed modern authority on color theory, was not able to avoid such errors, inaccuracies, and approximations. Presenting his twelve-part color circle (Fig. 8) in his book (unsuitable for printers), Itten accompanies it with the following text: «… Isaac Newton obtained this closed circle, in which he added the missing purple color to the spectral colors, which enhanced its overall constructiveness. ...» [2].

Figure 8 – Itten's twelve-part circle

Questions arise regarding Itten:

– But Newton didn't have a twelve-part color circle. His circle consisted of 7 parts, the origins of which we have examined in detail;

– But there is no purple in this circle;

– However, it should be noted that blue has appeared in Itten's circle, the disappearance of which we noted earlier.

Let's conduct a comparative experiment: computer technology versus art paints. Let's try, using a computer (Fig. 9), to obtain mixtures from the primary colors accepted today in chromatics (we'll use a model in CorelDraw editor using the CMY module).

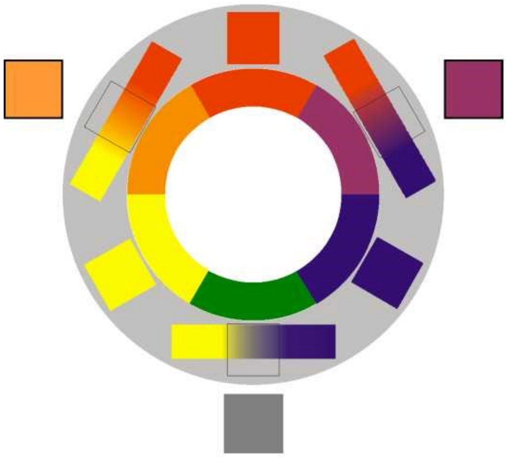

Figure 9 – Obtaining of mixed colors
from primary colors in the chromatic circle

In the center is a chromatics model. The primary colors are represented by squares on a gray background. The gradient strips demonstrate the process of generating color mixtures using a computer. The squares outside the gray background show the resulting mixed colors for each pair of primary colors.

We can see that the mixtures of red and yellow, and red and blue, correspond exactly to the derived colors in the central circle – orange and purple, respectively. But yellow and blue do not mix to make green! When mixed, they produce a gray color.

But since childhood, we've been told that green comes from mixing yellow and blue. And now a simple computer operation destroys what seemed like an indisputable fact. What's going on here?

If we look through a prism, following Newton's example (Fig. 10), we will see that in the spectrum, green is formed not between blue and yellow, but between cyan and yellow.

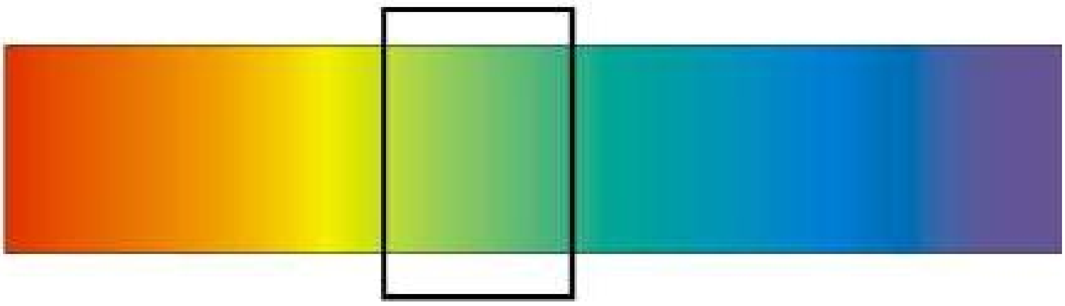

Figure 10 – Obtaining the green color in the spectrum

But in the world of chromatics, there's no such thing as cyan!

If, instead of a computer's digital model, we use art paints, we can create cyan from blue by adding white to it. But this follows a completely different pattern that doesn't align with the principles of the color circle.

We must acknowledge that for a painter, the issue of blue versus cyan is not so fundamental. He selects the components of the mixture based on experience and obtains a wonderful green color by mixing ultramarine and lemon yellow (it is called lemon yellow precisely because it already has a greenish tint).

The colors of traditional art pigments do not match spectral colors. A digital computer model, however, is as close as possible to the pure spectrum, so for a designer, using blue instead of light blue is impossible. Yet the theory in the textbook says – use it...

However, the blue-yellow mixture, having persisted for over 100 years as a myth, has emerged as a problem right before our eyes, even within the artistic community. A few years ago, Michael Wilcox's book was published in English, dedicated to examining these issues, aptly titled: «Blue and Yellow Do Not Make Green: How to Get the Color You Really Want.»

Below is the modern Oswald color circle (Fig. 11). It is easy to understand by comparing the Oswald color circle with those of Newton and Goethe, whose theories should be studied for further practical application.

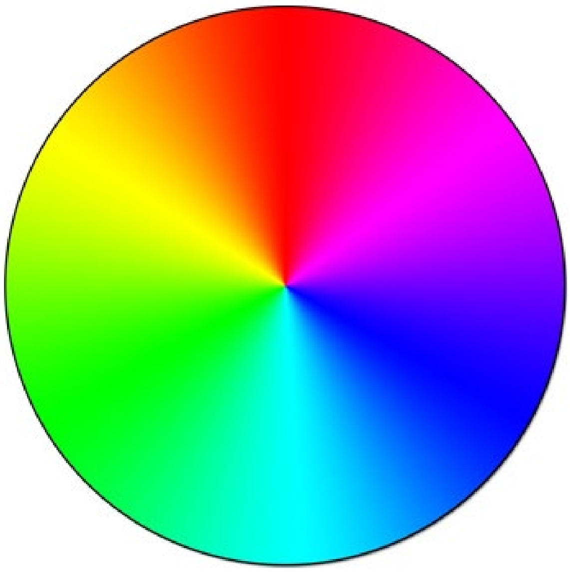

Figure 11 – Oswald's Modern Spectral Color Circle

The issues raised in this study require urgent resolution. It is impossible to address them theoretically. It is likely necessary to establish some kind of body (such as a color-based consortium) that would issue the necessary and binding decisions in accordance with international standards.

For our part, we will attempt to explain the reasons behind such absurdities.

One of the significant reasons in our literature is the incorrect translation of the results and conclusions of foreign studies, the originals of which are written in English and German. First example: in English and German, there are no distinct words for «blue» and «cyan» How the text is translated depends on the translator's competence.

You don't have to look far for examples; just flip through various textbooks. Not only do the listed colors not match, but the colors in the illustrations also don't match their names. What can we learn from this? Add to that the context-dependence of English, where the same word takes on different meanings in specific contexts.

But the most important thing, in our view, is this: Newton's and Goethe's respective approaches to color illustrate two completely different approaches to experimental research. We distinguish between them by calling them: theory-oriented (Newton) and research-oriented (Goethe).

A theory-driven approach is often considered the only appropriate method – this aligns with the «standard» conception of science, in which experiments are designed based on pre-formulated theories and serve primarily to test or demonstrate those theories. Theory dominates experimental work from its initial planning to the final details in the laboratory. Newton largely followed this approach in his experiments with color.

Exploratory experimentation has largely been ignored by historians and philosophers of science. A special feature of this approach is the systematic and significant change of experimental conditions to determine which of them are necessary for the phenomena under study or influence them.

Theory-oriented and exploratory experimentation are not mutually exclusive categories, but rather aspects of a spectrum of experimental research strategies. Which of them is more productive in a given context depends on many factors, including the state of development of the field, the type of knowledge (e.g., basic mechanisms versus the regularity of phenomena) that the physicist is mastering, and the complexity of the system under study.

Newton's research in optics was guided by a metaphysical belief that color was simply a subjective correlate of the mechanical properties of light rays. Therefore, he abstracted himself from the complex world of normal visual perception, working in a dark chamber illuminated by a single ray of sunlight. Thus, the system Newton studied was unambiguous and consisted of objects of a single type – rays with different angles of refraction – whose interactions and types of color mixing lay simply beyond the scope of his chosen approach. Newton's approach fully served his purpose: the mathematization of light and color was achieved using several specific effects. But the price paid was this: his experiments limited the relevance of color in ordinary perception.

The research style demonstrated by Goethe's experiments with color was, at the time, underestimated by his peers, with the exception of physicists. Johann Wolfgang Goethe's theory of color captivated and continues to captivate physicists for nearly two centuries, beginning with its publication in 1810.

As an embodiment of his research, Goethe proposed a symmetrical color circle, which he used in all the fields he studied. In contrast, Newton's color circle, with its seven colors and unequal angles, did not display the symmetry and interdependence that Goethe regarded as essential characteristics of color. For Newton, only spectral colors could be considered fundamental.

Goethe's more empirical approach led to the recognition of the significant role of non-spectral fuchsia in the full color circle, a role that still holds its place in all modern color systems. Painters, dyers, makeup artists – all those who work with color in practice generally feel much more connected to Goethe's color circle than to Newton's.

And today, even after firmly proving its value, Goethe's color theory remains in the literature as a backup or supplementary option to Newton's research. A paradox? Yes!

Research results

An analysis of the theoretical and practical material gathered as a result of this study suggests the following:

– currently, two distinct color theories coexist within the scientific community: Isaac Newton's color theory and Johann Wolfgang von Goethe's color theory, which emerged from two different approaches to the experimental study of color properties;

– each of them satisfies its own group of researchers and users of these theories: physicists, printers, artists, physiologists, psychologists, doctors, etc.;

– today there is no universal color theory, since there is no single formulation of laws that would unify and explain the research of Isaac Newton and Johann Wolfgang von Goethe;

– this last statement is indirectly supported by constant attempts to create new color models, as well as by the mathematical complexities of converting color coordinates from one color model to another.

Conclusions

An analysis of the main provisions of color theory has been conducted: the corpuscular theory of light, which explains the phenomena of light scattering and reflection (Isaac Newton's color theory), and the theory of the process of human perception and interpretation of color (Johann Wolfgang von Goethe's color theory). An attempt is made to explain why these theories exist separately from one another. The possibility of combining the interpretations of the main conclusions of Newton's and Goethe's research is considered. The hypothesis is put forward that there is no single, indivisible theory of color in the scientific community.

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