PHYSICS AND CHEMISTRY

Chapter 1 – The Secret Language of Color

THE REAL PRIMARY COLORS

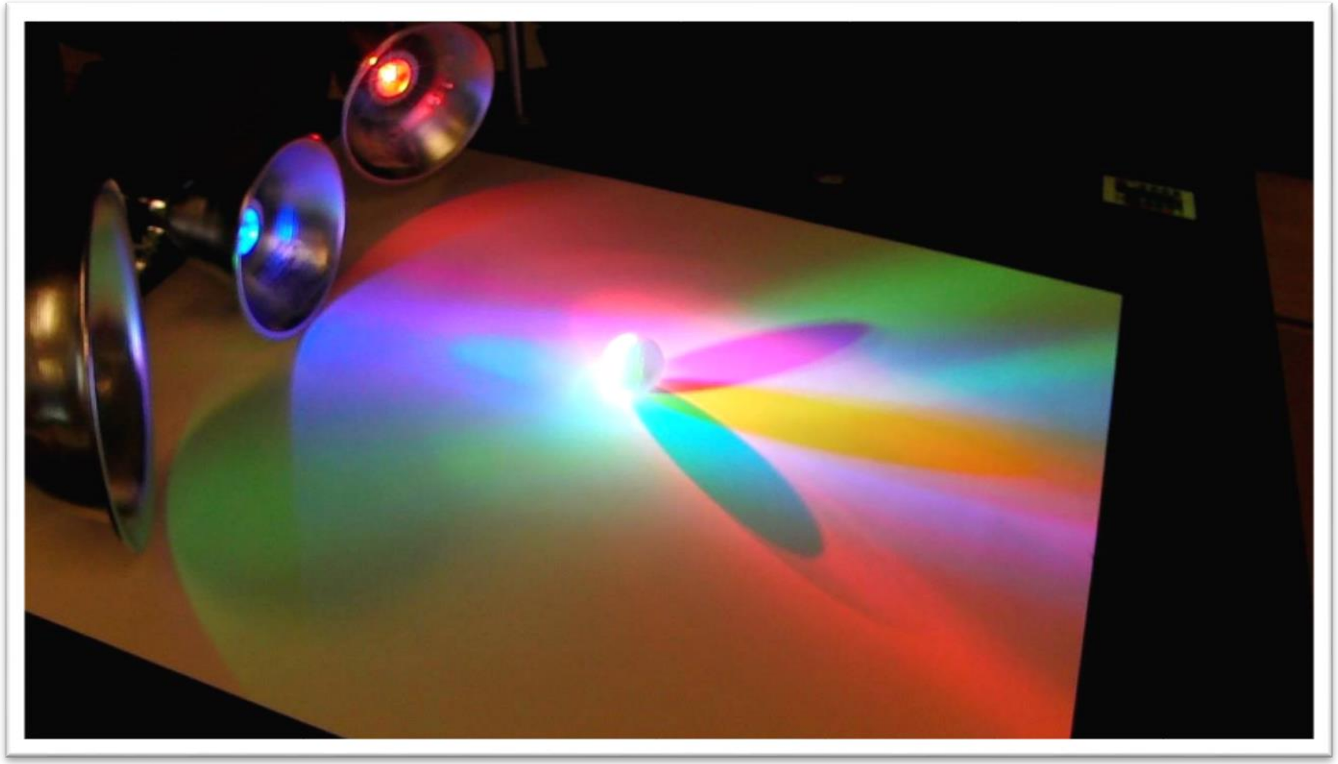
- In addition to determining the physical properties of color, scientists began to ask questions about our perceptions of color. Why and how to we see color? The answers to these questions lead us down a path that will counter almost everything you've ever learned about color. Take the "white" light Newton was passing through his prism. Newton's conclusion was that all the colors of the rainbow combined to create white.

THE REAL PRIMARY COLORS

- But if you mix red, orange, yellow, green, blue and violet paint in your palette, you get anything but white. (This, by the way, was the source of Goethe's skepticism about Newton's theories - he had watched painters mix paint in their palettes and had never seen a multitude of colors adding up to white).

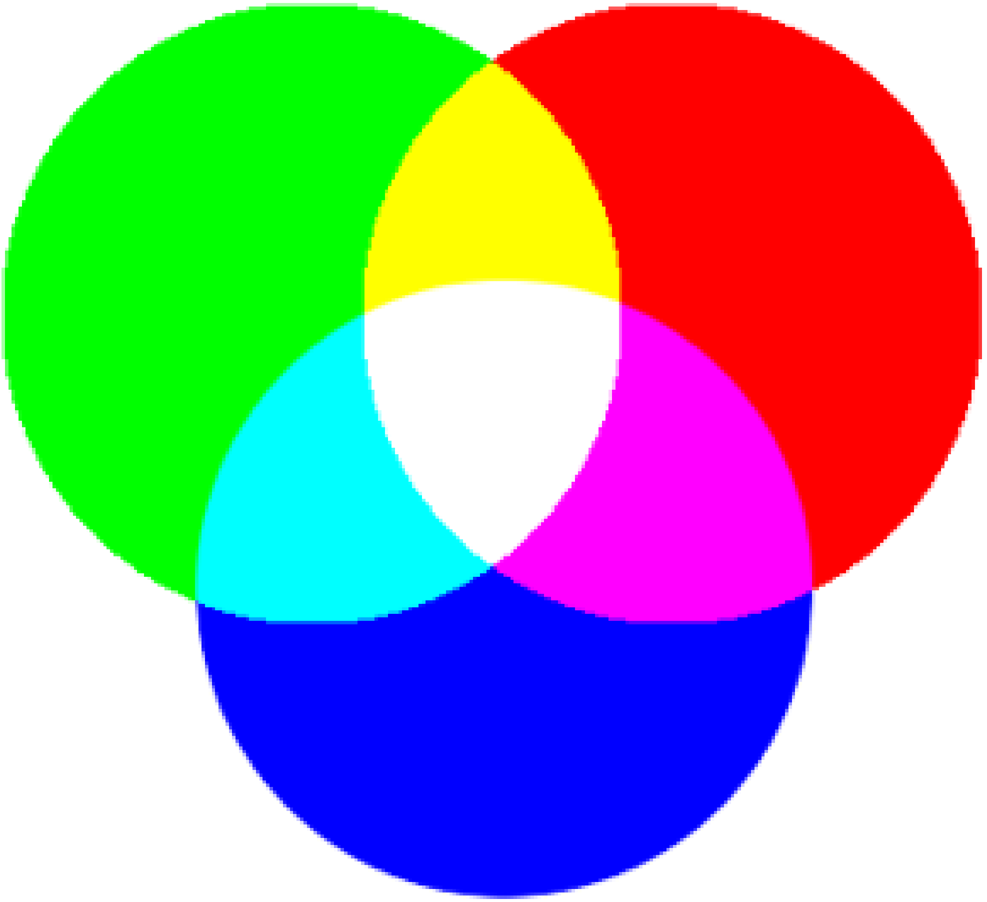
THE REAL PRIMARY COLORS

- Newton was not dealing with paint, however; he was dealing with light, and light mixes in an entirely different fashion. The mixing of light belongs to the realm of additive colors. When you add different wavelengths of light together, you don't get the muddy mess you see with paint and the mix doesn't always produce what you'd expect it to because, again, additive color doesn't work like paint.



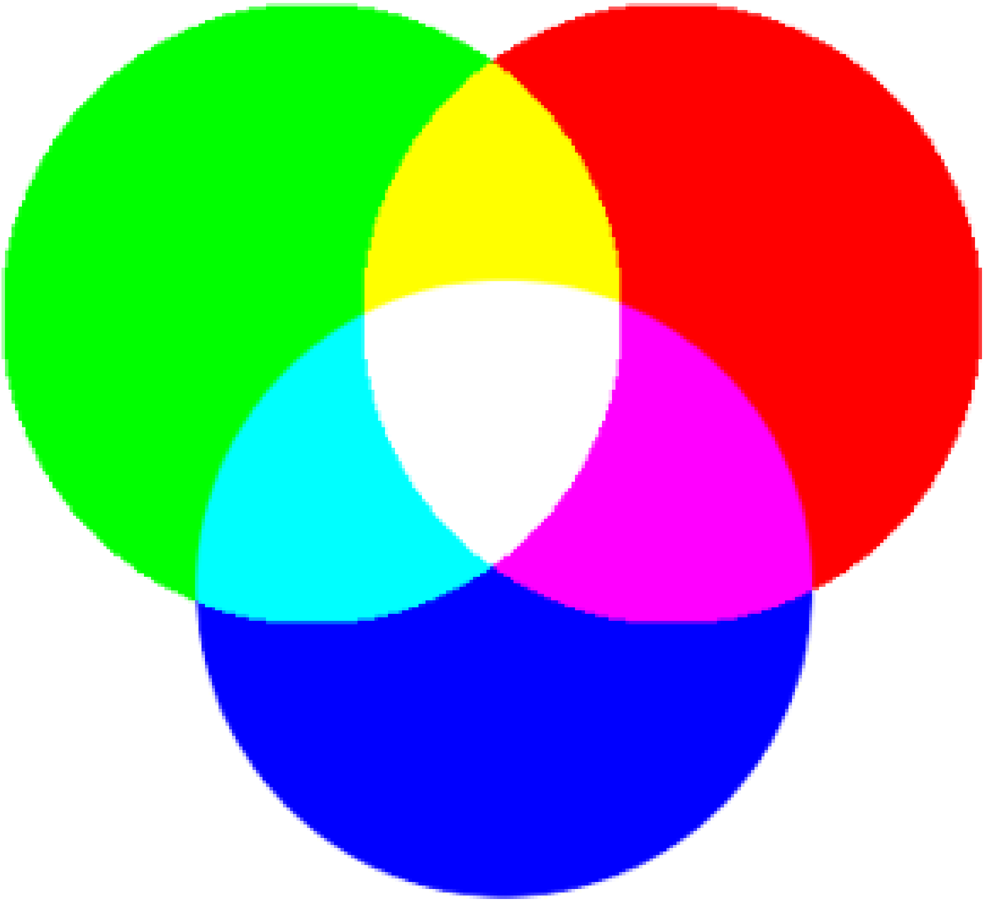
THE REAL PRIMARY COLORS

- In fact, every color of the rainbow can be achieved by mixing only three colors of like: Red, Green, and Blue. Wait….. Green?
- That's a different triad from the primary colors - the colors from which all other can theoretically be mixed - that we are taught about in school, namely, red, blue, and yellow. Where did green come from? And where did yellow go?



THE REAL PRIMARY COLORS

- These three new primary colors - red, green, and blue - make no sense from a young painter's perspective. Anyone who has ever mixed paint knows that you can't make yellow from any of these colors. Yet, when you mix what appears to our human eyes as red and green light, you do indeed get yellow.



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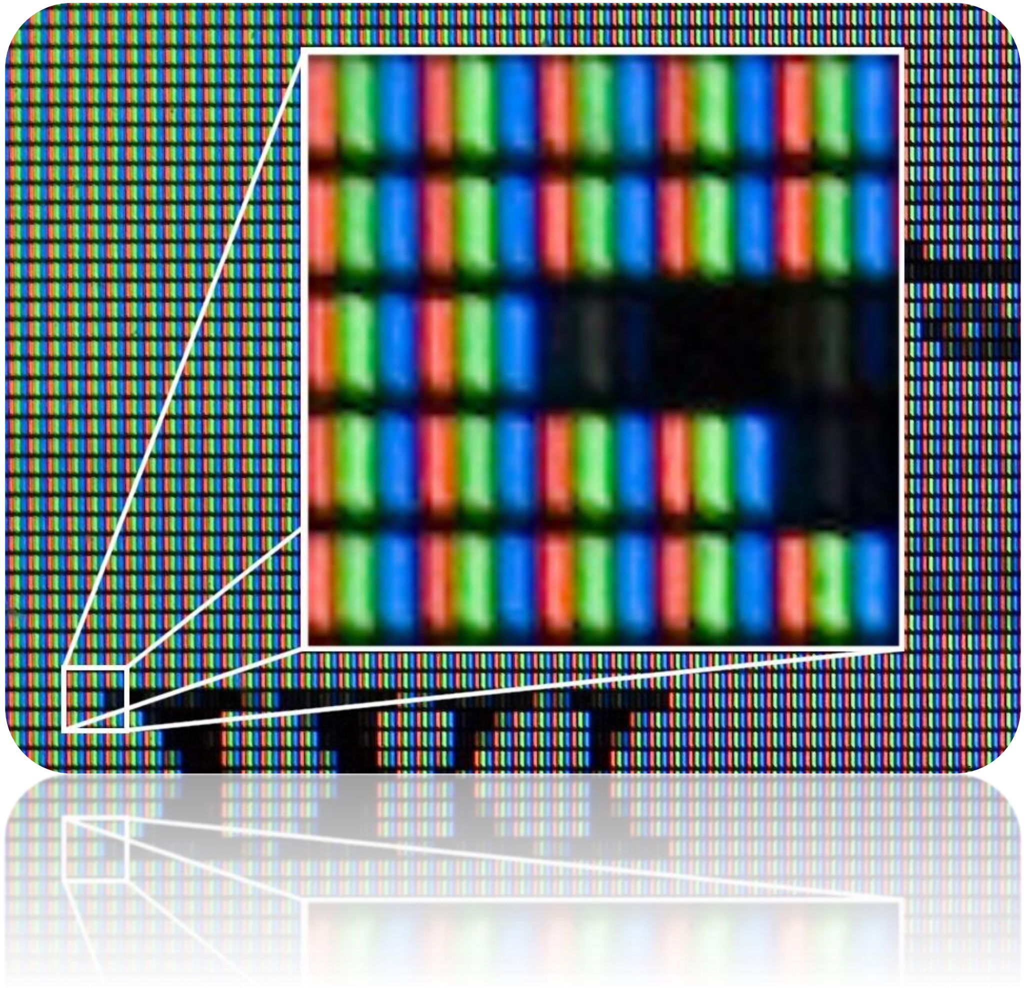
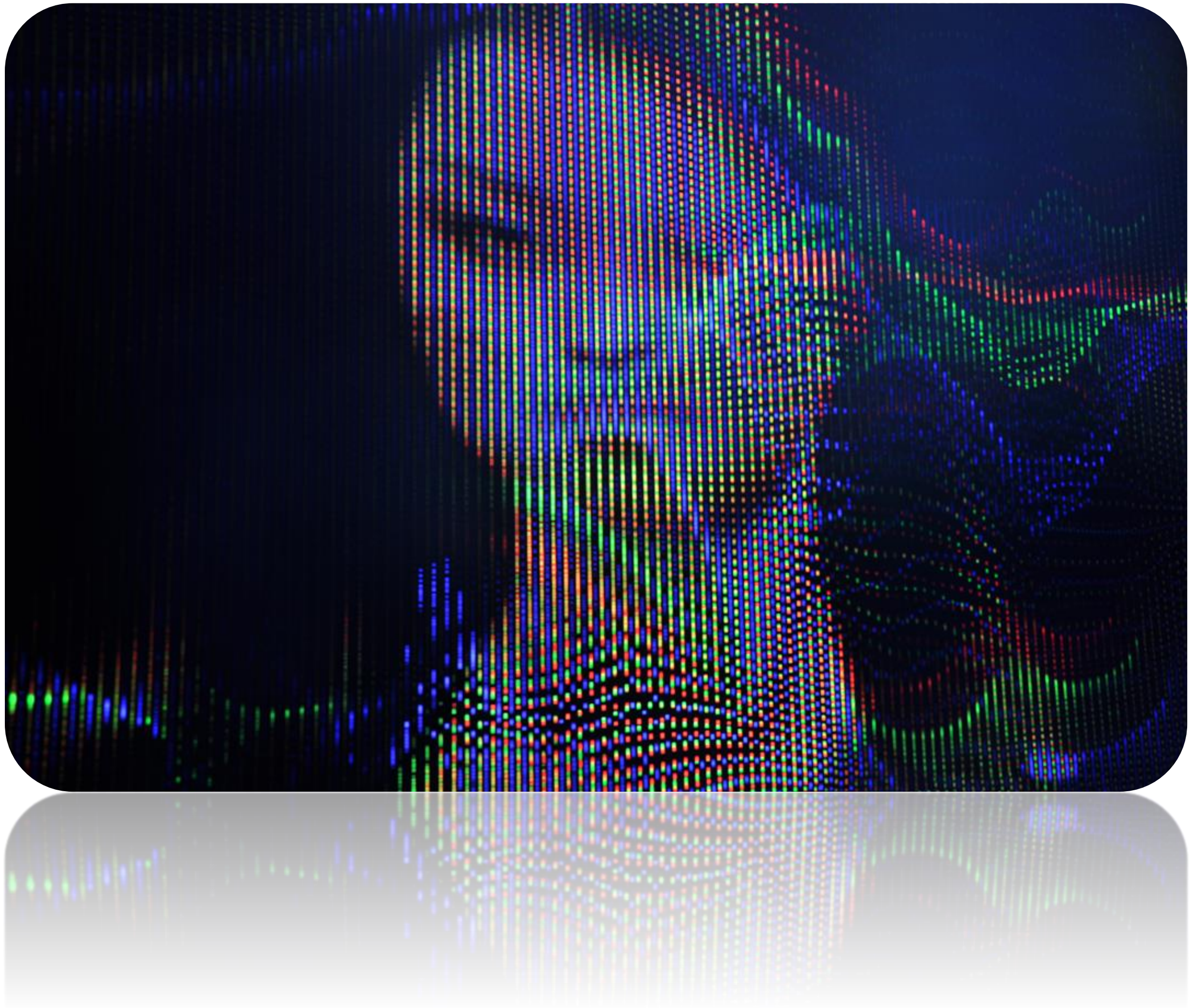
THE REAL PRIMARY COLORS

- You are probably more familiar than you think with this primary triad. Case in point: the RGB(red-green-blue) color model on your computer monitor. Obviously you see a wide range of colors on your screen, but if you got close enough to an old computer with visible pixels, you could actually see that the screen is entirely made up of red, green, and blue dots.

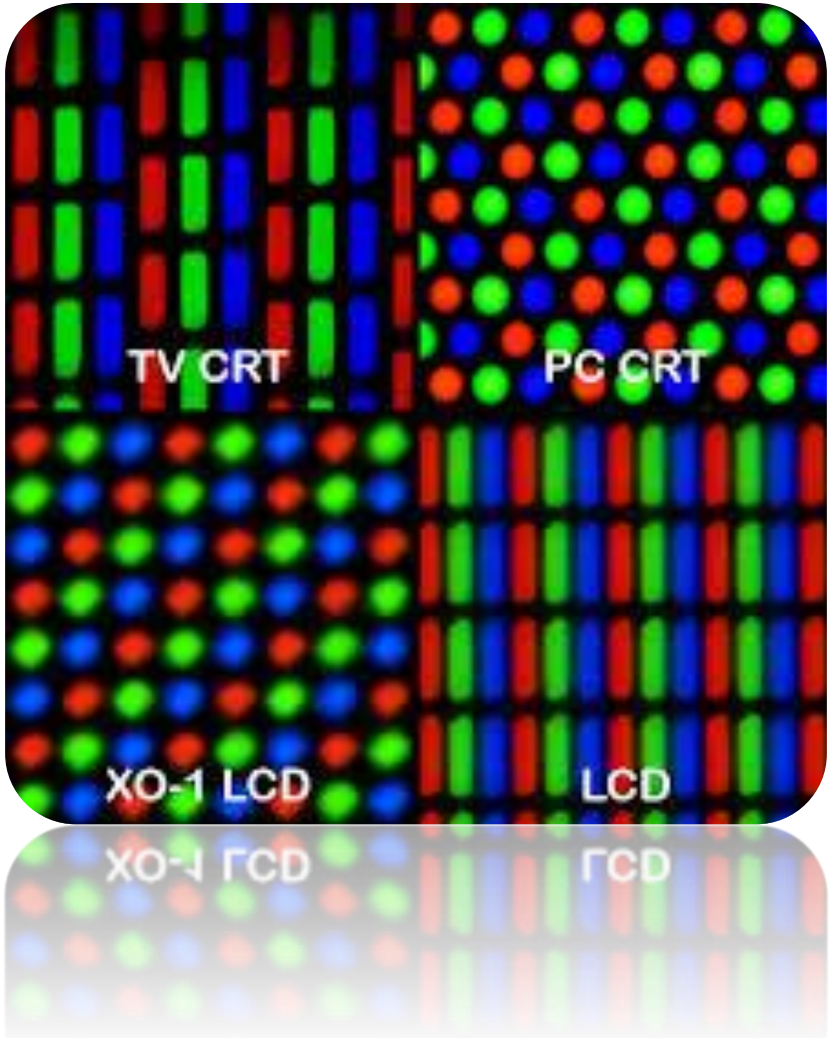


THE REAL PRIMARY COLORS

- The same is still true today; the dots are just harder to see. If you a magnifying glass to see your screen, you'd see that magenta type, a field of pumpkins, and a dull brown bunny were all comprised of these red, green, and blue dots. A white screen is the result of all three colors lighting up at the same maximum intensity, and a black screen is the result of the absence of color (light).

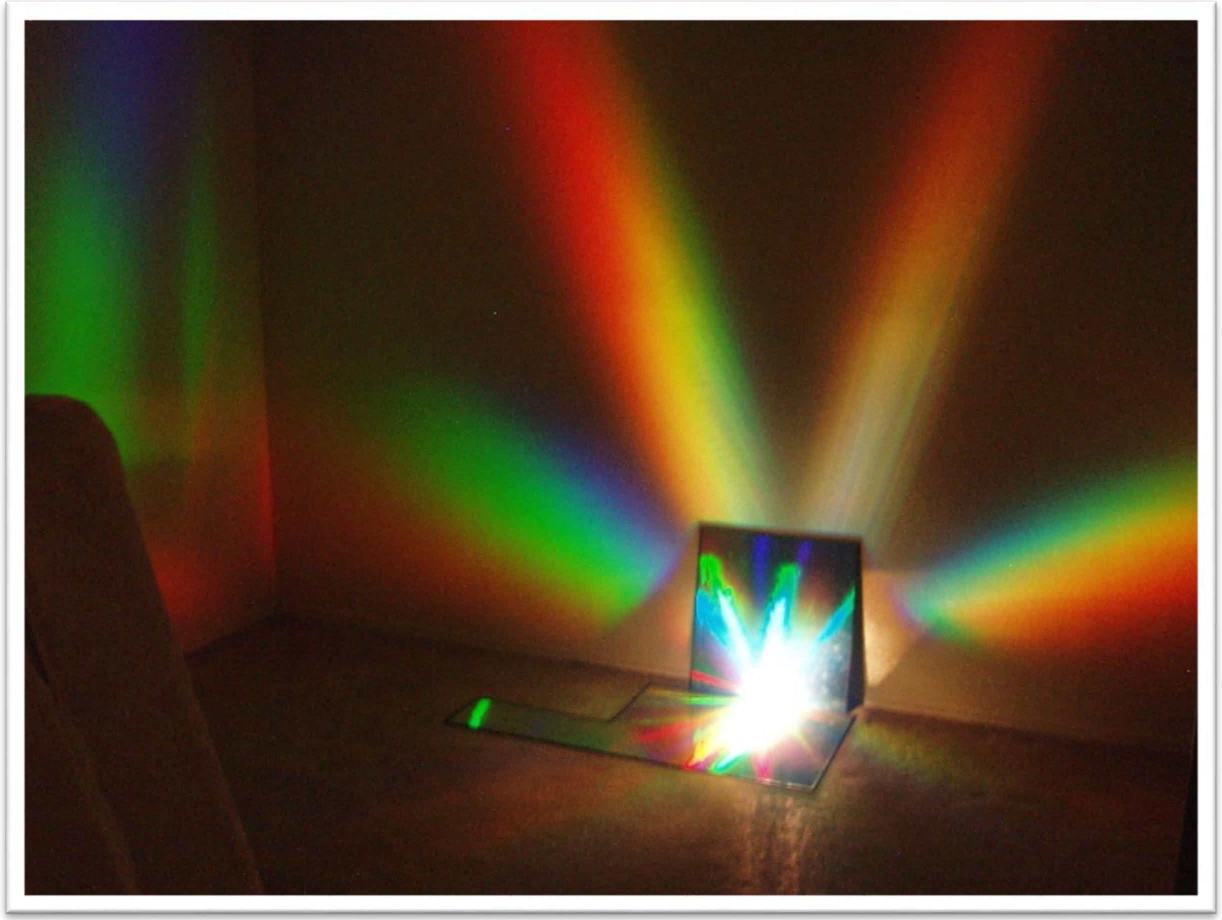


THE REAL PRIMARY COLORS



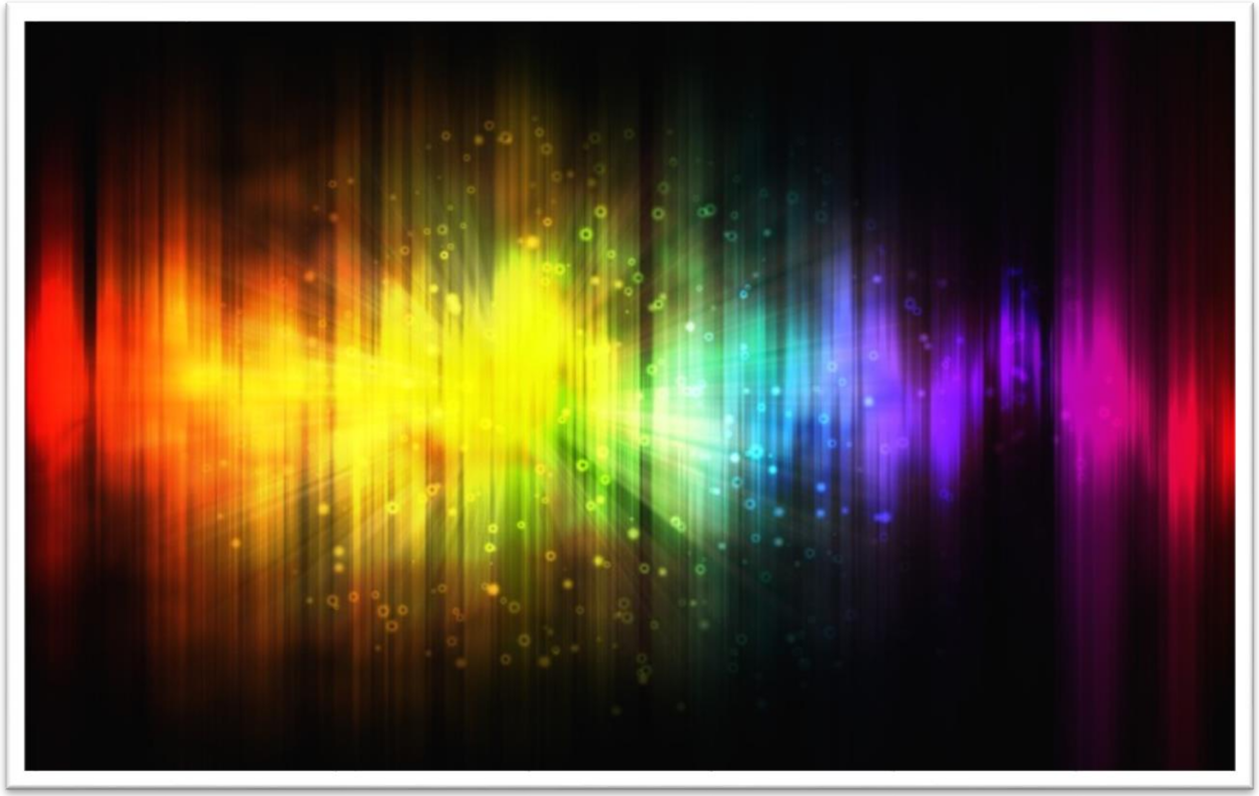
- Televisions and cameras also use an RGB color model, as down theater lighting. Similarly, the first color photography (a feat conducted by none of than James Clerk Maxwell in 1861) was a product of the layering of red filtered, green-filtered, and blue-filtered negatives on top of one another. Here, again you can see the logical underpinnings of the term additive color whereby adding colors together can beget every color of the rainbow.

YOUR BRAIN ON COLOR



- If there's one-color related axiom that bears repeating, it is this: Wavelengths of light do not exist as color until we see them. Without the eyes and the brain, there's no such thing as color. Light waves are colorless until the moment they hit our eyes, at which point our brains declare, "Blue sky, green grass, red rose." Most other animals - and even some humans- won't see any of the these colors when they look at the sky, the grass, or a rose because, again, none of these entities is intrinsically colored.

YOUR BRAIN ON COLOR

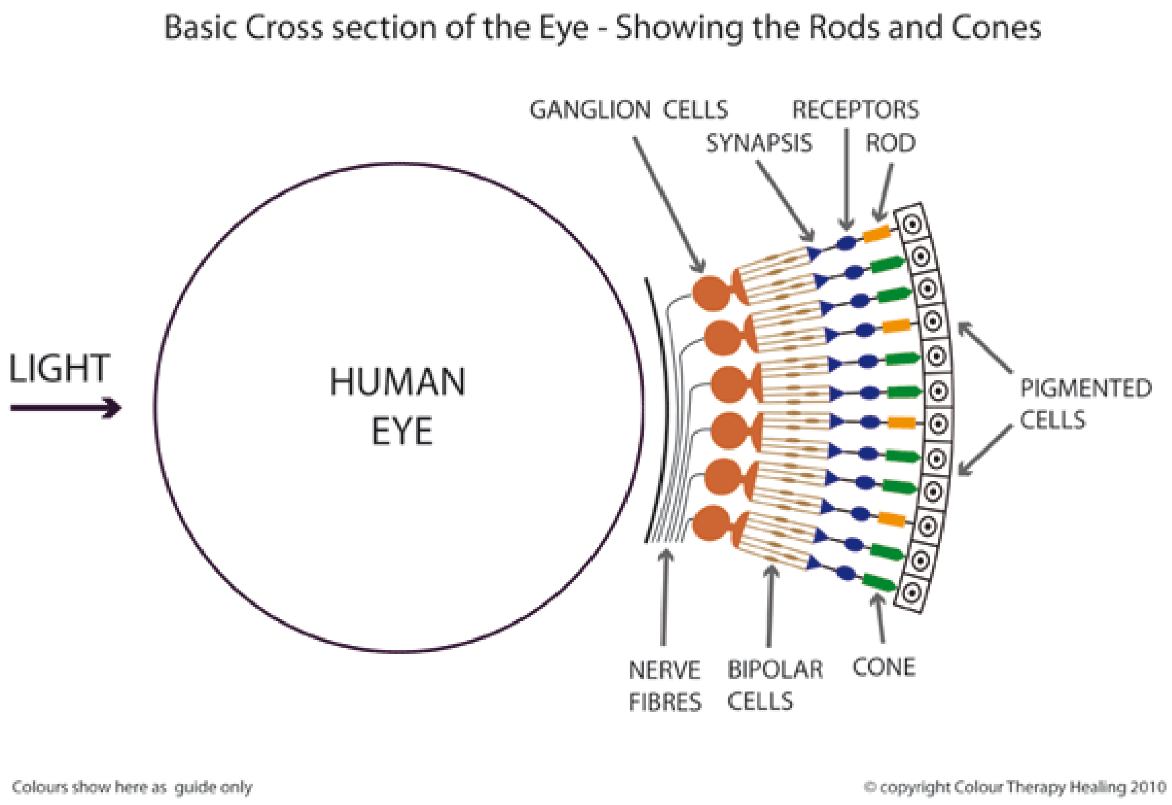


- This idea that color does not exist outside of our perception is difficult to swallow because it counters what appears to be a cold, hard reality. It took a long time for scientists even to consider a relationship between the brain and color. Aristotle, who got an amazing amount right about color way back in the 4th Century BC, was convinced that color was intrinsic to the surface of the object; Newton never touched on the perceptual side of the matter.

YOUR BRAIN ON COLOR

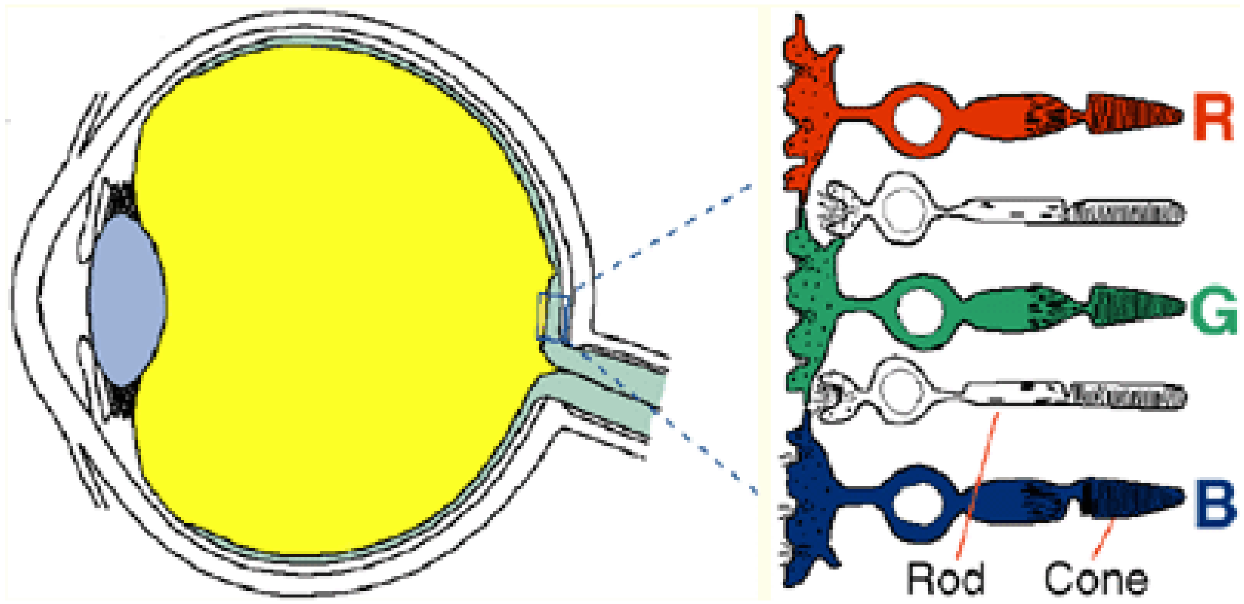
- All of the color that surrounds us is a construction of the brain. As we scan our surroundings, light enters our pupils and passes through our lenses, which focus images onto our retinas. Inside the retina, photoreceptors sense light's varying wavelengths; these photoreceptors are the key to which and how many colors we can see.

YOUR BRAIN ON COLOR



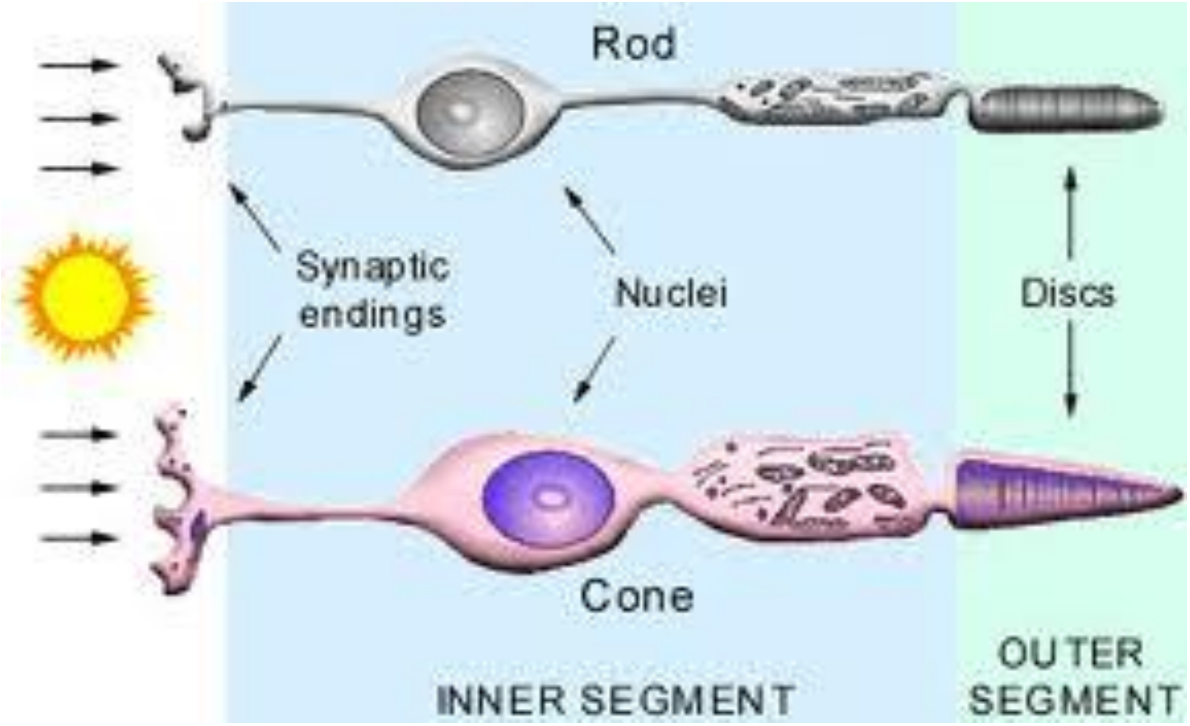
- The retina boasts all three types of cones, the color sensitive photoreceptor cells. At the moment light hits our eyes and makes its way to our cones, color is merely a sensation - a purely physical phenomenon, just as sound waves hit our ears as a sensation before we hear and categorize the noise as a certain of sound. Once our cones are activated, color is on its way to becoming a perception. Perception occurs after the brain's higher-order processing centers filter and interpret the information provided by a sensation.

YOUR BRAIN ON COLOR



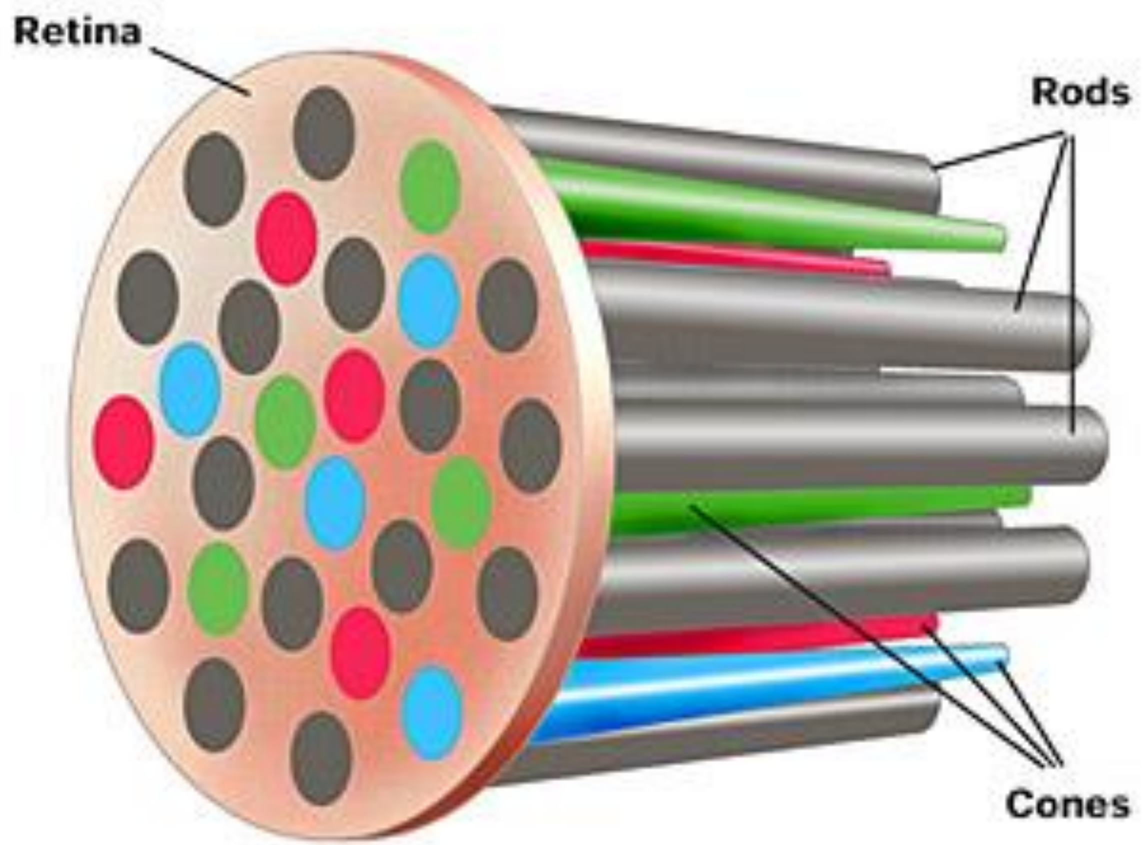
- Here's a more detailed picture of how the process works: When light hits the retina, two kinds of nerve signals are generate: one from our rods (the photoreceptor cells that perceive low levels of light) and one from our cones (the photoreceptor cells that perceive color). These signals leave the eye via the optic nerve, traveling to a type of neutrals crossroads in the brain called the optic chiasm.

YOUR BRAIN ON COLOR



- There, the nerve signals split; half of the signal from each eye moves to the opposite side of the brain along a group of axons called the optic tract. Information from the left visual field (the left side of each eyeball) travels to the right brain and vice versa. Eventually, the data connect in the specific region on the lateral surface of the thalamus (the Grand Central Station of sensory information) and is relayed to the occipital lobe, the primary visual cortex.

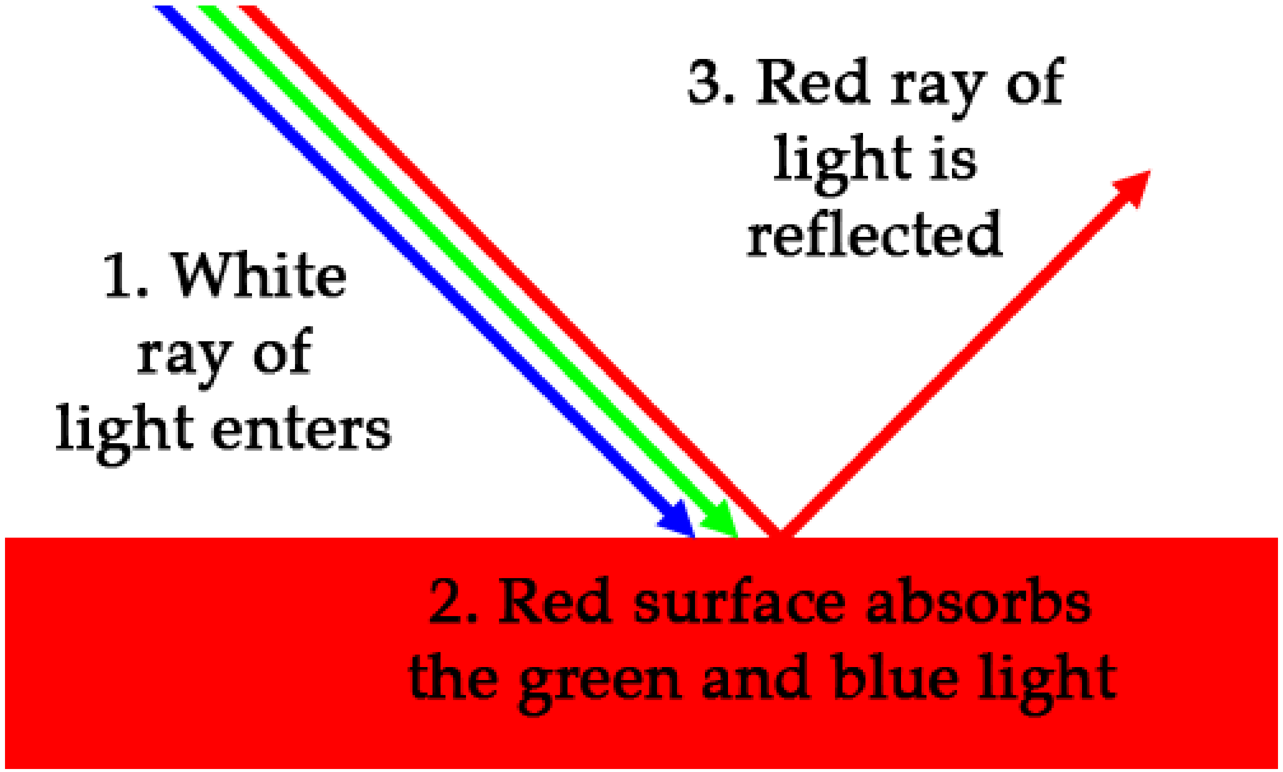
YOUR BRAIN ON COLOR



- Up to this point, the data are being processed in a very streamlined way. It's when the regions adjacent to the occipital lobe are called into action that more complex associations start to come into play. Rather than simply perceiving a red mass, the brain adds detail - large red couch, dark red pillows, a bluish stain.

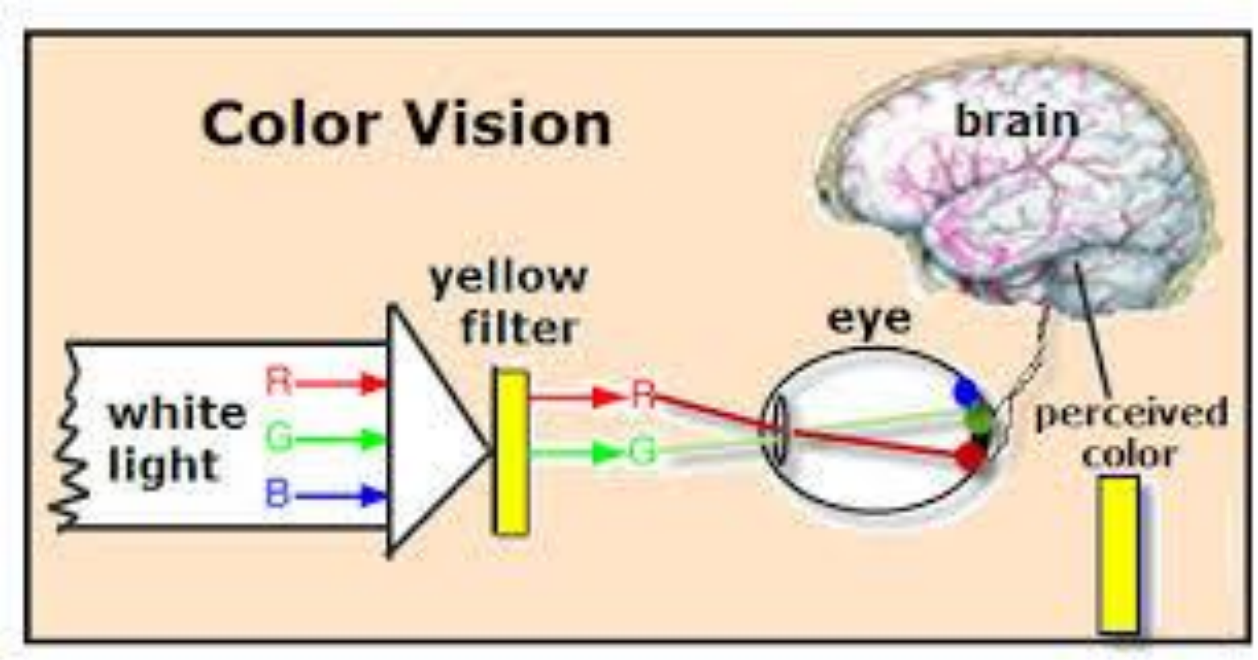
YOUR BRAIN ON COLOR

- The kind of cone that is activated by light, and in what amount, determines what colors we see. One type of cone senses short wavelengths (which helps us perceived blue and violets); one senses medium wavelengths (which helps us perceive greens and yellows); and one that senses long wavelengths (which helps perceive red, oranges, and yellows). The cones themselves are commonly referred to "red," "green," or "blue - and it's no accident that they match the same trio of primary colors found in the additive color model.



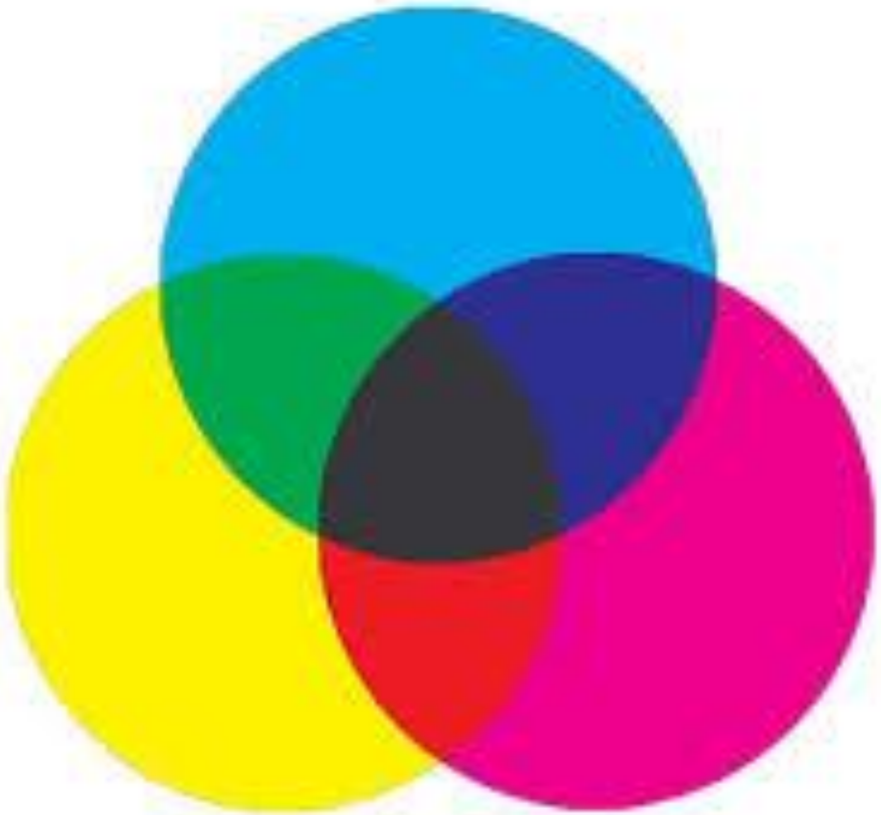
YOUR BRAIN ON COLOR

- By synthesizing the activity in each type of cone, our brains are able to perceive the ten million colors most of us can detect, from darkest to lightest, brightest to dullest. Although Thomas Young was not able to deduce exactly how all this transpired, he was responsible for the critical discovery that we had three kinds of receptors and that they are sensitive to red, green, or blue light.



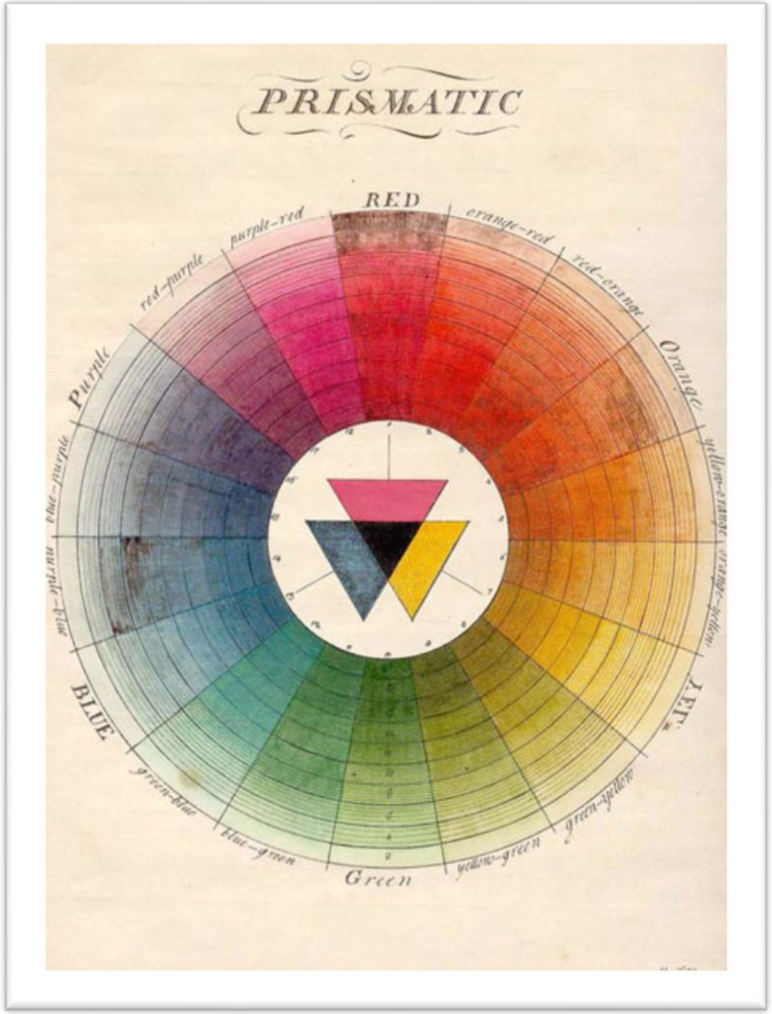
FROM ADDITION TO SUBTRACTION

- If you look at the interlocking circles, you'll see three colors in the places where the circles overlap, namely, yellow, cyan, and magenta.
- There are the very colors of ink you load into a printer. As evidenced by what your printer spits out, when mixed together, the ink from those cartridges can produce every color of the rainbow. That's because these colors, although they are secondary in the realm of additive colors, are the primary colors in the worlds of subtractive color: magenta, cyan, and yellow pigments are the basis for the plethora of color you see in the material objects all around you (including all those colors in the paint store).



FROM ADDITION TO SUBTRACTION

- Though Le Blon's color prints were beautiful, he was unable to successfully reproduce many colors. Still, his legacy lives on to this day in the form of frustrated elementary school children who were unable to mix bright greens, purples, or oranges withy their standard red, blue, and yellow tempera paints. Art teachers, take pity: break out the turquoise and bright purple (cyan or magenta would be more precise!)

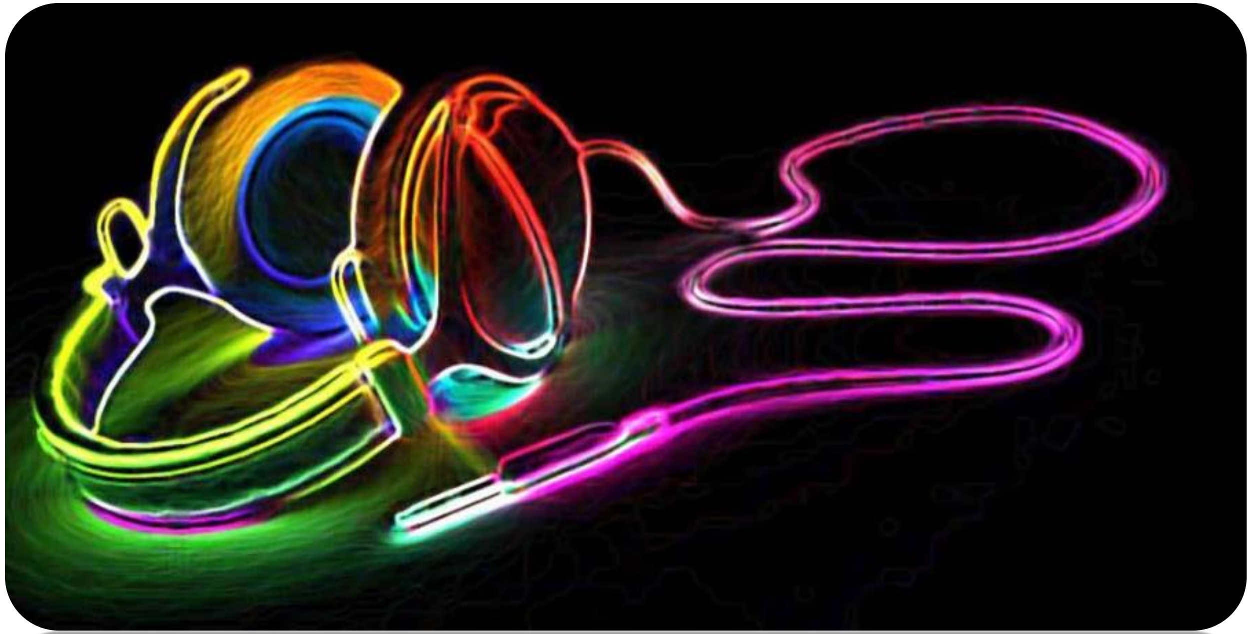


FROM ADDITION TO SUBTRACTION

- All that said, the real head scratcher in subtractive color has to do with the completely counterintuitive way we see it. To be perfectly blunt: when it comes to subtractive color, what you're seeing isn't really there at all. With most material objects, matter absorbs (or subtracts) particular wavelengths of the visible spectrum and reflects back the remaining wavelengths.

FROM ADDITION TO SUBTRACTION

- The make matters more confusing, we rarely perceive pure colors. Red fabric is likely to reflect back at least trace amounts of all the colors of the visible spectrum, even thought we might not perceived their existence. That's why we see the vast numbers of colors that we do; there are millions of combinations of wavelengths in the visible spectrum.



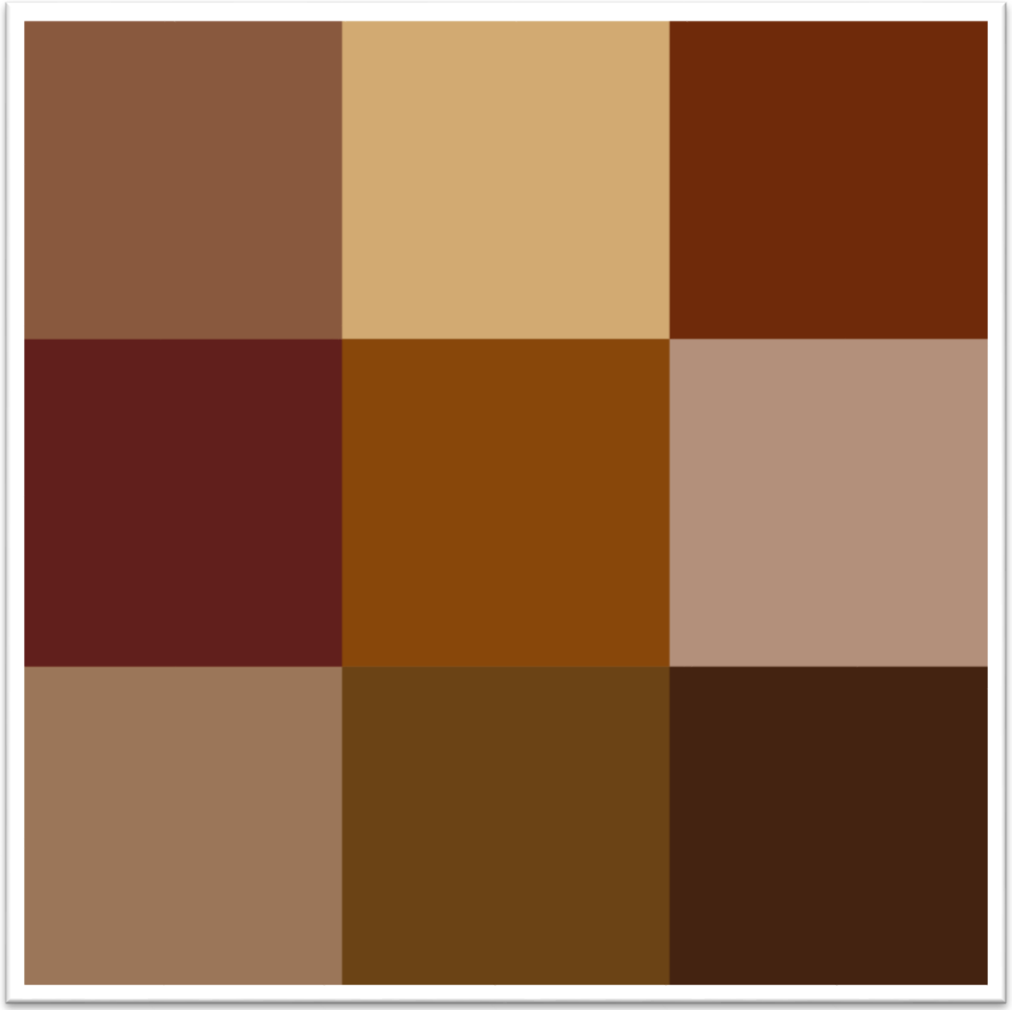
BLACK & WHITE: NON-SPECTRAL

- How do black and white play into this mix? As Newton discovered, in the realm of additive color, white is not one color; rather, it is the product of all colors of the spectrum mixing together at once. Conversely, black is the absence of light altogether - think outer space. In the subtractive system, white is perceived when all light is reflected back from an object, and black when an object absorbs all light.

BLACK & WHITE: NON-SPECTRAL

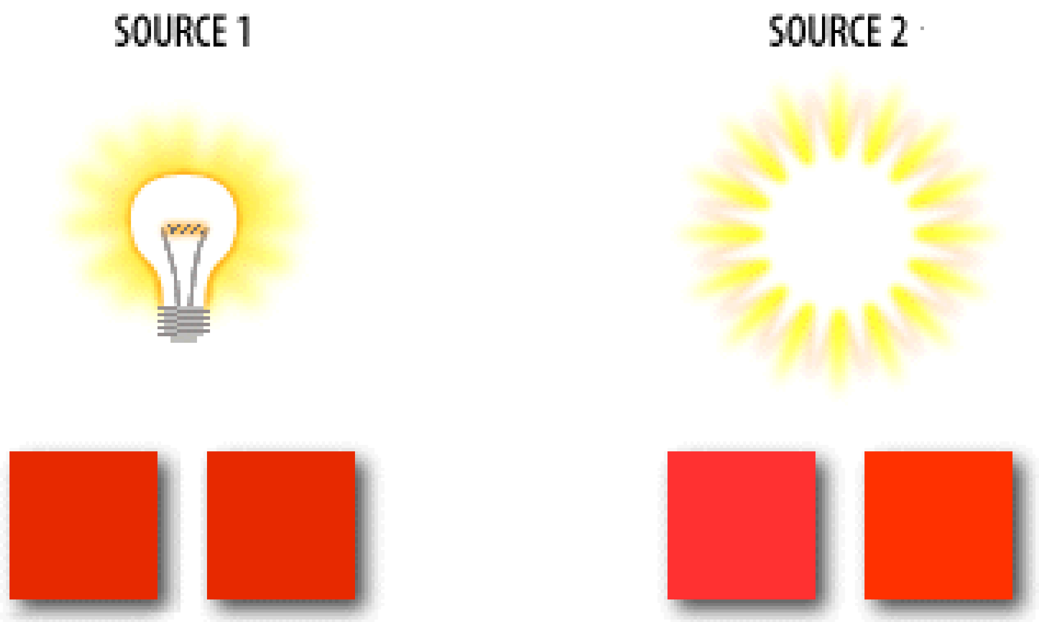
- Then there's gray. Logic would leave you to believed that anything between black and white, between the absence of color and the presence of all colors, would have to be a color of some sort. This is true, except in cases where all the wavelengths of light are equally absorbed and reflected. In the case of subtractive color, if 80% of the projected wavelengths are absorbed into a gray object, you'd perceive a very dark gray, with only a small percentage of light's wavelengths reflected back into the eye. If 20% of the wavelengths were absorbed, you'd perceived a light gray, with the vast majority of the wavelengths being reflected.

BLACK & WHITE: NON-SPECTRAL



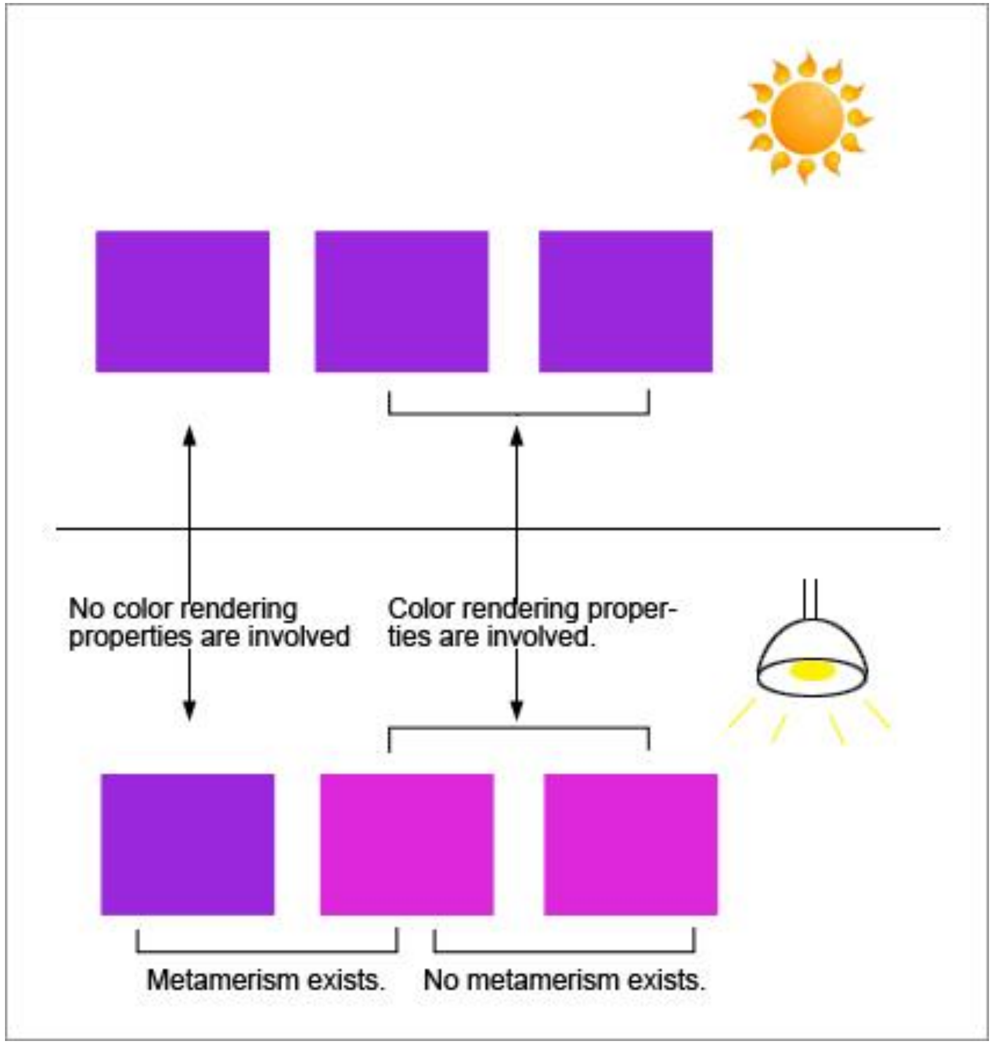
- What about brown? We think of it as a neutral color like black, white, and gray, but it's really a form of orange. The colors that surround us are rarely pure. As they mutate from dark to light and from dull to bright, innumerable gradations appear within each hue. Take pure orange, change its value by darkening it, and change its chroma by dulling it, and you'll have brown.

THE METAMERISM MATCH



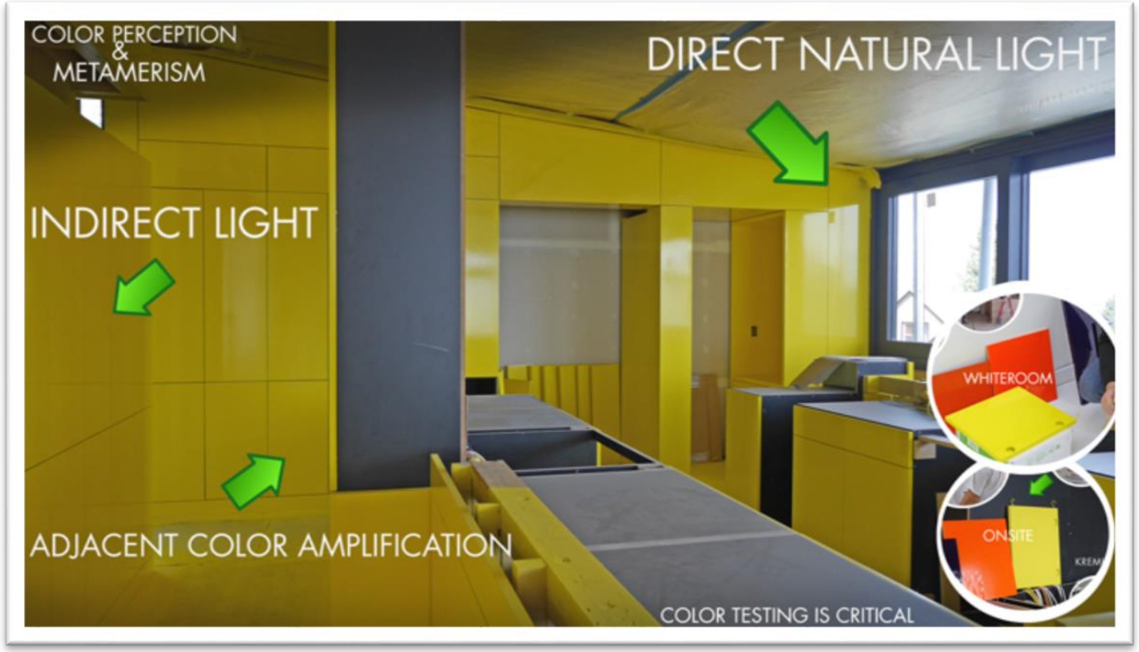
- Differences in lighting conditions can make it quite frustrating to match colors, especially if you're matching them in one environment and taking them home to another. The swatch of fabric that, under the rug store's fluorescent light, appears to be a perfect match for your couch might not be such a dead ringer in the incandescent light of your living room.

THE METAMERISM MATCH



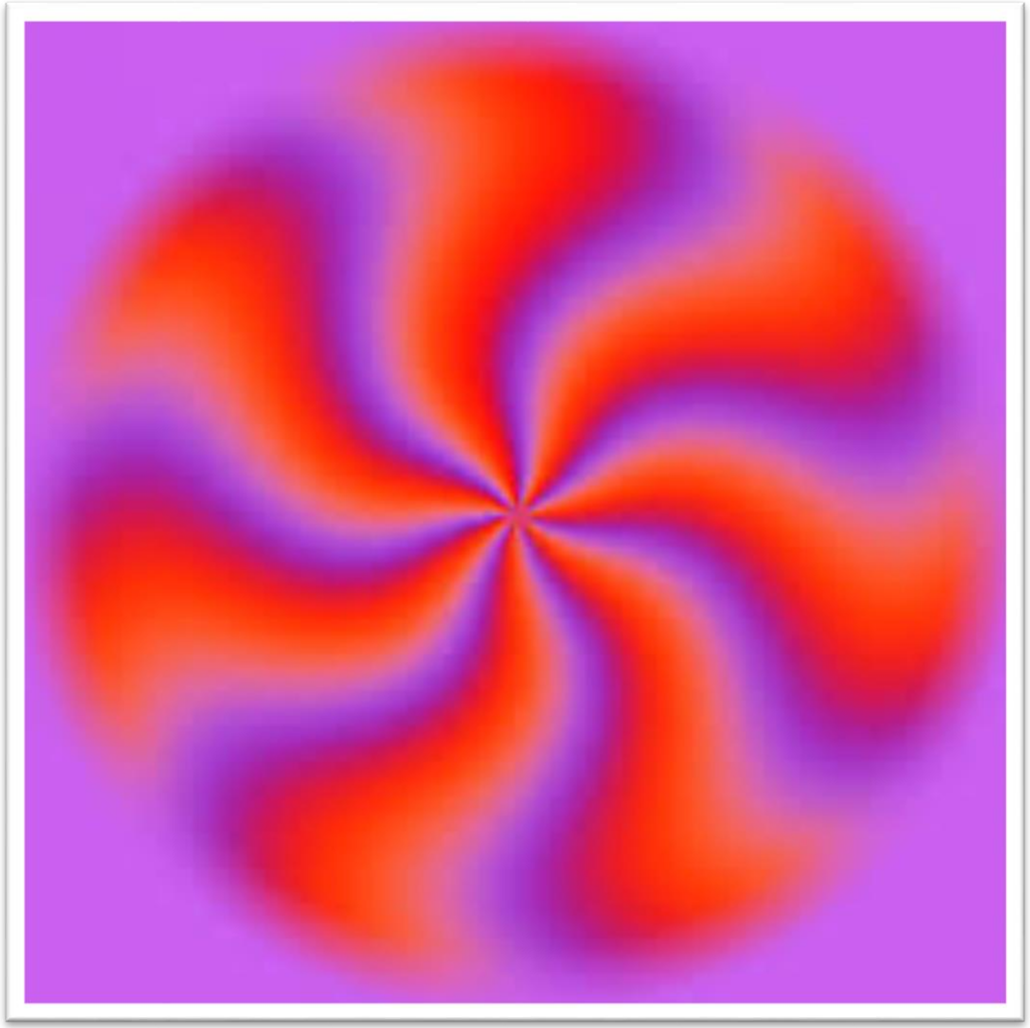
- There's more to it than just the light source. If the rug and the couch were made from the same exact materials, they could be a match in both kinds of light. But if the rug and couch are made from different materials, then, even if the same day or paint it used on both, they will absorb light differently.

THE METAMERISM MATCH



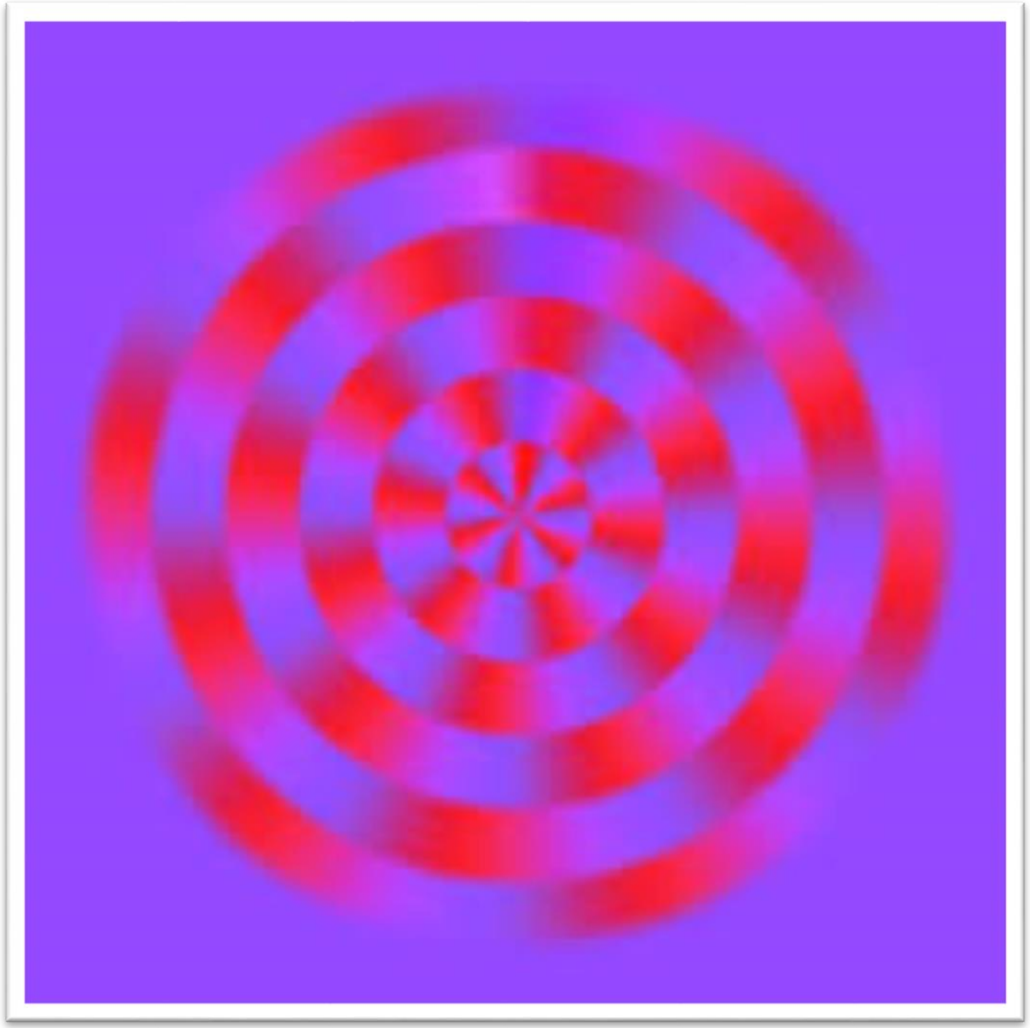
- Fortunately for interior designers and dedicated shoppers, precise measuring devices and complex mathematical formulas have closed the gap; an advanced matching process called metamerism makes it all possible. Use for all sorts of products in the all sorts of industries - from cars to clothes to printing - metamerism makes it all possible. Used for all sorts of products in all sorts of industries - from cars to clothes to printing - metamerism is the reason your dashboard, leather seats, and steering wheel maintain their aesthetic integrity, not matter the light conditions.

COLOR GAMES



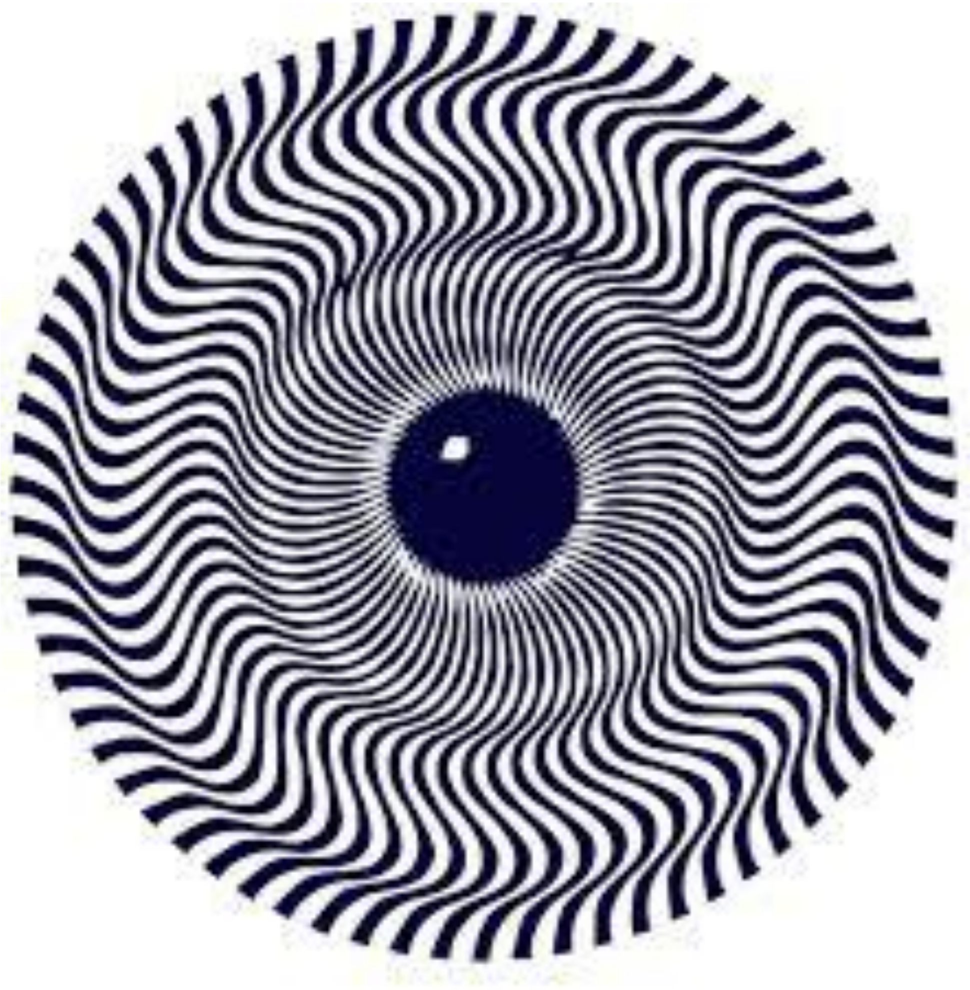
- What Newton, Maxwell, Young, or Einstein were unable to explain is the reason can take on two different reds depending on whether it is topped with a slew of orange or blue throw pillows. It took neuroscientists to solve this mystery, which comes down to a complex set of brain-level processes that offer a fascinating challenge to our notions of reality.

COLOR GAMES



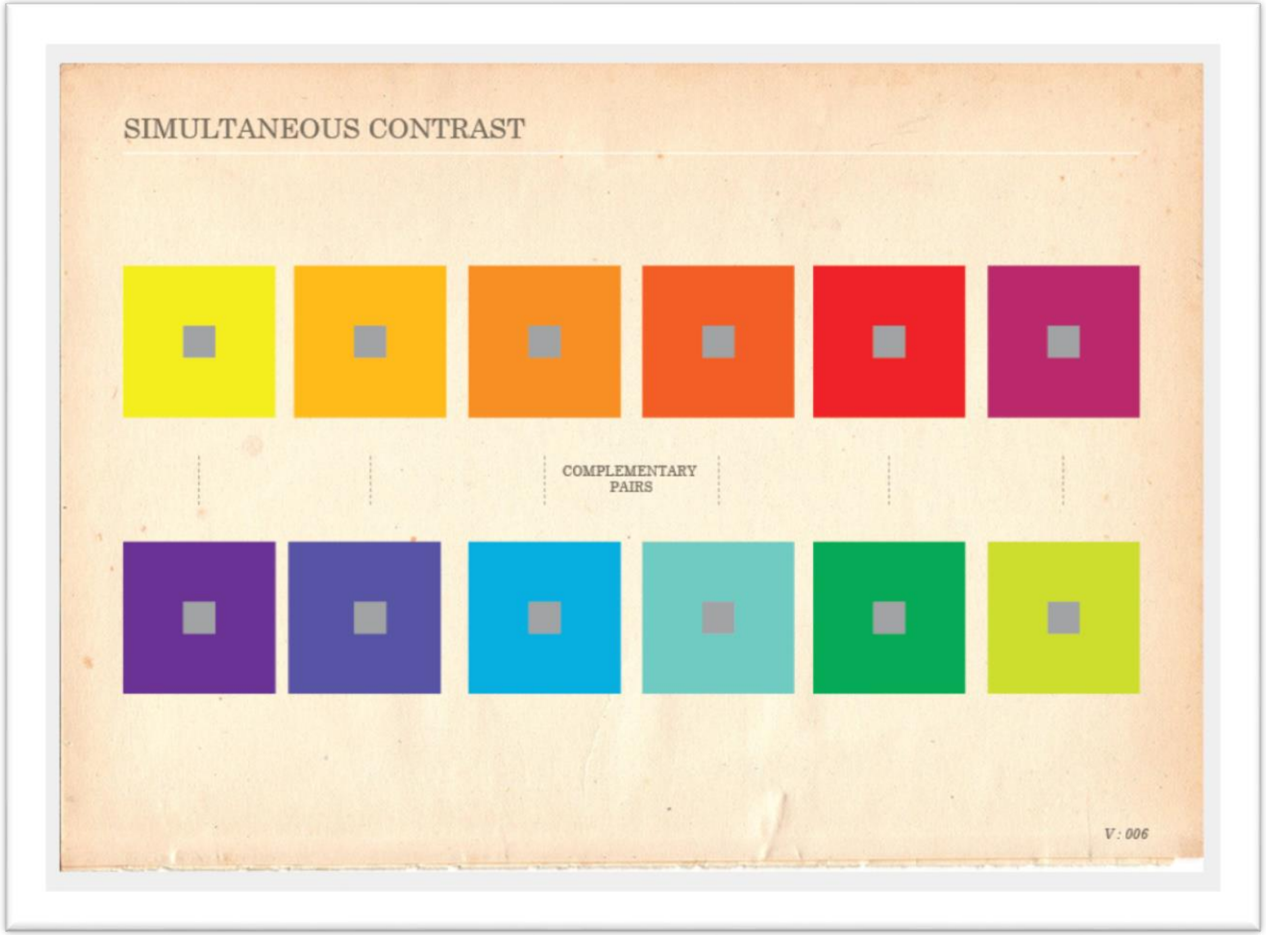
- The human brain is constantly gathering information and making interpretations based on what it takes in; the amount of information is so vast that the brain valiantly attempts to sequester its intake into categories to avoid overload. As it does this work, the brain also likes to fill in gaps, fabricating "logical" conclusions to avoid perceptual downfalls. These novelistic tendencies are part and parcel of the brain's efforts to prevent a full tilt shutdown in the face of hundreds of discrete pieces of sensory stimuli.

COLOR GAMES



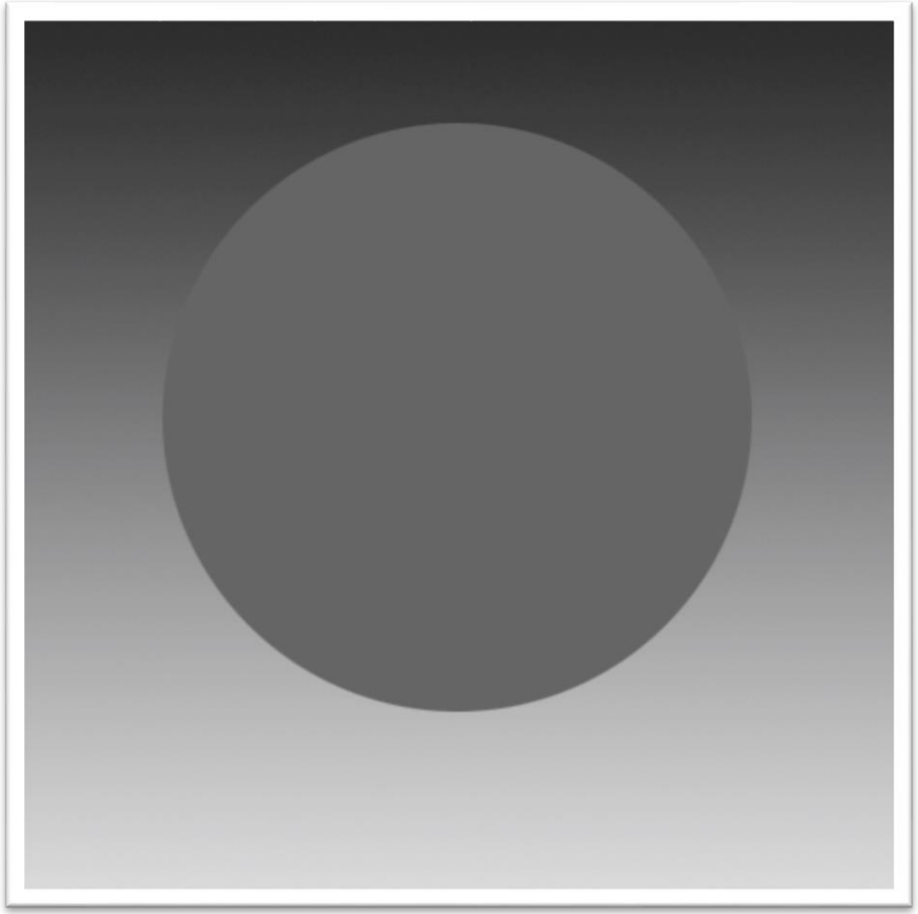
- Whereas the chemistry of given material colludes with our visual cones to present us with the perception of particular colors, the colors themselves are not actually fixed. Sometimes a color can seamlessly shift from looking more like the neighbor to its left on the electromagnetic spectrum to looking more like the neighbor on its right. Sometimes we even see color that isn't there.

SIMULTANEOUS CONTRAST



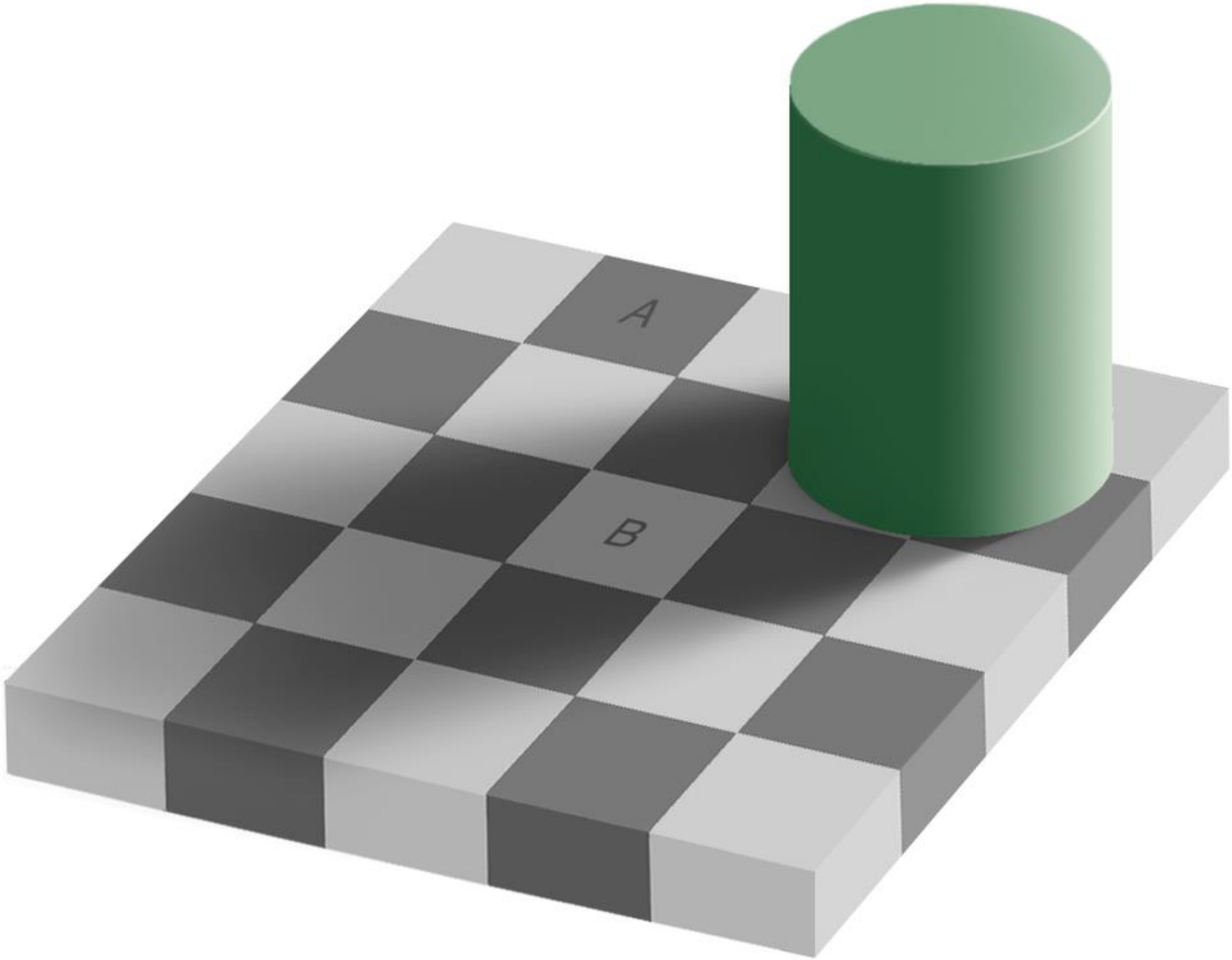
- Because color is interpreted by our brains, a single color has the ability to shift and chance depending on the color adjacent to it. A particular red placed beside a blue will appear quite different when it is set next to an orange. This phenomenon is known as simultaneous contrast.

SIMULTANEOUS CONTRAST

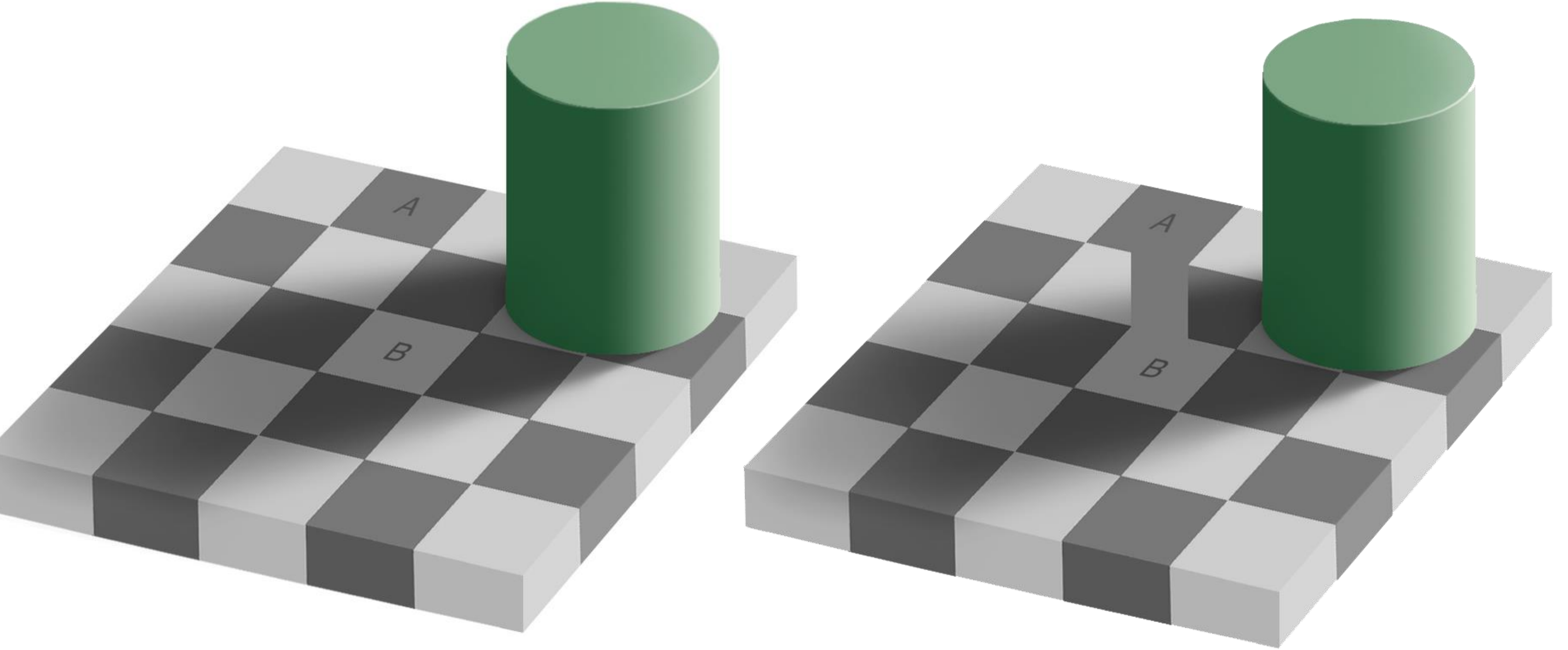


- To understand how simultaneous contrast works, take a look at the black and white image below, designed by physicist/chemist, Robert Shapely and psychologist, James Gordon.
- Pay particular attention to the upper and lower parts of the sphere.

SIMULTANEOUS CONTRAST



SIMULTANEOUS CONTRAST



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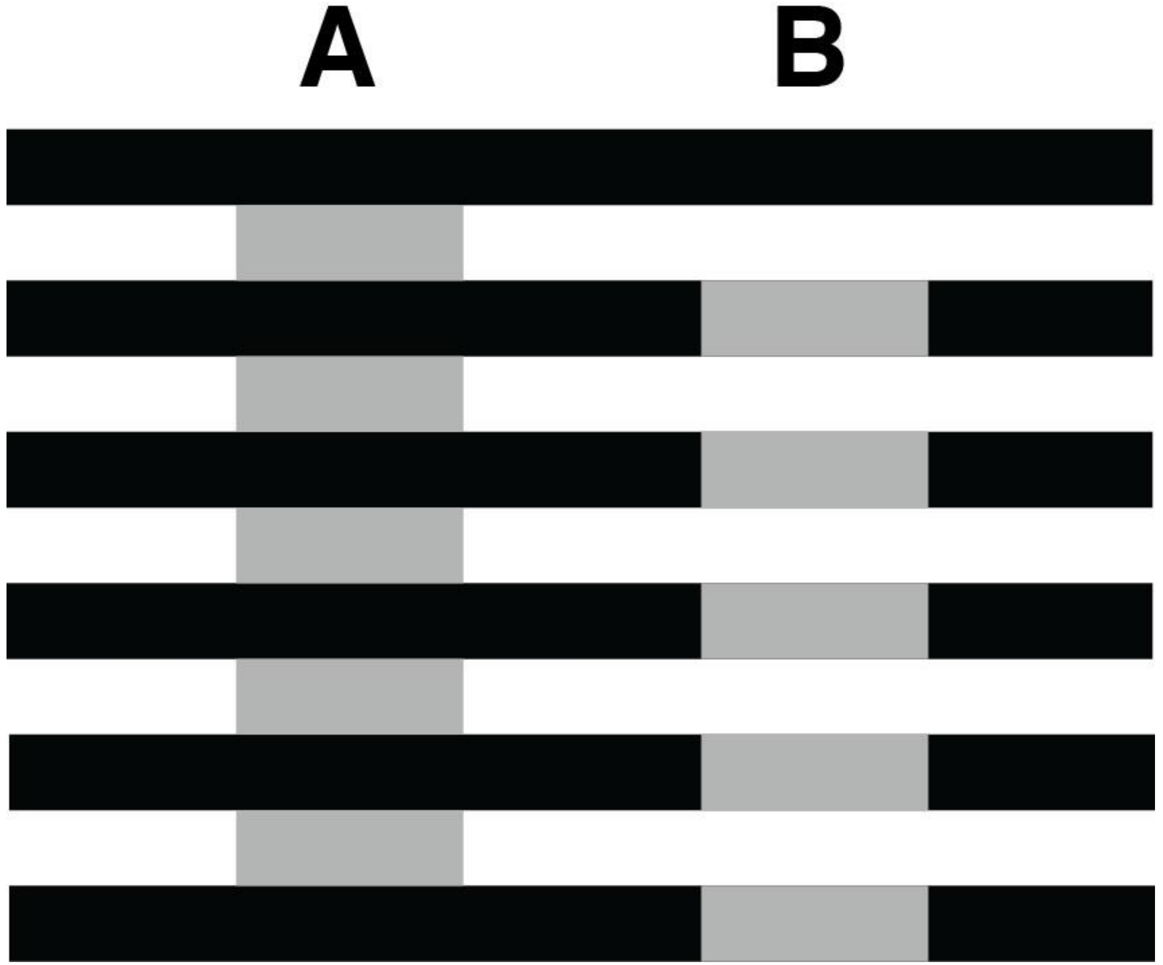
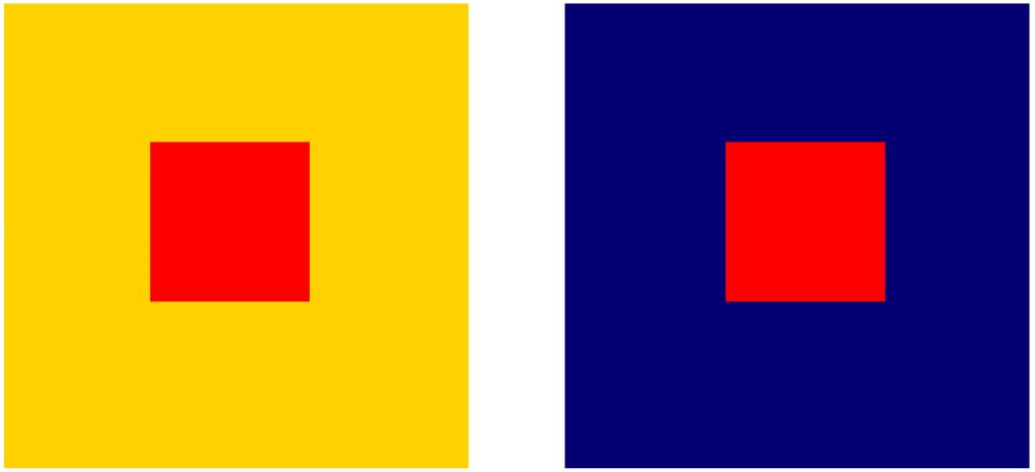


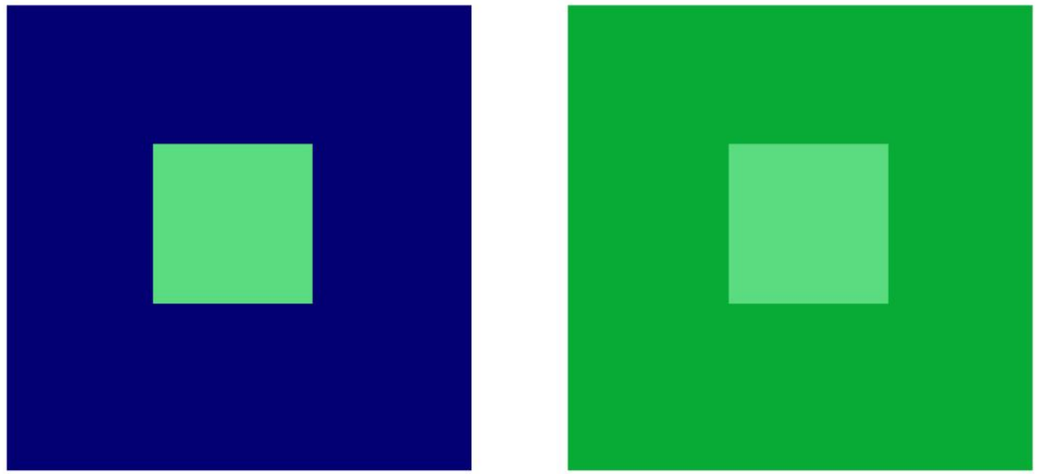
- Now look at the intersecting line below in this exercise designed by Michael White. The gray lines on the top appear significantly lighter than the gray lines on the left. And yet a machine that measures color, will tell you they're exactly the same.

SIMULTANEOUS CONTRAST



- Now comes color and simultaneous contrast. Check out the squares:
- The red square on the left appears to be darker than the red square on the right. But they are exactly the same

SIMULTANEOUS CONTRAST



- The same holds true for these green squares:
- The green square on the left looks brighter than the one of the right, but the hue, just as in the last example, is the same. In each case, when the squares are placed on top of the lighter color, they look darker; placed on the darker background, they look brighter.

THE ART OF SCIENCE AND THE SCIENCE OF ART

- The year 1839 saw the publication of the defining text on simultaneous contrast, *Principles of Harmony and Contrast of Colours* by chemist Michel Eugene Chevreul. Chevreul had served as the director of dyeing at a tapestry company in Paris, and he found himself fielding constant complains about the "want of vigour" in the black pigments.

THE ART OF SCIENCE AND THE SCIENCE OF ART

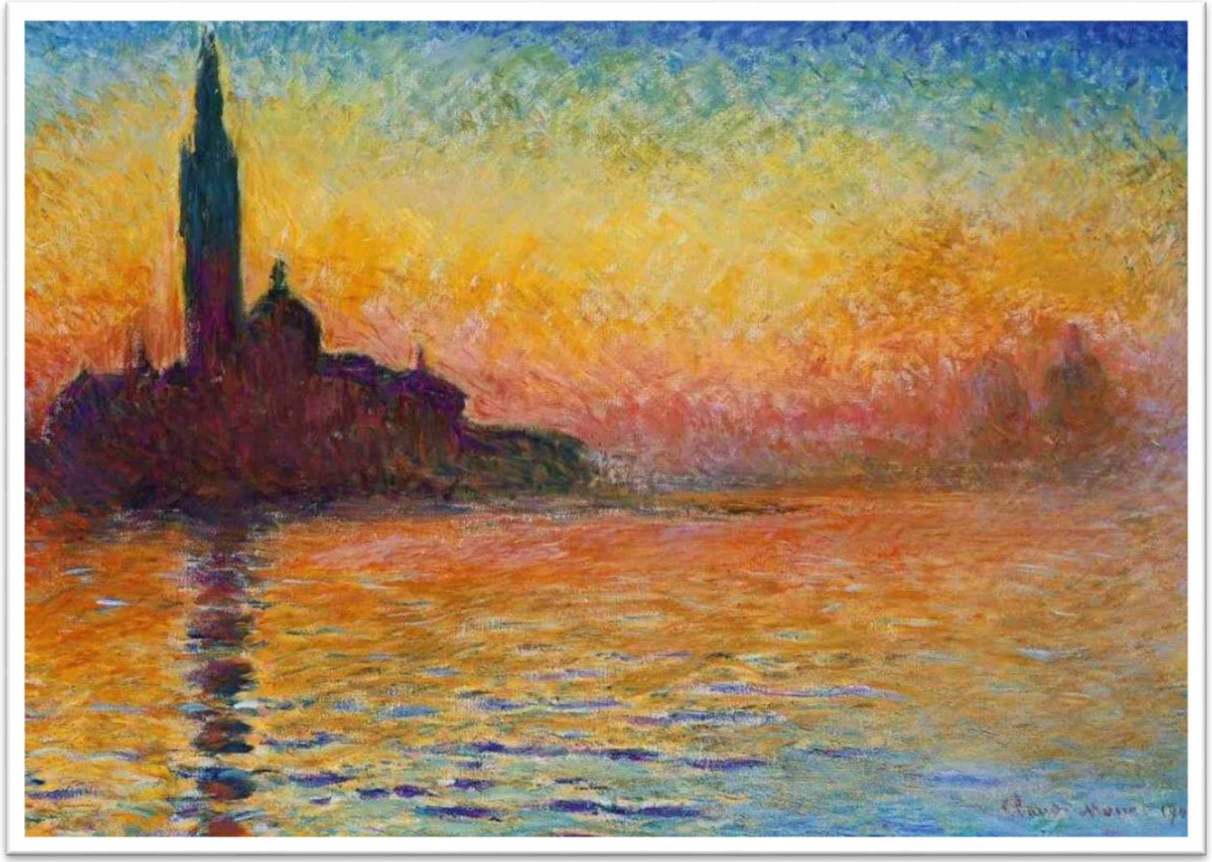
- He also noticed that the actual point of contact between two highly contrasting colors had the most "pop." The artists of the Renaissance had seen the power of this principle and made the most of it via a technique called *chiaroscuro* - the simultaneous use of very dark and very light paints to create an effect of light, movement, and three-dimensionality; but Chevreul was the first chemist to study and name the law of simultaneous contrast.

THE ART OF SCIENCE AND THE SCIENCE OF ART

- Today, paint of seemingly every hue, value, and chroma is available in ready to use tubes at your local art supply store, but it wasn't until the mid-18th century-just over a decade after Chevreul wrote *Principles of Harmony and Contrast of Colours* -that this was so. For the bulk of human history, the science and art of color were not divided.

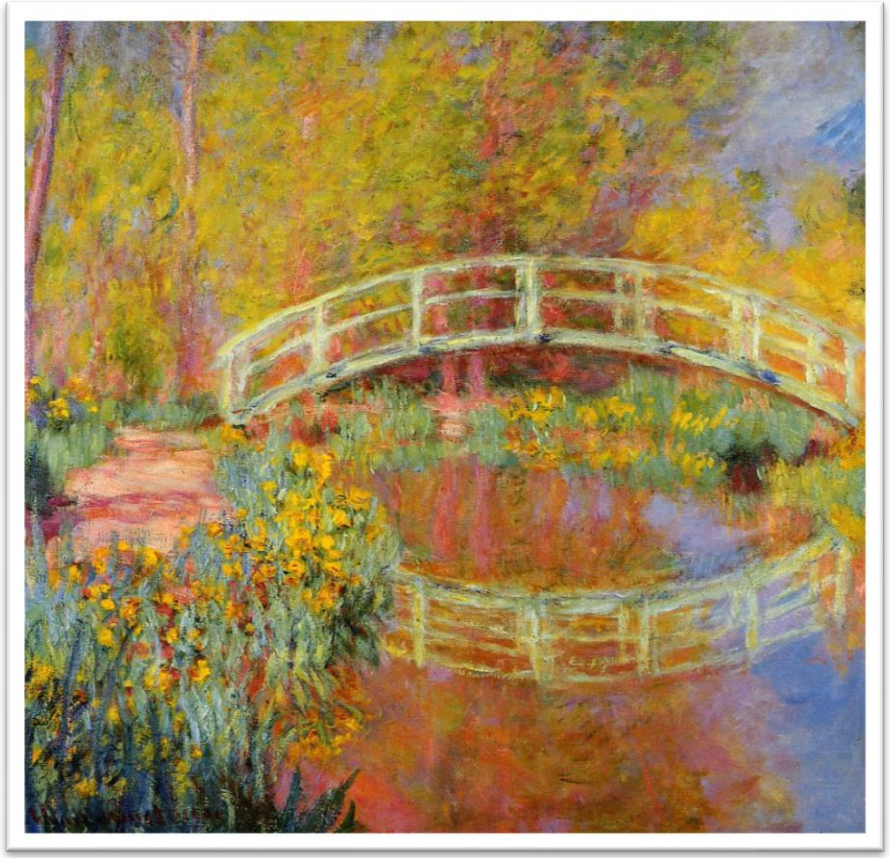
THE ART OF SCIENCE AND THE SCIENCE OF ART

- By the time the Impressionists started painting, modern chemistry could offer close to 2000 colors. Against the backdrop of the scientific knowledge that Newton and Chevreul had supplied, color suddenly went from a tool used for rendering form and invoking symbolism (like the Virgin Mary's blue cloak), to a tool used to express a wide range of artistic intentions.



THE ART OF SCIENCE AND THE SCIENCE OF ART





- The groundbreaking science behind color was an integral part of the Impressionists' method, and with the science and availability of color in a lock step, a new kind of artistic reality was born.

THE ART OF SCIENCE AND THE SCIENCE OF ART

- Scientifically minded painter like Georges Seurat believed that if, per Newton, light was made up of all colors of the spectrum, it would be truer to nature to depict color using tiny dots or small brushstrokes that spanned the entire spectrum.

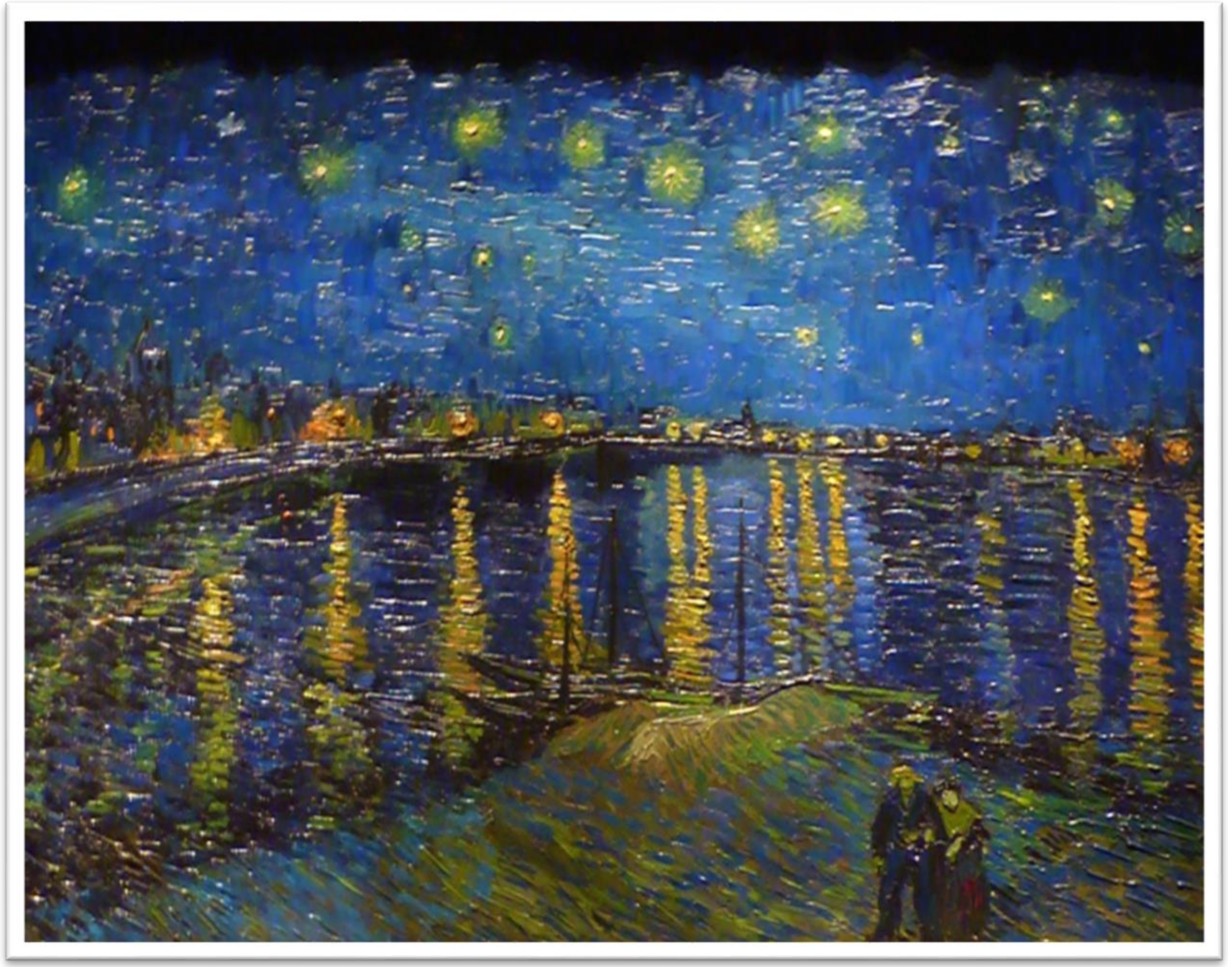
THE ART OF SCIENCE AND THE SCIENCE OF ART

- Seurat and his fellow Impressionists also put Chevreul's theory into practice with these small strokes of contrasting or similar colors to create dimension and the illusion of light. A tree in a Seurat painting may appear green from a few feet away, but get up close and you'll see reds and oranges, yellows and blues carefully placed beside greens that dominate. The resulting effects were much deeper and strangely more realistic when viewed from afar.

THE ART OF SCIENCE AND THE SCIENCE OF ART

THE ART OF SCIENCE AND THE SCIENCE OF ART

- Observers of the art world in the late 19th century would have been hard pressed to believe that color could come to an even greater prominence than it already held; but when the Russian Constructivists, Neo-realists, Fauves, and Abstract Expressionists arrived on the scene in the early 20th century (to name just a few of the art movements that embraced the prominence of color) color took center stage. Newton and Chevreul's theories continued to play starring roles in art, sometimes intentionally, sometimes not.



THE ART OF SCIENCE AND THE SCIENCE OF ART

- Today, for many artists, the abundance and low cost of paint have diminished or even eradicated the relationship between science and color; indeed the science of color is not part of the curriculum in most art departments at any level of education. Children continue to be taught the subtractive model of color (without knowing what it is called), and red, yellow, and blue remain the primary colors, even though science gave us a much more precise model some time ago. The science of color is by no means purely academic, as one can use the lens of color to explore the very nature of our universe. In fact - that's just were we are headed next.