Chapter 6 Lighting design - color applied

Osvaldo Perrenoud, light designer

Abstract

This chapter discusses the ways to illuminate and apply colors in lighting projects.

Keywords:
Design, Color, Lighting, Stage, Architecture, Perception

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1.Introduction

The creative process and creation.

The creative process can be described and theorized as a chain of decisions that guide the construction of a final product and creation must be understood as the formal result itself.
In the case of Lighting Designers, we can generate specific works empirically or from a clearly established creative process. An empirical creative process is just gestation, like a flowering seed.
Some professionals make their creations without thinking about organizing their way of thinking and developing a new product, but this way it can, at any time, be understood, conceptualized and transformed into a theory about this creative process.
Above all, creating is using the way we see and understand the world within a given context.
I usually work with a lot of freedom, without strings attached, but I make decisions based on a creative process that I developed over the years and that guides me with clear ideas.
LDs often need to share and commit their ideas with others; whether professionals or clients involved in the construction of a work.
It is this expertise and knowledge accumulated throughout my professional life and as a teacher that I want to talk about from now on!

When you find an indication in the center of the page with the word "Internet" it is an invitation for the reader to search for that image. Sometimes there will be a link accompanying it to make your job easier

2.Light Art

Lighting is not just making visible, putting an end to darkness, but creating out of light. In view of this bias, some LDs say they do LIGHT.
We must think of light not as a way of giving visibility to the world, but as part of an interpretive artistic procedure that involves sensation and perception.
These are the main ingredients of Light Art.
From the moment we come into contact with an illuminated environment, we start to have emotions, feelings and to attribute meaning to what we see.
The more direct the message, the greater the chance of reaching its final destination, the observer, with clarity.

Internet
Dan Flavin - Untitled, 1973. Pinakothek der Moderne, Munich, Germany.
James Turrel - Alpha (East) Tunnel. Roden Crater, Flagstaff, United States.
Dan Flavin - Untitled to Bob and Pat Rohm, 1970. Weltraum Gallery, Munich, Germany.
James Turrel - Inner Way, 1999. Munich RE, Munich, Germany.

The ideas of the artworks above are congruent, modifying the space through the inclusion of the observer in a reality that is different from everyday life.
Internet
Dan Flavin - Chiesa Rossa, 1996. Milan, Italy.
James Turrel - Memorial Chappel at Dorotheenstädtischer Cemetery. Berlin, Germany, 2015.
The technology of fluorescent lamps allowed only one color per light source, currently, with LED technology we can have several colors using the same devices.

2.1 Sensation, perception and interpretation

About 15.000.000 years ago. Very hot, very dense and disorganized. No life, no stars, no galaxies, no molecules, no atoms, no atomic nuclei. A soup of elementary particles: electrons, photons and also quarks and neutrinos, the future constituents of atoms.
And then, the Big Bang.
Carbon, Hydrogen and Oxigen… But we get a Sulfur…

Figure 2. CHO and S.

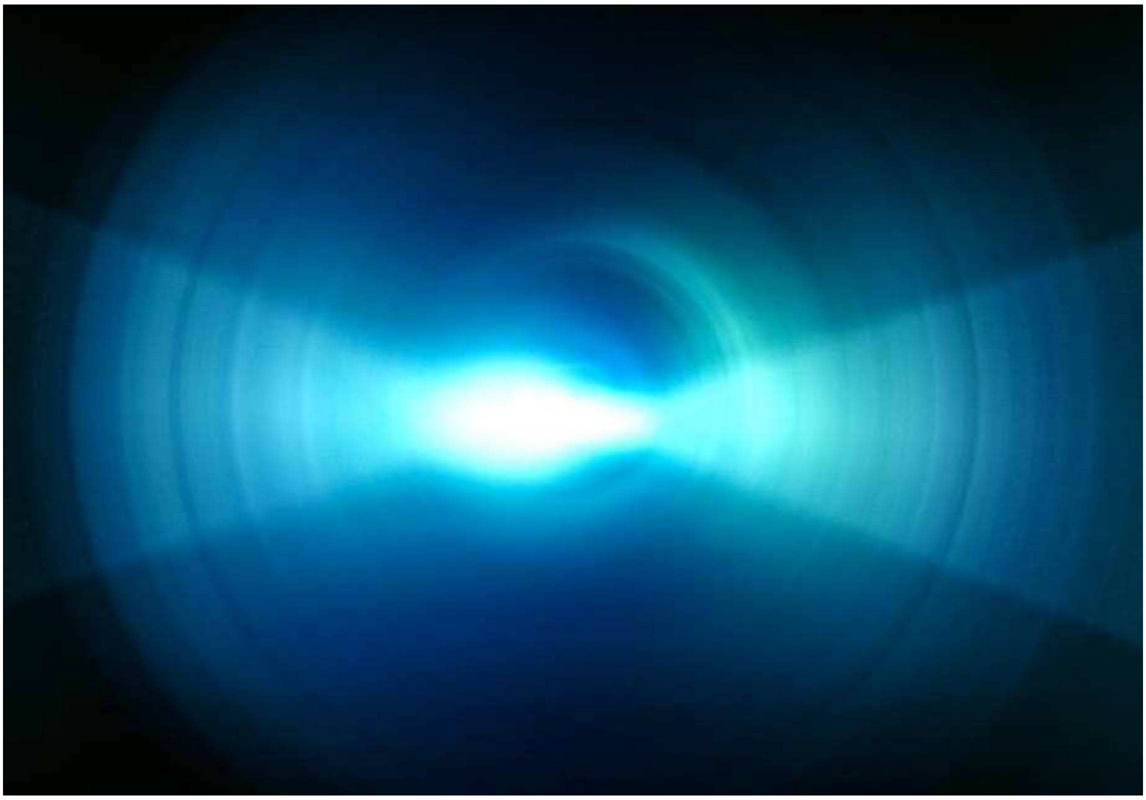

Figure 3. My Big Bang.

After that, our solar system exists.

Sensation is our body and brain's first reaction when we come into contact with something in the world. Imagine human beings from the remote past watching the next scenes. Certainly because they did not have scientific explanations (and there was no science yet, only knowledge through life experience) they attributed these phenomena to primordial gods, naturally, to the gods of nature.

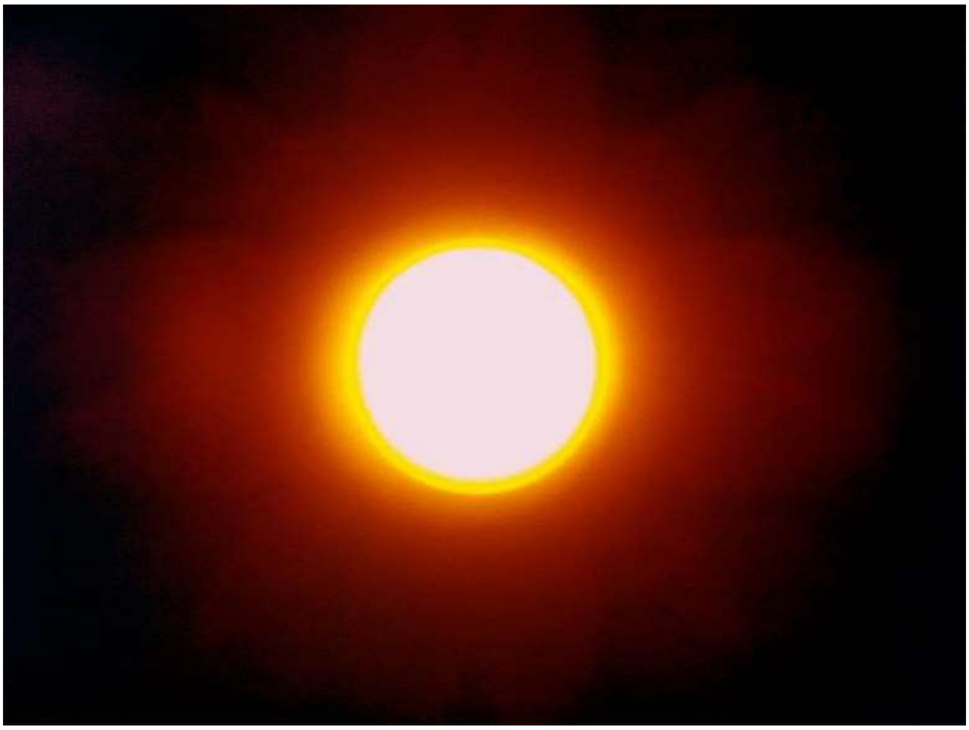

Figure 4. The Sun.

Figure 5. Maranguape, Brasil.

Figure 6. The Moon.

After the sensations, we make connections between what we are experiencing and the repertoire of knowledge from past experiences, consciously or unconsciously fixed in us. We form, then, a concept and a value judgment, the Perception.

A painter goes through this process when observing an everyday scene. When we see a painting, we follow the same path, but usually without the real scene in front of us and this is the magic!

The same can happen when we are faced with the vision of a scenography or a scenic lighting.

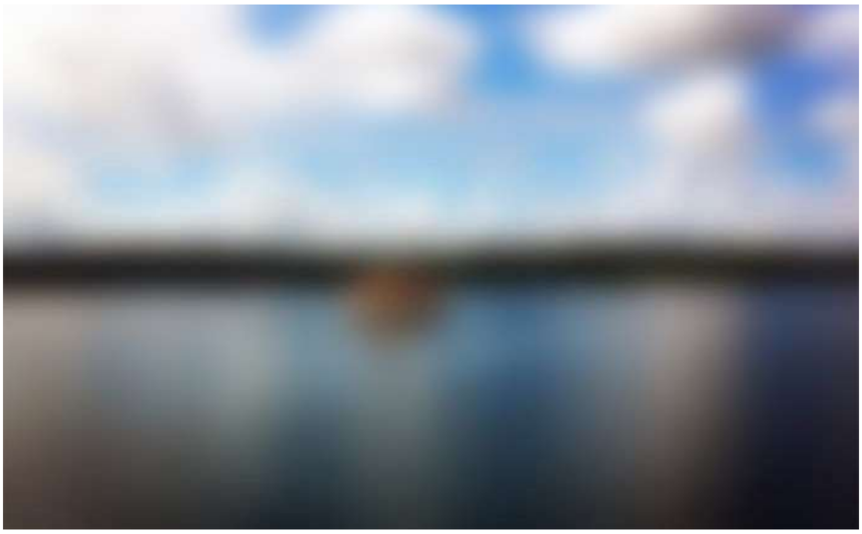

Figure 7. Piranhas, Brasil.

Figure 8. Concert, Canoas, Brasil, 2009.

And the images seemingly confused but that have definite meaning?

Figure 9. Grafitti Wall, Street Art.[3]

The perception will be much more requested to decoup and resignify the image and, for some, it is impossible to be understood.

Interpretation is an accomplished perception but it can also be a new form of expression based on what was previously registered by any form of communication and perceived by one or more senses of the observer.

[3] Image by ShonEjai from Pixabay.

Figure 10. Interpretation of Rembrandt's paint Philosopher in Meditation, 1632.[4]

Light has no smell, sound or taste, but bright environments can encourage the use of these elements. Touch is rarer to be used, but the feeling of heat or the material of some luminaires can sometimes be part of the work itself.

How to make a big bang with light? We have to ask ourselves some questions. At where? When? Who are the observers? How much investment can be made in this work… of money… of time? How long will this be available for observation? Is a Big Bang a short timed effect or do we want to show the whole process? Hmmmmmmmm...

The previous Big Bang was made by me, with light and phone camera.
We can divide the basics of lighting with reference to some aesthetic and technical aspects and appropriate a type or a set of them to conceive lighting in the broad sense of the word, to make LIGHT.

[4] Rembrandt: Study in realtime lighting techniques, work by Alexandros Demetriades.

Figure 11. Technical.[5]

Figure 12. Conceptual.[6]

[5] Exposition Casa Cor, Belo Horizonte, Brasil.

[6] Exposition Storia e Leggenda dei Cavalieri del Tempio, Milan, Italy.

Figure 13. Historical.[7]

Figure 14. Contextual.[8]

Light has many facets and forms of interpretation.
A lighting project must consider many aspects before it is conceived.
We may create from the dark but is more important make sense, and make sense mean permits sensations, the perception belong to observers.

[7] The Painted Hall, King William Walk, Greenwich, London, UK.

[8] Night Club, Boston, USA.

Figure 15. Artistical.[9]

Figure 16. Symbolical.[10]

[9] U.nico Produções Artísticas - The Great Attraction. Artists: Luciano Albo and Fernando Pezão. Photo: Gerson de Oliveira.

[10] Galleria Vittorio Emanuele II, Milan, Italy.

Figure 17. Material.

Figure 18. Inventive.

Figure 19. Poetical.[11]

[11] Model: Felipe Lopes Perrenoud.

3.Light and color, color and light

Probably light and color are the same thing?
Different perceptions of the same effect?

3.1 Corpuscular, undulatory and quantum theories

17th century.
Newton - corpuscular theory. All matter is made up of tiny particles called corpuscles.
Huygens - undulatory theory. Light is transmitted as waves.

Early 18th century.
Thomas Young - light IS a wave.

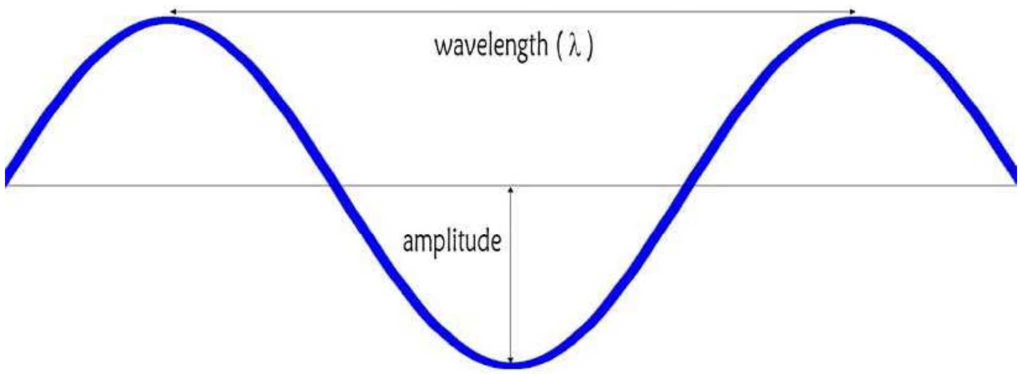

Figure 20. Wavelength.

Wavelength - distance between two successive peaks.
Amplitude - difference in level between a peak and a valley.
Frequency - a single occurrence per second in Hertz (Hz = 1 / sec).
Speed - movement referred to a timeline.

19th and early 20th century.
Kirchoff, Rayleigh, Wien, Planck and Eisntein.
Light just as an electromagnetic wave does not explain some phenomena that are understood if light also has a corpuscular characteristic.
Planck sought to discover the reason why an object's radiation changes color from red to orange and, finally, to blue as its temperature increases.

20th century.
Heisenberg and Schrödinger - quantum theory. Light is emitted in packets instead of a steady stream, the packet of light is the quantum.

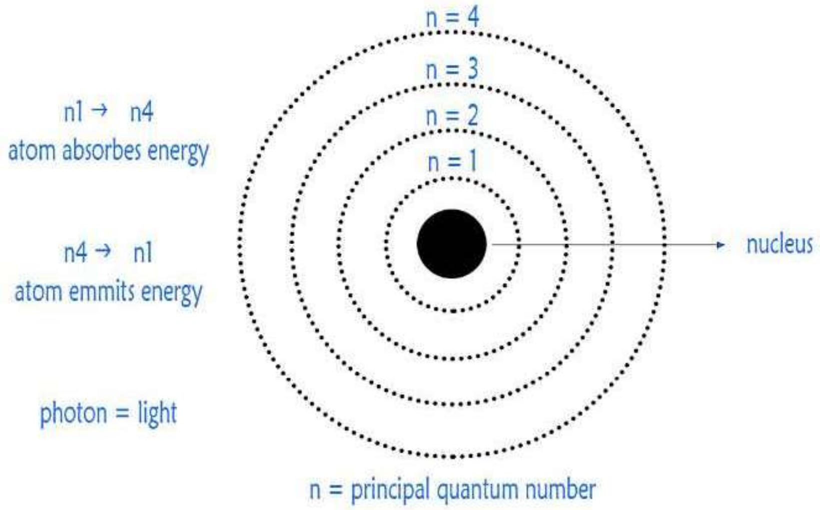

Figure 21. Quantum Theory.

This theory becomes practical with its various uses and studies in the present and we hope that some will always be in the past.
Subatomic particles - studies about the evolution of the Universe.
Atom and molecules - materials and technology.
Quantum optics - communications, lasers, quantum computing, quantum cryptography.
Nuclear physics - bombs, medical uses, power.

Physics: light is an energy. 300.000 kilometres per second. Radiated in a straight direction. Straight Direction? Certain kinds of laser beam can follow curved trajectories in free space.
It is to think small that only we human beings know what the world is like, we do not know it completely or what is on Earth and we continue to learn, when we do not stop in time accepting previous studies as absolute truths. Thus walks humanity. One day medical scalpels will only exist in museums.
Studies done by the American Physical Society show numerical simulations and experimental demonstrations for the side view propagation of a non-paraxial Weber acceleration beam and a paraxial Airy beam along parabolic trajectories. This means that light bends even in the air, because in the water we already knew. Or not?

Figure 22. Remember?

3.2 Incident light on object: reflection, absorption and transmission/refraction

It is the effect generated by the action of light on material substances and captured by an optical system; in the case of man, captured through our eyes and perceived by our brain.
Each lens or set of lenses captures light and color differently.

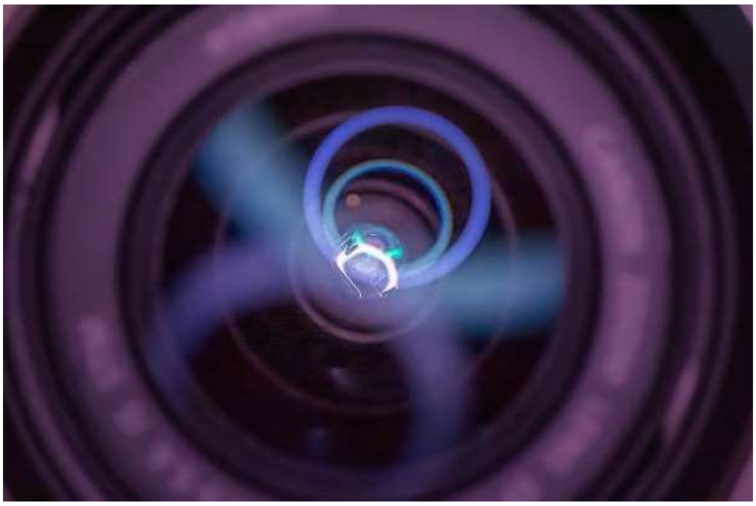

Figure 23. Artificial eye.[12]

[12] Photo: Camila Perrenoud.

Drone cameras, 35mm film, rangefinder, SLR/DSRL, medium format, compact, mirrorless, action, Polaroid, video, phone and 360 degree.

Photo means light in greek…

The photographer must master and know the possibilities of each camera and, in particular, the appropriate lenses for each situation because they capture the light and the professional can define the result through appropriate adjustments.
Just as our eyes have limits, so do lenses.

When we talk about animals, there is a much greater diversity of ways to see the world around us.
Some see better, some worse, but surely all eyes are suited to the specific needs of each being.

Figure 24. Animals.[13]

[13] Model: Photo: Camila Perrenoud.

Figure 25. Our apparatus.[14]

Necessary elements for the perception of colors by human being: the stimulus effected by the light and reception of light through our vision.
Each substratum or object has characteristics that are linked to its power to reflect, transmit or absorb portions of light and, depending on these characteristics our senses are stimulated and we see colors.

Figure 26. Incident light.

[14] Model: Débora Sales. Photo: Camila Perrenoud.

The absorbed part is transformed into another type of energy, usually heat. Dark objects tend to be hotter than bright objects when subjected to sunlight or even an artificial light that emits heat.
Reflection and refraction can occur specularly and / or in a diffuse way and this depends not only on the object, but also on the qualities of the light. Elements, molecules and even cellular structures have unique reflectance signatures. A graph of the reflectance of an object in a spectrum is called a Spectral Signature, this is very important in star studies, for example:

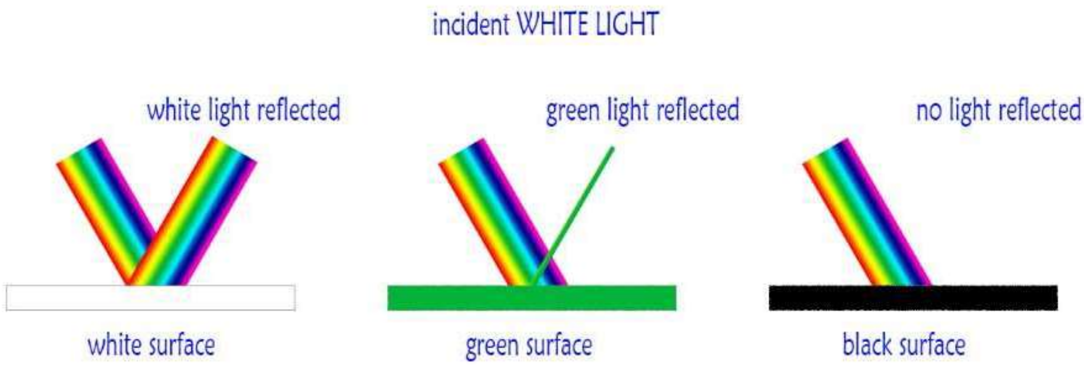

Figure 27. Reflexion and absorption.

What mean white light? What mean no light reflected?
Does this happen in reality?
The answer is no, some portion of the light is reflected, sometimes a lot of light is reflected by everything that looks black and we end up seeing a brownish fabric for example.
Some experiments and research are being done in order to obtain a perfect black, not reflective at all.

The Vantablack developed by Surrey NanoSystems using carbon nanotubes reaches 99.965% of absorption of incident light rays.
Engineers at MIT (Massachusetts Institute of Technology) developed Blackest Black with the vertical alignment technique of carbon nanotubes and managed to achieve 99.995% of absorption.
The Redemption of Vanity: that artwork was conceived by Diemut Strebe in collaboration with Brian Wardle, covering a real diamond estimated to be worth $2 million with blackest black.

Internet
Vantablack.
MIT - The Redemption of Vanity.

About refraction:

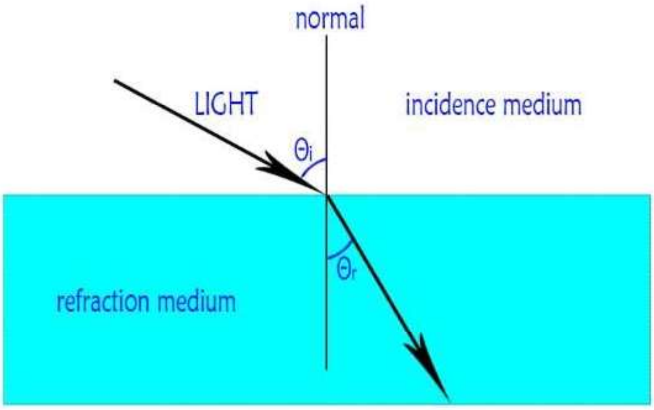

Figure 28. Law of Refraction, Snell-Descarte's Law.

n_i - index of refraction of incidence medium
n_r - index of refraction of refraction medium
Θ_i - angle of incidence of light
Θ_r - refraction angle of light

$$n_i * \sin\theta_i = n_r * \sin\theta_r$$

Figure 29. White-backed stilt at Capão da Canoa, Brasil.[15]

The fish is always at a different point from the one the bird sees, this calculation is done automatically by daily experience, applied optics!

[15] Photo: Sérgio Ordobás.

4. Perceived light

Electromagnetic radiation can be considered as a stream of massless particles, called photons, which each have a certain amount of energy, moving in a wave pattern at the speed of light.
Electromagnetic spectrum is the range of all types of EM radiation. The amount of energy contained in the photons defines each type of radiation. The waves have variable energy as can be seen in the figure below.

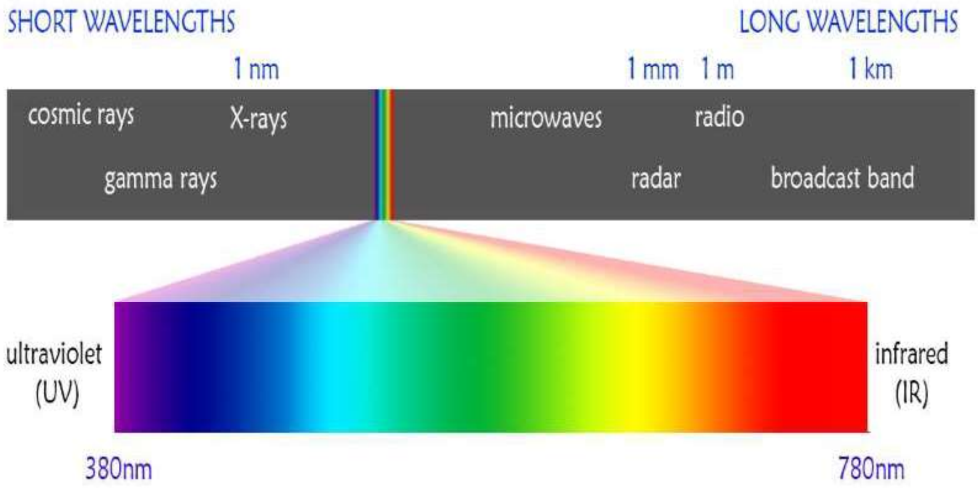

Figure 30. Electromagnetic Spectrum.

If we consider the electromagnetic radiation that reaches Earth from the Sun, light is the part that allows us to see things in the world.
Otherwise, when we call all this energy light, then the portion that the human being can see will be called visible light.
There is a misunderstanding here because "visible light" only exists when it reaches our eyes directly and we see the color of the light source or when there is a substratum that allows this visibility.
Light is radiation that allows us to see!
For this reason I prefer the first option, electromagnetic radiation is all the energy emanating from the sun that reaches us and the portion between 380nm and 780nm is called light. If we use the frequency to measure each portion of the light, we have the range between 430THz (terahertz) and 750THz, this makes it easier to understand the terms Infrared and Ultraviolet.
A radiation composed of a single wave of fixed amplitude and frequency is called monochromatic; the spectrum is composed of several monochromatic radiations with their relative frequencies.

COLOR	λ(nm)	ν(THz)
Infrared	>1000	<300
Red	~ 700–635	~ 430–480
Orange	~ 635–590	~ 480–510
Yellow	~ 590–560	~ 510–540
Green	~ 560–520	~ 540–580
Cyan	~ 520–490	~ 580–610
Blue	~ 490–450	~ 610–670
Violet (visible)	~ 450–400	~ 670–750
Near ultraviolet	300	1000
Far ultraviolet	<200	>1500

Figure 31. Colors - amplitude and frequencies.

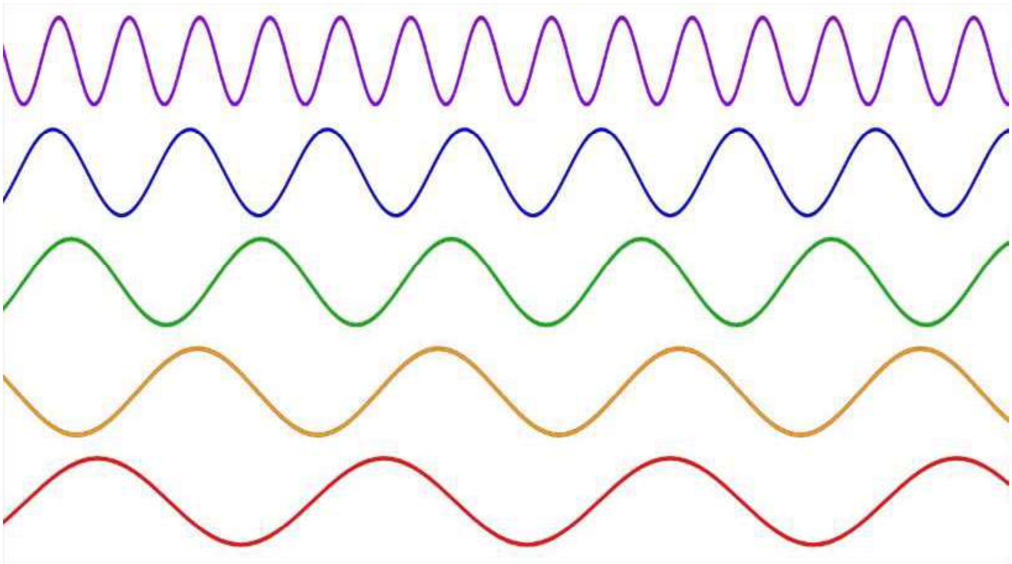

Figure 32. Colors - short and long wavelengths.

4.1 The visual process of human eye

Visible radiations (color stimuli) are directed by the eye to the reticular membrane that transforms them into physiological excitation.

The reticular message receptors send this excitation, through nerve fibers, to the optic nerve and through it to the brain.

This excitement becomes a sensation in the sulcus calcarine that is connected with the cerebral cortex and then into conscious vision (perception).

For the formation of the image two systems come into action:

the optical system and the neurological system.
Optical system: eyeballs, consisting of 3 concentric membranes (sclera, choroid and retina) and a set of dioptric means.
Neurological system: nerves and brain.

4.2 Cones and rods

The traditional explanation is that cones and rods define our initial ability to see; through our eyes, colors and light levels as well as differences in movement.

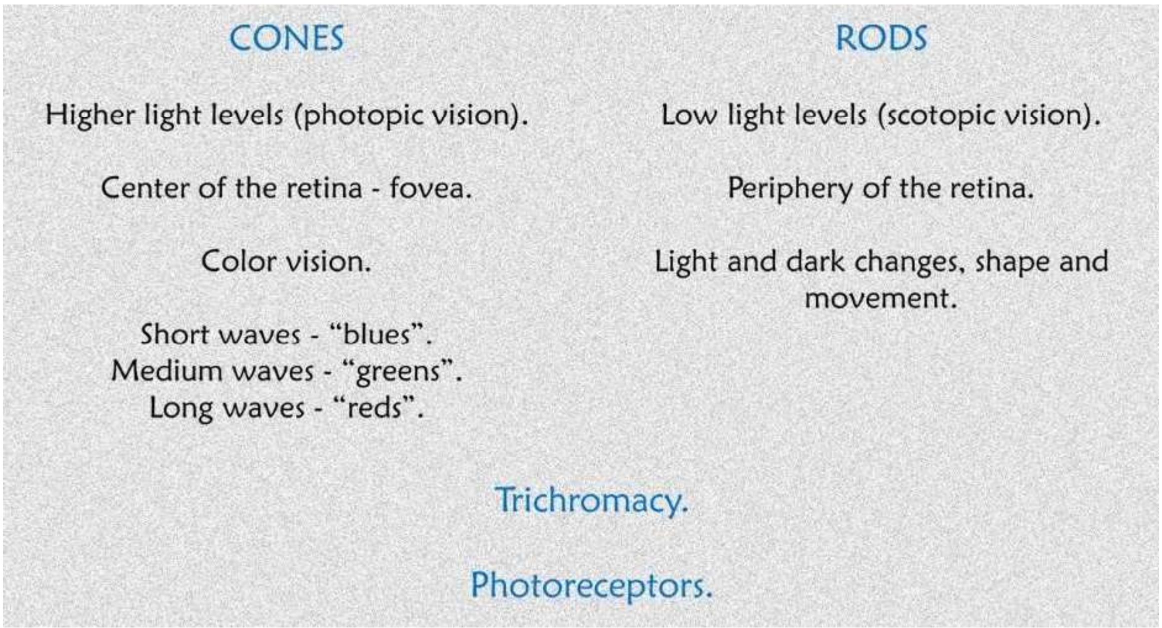

Figure 33. Cones and rods.

The fovea is the point where the greatest number of cones are concentrated and there is a very defined blind spot.

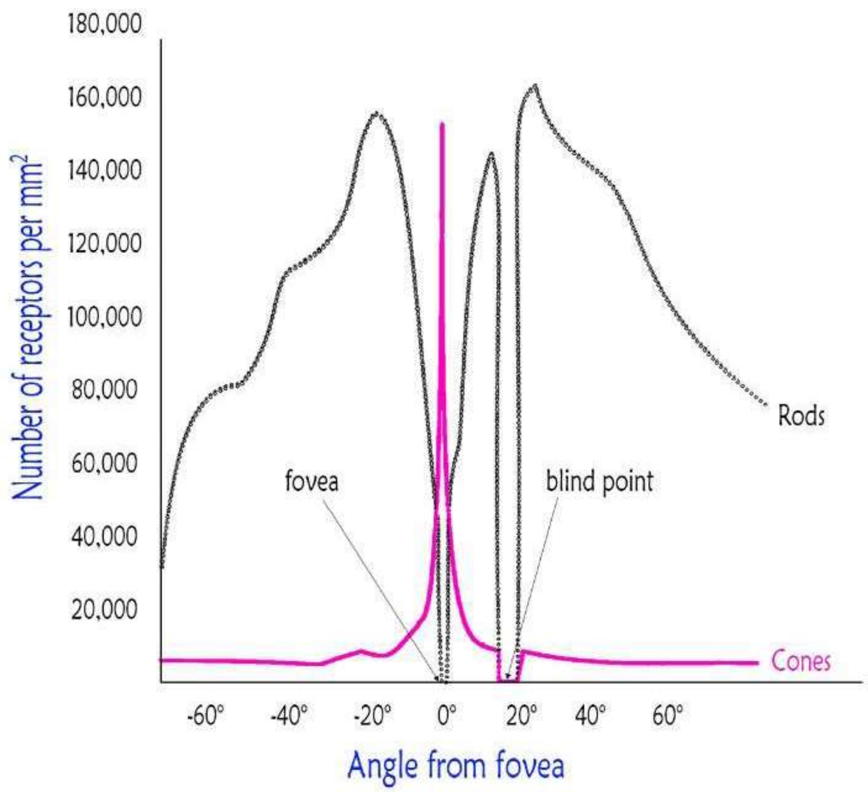

Figure 34. Receptors.

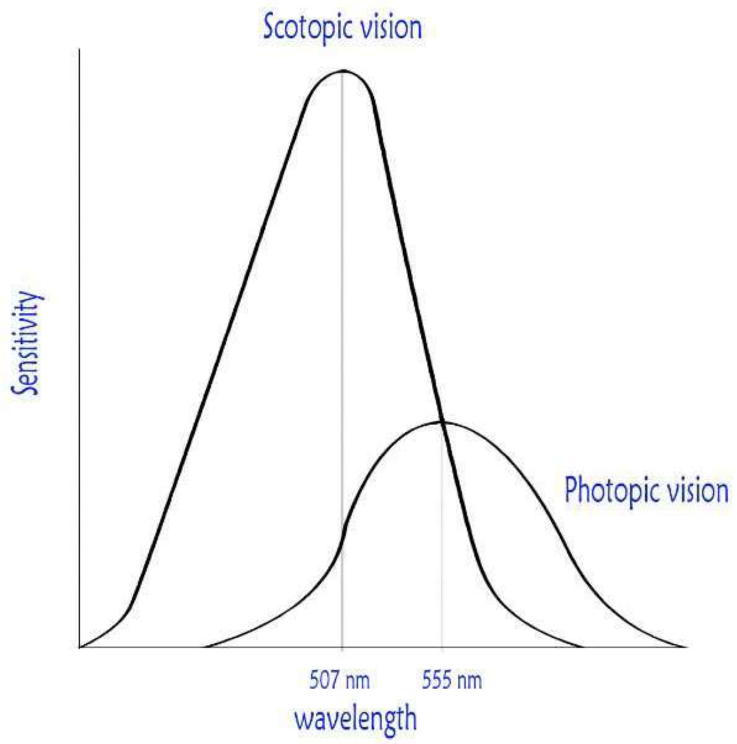

Figure 35. Photopic and scotopic vision.

4.3 Trichromacy

Traditionally, we've accepted the idea that humans are trichromats because we have three types of rods, each working more in a certain region of the spectrum, with greater sensitivity to certain wavelengths.

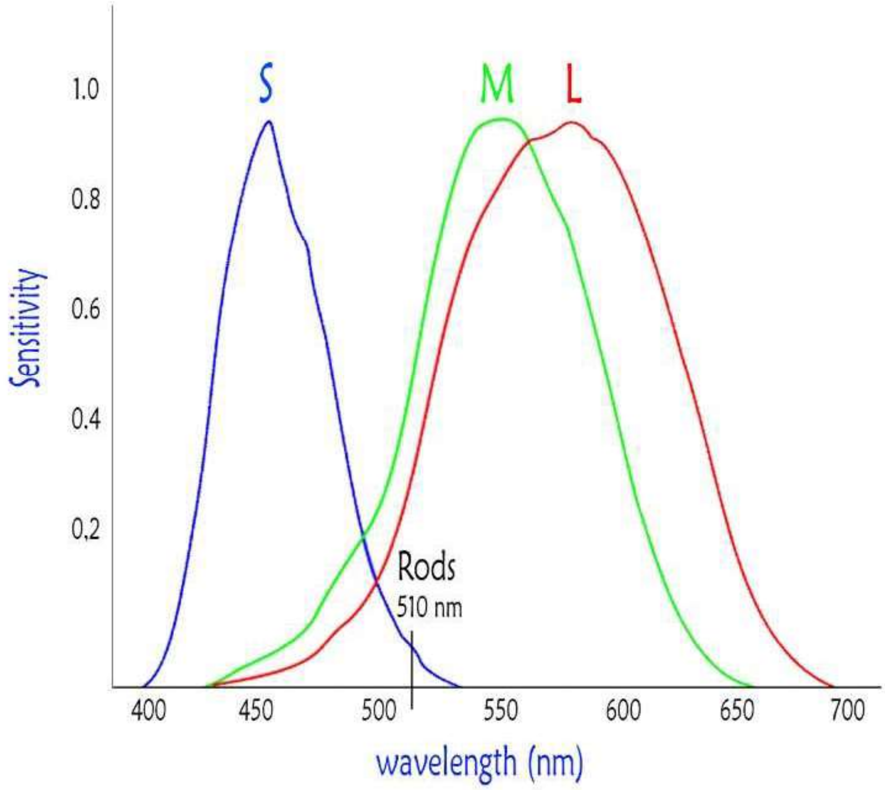

Figure 36. Eye sensitivity.

Today, the Opponent's Color Theory states that the visual system interprets colors in an antagonistic way: Red x Green, Blue x Yellow, Black x White. But note that this does not make the colors green and red complementary. The issue of complementarity concerns the mixture of colored lights that our eyes receive directly (in the case of monitors, for example) or through the reflection coming from a substratum.

4.4 4th cone?

The cones responsible for the vision of reds and greens are encoded by genes located on the X chromosome.

The cones that see most in the blue area are encoded by a gene on chromosome 7 and are rarely subject to genetic errors.

Women, having two X chromosomes, can carry the normal red and green genes on one of their X chromosomes and an anomalous gene on the other.
Due to this genetic pattern it allows it to express four types of cones.
Do not believe in simple tests done on the internet, the analysis is much more complex than you might believe.
A serious study in this regard is being done by the Tetrachromacy Project at Newcastle University, UK.

4.5 CIE observer

We perceive color and appearance subjectively and differently, which is why the CIE (Commission Internationale de l'Eclaraige) standardizes the human observer as a numerical representation of what the average person sees by establishing two basic viewing angles we may see in the next table.

view angle	distance	diameter observed
2º	50cm	1,7cm
10º	50cm	8,8cm

Table 1- CIE observer.

4.6 Tristimulus

Through calculations that consider the spectral distribution of the illuminant, the spectral reflectance of the object and the color matching functions of the observer (2º) we obtain the values of Tristimulus.(X/Y/Z).

4.7 CIE 1931 chromaticity diagram

Using the values X, Y and Z for the Tristimulus two values are reached and we can distribute them in a diagram.

$$x = \frac{X}{X + Y + Z}$$

$$y = \frac{Y}{X + Y + Z}$$

The main characteristics that we can found when looking at the chart and graph bellow (the CIE 1931 Chromaticity Diagram) are: linearity, purity, dominant wavelength, complementary wavelength and, as a result, complementary colors.
We consider (x,y,z) = (0.33,0.33,0.33) as a white point, the flat spectrum.
At the edge purity is 100% and and decreases towards the white point.

We obtain the dominant wavelength of a color (x,y,z), by extending a line from the white point through (x,y,z) until we reach the edge of the curve. Drawing a line connecting two points on the edge passing through the white point indicates complementary wavelengths and can give that white.
Mixing two wavelengths in different amounts (light again not subtractive mixture) can produce all the colors on the line joining the two points (x_1, y_1, z_1) and (x_2, y_2, z_2) on the graph.

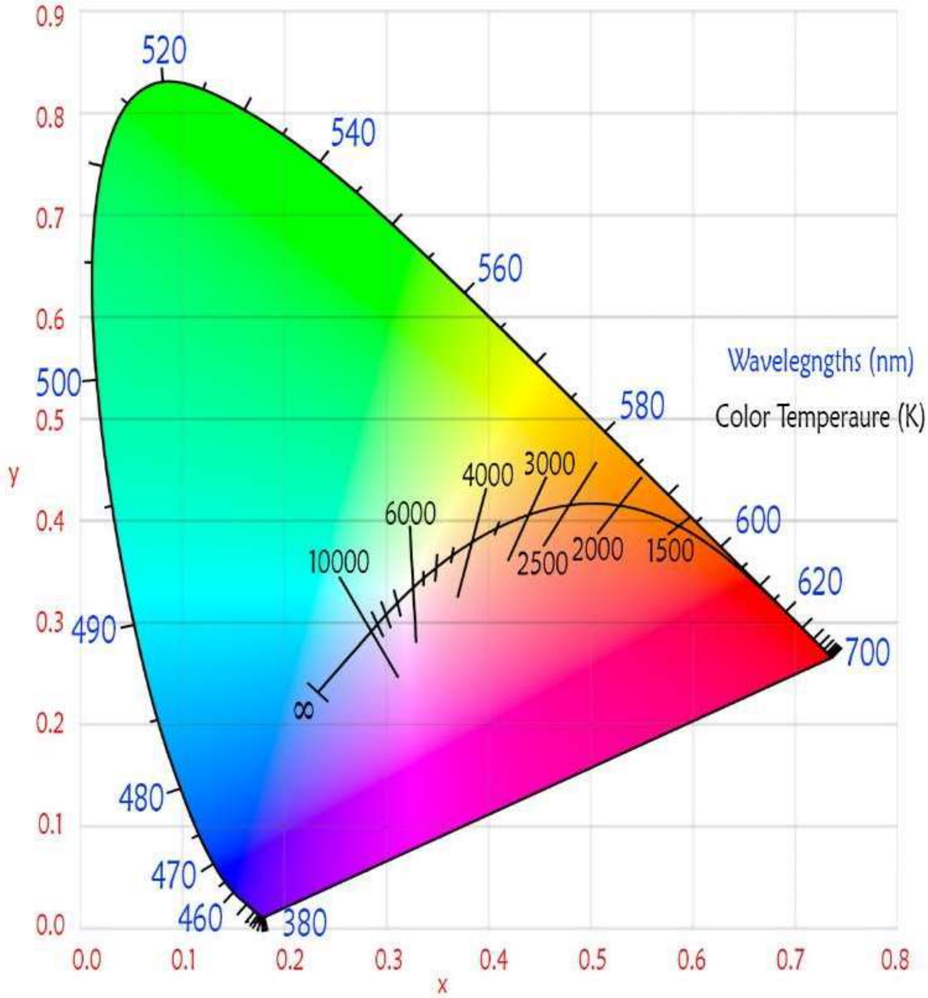

Figure 37. CIE 1931 Chromaticity Diagram.

5. Perceived color

Imagine the qualitative leap from black and white films, “noir”, to Edward Raymond Turner's color film in 1902!
How many different colors are there?
What means different?

If we consider one-nanometer intervals in the spectrum, we would only have 401 pure tones (from 380nm to 780nm), but is it even possible to see more colors than that?
Why is magenta not present in the visible spectrum, but in the CIE 1931 chromaticity diagram? This hue is a perception made by our brain, it is a non-spectral color.
But after all, how many different colors are there around us, which are visible and which are invisible to us?
Does anyone with 4 cones or animals see more colors than we normally see? How do pigeons distinguish crumbs from stones? This little crustacean Peacock Mantis Shrimp *(Odontodactylus Scyllarus)* has 12 distinct types of photoreceptors, does it really see more colors than we do, more nuances? Does it see outside what we call the visible range of electromagnetic waves? If we consider the possibility that R, G and B are between 0 and 255 (to suit the computational world), we can have 16,777,216 colors; one of which is total black, darkness, no light.

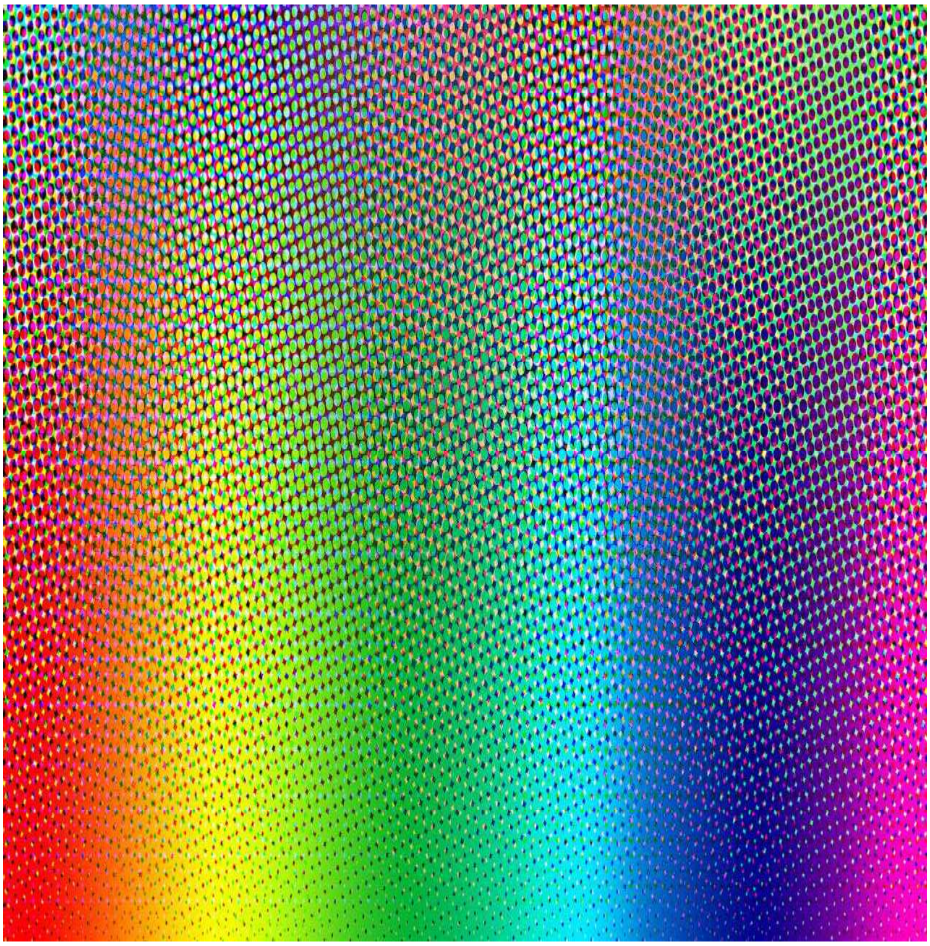

Figure 38. Colors.

5.1 Daltonism

John Dalton first describes dyschromatopsia in 1794.
Anomaly trichromacy - the person has all the cones but some of them have mutations: Protanomaly (L-cone), Deuteranomaly (M-cone) or Tritanomaly (S-cone).
Dichromacy - absence of a type of cone: Protanopia (L-cone), Deuteranopia (M-cone) or Tritanopia (S-cone).
Rod Monochromacy (achromatopsia) - cone photoreceptor disorder.
Cone Monochromacy - Atypical (there is only one type of cone) or Typical (inability to see colors).

The Shinobu Ishihara test for adults was created for the forces of Japan during the First World War, based on Jakob Stilling's (1877) pseudo-isochromatic images composed of similar dots and brightness, but different hues arranged to form visible numbers for test subjects. with normal vision and uses 38 dishes divided into 4 types:
Transformation: colorblinds perceive symbols different from those who do not have anomalies.
Disappearing drawing: only people with color blindness can notice the differences.
Hidden digits: only colorblind people see these symbols.
Classification: the board has two sides to detect red or green blindness.

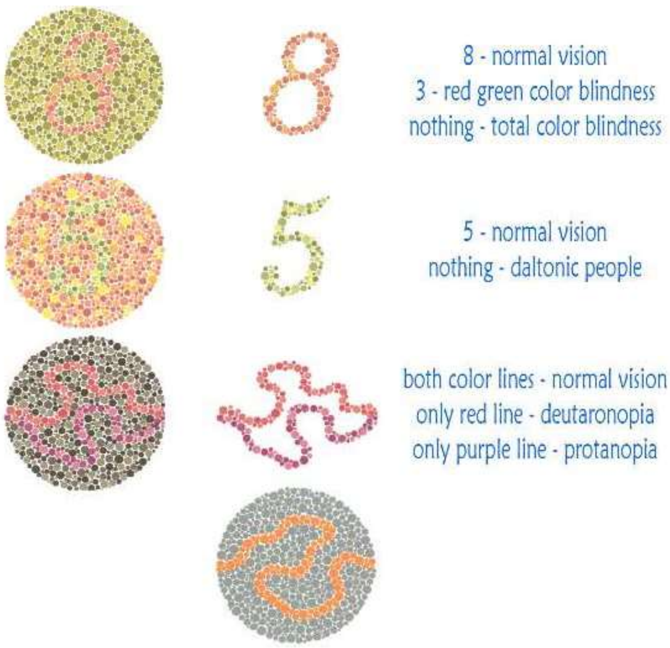

Figure 39. Some Ishihara plates for detect Daltonism.

With a little thought I came to the conclusion that a very simple test can be done for an initial detection.
Please note, I am neither a doctor nor an ophthalmologist, but I understand a little about the mystery of colors.

On the next page, look at the circle on the left, the one a little bigger, and compare it to the circles on the right. If the circle on the left looks **a lot** like one of the circles on the right, you should see an ophthalmologist.

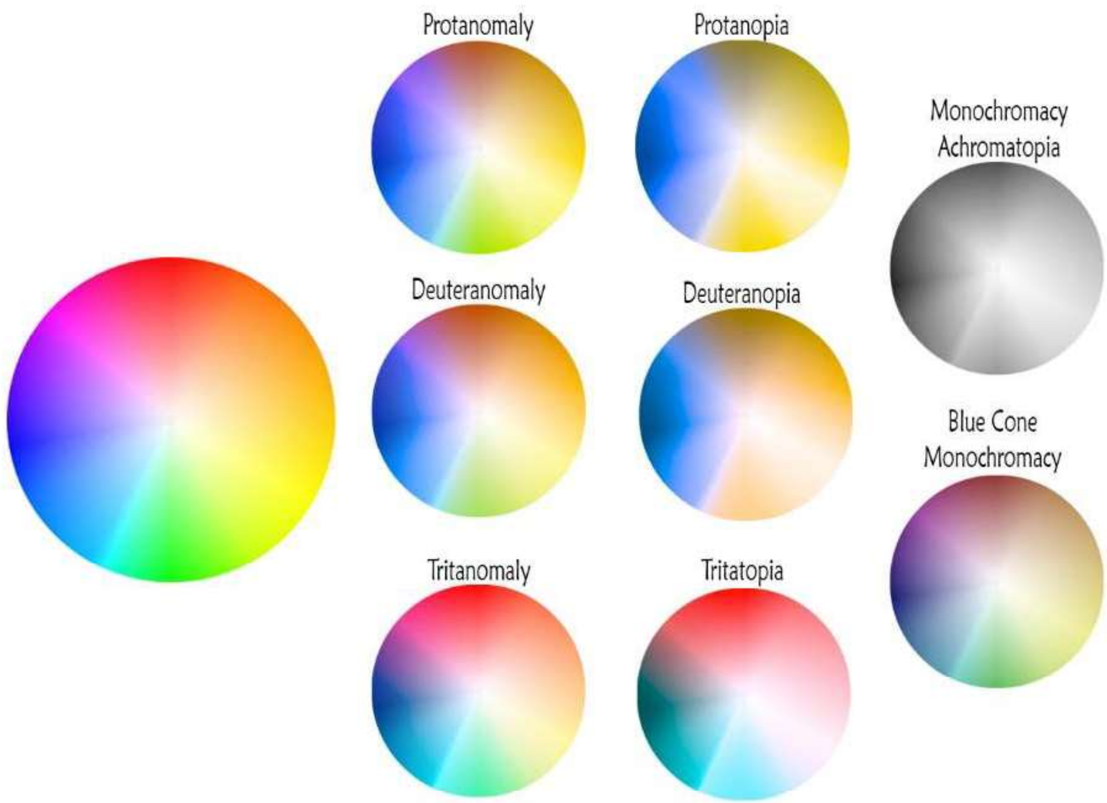

Figure 40. Practical verification.

5.2 Light, observer and material substances

What influences the perception of color?
If we think about the spectral qualities of the light, we must consider the lighting conditions, the color of the chosen light, as well as taking into account the surrounding lights, colored or not.
When we talk about the observer's visual mechanism, it is influenced by the distance and angle of vision, as well as the conditions and characteristics of that vision. Are the observer and the illuminated object still or are any of them moving? Does something hinder or confuse your vision?

Look at the next image.
As mentioned earlier, we need a substrate for light to be visible and for us to perceive colors. What color is a supposed artificial light that enters through the window, from the outside, at 30º? We don't see her in the photo, but we know she doesn't touch anything and leaves the room directly through a hole in the floor. No, it's not sunlight, it's artificial.

Figure 41. Color and light perception.

Well, without substrate, something solid, even in very fine particles, there is no perception of color. There is no vision of light. There is no perception of light. But we can perceive light without substrate is if it comes directly to our eyes because we will see the light source and its color. Screens and monitors are the best example.
The characteristics of material substances; its size, material, shape, textures and inherent color also influence our perception.
But what about that blue sky and white clouds we see behind the window?
Sunlight, which we assume to be white, is actually invisible as we've seen before; but as it passes through our atmosphere, it causes the electrons and protons inside the molecules to oscillate, producing electromagnetic radiation at the same frequency as the incident rays and being redirected in various directions, which we call scattering. Due to their shorter wavelength and higher frequencies, "blues" cause the oscillation of charged particles to be greater, producing greater scattering. At sunset, we see more wavelengths closer to red because the dispersion is smaller due to the greater distance from

the sun. In space outside our atmosphere, light is black and our planet appears blue.
Clouds are composed of water droplets much larger than air particles and the difference in dispersion is much greater; internally the light is refracted, reflected and diffracted. Clouds are not white, look at them...they are shades of white and they have subtle colors, mainly yellow and blue, which provide the vision of white. Great Van Gogh!!!

5.3 Contrast

Contrast is the difference in luminance and / or color that makes an object distinguishable.
Visual acuity is the ability to distinguish details depending on the object: dimensions, shape and texture. The speed at which they move, the quantity and quality of incident light and the contrast in relation to the background also has an influence.
Michelson - measure of luminance contrast (C)

$$C = \frac{Lmax - Lmin}{Lmax + Lmin}$$

Luminance is measured in cd / area. L_{max} is the luminance of the lighter area and L_{min} is the luminance of the darker area.

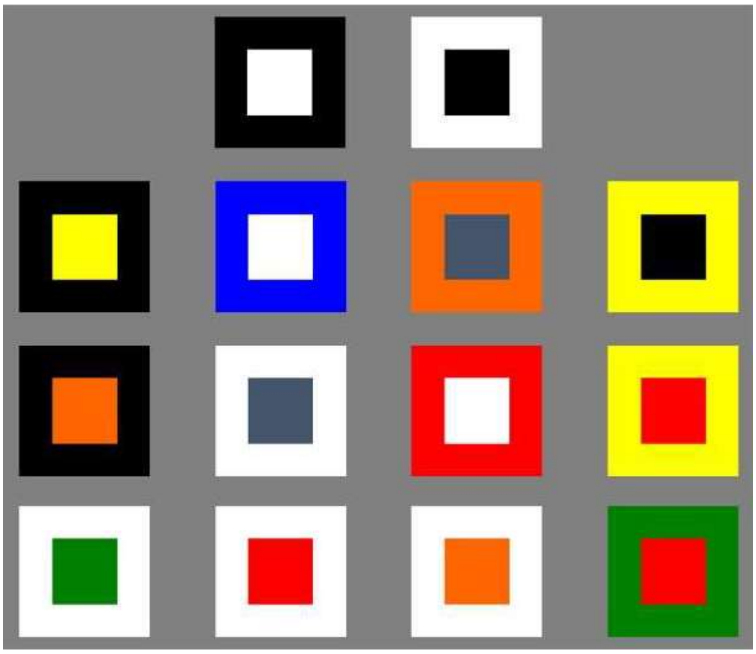

Figure 42. Color contrasts.

From left to right and top to bottom the color pairs are ordered from highest to lowest contrast.
Sometimes I ask myself: if making white paper is expensive and maybe pollutes our environment and white ink without added dyes is cheaper, why not make notebooks with dark recycled sheets, almost black, and pens with white ink?

Figure 43. Contrasts in lighting.[16]

The different levels of lighting allow contrasts and varied views of the same environment. In this specific case the store has two sales calls depending on the ambient lighting, in the image above the high contrast takes us to a fashion store and the similar luminances below are more characteristic of a commercial store.
Note that in the first image we have focal points that direct our gaze, create our interest, the lighting in the image below is more general, almost a "bath of light", wash light.

[16] Image by LEDiL - LED Optics for Light that is Right.

It is also worth noting the color of the ceiling, walls and floor that help in the beautiful final effect. If you want use the term dramatic for describe the first image, feel free, but better say more contrasted.

You would ask me:
- But after all, what is the correct light?
Both I would answer, each has its specific goal.
Return to the images and look at the mannequin's shoes.

5.4 Simultaneous contrast

Simultaneous contrast is the way in which two or more colors are affected when they are present in the same context.

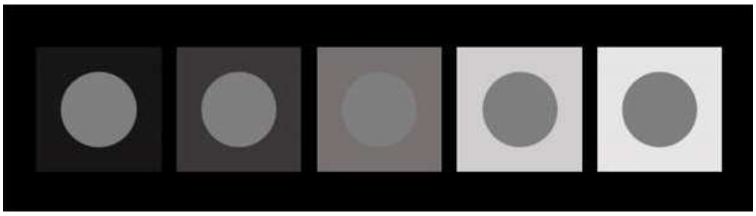

Figure 44. Simultaneous contrast.

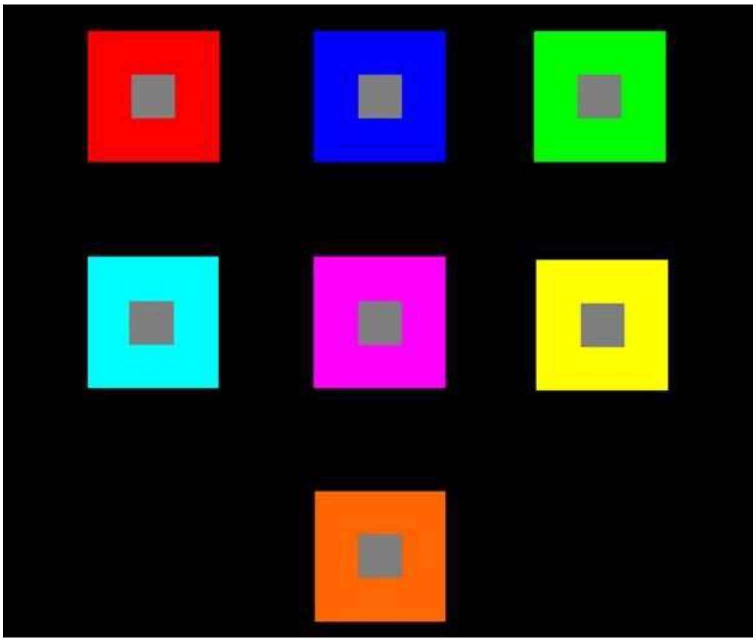

Figure 45. Simultaneous contrast.

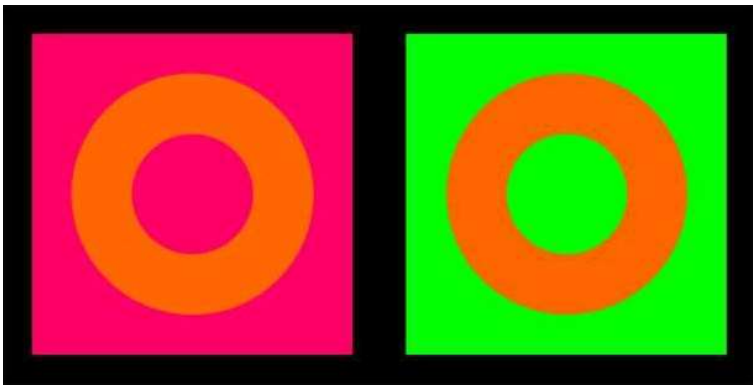

Figure 46. Simultaneous contrast.

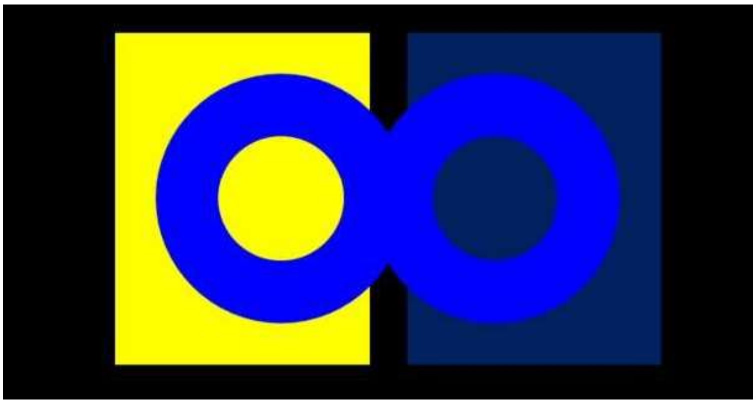

Figure 47. Simultaneous contrast.

Colors are not absolute, colors change according to the environment and according to incident lighting, the perception of colors depends on the context in which they are inserted.

The wavelengths of nearby colors are interrelated, causing the color assimilation effect (or propagation effect) to occur, one color influences the appearance of another color and vice versa.

The size of the areas in question is extremely important in the perception of this interactivity and interdependence.

Figure 48. Digital pointillism - Atlântida, Brasil.

The pointillism technique and printing in the graphic industry are based on this principle and knowledge.

6. Natural and artificial light

Normally, when we refer to natural light, we are talking about sunlight, although starlight and moonlight are also natural light sources.
Lightning is natural in the same way; we can't master it yet, but let's go. Light from fireflies, for example? It's natural.
Artificial means what is produced not by nature but by a technique.
But what if we reflect sunlight through a corrugated metal surface, creating an effect inside a home? Is this light natural or artificial? It is produced.

A carrot generated without contaminants is called organic, but again I ask, should a carrot produced with the aid of fertilizers and using pesticides be called inorganic?

The full moon said to the firefly: - Look at the light that I emanate, white and I can illuminate the sea and the land, and you already have this little green and weak light that, by the way, keeps blinking...
The firefly replied: - Yes, you are right, but this light is mine.

Okay, let's get back to the lighting.

6.1 History of produced light

From prehistory: bonfires, torches, candles, oil lamps, chandeliers, bulbs, luminaires, lanterns, etc.
But in Greek theatre there were ways to reflect sunlight or full moon light to create different effects and moods on the stage.
From 1800 to 1900: gas lighting in England, UK; carbon arc lamp used on street lighting in Paris, France; Thomas Edison and Joseph Swan patented incandescent carbon wire lamps (1879) and in a few years reaching massive use; Nikola Tesla demonstrated the first wireless lighting; Walter Nernst developed the first incandescent lamp based on solid state electrolytes.
From 1900 to 1950: Mercury vapor lighting; metal halide sources; sodium vapor followed; fluorescent; incandescent lamp with new gases and filament advances.
While this the academy and the scholars began to organize themselves creating the Illuminating Engineering Society (IES) in 1906 and the Commission Internationale de Eclairage (CIE) in 1921.
In 1927 Oleg Losev created a green LED in Russia proposed the first theory that is still valid today about how LEDs worked and used them to generate electroluminescence.
From 1950 to 2000: halogen lamp; laser; Nick Holonyak Jr. invented an LED that emitted visible red; high pressure sodium; yellow and violet LEDs were invented; compact fluorescent; OLED was created in 1987; sulfur and induction lamps; bright blue LED and white LED.
At this point we started solid-state lighting era.
Improvements continued in miniaturization, effectiveness, longevity and, finally, color.
There is also something important that is what differentiates the Sun from the LED, it has explosions which means that the light that reaches us does not have a fixed and constant emission. The "dead light" impression that we have with the LED, with a light source that only illuminates, is exactly why. We would need small explosions to change our sensations.
The improvements continued in effectiveness, longevity and, finally, color, but have declined in recent times.
I can say here that there is still much to be discovered and invented not only about LEDs, because we humans are in the habit of thinking that what we do is as evolved as possible. Perhaps in the moment we live this is true, but one day scalpels will only exist in museums.

Internet
Keraunoskopeion (Ioúlios Polydeúkēs).
Sebastiano Serlio.
Leone di Somi.
Nicola Sabbatini.
The Globe.
Blackfriars Playhouse
Giuseppe Furtenbach.
William Murdoch.
Philipe Le Bon.
David Garrich.
Chestnut Street Theatre.
Henry Drummond.
Adolphe Appia.
Edward Gordon Craig.
Jean Rosenthal.
Richard Pilbrow.

6.2 SPD

SPD (Spectral Power Distribution) describes graphically the power per unit area per unit wavelength of an illumination.

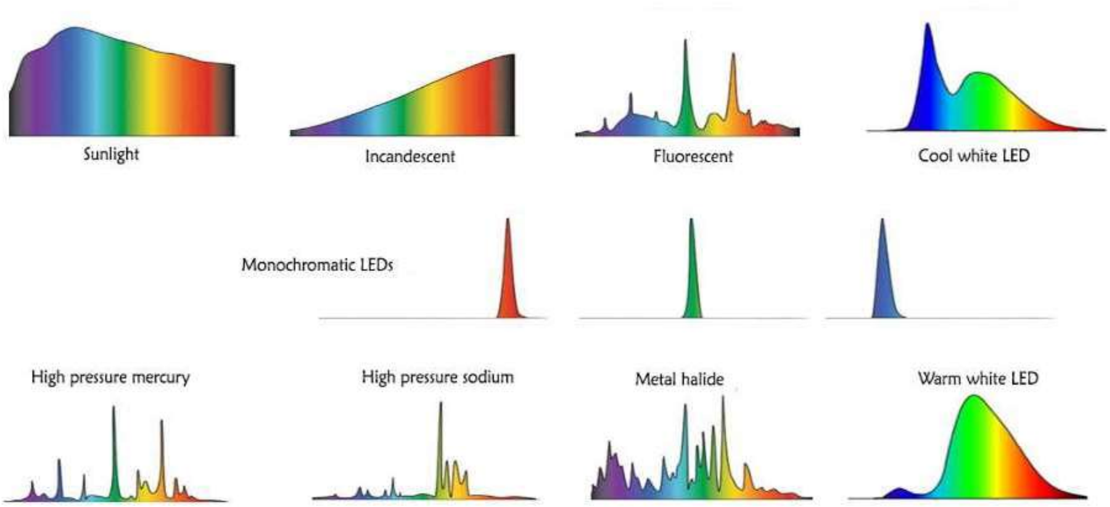

Figure 49. Several typical SPDs.

Does sunlight have a single, immutable SPD?
The answer again is: no, it varies with the seasons, according to the location of the globe, the conditions of the sky and, mainly, it varies throughout the day.
Anyway, taking into account the differences is a good start!

6.3 SPD x tristimulus

Spectral distribution refers to physical reality while the tristimulus values are related to our mind.
Between these two ways of literally seeing light, some differences can be observed and often these differences are maximized or diminished in our eyes, we should be asked for a more careful observation, when this is possible. Some observable effects are described below.

6.4 Metamerism

The metamerism describes a pair of objects that match under a certain light source or set of viewing conditions, but not under another.

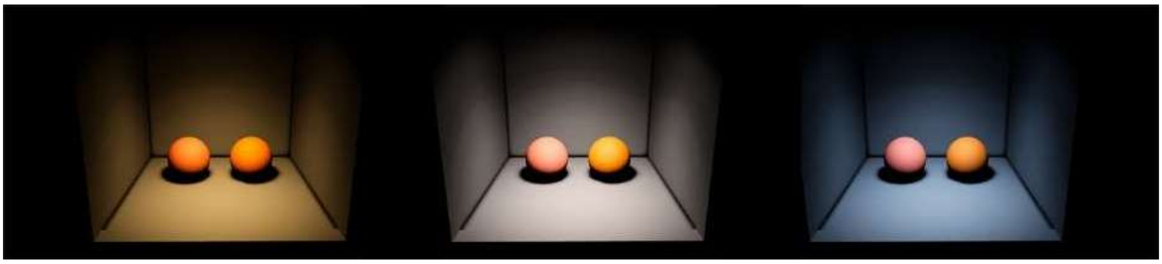

Figure 50. Metamerism.

6.5 Visual constancy

Visual constancy is the ability to recognize objects even as their size, shape, color or orientation change.

6.6 Color constancy

Color constancy is the ability to perceive colors of objects, invariant to the color of the incident light.

Figure 51. Color constancy.

6.6 Color consistency

Color consistency is of utmost importance so that there is no difference between the color or the white emitted by light sources of the same type used in a project.

It is also essential that this color remains as constant as possible throughout the life of the lamp or LED.

7. Correlated color temperature

7.1 CCT

Color emitted by a black body correlated with its temperature.

A black body is a theoretic object that absorbs radiation in all frequencies.

If we consider an iron bar being heated, at each temperature in degrees Kelvin, we will perceive a different color that corresponds to a specific color temperature.

Color appearance of the light emitted by a light source.

The reddish light resembles fire and seems hot to us. The “warm” light gives us a sensation of cosiness; on the opposite side is the bluish light that resembles a cold glacier. The “cool” light demands more attention.

Figure 52. CCT - psychology.

The CCT starts to be described numerically from 1000K (red) passing through what we can call neutral white, going up to approximately 10000K (blue) and from there tending to infinity.

Figure 53. CCT - range.

Calculation of a CCT for LEDs from the (x, y) coordinates in the CIE 1931 chromaticity diagram using the McCamy formula:
Determine the parameter n with the values of the x and y coordinates.

$$n = \frac{x - 0.3320}{0.1858 - y}$$

Insert the n value into McCamy's formula:

$$CCT = 449 * n^3 + 3525 * n^2 + 6823{,}3 * n + 5520{,}33$$

According to this formula, the white point that is defined in the chromaticity diagram as x = 0.3127 and y = 0.3290 corresponds to the CCT of 6508K.

We can have the same CCT but different apparent colors, take a look at 5000K in the next figure.

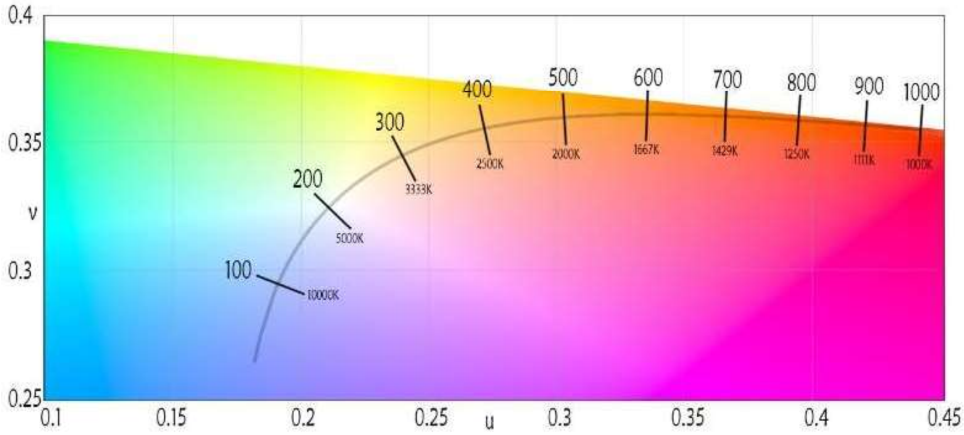

Figure 54. Planck Locus at CIE 1960 (u,v) Chromaticity Space - Mired and CCT.

Then we'll understand what Mired means and what is its use in lighting, but here's the tip: the color temperature of a light source and its relationship with heat and cold sensations are inverted, correct?

The idea is to fix this.

What was the temperature in degrees Kelvin at the sites when the next four photos were taken?

Figure 55. Rio Grande do Sul, Brasil, under the sky.[17]

[17] Photo: Simone Lopes

Figure 56. Angera from Arona, Italy.

Figure 57. Genova, Italy.

Figure 58. Mechanical workshop - São Paulo, Brasil.

What was the temperature in degrees Kelvin at the sites?
We can't say, we don't know at all.
It is worth remembering that the CCT is a reference to the perception we have or want the observer (human, artificial or animal system to capture the illumination reflected by objects) to have and not the absolute temperature of the place or the source light, if that were the In this case, we would be burned when touching a fluorescent lamp with CCT 5000K.

Figure 59. Colosseo, Roma, Italy.

The mixture of CCTs can sometimes be desired and interesting precisely because it creates contrasts.

The neutral white considered for lighting is around 4000K, but our eye tends to use ambient light and "calibrate" it to neutral white with the exception of extreme “hot” or “cold” CCTs, where we perceive the lighting more reddish or more bluish.

Figure 60. Neutral white.

7.2 Mired Shift

The fact that a higher CCT corresponds to a “cold light” and a lower CCT to a “hot light” causes some confusion…
Irwin G. Priest observed that the difference in the perception of color temperature between two illuminants is based on the difference in the reciprocal of their temperatures, not in the temperatures themselves.
MIRED is an acronym for Micro Reciprocal Degrees, it is a unit of measurement used to describe the Color Temperature for a light source.
The Mired Shift refers to the result of the calculation that indicates, through information from the filter manufacturers, which one to use to change or correct the color temperature of a light source from the original to a desired CCT.

$$M = \frac{1{,}000{,}000}{CCT}$$

M is the mired value for a CCT in Kelvins.

$$MS = Mc - Mo$$

MS is the Mired Shift.
Mc is the Mired to the converted source.
Mo is the Mired of the original source

For example if 3200K is the original CCT and we need to convert to 5700K.
Mc for 5700K = 1,000,000/5700 = 175,4
Mo for 3200K = 1,000,000/3200 = 312,5
MS = *Mc* - *Mo* = 175,4 - 312,5 = -137,1
Then we need a filter with mired shift of -137,1.

In this example, it is evident that we must "blue up" the appearance of the light source. The most blue or green filters have negative Mired values, while those with positive values are in shades of yellow, amber or red.
The filters by default are usually indicated as CTB (correction to blue), CTS (correction to straw) and CTO (correction to orange).

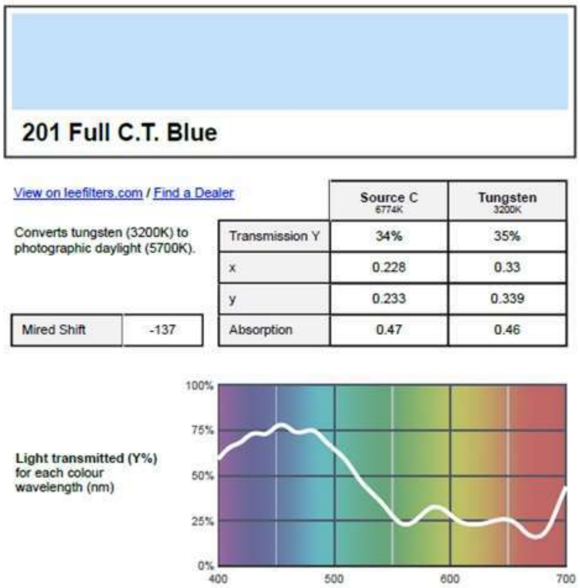

Figure 61. Full C.T. Blue.[18]

We can also use a Minus Green filter to correct fluorescents that normally have enough green in their composition or Plus Green if other light sources are being used and we want to balance them with fluorescent ones.

[18] Image by Lee Filters - Panavision.

We can selectively correct some areas of the spectrum.

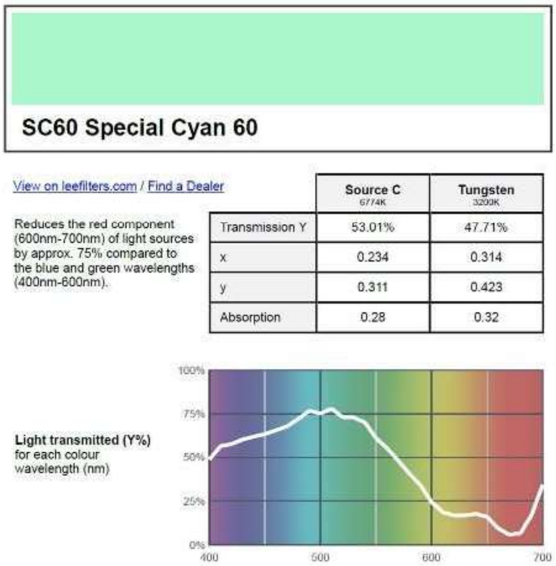

Figure 62. Special Cyan 60.[19]

8. Color rendering

How do you know if the colors the reader saw in the images in this book correspond to reality? And what would this reality be? Which light source are we comparing the observed colors to?
We hope that sunlight is the best reference, as it rules us.
As a result, quantitative metrics of a light source's ability to faithfully reveal color against a reference were created.

Figure 63. CRI.

[19] Image by Lee Filters - Panavision.

8.1 CRI

The color rendering index is a number that represents; on a scale of 0 to 100, how much the luminous flux emitted by a light source allows the perfect reproduction and visualization of the colors of the illuminated objects in relation to a standard illuminant.
Remember, it's not a percentage, 80%... it's a number: 80 for example.

It is based on experimentation with some samples of test colors and is represented by *Ri*, where *R* is the rendering score and *i* is the number of the TCS index.

.

The evaluation method consists of determining the CCT of the light source to be tested using a standard illuminant with the same CCT for reference, checking the chromaticity of the color samples (Ra or Re) under the test light and under the reference illuminant and then finally determining the mean difference in chromacity for the two sets, establishing the Ri.

Theoretically, if from R1 to R8 and from R10 to R15 a light source had a rating of 100 and for R9 equal to zero, what would be the Re? This data can deceive us: Re 92.9! Nice!!! But zero at R9, the red sample. This becomes worrying when it comes to LEDs.

A problem that is still very recurrent in 2021 is that some CRI declared by manufacturers have different measures, generally worse when really measured.

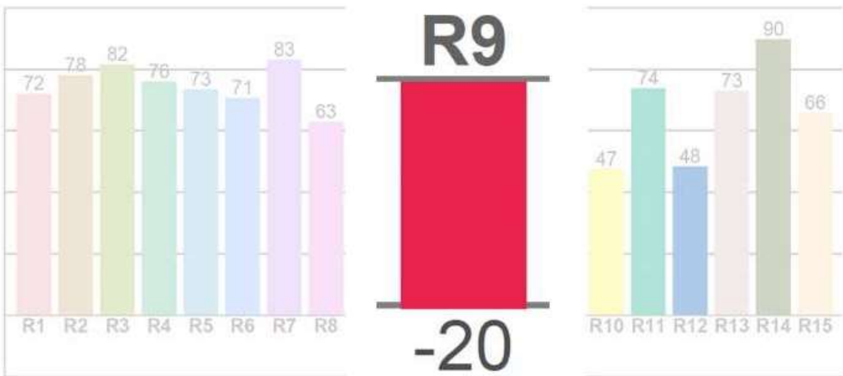

Figure 64. Very low evaluation on R9.[20]

[20] Stella | Lighting, Brasil. Reports from Stella´s Laboratory.

Figure 65. Effect caused by a lamp with low CRI on R9.

We can use the white tone of the lighting to our advantage, objects that have a warm color (bread, meat, gold, etc.) should be lit with low CCT; conversely, objects with cool colors (lettuce, silver, aluminum, etc.) will look much more attractive when illuminated with high CCT.

Anyway the higher the CRI the better.

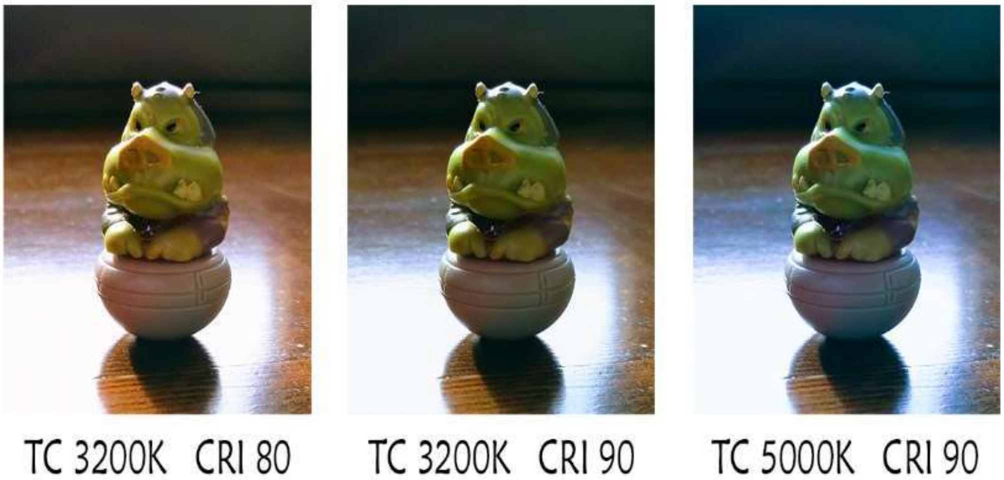

Figure 66. Lamps with different CCT and CRI.

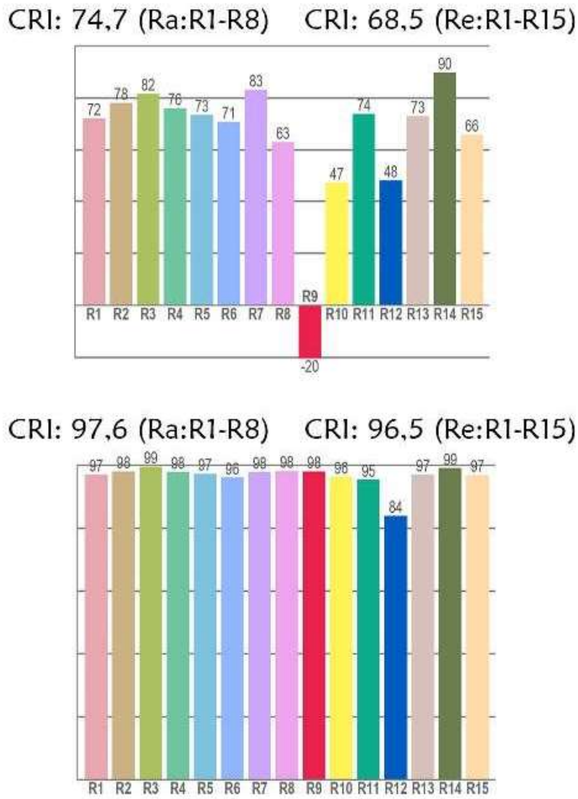

Figure 67. Comparison of CRI between LEDs of different qualities.[21]

Some problems were noticed when analyzing LED sources using the CRI method.
Certain light sources are severely penalized with low indexes when in fact they have a great yield and, on the other hand, incandescent and halogen which slightly yellow the luminous result are considered excellent color reproducers.

8.2 CQS

With the intention of trying to solve some of these divergences, the CQS (Color Quality Scale) is as an alternative developed by NIST (National Institute of Standards and Technology) using some CRI metrics but creating new ways to evaluate the color reproduction
In CQS, 15 highly saturated colors are used to compare chromatic discrimination, human preference and color reproduction.

[21] Stella | Lighting, Brasil. Reports from Stella´s Laboratory.

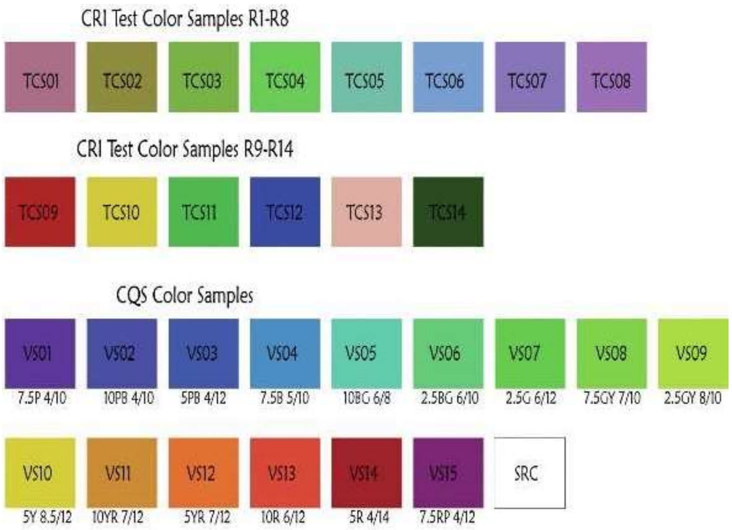

Figure 68. Comparing the samples of CRI and CQS.

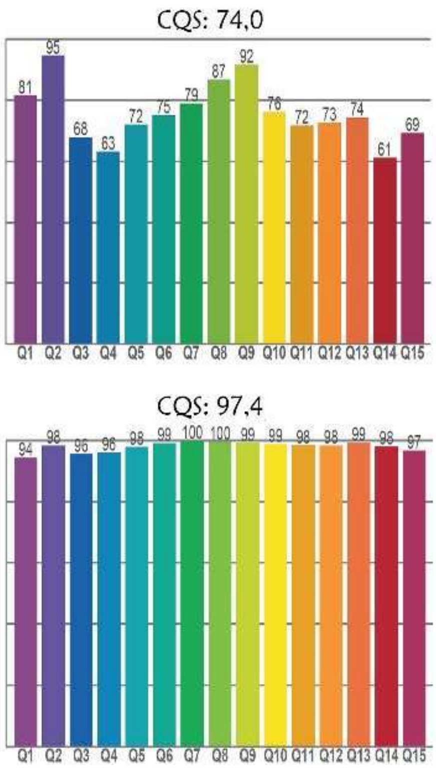

Figure 69. CQS: comparison between the same LEDs in figure 66.[22]

[22] Stella | Lighting, Brasil. Reports from Stella´s Laboratory.

8.3 IES TM-30-15 (IES TM-30-18)

Created by the Illuminating Engineering Society and communicated through Technical Memorandum 30 in 2015 (there was a review in 2018, distributed through IES TM-30-18).
Method for evaluating color reproduction, where photopic vision is dominant, is a system composed of two metrics: color fidelity index and color gamut (gamma) index and produces a Color Vector Chart.
99 Color evaluation samples (CES) of real world objects ordered by hue under the sun (5000K) and divided into groups: nature, skin color, fabrics, paints, plastics, printed material and color systems.

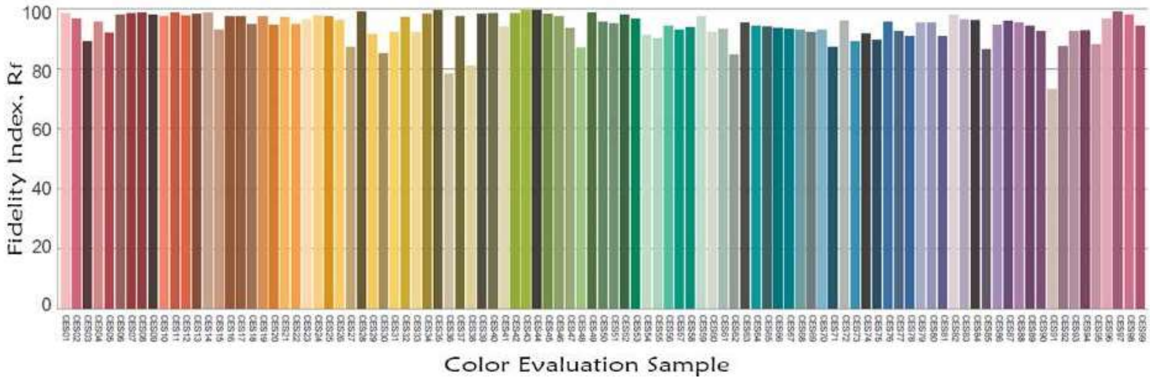

Figure 70. Fidelity index by sample.[23]

Figure 71. IES TM 30-15 - color types (W refers to white).

[23] Stella | Lighting, Brasil. Reports from Stella´s Laboratory.

A	B	C	D	E	F	G
Nature	Skin color	Textiles	Paints	Plastics	Printed material	Color systems

Table 2. IES TM 30-15 - color types.

8.3.1 Color Fidelity Index (R_f)

Used to measure the light source's closeness to a reference source, like the CRI method.

$$0 < Rf \leq 100$$

R_f equal to 100 represents the perfect combination between the samples illuminated by the reference and the tested light source.

8.3.2 Color Gamut Index (R_g)

To measure the increase or decrease of the color's purity of a light source, calculated by comparing the area of the color space of the tested light source and the reference.

$$60 < Rg \leq 140$$

R_g equal to 100 means that the saturation of the light source is equal to that of natural light.
R_g greater than 100 which means that the light source can increase color saturation, lower than 100 the color saturation is scant.

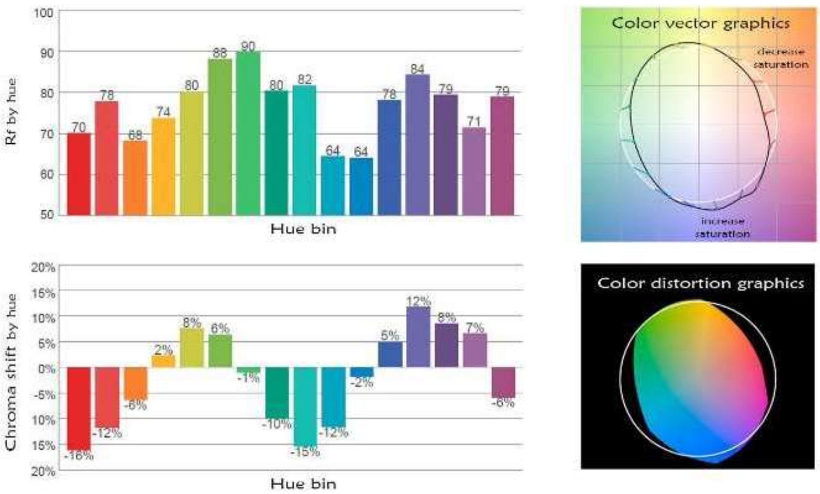

Figure 72. Color and hue analisys.[24]

[24] Stella | Lighting, Brasil. Reports from Stella´s Laboratory.

8.3.3 Color Vector Graphic

This graph, above and to the right in figure 71, shows the changes in hue and saturation in an observed light, if the colors appear more or less vivid.
The near-perfect circle represents the standard illuminant and the arrows the deviation according to wavelengths.

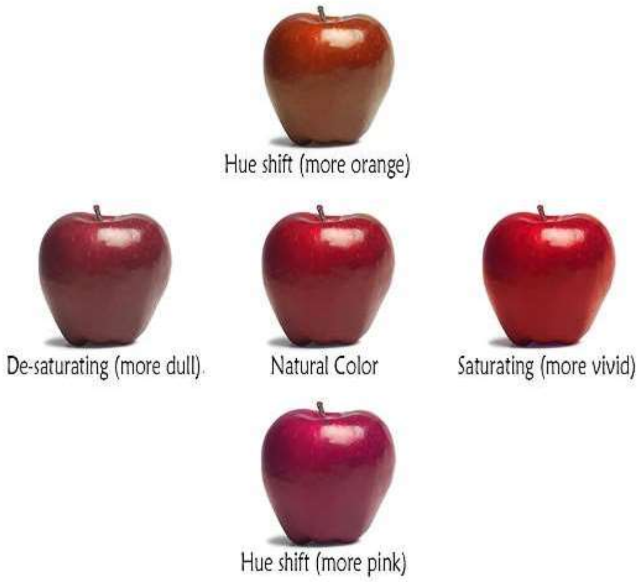

Figure 73. Changes in hue and saturation.

9. Color designation

9.1. Verbal

Verbal designation is a variable and inaccurate nomenclature.
For everything there is a word, for every word there are many things.
For every color may have a word, but for every word there are many colors.
When I say TREE, you imagine any tree, your tree.In the same way when I say RED, each one imagines its red and even when I show the color I am referring to, it is difficult to name it.

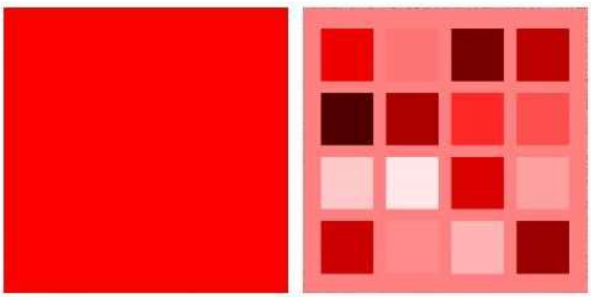

Figure 74. Red, light reds and dark reds.

The verbal nomenclature also varies according to the language, in some places there is the term light red to name the rose also the light or dark blue in some places have a specific name.

Figure 75. Yellow, which yellow?

Try naming the colors in the next image, always clockwise from the left circle to the right one.

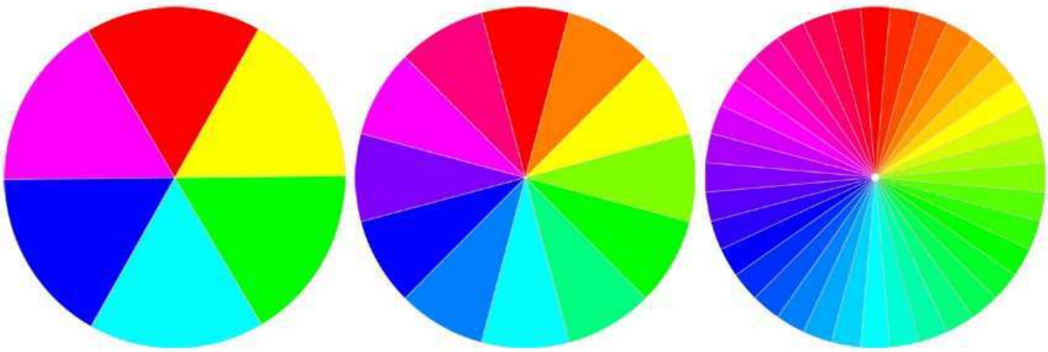

Figure 76. Chromatic Circles.

Naming colors is a completely individual act and usually just an approximation to colors of real objects that are not always standardized, usually companies usually catalog their colors in this way.
"Egg yolk". What color would it be?
Try to point out in the circle on the right what that color would be.
We've already seen so many gems with different colors, meaning we can't choose one of the four or five options.

9.2 Mathematic

In the mathematical designation a color is defined by values in coordinates within a chromaticity diagram.

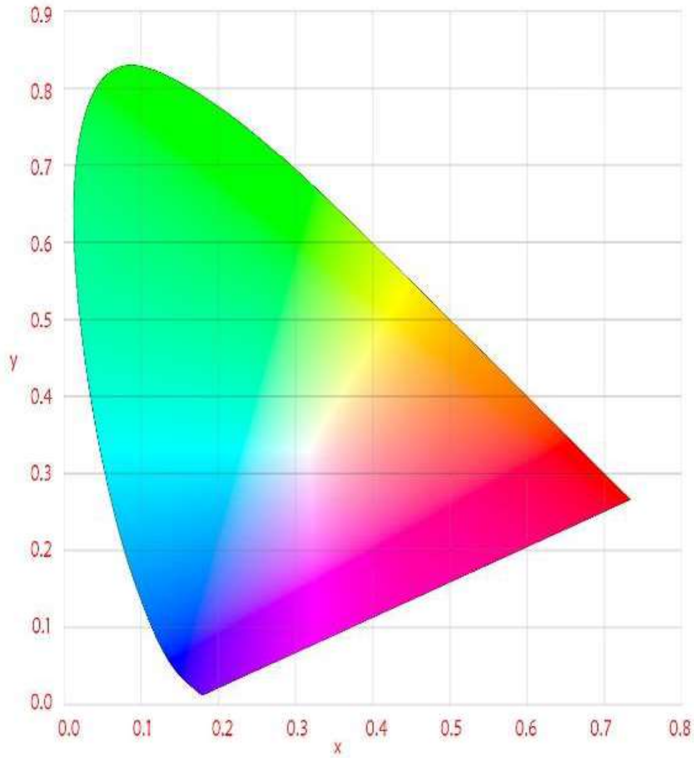

Figure 77. CIE 1931 Chromaticity Diagram, x and y coordinates

What is the color (x,y) = (0.247,0.355)? Yes, it's a dot within the diagram that defines a hue, but it's not practical for non-professionals.

9.3 Chromatic languages

These are standardized systems and notations where each color receives a value for hue, luminosity and chroma, for example.

9.3.1 Munsell and NCS notations

5R 4/10 is a typical notation for Munsell and for NCS we have, for example that one: S 2050-Y40R.

At first it seems complex, but if we understand the proposals and their codes, the notations make sense and give us the possibility to communicate with customers and other users of the systems.

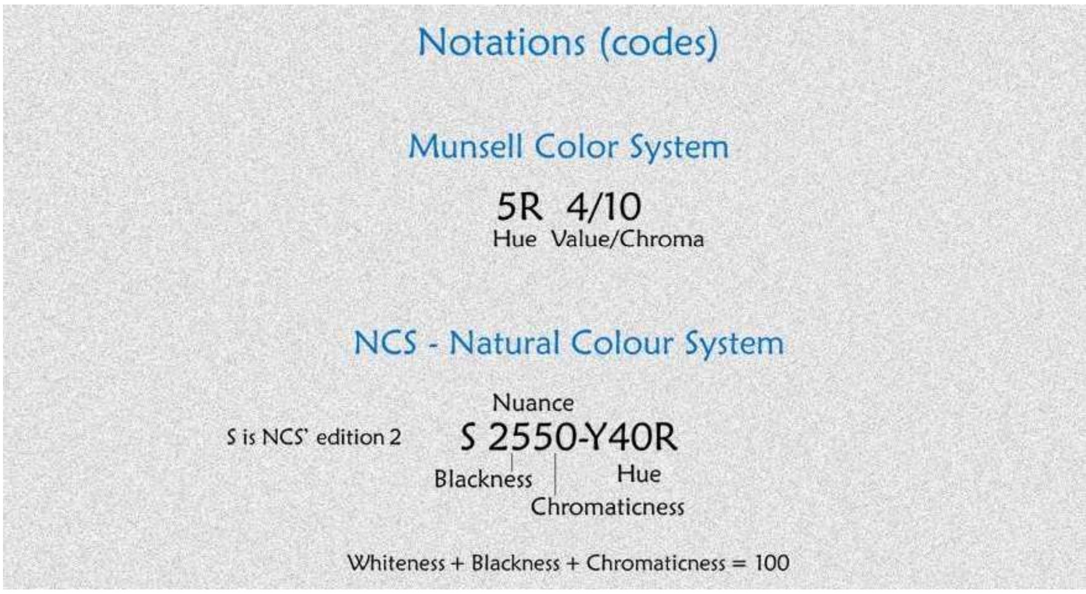

Figure 78. Notations.

9.3.1.1 Munsell System

The Atlas of the Munsell Color System was first published in 1913 with colors ordered by equidistance in perception. It consisted of two sets of charts illustrating Albert H. Munsell's color measurement system.
Was revised and republished in 1929, as The Munsell Book of Color.

Internet

https://munsell.com

As a function of being organized by steps of differences, regularity of differences; note that the graphics have different sizes.

9.3.1.2 Natural Color System

The basis of the Natural Color System, a proprietary perceptual color model, is supported by Ewald Hering's thesis that six are the primary psychological colors and are opposed to pairs, as mentioned earlier. All colors can be defined in terms of similarities with their component elementary colors and with black and white.

Internet

https://ncscolour.com/ncs/

9.3.2 Other color organization and communication systems

Companies and institutions have created their own color communication system and some have become standard in different market applications.

9.3.2.1 RAL

In 1927, the German commission Reichs-Ausschuß für Lieferbedingungen (National Committee for Delivery and Quality Assurance), for short called RAL, created a collection of 40 colors for the definition of technical standards. It currently has a range of products designed to control color reproduction for industry, graphic arts and digital systems.

Internet

https://ralcolor.com

9.3.2.2 Pantone

Pantone was founded in 1963 by Lawrence Herbert, to identify, combine and communicate colors in the graphic arts environment, today operating in various types of industries.

Internet

https://www.pantone.com

Consult the websites' Pantone and RAL tables and look for the differences between them. You will also find similar colors with different denominations. Marsala in Pantone tables, for example, is Orient Red in RAL tables and evidently, the reverse path can be done.

10. Colorful world

Our world is not just colorful, it's multicolored.

Internet

Daigo-ji Temple, Kyoto, Japan. Manarola, Cinque Terre, Liguria, Italy.

Pink Sand Beach, Komodo National Park, Indonesia. Brazilian Opals.

Aurora Borealis, Finland. Caño Cristales River, Colombia.

Zhangye Danxia, China. Eucalypthus Deglupta, Maui, Hawaii.

Malabar Giant Squirel, India. Corn, Aksaray, Turkey.

Tosanoides Aprhodite, Brasil.

10.1 Light painting

Newton considered physical aspects of light and color as a starting point for his studies; Goethe, in turn, was interested in aspects involving the psyche. Renaissance painters mixed pigments to make their work material, used brushes and chisels as instruments and fabric as the main support base for their creations. However, light was extremely important in the formation of his works, even more than the paint colors themselves. Different paths were taken in this relationship between the observer and the artistic product. Much later, someone thought about using light to paint.

Internet

Janne Parviainen - Light Topography, Dhamma. 2016.

Brent Person - Spider On The Track. 2009.

Eric Staller - Lighting Drawings. 1970.

Gjon Mili photographs Pablo Picasso - 1949.

Frank and Lillian Moller Gilbreth - 1914.

11. Paradigms of light

11.1 Attribute light

Property light, the venerated light, light belonging to bodies, up to the Renaissance.

Internet

MNAC Museum's - Romanesque Art.

11.2 Effect light

Effect light, domesticated light, Renaissance and Baroque.

Internet

Beato Angelico, Fra Angelico - Virgin Annunciate.

Darkness is a starting point, the light enters the “dark room” and from there to the photograph.

Internet

Camera obscura.

Penetrates the eyes: Impressionism and Pointillism.

Figure 79. Impressionism style.[25]

11.3 Light cause

Instrumented lighting, support or material for light art.
Characterization of spaces, paths and environments for architectural surfaces, with greater visual richness.
That's what we'll cover in our next topics.

Internet

Adolphe Appia - Orpheus Hellerau. 1913.

11.4 Lighting Design for stages

The central axis of modern Lighting Design is the change from an instrument of visibility into a structural and structuring element of scenic writing, constituting itself as a language.

Internet
Bela Bartók - Bluebeard's Castle (1911) by Ópera Perú. 2015.
http://operaperu.blogspot.com/

[25] Model: Lia Neusa Meirelles Perrenoud. Photo: Gastão Perrenoud.

12. From light to non-light

We can make a sensory path from light to dark, from light to non-light. And all these little rides are noticeable and carry a definite emotional charge.

12.1 General lighting

It is the lighting used for catwalk, for example, with uniform lighting and covering the entire area of action.

Internet

Graduate Fashion Week.

https://www.graduatefashionweek.com

12.2 Specific focuses

In this case, we use some light points that attract the audience's view.

Internet

Ford’s Theatre - Fly.

https://www.fords.org/performances/past-productions/fly/

12.3 Using shapes – Gobo

Gobo is the acronym for Goes Before Objective used in a luminaire called ellipsoidal. This light source has an elliptical mirror that reflects light and its optics create a focal point for the crossing of light rays inside the device. In this location, the gobo can be placed. An iris can also be used to reduce the beam of light or shutters to cut this beam.

Internet

The Crucible @ Henderson State University Stage & Lighting.

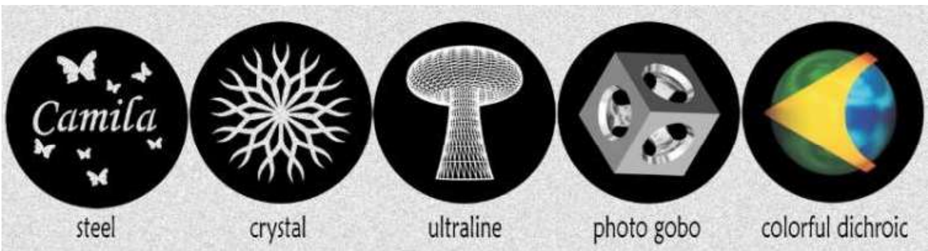

Figure 80. Gobos.[26]

[26] Images by Gobos do Brasil.

12.4 Through projection

Image projection has been increasingly used to recreate virtual scenarios that do not need to be physically, materially constructed.

Internet

Video Mapping.

12.5 Shadow design

Not lighting is also a function of Lighting Design.
Besides the light we should think about how the shadows produce sensations. Volumes are extremely influenced by the clear and dark of an image because they give the impression of approaching and moving away from us.

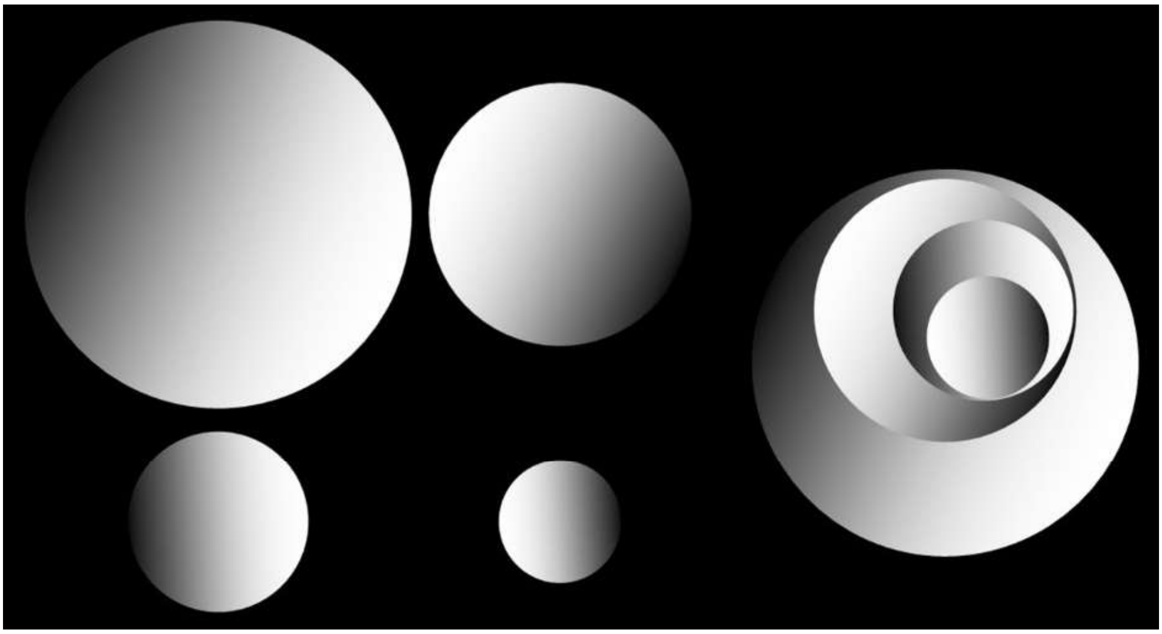

Figure 81. Shapes and volumes.

Shadows communicate and we can give a specific meaning to this communication. How about a puppet that creates its own bird with light?

Internet
Kumi Yamashita.

Figure 82. Light and shadow.[27]

13. Photometric quantities

Technical parameters of the physical and optical qualities of light, mostly used in Lighting Design for architecture.

13.1 Luminous flux

Total amount of light emitted in all directions by a light source.
symbol: Φ
unit of measure: lumen (lm).

13.2 Light intensity

Intensity of the luminous flux projected by a light source in a given direction; it's the ability to illuminate, measured per unit of a solid angle.
symbol: I
unit of measure: candela (cd).

[27] Shadow dramaturgies - Companhia Teatro Lumbra 2021, Brasil. Photo: Alexandre Fávero

13.3 Illuminance

The intensity of light reaching a surface after being emitted by a light source.
symbol: E
unit of measure: lux (lx).

13.3.1 Horizontal illuminance

$$Eh = \frac{I * cos^3 Ø}{h^2}$$

when the angle Ø is zero, the cosine is 1 and this formula may be simplified:

$$Eh = \frac{I}{h^2}$$

Each time we move a light source away from the illuminated object, we have "less light"; and, from this formula it is understood that the illuminance decays according to the square of that distance.

13.3.2 Vertical illuminance

$$Ev = \frac{I * cos^2 Ø * sin Ø}{h^2}$$

$$E = \sqrt{Eh^2 + Ev^2}$$

13.3.3 Semi-cylindrical illuminance

The measurement of semi-cylindrical lighting gives us an idea of the balance between diffused and concentrated lighting.
The recommended needs vary according to the activity carried out at the considered site.
The calculation of the average cylindrical illuminance is done at 1.2 m above ground level (in normal situations) and we need to maintain an uniformity of illuminance equal to or greater than 0.1.
For good ambient lighting, we must have at least 50 lux, but in the case of offices and educational establishments, for example, the average cylindrical illuminance cannot be less than 150 lx.

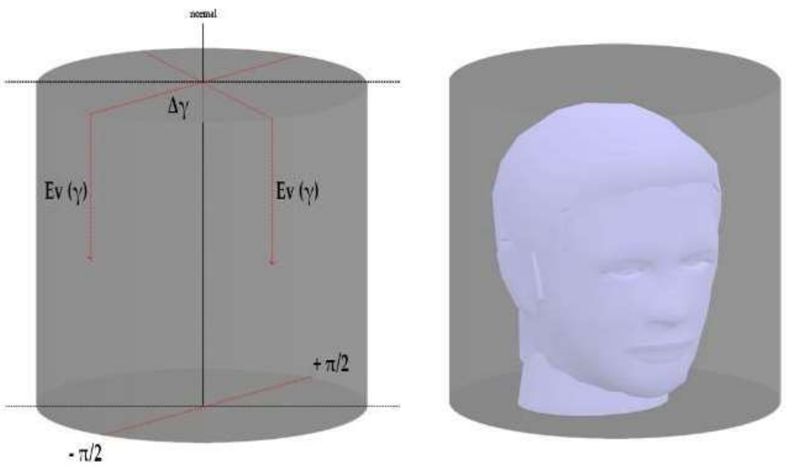

Figure 83. Semi-cylindrical illuminance.

For a good perception of the details of the faces, the minimum luminance (see on 13.4) should be 15 cd / m^2, but that already depends on the reflective surfaces of the place.

13.4 Luminance

The amount of incident light that is reflected by a surface in a given direction. It depends on the material and texture of the surface.
symbol: L
unit of measure: candela / area (cd / m^2).

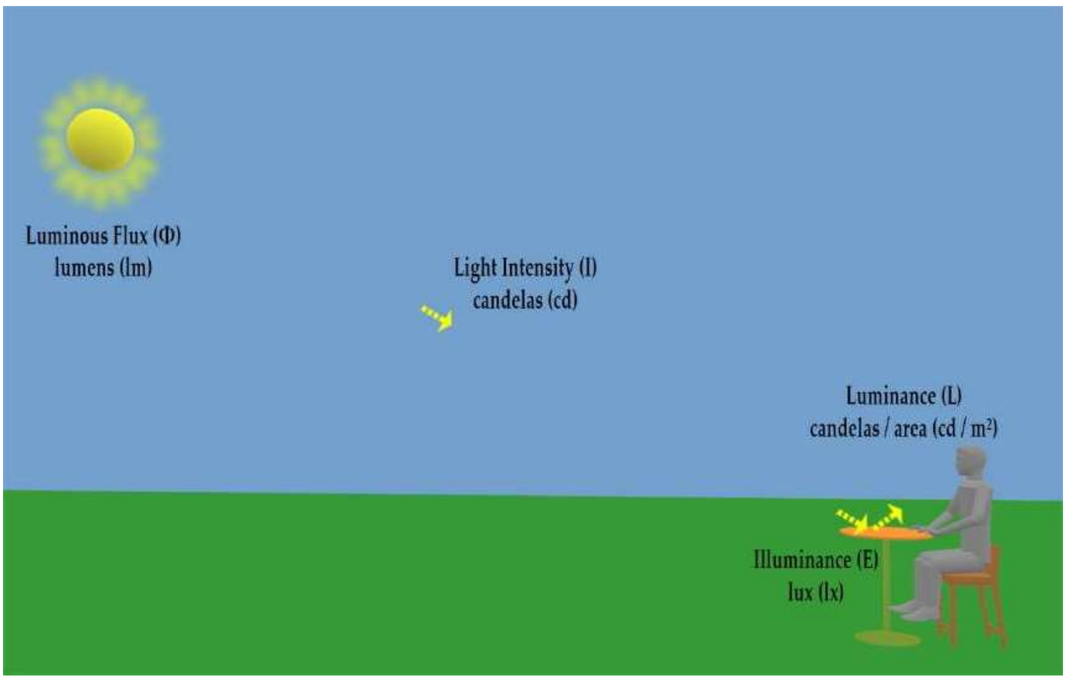

Figure 84. Photometric quantities.

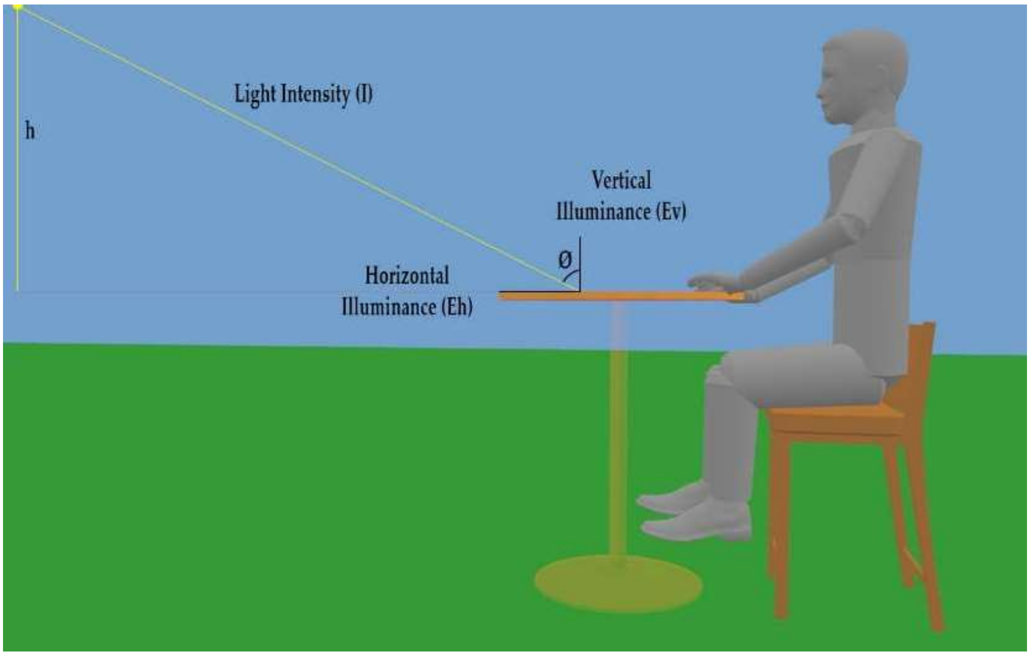

Figure 85. Photometric quantities.

13.5 Equipment and more metrics

13.5.1 Goniophotometer

A goniophotometer is a photometric device used mainly to test and measure the luminous flux generated by a directed light source, at different angles.
It is a photometer with a rotating arm containing a circular mirror. The light hits this mirror at different angles according to the rotation of the arm.
We obtain information about the luminous flux, intensity distribution, color uniformity and, finally; we can know the efficiency of the light source.

13.5.2 Integrating Sphere

The integrating sphere is a structure used to measure diffuse and undirected light sources.
The main element is the inner lining of the measuring sphere and we have basically two types: the Ulbricht sphere with a diffuse internal structure and the Coblentz square whose internal structure is mirrored.
The biggest advantage of this type of instrument is being able to measure the total power of a source.

13.5.3 Photometric curve, polar distribution

Also called the light distribution curve. First of all, the direction of the luminous flux can be verified in relation to the line that goes from 90º to 90º and that passes through the center of the diagram.
From the center of the diagram to one of the points on the outline of the figure we have the value of luminous intensity.

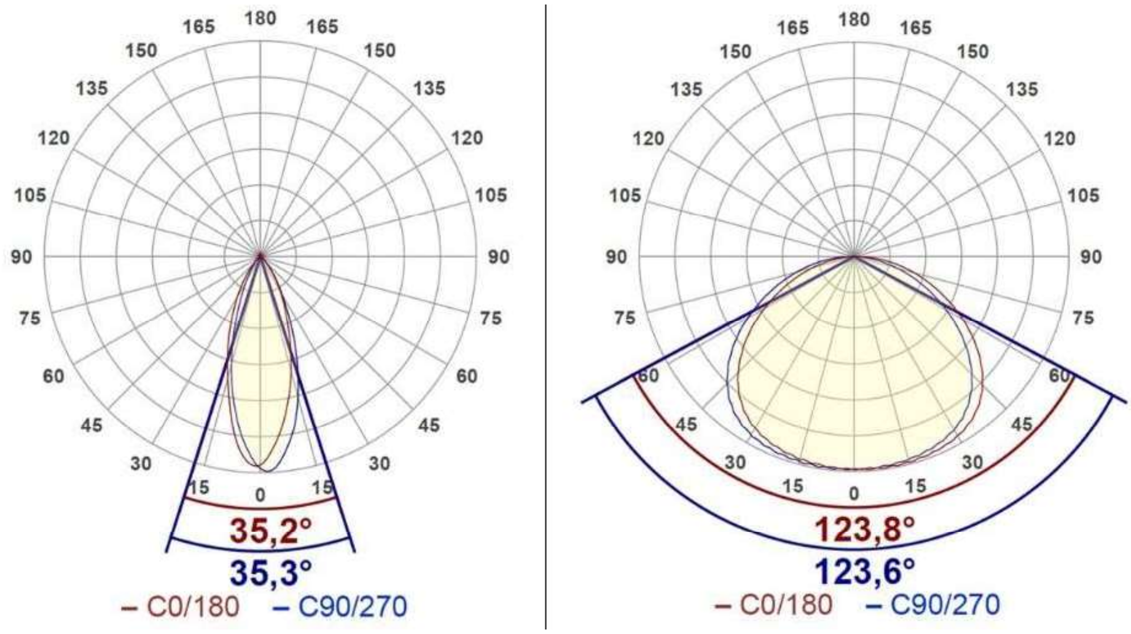

Figure 86. Beam angle and light distribution.[28]

The drawing on the right represents a light source with a wide beam, while the one on the left is a source with a narrower beam.

As in none of the drawings there is a component above line 90-90, the light comes out directly from the light source in only one direction.

All light can be, after leaving the device, direct or indirect depending on the reference object.
A beam of light comes out of a projector or reflector, illuminates a painting on a museum wall, but also bounces off the face of the viewer. Is this light direct or indirect? If we consider the painting it is direct, while the light is indirect in the viewer's face.

[28] Stella | Lighting, Brasil. Reports from Stella´s Laboratory.

13.5.4 Photometric cone

The photometric cone gives us indications of how the luminous flux varies with each distance interval. Light decays sensibly with each meter covered, remember: 1/4.

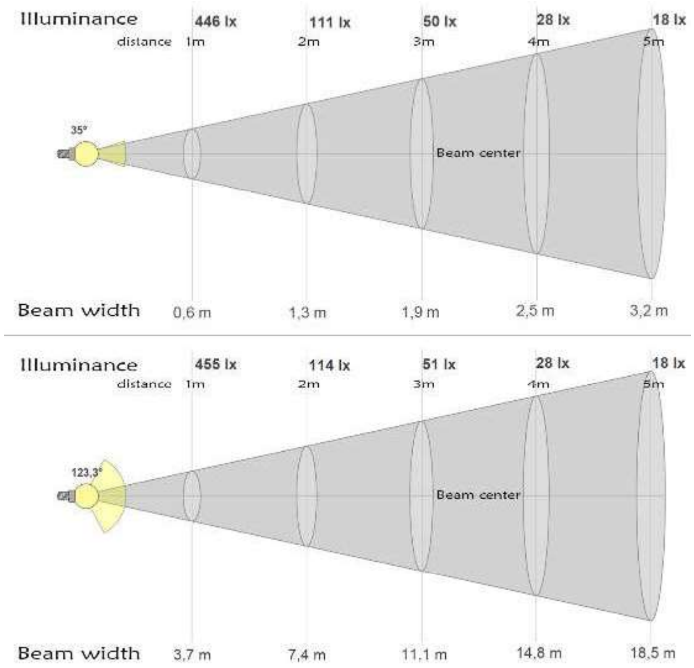

Figure 87. Photometric Cone.[29]

13.5.5 Beam and Field angles

The angular dimension of the cone of light is measured taking into account how much light is lost as we move away from the center of the beam.

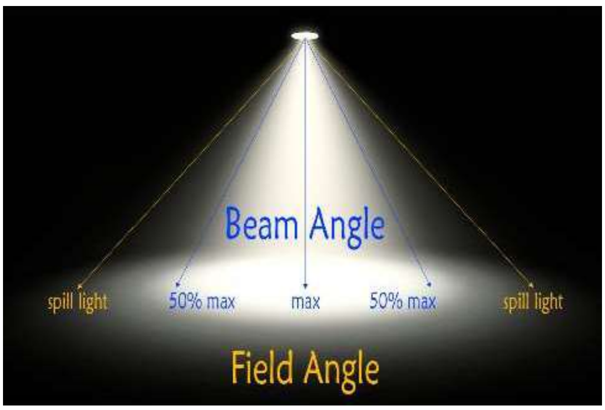

Figure 88. Beam and Field angles.

[29] Stella | Lighting, Brasil. Reports from Stella´s Laboratory.

13.5.6 Illuminated diameter

Diameter illuminated by a light source perpendicular to the considered surface. Note that when tilting this light source in relation to its illuminated surface, the calculation will be much more complex because we will have an oblique cone and no longer a right cone.

$$\emptyset = \frac{2 * d * tan\,\alpha/2}{2}$$

angle	-	diameter = index * distance
8°	-	diameter = 0.14 * d
12°	-	diameter = 0.21 * d
24°	-	diameter = 0.43 * d
28°	-	diameter = 0.50 * d
36°	-	diameter = 0.65 * d
41°	-	diameter = 0.75 * d
53°	-	diameter = 1.00 * d

Figure 89. Practical use.

To control the beam diameter, we may use certain accessories in the luminaire itself, internally, to decrease the beam size (iris, framing shutters) or externally, to reduce the beam size (barndoor, tophat, halfhat and donut).
We can also diffuse the light with garnitures placed outside the luminaire but connected to it; such as a soft box, for example.

Internet
Iris, framing shutters, barndoor, tophat, halfhat, donut, soft box.

13.5.7 Uniformity

The IESNA (Illuminating Engineering Society of North America) recommends that the illumination in the area immediately surrounding the task area not be five times greater than or less than one fifth the illumination in the task area itself.
Good uniformity (a ratio less than 5:1) improves visual comfort and reduces shadows.

13.5.8 Luminous efficacy

Relationship between the amount of light produced and the power consumed by a light source.
Watts do not determine the luminous intensity, only the consumption.
unit of measure: lumens / watt (lm / W).

Light source - 1800 lumens	Power (W)	Luminous Efficacy (lm/W)
Incandescent	75	24
Compact Flurescent	24	90
LED	15	120

Figure 90. An example of comparative luminous efficacy.

14. Qualities of light

14.1 Direction

An object illuminated by light coming from a certain direction can be perceived by an observer in very different ways depending on the position of the observer. Fixing the observer and changing the position of the light and/or the object will also generate new perceptions.
The fact is that we can illuminate an object of any position in 360º using one or more luminaires. Yes, the possibilities are endless.
Generally, the similar positions of the sunlight will be considered more "normal" and those that come from below will cause strangeness because we are not accustomed to seeing them in our everyday life.

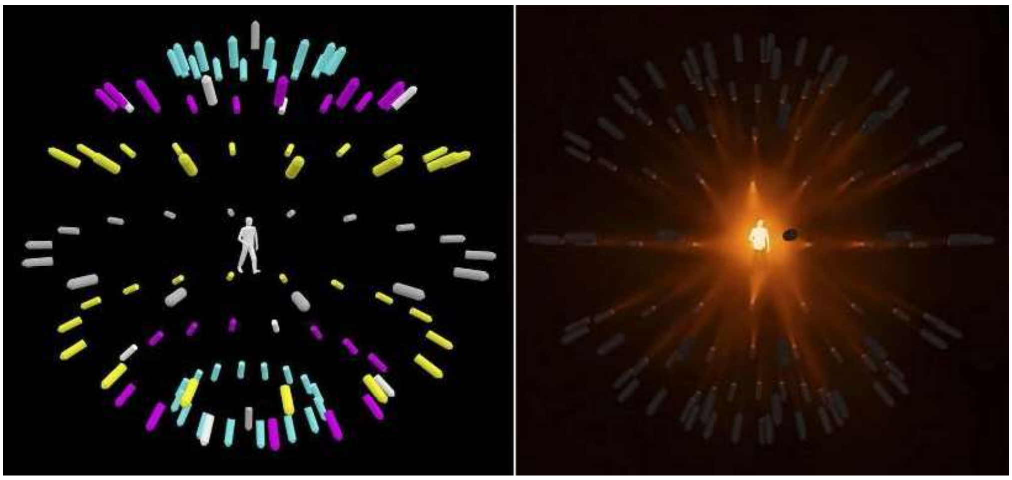

Figure 91. Lighting 360º.

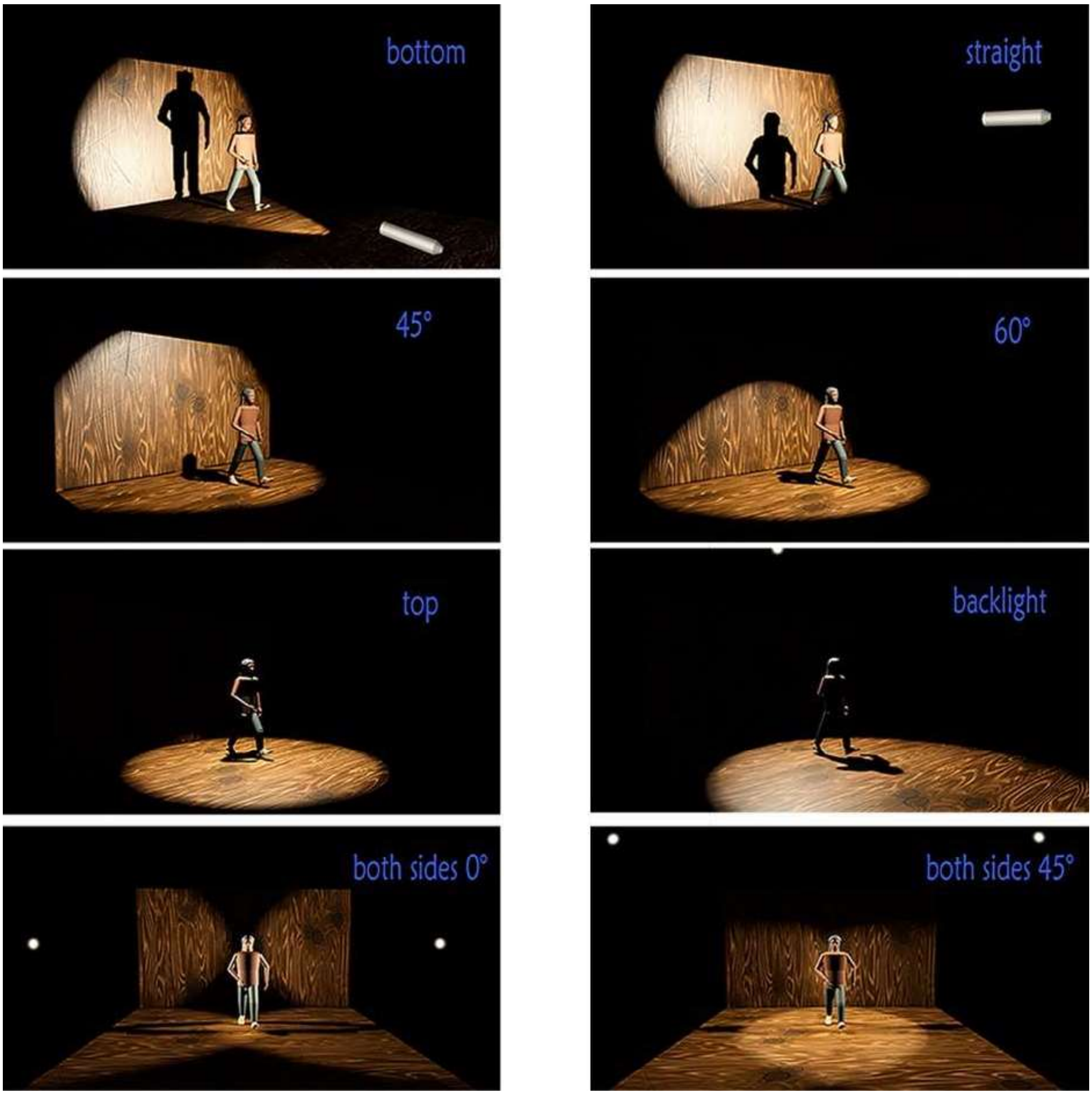

Figure 92. Some lighting positions.

14.1.1 Direct and indirect light

Regardless of what happens inside the light source, direct light comes from this source and reaches its objective without being deflected by external obstacles; indirect light, in turn, is redirected before reaching its destination, as we have already said.

In the image on the next page, sunlight is directly above the walkway and indirect at the base of it. On the walls we have both components.

Figure 93. Direct AND indirect light.

14.1.2 Sunlight system

The sunlight arrives directly from the star and reaches the earth but is a system and should be considered as such.

The quality of filtering should be taken into account, depending on the presence or absence of clouds, rain, snow, dust, smoke and other particles in the environment.

In order to illuminate objects and people with artificial lights in a pleasant and naturalistic way, we must use more than one light direction.

Figure 94. Direct sunlight.

Figure 95. Diffused sky light (filtered light).

Figure 96. Reflexes (indirect light).

Figure 97. The system.

14.2 Color

We will have the opportunity to further discuss color and its physical and psychological effects on illuminated objects and on viewers in the next topics. Needless to say, color is not everything, but it is 100%!
Now a question: are black and white colors?
What are the man's hair colors in the next image?

Figure 98. Foggy afternoon, somewhere, UK.

The answer is: yes, but they are neutral or unsaturated colors. These are the extremes of the gray scale.
Perhaps the only color that can be considered colorless is total black, but this will only be true when we reach 100% absorption by the illuminated objects, that is, 0% reflection.

14.2.1 Filters

When we talk about filters, we are referring to something that changes not only the color of an observed object but also its shape appearence.
On where to place the filters, we have some possibilities:
Position them on the luminaire itself.
It can be something between the light source and the object; a fabric stretched, an acrylic plate, etc
Can be an artefact placed on the camera lens.
Worn by the observer, such as sunglasses, for example.
Basically, we have some basic types of filters:

Colorizers - change the color of the light or its reception and, therefore, the color of the illuminated object. They can be correctors or converters of the color of light.
Diffusers - alter the quality of light with respect to the dispersion of rays and light.
Polarizers - allows the passage or blocks the light waves according to their polarization.
Neutral density - changes the intensity of the light source to less.
Reflectors - silver, golden, black or white metallic plates that allow, through various surface treatments, smoother or harder reflections to redirect the light or fill the shadow areas that require more illumination.
UV - absorbs only the emission of ultraviolet avoiding the deterioration of the color of the objects.

14.2.2 Colorizer Filters

With the advent of LED and the possibility of emitting already colored light, color filters are disappearing for some applications, but they are still widely used. Filters are made mainly of polymeric materials or glass.

Figure 99. Old swatchbook.[30]

14.3 Hardness (diffusion)

When we speak of diffused or concentrated light, we are referring to the diffraction of light rays from a source and not to the size of the illuminated area, in this case we should refer to a narrow or wide beam.

[30] Image by Lee Filters - Panavision.

We can observe the type of shadow caused by the objects to assess the hardness of the light.

Figure 100. Diffuse light.

Figure 101. Concentrated light.

Sunlight can be concentrated or diffused!

14.3.1 Diffuser Filters

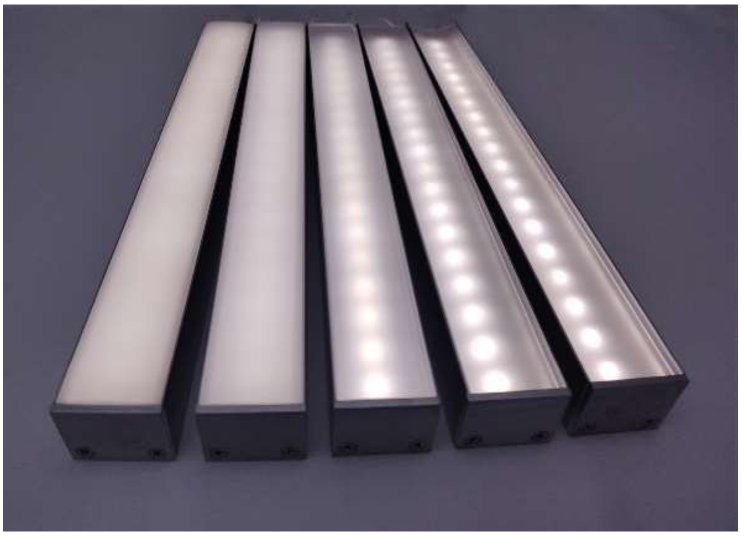

Figure 102. Difusers.[31]

We can have the same luminaire, the same lamp and a variety of diffusers to choose from.

14.4 Intensity

The intensity of a light source can range from zero (off) to the full flux of its lighting (on), usually when the maximum current allowed for the lamp or LED to survive is reached.
This can be done with the click of a switch or by dimming.

Figure 103. 10% illuminated bike.

[31] Perfil 30, Luminescence. Photo: Andre de Bacco.


Figure 104. 50% illuminated bike.


Figure 105. 100% illuminated bike.


Figure 106. 100% illuminated bike + midday sun.

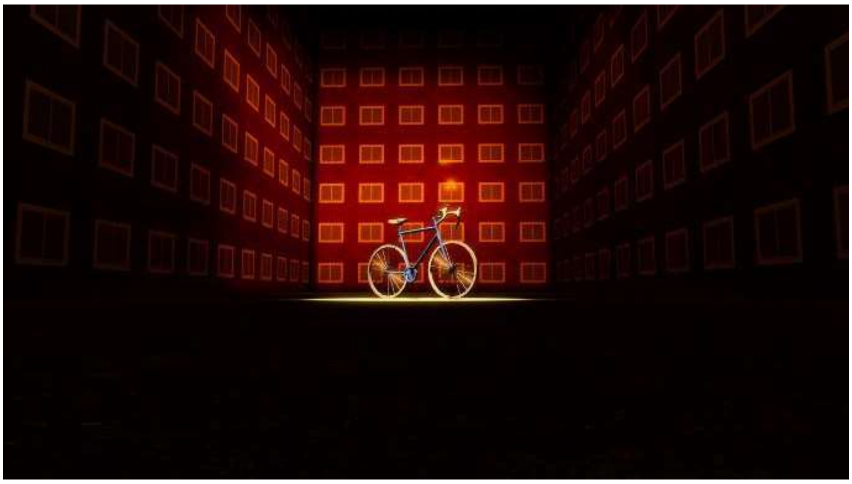

Figure 107. 100% illuminated bike + sunset.

14.4.1 ND Filters

They are filters that attenuate the light flow that enters the camera or emitted by lighting fixtures; without changing the color of this light. Sometimes metallic filters can be placed directly on luminaires that emit, in addition to light, a lot of heat.

Figure 108. ND filters.

14.5 Dimerization

Dimming allows you to vary the luminous flux (light intensity) emitted by a light source, allowing the creation of different lighting atmospheres with the same luminaires, usually taking advantage of the possibility of taking some time to turn on, off, lighten or darken the environment.

14.6 Duration

The duration concerns the chronological and dramatic times.
The way we turn a light on or off is related to both; we can turn it on with a click or take 10 seconds to do so, the results will be quite different with regard to psychological responses.
For a scene on stage that takes place in one minute, through lighting it is possible to represent the passage of the night until the morning.
In some performances by Kabuki, Japanese theatre, the exchange of light between one scene and another can take several minutes. In the past, this was done manually, today, with the advent of digital computing and control consoles, it has become much simpler and more accurate.

14.7 Movement

The movements concern both the displacement of the light beams and changes in the lighting atmosphere.
Nowadays with the aid of computerized systems the light beam can be moved manually or automatically following pre-established time rules.
In the past, torches already fulfilled the role of accompanying man on his nocturnal journeys, today a role played by lanterns.
Lighthouse lights have always been a guide and safety for navigators and continue to be a symbol of movement, direction and security.

Figure 109. Lighthouse.[32]

15. Methods of lighting the human figure

For the desired lighting, we must choose the way to reveal, as well as define the use of different light qualities (color, direction, intensity, hardness,

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[32] Eduardo Becker LD – Atelier de Iluminação Logo

duration and movement), as they will cause different views in the shape, size, material and texture of the objects and surfaces as a function of different reflections, absorptions, refractions and transmissions of light. These methods below can be used to light any type of object.

15.1 Stage lighting

Probably the method most used by Lighting Designers was created by Stanley McCandeless and published in 1932 with the aim of lighting the entire stage and providing a daytime or night time atmosphere and modelling the human figure. He recommended using four fixtures 90º apart from each other in relation to an actor in the center of each of the nine areas. The light sources must be at 45º vertically and horizontally from this actor's face, taking advantage of Rembrandt's technique!

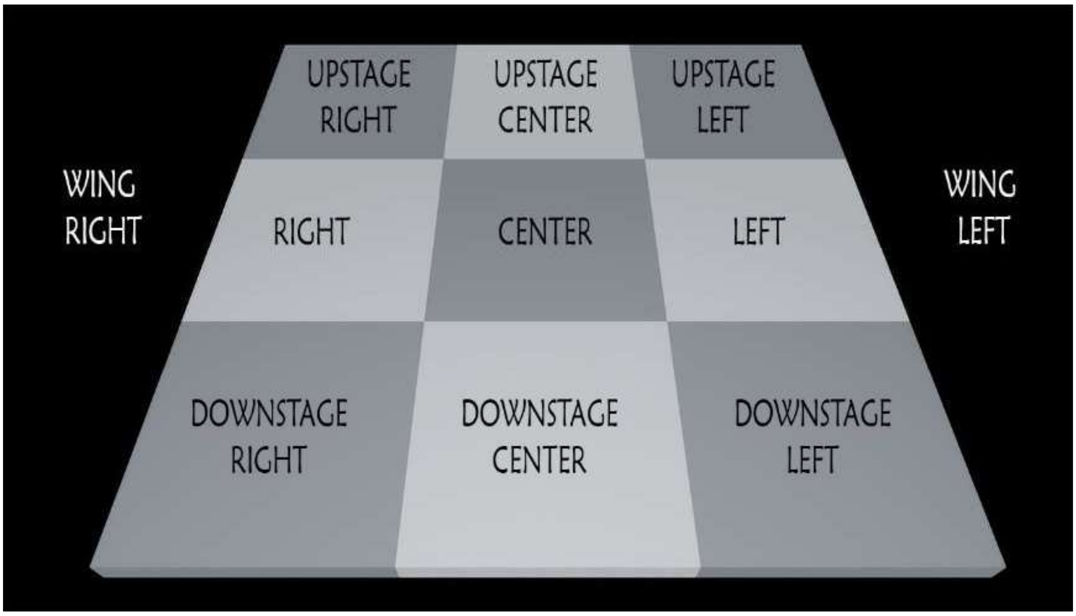

Figure 110. Positions on stage.

On one diagonal we should have the light sources corrected with amber filters and on the other diagonal with blue filters.
Let's take a look at some possibilities through an observer's frontal view.

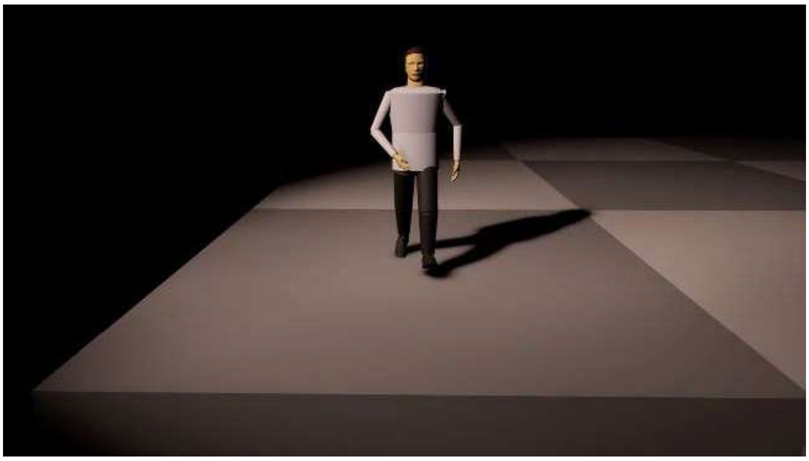

Figure 111 Warm front from left .

Figure 112. Cold front from right .

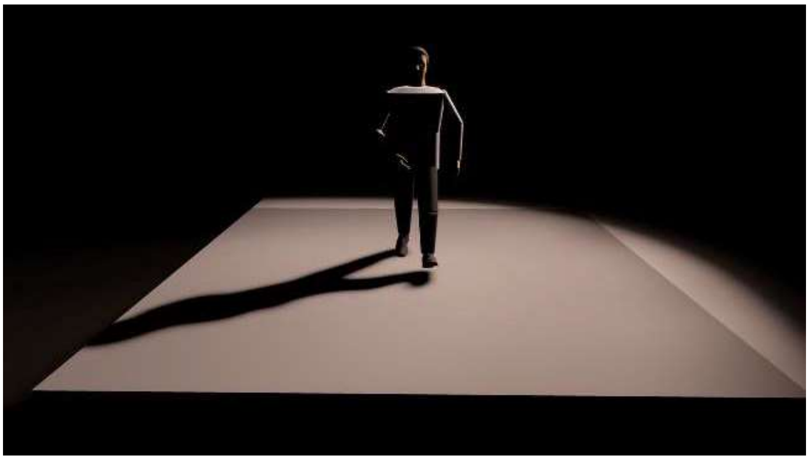

Figure 113. Warm backlight from right .

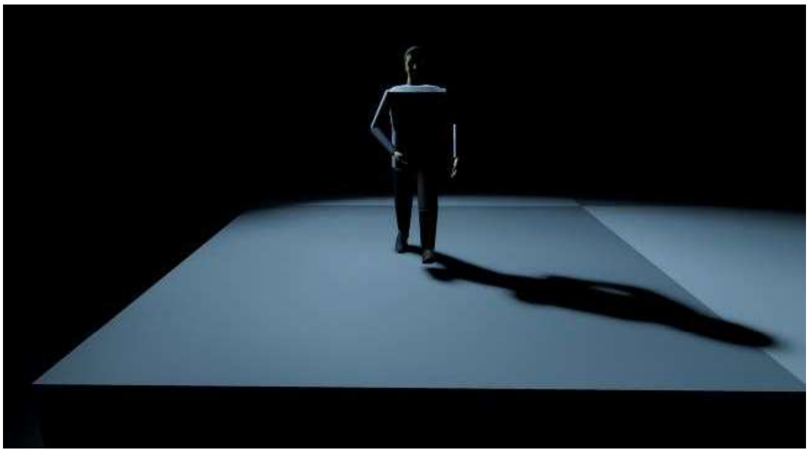

Figure 114. Cold backlight from left.

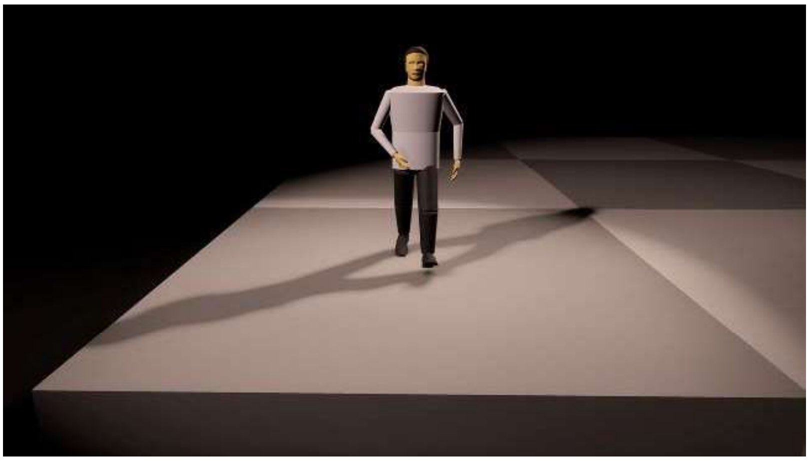

Figure 115. Warm criss-cross .

Figure 116. Cold criss-cross.

Figure 117. Front and backlight from left.

Figure 118. Front and backlight from right.

Figure 119. Front light from both sides.

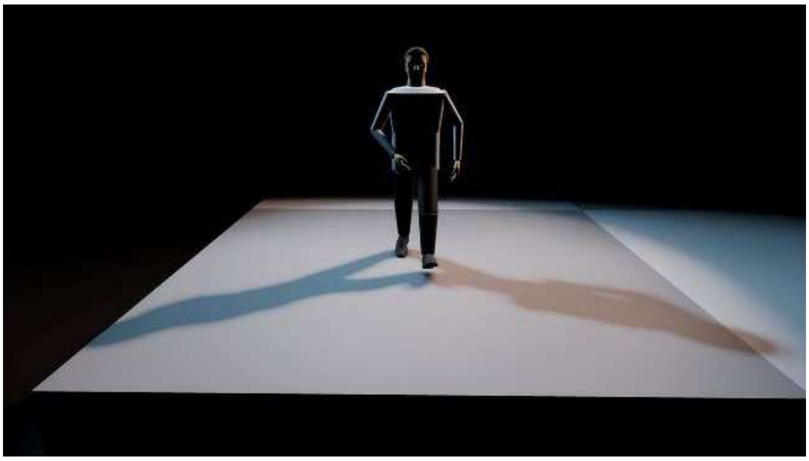

Figure 120. Backlight.from both sides

Figure 121. All at 100%.

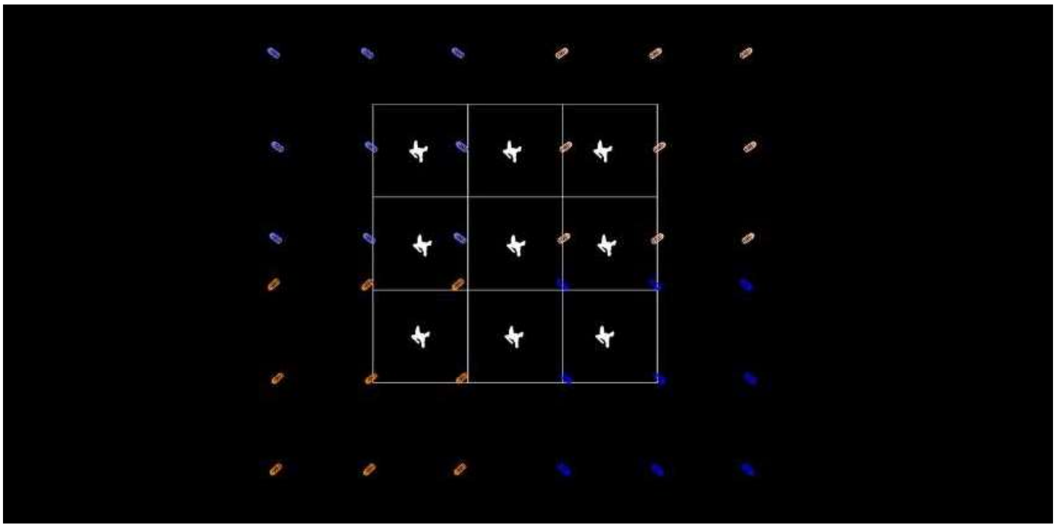

Figure 122. 9 areas.

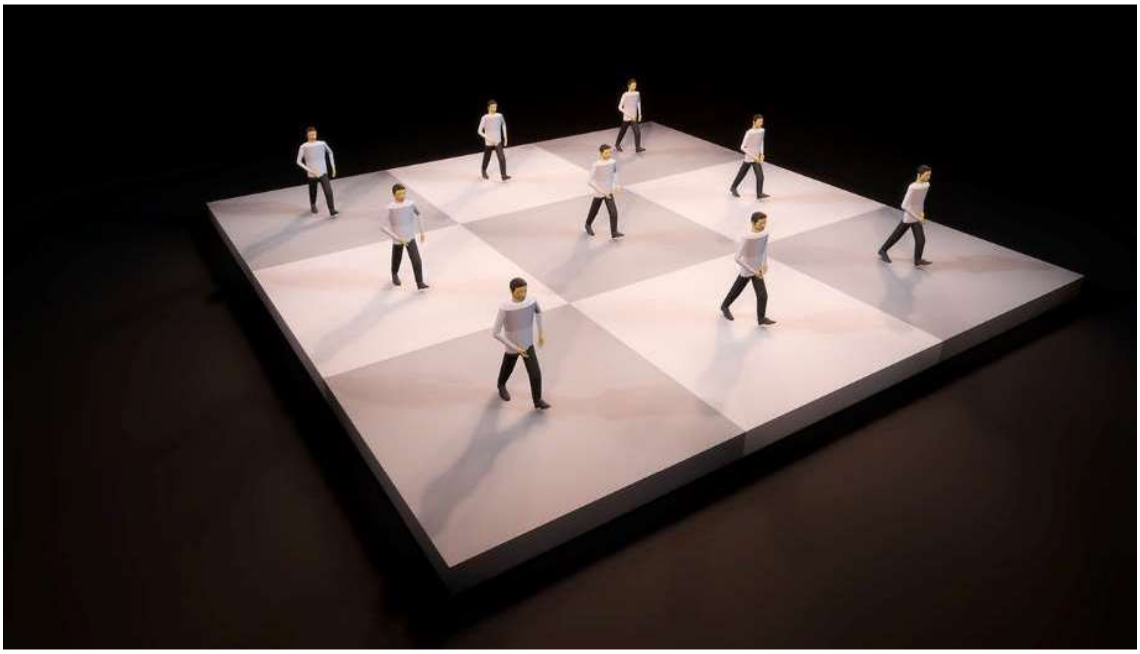

Figure 123. Illuminated areas.

Unlike the stage where we have observers at various points, for cinema the point of view is just a camera's eye. When using more than one camera in the same scene, we have to think about the necessary lighting for each one.

15.2 Cinema / video

One of the most used techniques is lighting based on three points of light directed to the objective to be illuminated and, sometimes, another light that complements the effect.

Key Light - It is the main illumination; usually it comes from the front of the object to be illuminated.

Filling Light - It is a more diffuse than the key light, a secondary light which helps to illuminate the still dark areas.

Backlight - It is the light effect to create the illusion of the third dimension and which removes the figure of the object from the background. Its light flux is harder and more intense (2 or 3 times) than that of the key light.

Light on the background or scenery - This lighting normally helps to detach the figure from the background. It is the lighting that defines the dimensions of the space, determining the width and depth where the illuminated figure is located.

Figure 124. Key, filling and scenery lights. Only sunlight, a system.[33]

16. Architectural Lighting

16.1 Concepts

The building is a living organism, multipurpose aggregator and has personality so we divide the building into layers to better understand this personality and to define the hierarchy we intend to give to the building parts using formal or functional lighting.

16.2 Light sources

There are numerous light sources and we can classify them by the type of light emitter, the type of bulb (if any), the type of socket (if any), the type of reflector (if any); but the most interesting is the type, the characteristics of lighting this device produces!!!

[33] Model: Camila Perrenoud. Photo: Rafael Azevedo da Silva.

16.3 Light fixtures

Houses and protects the light source, controls the distribution of the emitted light and contains power suppliers and wirings.

We have a lot of types: flush recessed, flush light panel, exposed canister, suspended luminary, eyeball down spot, pendant, adjustable, reel, track lighting, suspended hanging, coffered light recess, full room luminous ceiling, surface mounted luminary, surface mounted fixture, coffered light recess…

Again, what matters is knowing the luminous result to decide how to use the luminaire… think about.

16.4 Areas of architectural lighting

Industrial - Manufacturing facilities and hazardous locations (chemical plants, mines and refineries).

Commercial - Businesses that aren't manufacturing including corporate: hotels, restaurants, retail stores, warehouses, offices, hospitals, schools, condominiums. Public lighting on streets, bridges and government facilities.

Residential - Our homes, paths and landscapes.

For all these areas, we can subdivide the lighting into indoor and outdoor and will have different needs and characteristics.

And nothing, I said NOTHING prevents us from using lamps and luminaires in a different way, the rules are there to be creatively broken.

16.5 Indoor - outdoor

The main care is in relation to electricity and its conductors; in the background, we must consider that lamps and peripheral equipment must be protected from the weather.

16.6 International Protection system marking

The International Engineering Consortium (IEC) has established a coding system that aims to ensure that manufactured products are tested for the infiltration of contaminants inside the luminaires.

They are given an IP code (IP65, IP67 for example) with two numbers, the first referring to dust and the second referring to liquids more specifically, water.

1st digit	Protection against solid ingress	2nd digit	Protection against liquid ingress
0	Non-protected	0	Non-protected
1	> 50 mm gap for entry	1	Vertically dripping water
2	> 12 mm gap for entry	2	Dripping water tilted at 15°
3	> 2.5 mm gap for entry	3	Spraying water at an angle up to 60°
4	1.0 mm gap for entry	4	Splashing water at any direction
5	Dust protected	5	Jets of water fro any direction
6	Dust tight	6	Heavy seas or owerful jets of water
		6K	Powerful water jets with increased pressure
		7	Harmful ingress of water when immersed between a depth of 100 mm to 1,000 mm (5.9 to 40 in)
		8	Continuous immersion in water
		9K	Powerful high temperature water jets

Figure 125. IP.

17. Architectural Lighting Design

For a long time, it was enough to place a light source on the ceiling and in the geometric center of the room, to imitate the sun, to generally illuminate the whole place. The doubts to resolve were how much light do I have? How is the distribution and uniformity of this? And it was enough to meet the technical requirements and we used to use incandescent or halogen lamps to do the job.

This way of thinking about light has been changing both through the exchange of experiences and knowledge between professionals responsible for architectural lighting and with their peers in the performing arts area.

17.1 Methods of calculating architectural lighting

17.1.1 Point by point

This method takes into account the lighting of the luminaires that arrive directly at the work plane.

Using the intensity data for each luminaire at a given angle, the illuminance at each point is measured using calculations based on the inverse square and cosine laws.

17.1.2 Lumen (zonal cavity method)

Lumen method is a series of calculations that uses the horizontal illuminance criteria to establish a uniform luminaire layout in a space.
It is certainly a more complex method that uses a series of calculations based on horizontal illuminance and proposes a luminaire layout with the scope of the photometric curves of the sources and some technical data:
Light Loss Factors (LLF); Ballast Factor (BF); depreciation of the lumens emitted by the lamp, the Lamp Lumen Depreciation (LLD); depreciation due to accumulation of dirt in the luminaire, the Luminaire Dirt Depreciation (LDD); depreciation due to accumulation of dirt on the surface of the room, the Room Surface Dirt Depreciation (RSDD) and others.

But Lighting Design is much more than these methods... notice the layers of light in this image… and directions… and colors.

Figure 126. Layers.[34]

17.2 Human dimension

Now that more than ever we are focused on the human being when projecting lighting design, we must consider the use of the precepts of holistic and interdisciplinary neuroscience, the Human dimension.
Some aspects should be highlighted in the next topics.

[34] U.nico Produções Artísticas - The Great Attraction. Artists: Fernanda Takai and Claudio Levitan. Photo: Gerson de Oliveira.

17.2.1 Circadian rhythm

Living beings have always been governed by the movements and alternations of light during the 24 hours of the day (then called Circadian cycle), with changes in the seasons of the year according to the climatic conditions of each location. Observing and respecting the individual characteristics of beings is essential.

17.2.1.1 Lighting automation

Fixed lighting is not natural; one of the ideas is to use dynamic lighting to match natural light. According to a timeline, we can program the color temperature and intensity with dimmers for each luminaire creating lighting scenes even for special moments; analogically through manual controls or by computerized automation.
Using the dimension of time and varying the atmosphere of the environments, we stimulate ourselves visually or we can also relax because we need to refresh our eyes and brain.

17.2.2 Environmentally sustainable

Nowadays it seems obvious, but we still have to make a big effort both to make light sources less polluting and to dispose of them.
Remember that when you throw something away, there is no "outside" here.

Figure 127. Apt, France.

17.2.2.1 Liter of Light

The organization Liter of Light was inspired by the “Moser Lamp” created by the Brasilian mechanic Alfredo Moser, in 2002. One liter pet bottle with water and bleach inserted in a hole in the roof of the houses providing lighting by refraction. A simple way to rethink the use of natural resources and discard at virtually no cost.

Internet

Liter of Light.

Figure 128. Let's spread this idea.

17.2.3 Visual message

Our mood is impacted by the light and colors of the environments and by the planned or unplanned changes that occur in the spaces.

Figure 129. High spirits, not war of course.

17.2.4 Communication codes

With the evolution of theories and practical studies, Lighting Design evolves creating its own form of communication, its language.

17.2.5 According to activities

Efficient and effective lighting for users according to the activities being developed and which is directly related to visual comfort.

In lighting design connected to the world of sales, depending on the environment, we must pay more attention to some items without obviously forgetting the others. In supermarkets, for example, energy efficiency and system maintenance play an important role, but it is visual comfort that will determine the customer's stay in the store. For retail, we must guide the buyer to the products, create atmospheres and highlight the brand. In the case of shop displays, contrast is extremely important to draw attention to the products and to hide the luminaires and avoid glare is essential. In all these cases the quality of color reproduction is essential.

17.2.6 Flexible

Lighting must be flexible; if necessary and possible, according to the age and skills of the users.

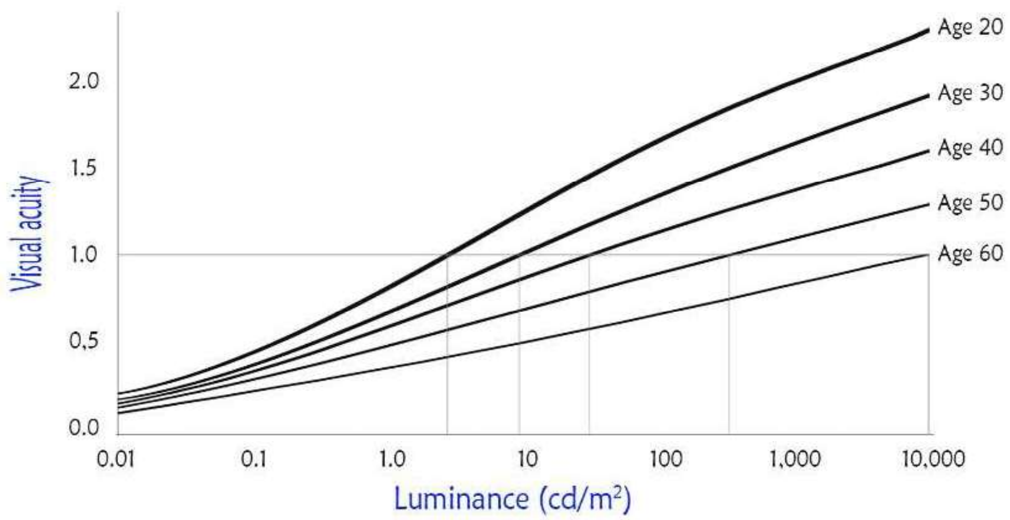

Figure 130. Visual acuity, luminance and ages.

17.3 Technical and artistic dimensions

There are two main axes of the lighting project itself, one with a technical bias focused on established ***luminotechnical*** concepts and calculations, and the other, more free and without prejudice, artistic, based on the ***luminoscenic*** studies, the dramaturgical universe.

17.3.1 Integrate natural and artificial lighting

Both at night and during the day, the more we use natural light, the better. Be it live from the light coming from the sun or storing energy to be used for illumination when we need it.

17.3.2 Space composition

It is the light that allows the visualization of spaces and their perception.

Figure 131. Milano at night.

17.3.3 Controlled lighting with excellent spatial distribution

Keep it simple. less is more. Spend time thinking ahead and not solving problems later.

Figure 132. Distribution.

17.3.4 Make selectively visible by defining interest levels

A standard concept, what you want to see is illuminated, what is not so important can be without light. This rule can often be transgressed and sometimes even, broken.

Figure 133.Interest levels? [35]

Figure 134. Be Brasil - APEX, Milano, Italy.

[35] Artist: Arthur de Faria. Photo: Eneida Serrano.

17.3.5 Modulation of shapes and volumes (3D)

That is an example of bad lighting, simply by the fact that you need to think to understand the shapes. This Lighting Design was made by me and, of course, corrected before the opening of this exhibition.

Figure 135. Be Brasil - APEX, Milano, Italy.

17.3.6 Efficient energy and technology for each location

Figure 136. Ancient Theatre of Epidaurus, Greece.

17.3.7 Easy maintenance

At the time of the project, we must already foresee how the maintenance of the luminaires will be carried out.

Figure 137. Brasilia Museum, Brasília, Brasil.

17.4 Method of approach

How to commit to the work to be done? Having a clear idea of the direction we are going to take the boat in this endeavour.

17.4.1 Location and culture

The way to illuminate and perceive the lighting varies according to the location, something beautiful in one place can be horrible in another and vice versa. Designing artistically and globally is extremely complex and needs discussions and more discussions about the final product, even if it's the Lighting Designer with himself.

17.4.2 Objectives of the contractors

It may seem obvious, but if this item is not very clear and documented, we may have to take a much more hectic route than expected and things can even get complicated during the project development process.

Figure 138. What about the Lighting Design?

17.4.3 Existing lighting conditions

We must always consider the existing lighting at the location of our intervention, regardless of whether the location already has lighting or external influences that may or may not be controlled.

17.4.4 Restrictions

The standards vary according to the location of the globe where we operate and according to the type of the same, being aware of the standards is extremely important and avoids future problems.

Regionalism depends on the sun and climate and affects the Lighting and Luminaire Design. Ventilation and specific visual identity are also within the parameters of our applied science. If there is not much difference in heat stroke between places, there will be more cultural differences.

With the development of the LED sector, the control of actions goes a little out of design and gets closer to technique.

Specifically regarding the manufacture of luminaires, there is a well-established path between their creation and their manufacture.

The designers have inspirations that are reinforced at the Milan fairs resulting in design creations based on new technologies and colors. In Germany, finishes and thermal and shock protection are being developed for these luminaires. Finally, in China, manufacturing takes place according to the previous precepts.

17.4.5 Aesthetics of Lighting Design

What is Lighting Design?
What is it for?
How is done?

17.4.5.1 The way to reveal

For the desired lighting, we must choose the way to reveal, as well as define the use of different light qualities (color, direction, intensity, hardness, duration and movement), as they will cause different views in the shape, size, material and texture of the objects and surfaces as a function of different reflections, absorptions, refractions and transmissions of light.
Hey, I've read that phrase before. Yes, I am repeating it for its importance.

Figure 139. Definition of Lighting Design.

17.4.5.2 Luminous concept

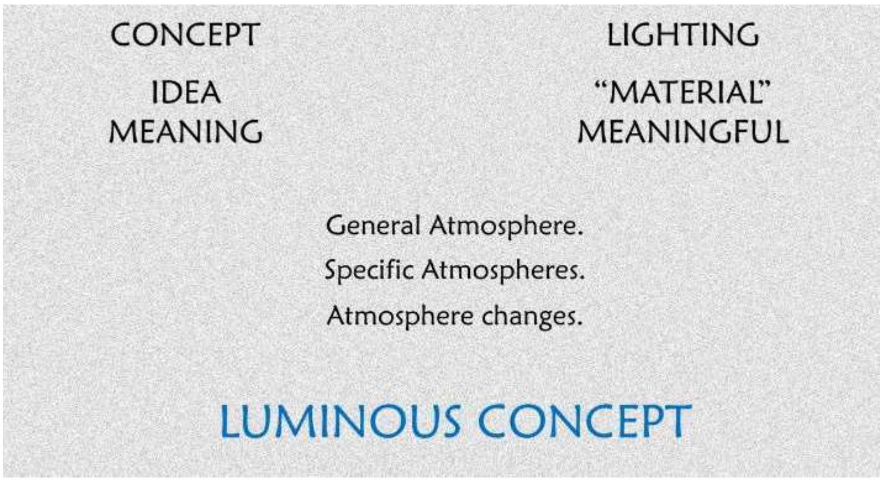

Figure 140. Luminous Concept.

17.4.5.3 Pictorial composition

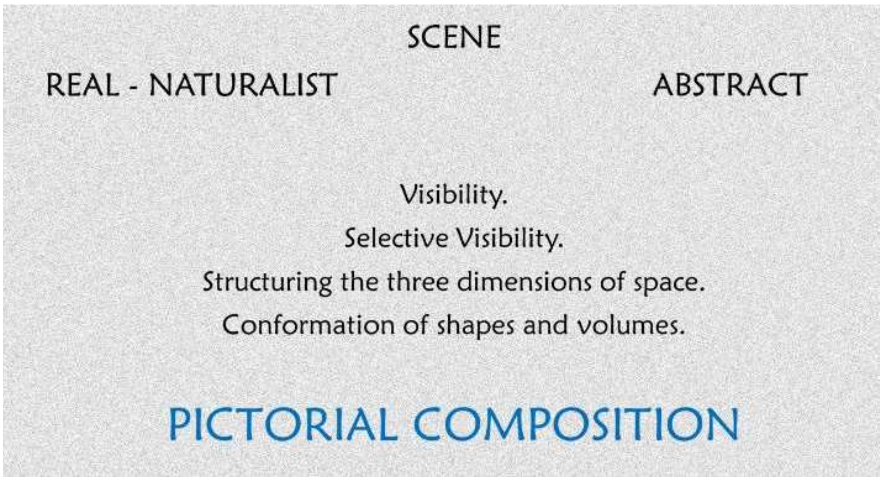

Figure 141. Pictorial Composition.

17.4.6 Technical aspects of Lighting Design

17.4.6.1 Lighting requirements - functional

Some questions we must answer:
What needs to be illuminated?
What are the illuminance levels to be used?
What balance between technical and artistic should I provide?

17.4.6.2 Lighting performance - quality

What is the quality of the light?
Can I use different CCTs?
Can I or should I use colors?
In relation to the other qualities of light, what should I formalize in lighting?

17.4.6.3 Lighting maintenance

Remember that there will be someone at the top of the stairs, twisting behind a panel or even taking apart an entire piece of furniture to change a simple light source before designing it!
Never change the lamps of a theatre chandelier one by one ... the ideal is to make a general change of luminaires or lamps with 75% of the useful life completed and to make them all at the same time. Then use the ones you remove in places with easy access and that can burn without problems of operation or for the safety of the place. In some specific cases related to health and safety, this change can be made even earlier.

17.5 Criteria

Some criteria to be used and that are more or less important and according to the use itself.

17.5.1 CCT

CCT is a slightly more artistic than technical criterion.

17.5.2 CRI

CRI, in turn, is more technical than artistic.

17.5.3 The levels of illumination

But, it's amazing, if you measure the light levels with a luxmeter after running your creative light, you'll notice that the standardized levels aren't too far from what you used. Our good taste and everyday habits lead us to make the right choices.

17.5.4 Balanced distribution of luminance

You can have a balance, but that balance can create high or low light contrasts using varying levels of lighting.
We can have little contrast with a lot of light and we can have high contrast with lower light levels.

17.5.5 Direction of the light

As I mentioned before, the direction and sense of the light makes all the difference when we see an image, a pictorial composition.
The light sends a message by itself, taking on meanings according to our previous experiences. A light coming from under the face is completely unnatural, so it scares us. Why light statues that way, then?

17.5.6 Distribution of shadows

The shadow, or the reflexes, can reveal the light, or at least denounce its presence and spectral qualities.
We can take advantage of this to improve a matte wall, for example.

Figure 142. Rhône River, Lyon, France.

Figure 143. Rhône River, Lyon, France.

17.5.7 Color deterioration

Light fades colors over time when it contains ultraviolet rays, which causes yellowing, flaking, weakening and / or disintegration of materials.
Some paints and some printed colors can disappear in a few hours in direct sunlight or just a few years in the near darkness of a museum.
Infrared also heats the surface of objects and impairs the long-term preservation of unstable man-made materials.
Some ceramic frescoes do not fade and can last for centuries in direct sunlight; it is interesting to read more about it.

17.5.8 Glare control

Glare: direct or reflected light that make us feel uncomfortable.
The reason for the lighting is the user, if we damage his vision we will be doing disservice.
Depending on the position of the light source in relation to the observer, if the brightness is unavoidable, we can control the brightness by cutting the angle of the luminaire, using a prismatic diffuser or anti-reflective film for example.

17.6 Drafts and preliminary designs

Like everything in life we start with sketches, in general the best ones start with doodles with what we have in hand, including restaurant napkins. When we arrived at the office we started to work more seriously, condensing these ideas in an organized way.

17.7 Verifications and final project

After a preliminary project, it is normal to make revisions until we reach the final project. The more organized your method of work and creation, the faster you will reach the final result and the more time left for new napkins!

17.8 Expectations alignment

I think the most important part in a creative process that involves a client; or boss, is the Alignment of Expectations, when simple conversations define the scope of the project and what each one expects to do and receive at the end of the work.

18. Chromatic circle

Circular color distribution conveniently organized based on a determined and explicit logic. The question is how conveniently this logic was used and the conclusions of that use!

18.1 Complementary colors

"Complementary colors are two colors that are on opposite sides of the color wheel."
This statement is not correct, first because there is no THE color wheel or THE chromatic circle and two opposing colors in a color wheel are not always complementary, they may be antagonists or they may simply be opposites in that circle.
The colors on opposite sides of a circle that we use at school to paint or color paper really make beautiful compositions and seem antagonistic to us; and they are, but they are not complementary.
Yellow-purple, blue-orange and red-green are not complementary pairs.
Two complementary colors are those that, when used together on a white substratum, form white (or near white) by additive synthesis or black (or near black) by subtractive mixing.

19. Color spaces

Color space, gamma or gamma is the set of colors that a device or peripheral is capable of capturing, producing or reproducing.
The information about the colors that pass from one analogue or digital medium to another must be perfectly represented and reproduced so that there is no discrepancy between what is "spoken" and what is "heard", so that the colors are seen as in the original, as faithfully as possible.
Each device has its own way of recognizing color, which can mean limitations in its transfer. This management is complex and involves decisions such as adding a mapping through an interrelation function that often delimits the standard color space to create new spaces (range), while restricting the number of colors that can be accurated reproduced.
We currently use the CIE 1931 chromaticity diagram to define the most complete color space, the standard reference environment.

20. The dimensions of colors

We tend to establish that colors have basically 3 dimensions: hue, luminosity and chroma. These terms vary from author to author, I mention here what I consider most coherent, of course like the other authors.

20.1 Hue

The optical system distinguishes hues based on their spectral position, it's the color itself, and actually there aren't many.
When viewing a hue on a color wheel we can see differences with the nearby colors but this obviously depends on how many hues this circle contains. In the continuous spectrum, would there be as many as it is possible to name?
If I say hues are the seven colors of the rainbow, magenta is off the list.
Some authors say that the hues are perceptually not similar to others hues, in this case green and blue look different? For some African tribes; no, they are very similar.
Hues can be the basic colors that our teachers taught us to recognize and name them with a single word in school. None of these hues can have a "last name", such as dark, light, bluish, etc. But rose whose name is simple is a light red and the violet is a dark blue with something red.
Nuances: variations of a single hue towards black or white passing through shades of gray.

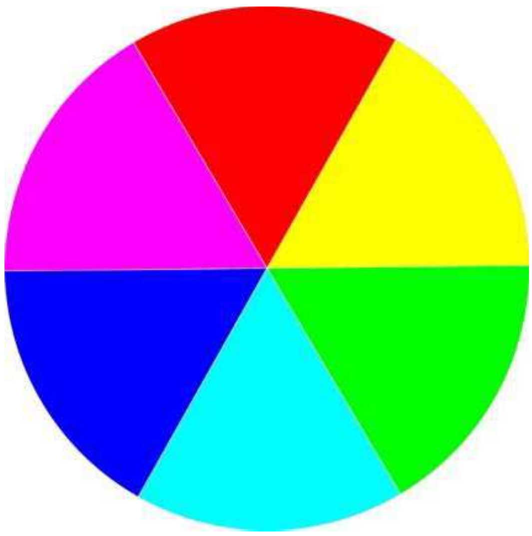

Figure 144. Red, Yellow, Green, Cyan, Blue and Magenta.

Where is amber?

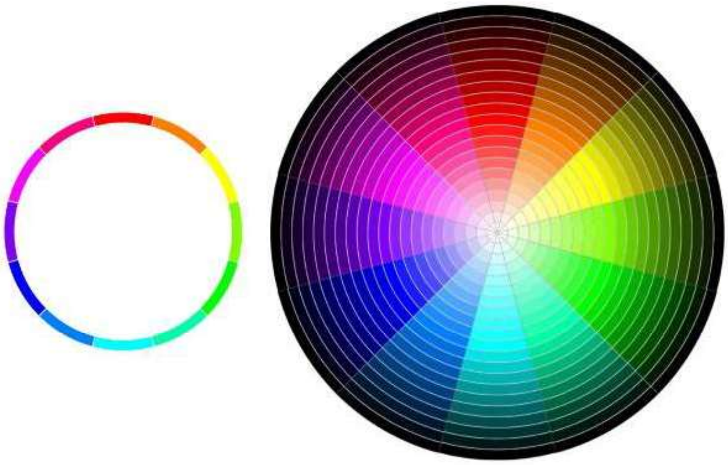

Figure 145. Red, Yellow, Green, Cyan, Blue, Magenta and other hues.

20.2 Luminosity

The blacker a hue, the lower its luminosity, and the hue saturation decreases.
Shades: variations of a hue when adding black, or taking out your own light.

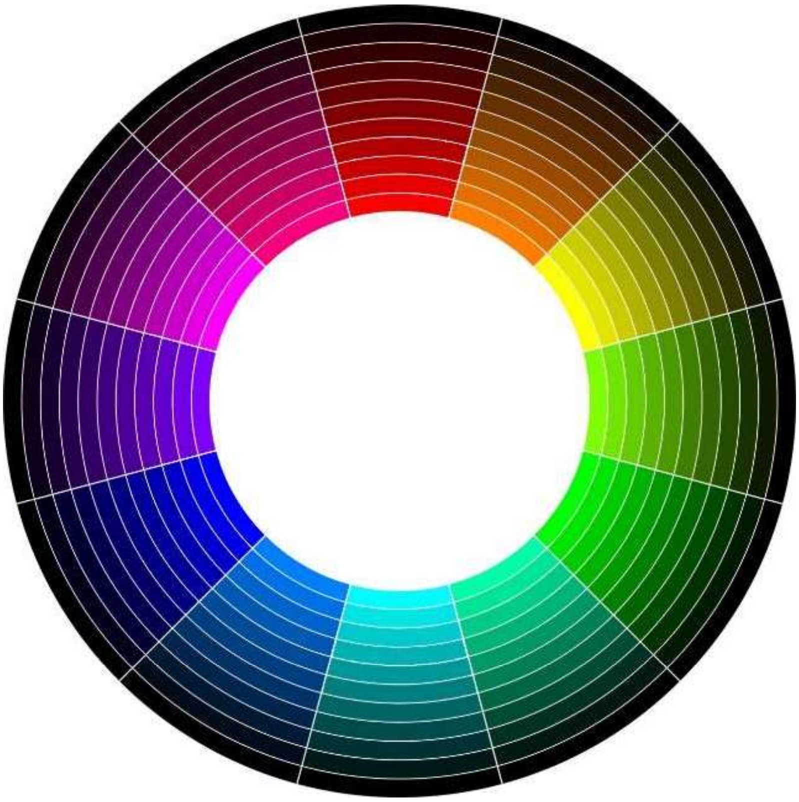

Figure 146. Luminosity.

20.2.1 Brightness and lightness

Brightness: how much white or fluorescent is a light source (luminance). Lightness: is directly related to the reflective surfaces (illuminance).

20.3 Chroma

The whiter, the lower the saturation of a pure hue, the lower the chroma of a pure hue.
The difference is that here the hue saturation is maintained as we increase the saturation of the other hues.
Shades: Variations of a hue by adding white or its complementary color.

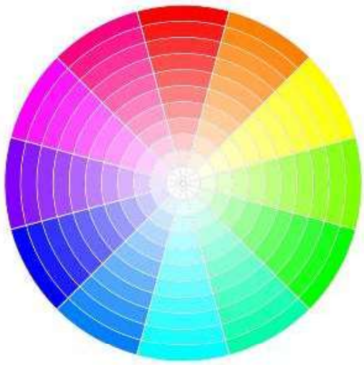

Figure 147. Chroma

21. Primary, secondary and tertiary colors

The choice of a color as a primary is related to the physiological response of the eye to light. There are usually three primary colors.
Thomas Young thinking about the constitution of our retina in 1802 assumed, very close to what we consider today the three primary colors of light, which would be red, green and violet.
Hermann von Helmholtz used the ophthalmoscope and ophthalmometer (or keratometer) made by him in 1851 concludes that the colors are a slightly purple red, a slightly yellowish green vegetation and an ultramarine blue.
James Clerk Maxwell, in a lecture at the Royal Institution of Great Britain in 1861, presented a theory of three primary colors; red, green and blue and a color photograph.
What do we consider primary colors? The generative but indecomposable colors used in a color synthesis.
The secondary colors are formed in balance by two primaries.
The tertiary are intermediate colors obtained by the balanced mixture of a primary and a secondary.

Go back to Figure 143. The opposite colors in the circle are a primary and a secondary, and they are complementary to each other.

22. Mixtures, syntheses

We mix radiations, not colors.
Opaque pigments - subtractive mixture.
Translucent pigments - subtractive mixture.
Lights - addictive synthesis.
The subtractive mixture refers to the use of opaque or translucent filters, when we talk about additive synthesis; we are referring to more than one source emitting light at the same considered point.
Yes, when using paints for example, we are subtracting light, avoiding the reflected light from the painted substratum.

22.1 Opaque pigments - subtractive mixture

Opaque pigments are mainly used in coating paints. The type of material used for the inks as well as the characteristics of the substrate influence the final result, which can vary. The mixtures depend on the covering capacity that each pigment or ink has.
Some painters have long used palettes with more than the three misnamed primary colors because of the difficulty of getting other colors simply by mixing these paints.
The notations inside the squares refer to the numeric description in hexadecimal and RGB (0-255).

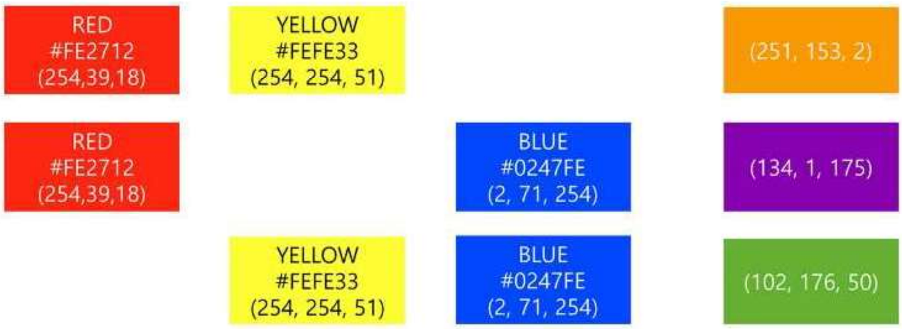

Figure 148. RYB.

22.2 Translucent pigments - subtractive mixture

Mixture used in graphic arts.
The mixture of the three primary colors Cyan, Magenta and Yellow generally produces a color near the black. To use less ink and decrease the drying time of printing, we use a fourth color, Black (key black), because of this the name of CMYK color model.

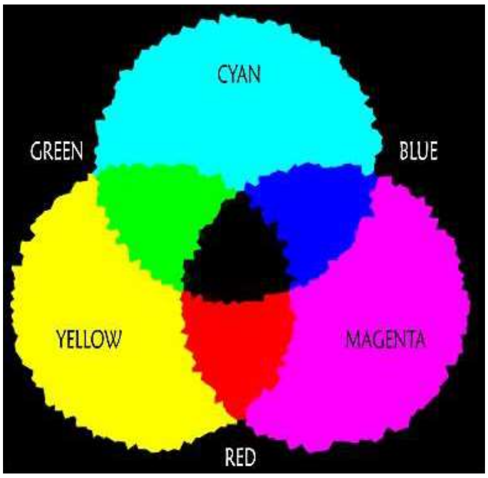

Figure 149. CMYK.

22.3 Lights - addictive synthesis

Natural and artificial lighting.
In addition to the lighting itself, this mixture is also used for TV screens, monitors, cell phones, video projectors, etc.
When we add the three primary colors white results.
The same happens when we add its complementary color to a primary color.

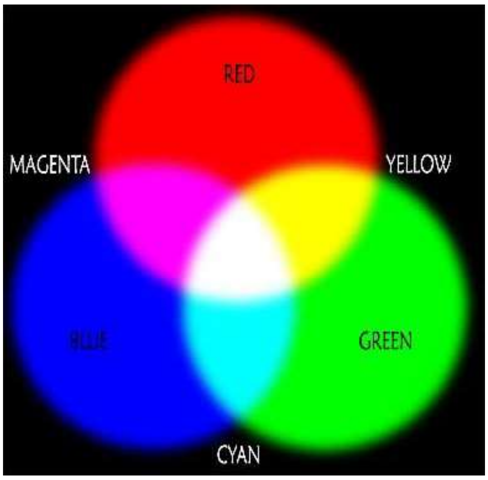

Figure 150. RGB.

23. Simplifying RGB synthesis

In practice, we can use the RGB mix for any light sources and, more modernly, for LED sources. We are very grateful to Isamu Akasaki, Hiroshi Amano and Shuji Nakamura because the development of the blue LED allowed us to obtain the single white LED. The best devices today have RGBWAUV LEDs; in addition to red, green and blue, we have cold white, amber and ultraviolet, which is actually the last violet that allows our vision. Today we can perform color mixtures (synthesis of the luminous fluxes of each LED) and color temperature changes.
Here we are talking about approximate colors to be used in everyday practice, the white formed by the combination of light sources can vary.

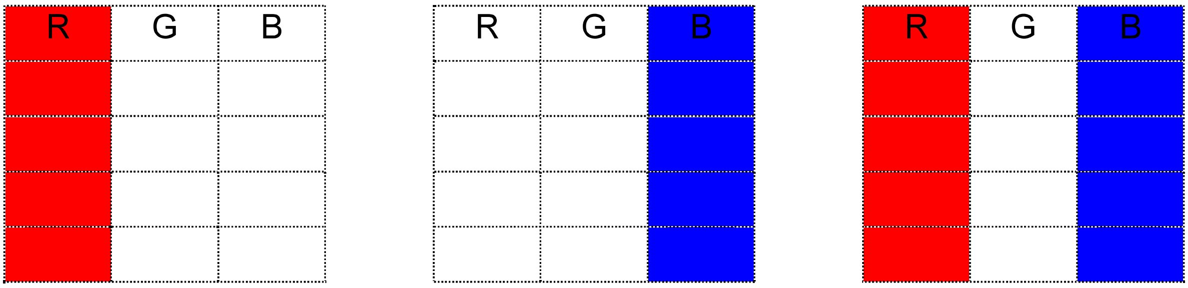

Table 3. Magenta.

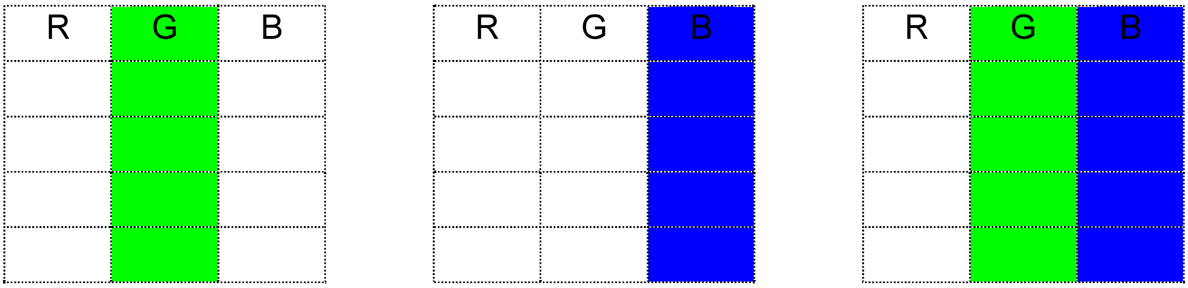

Table 4. Cyan.

R	G	B

R	G	B

R	G	B

Table 5. Yellow.

R	G	B

Table 6. White.

How many colors are needed to form this white? All the colors of the rainbow? The three RGB primaries? One primary and one secondary? Two colors that compliment each other?

R	G	B

R	G	B

R	G	B

Table 7. Complementary magenta and green.

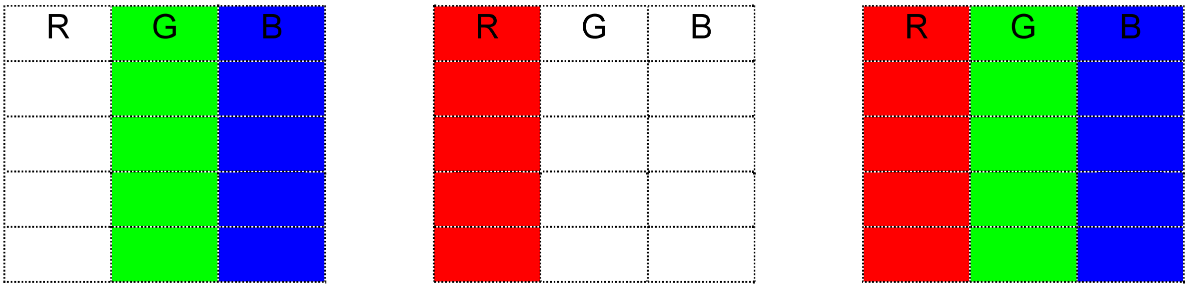

Table 8. Complementary cyan and red.

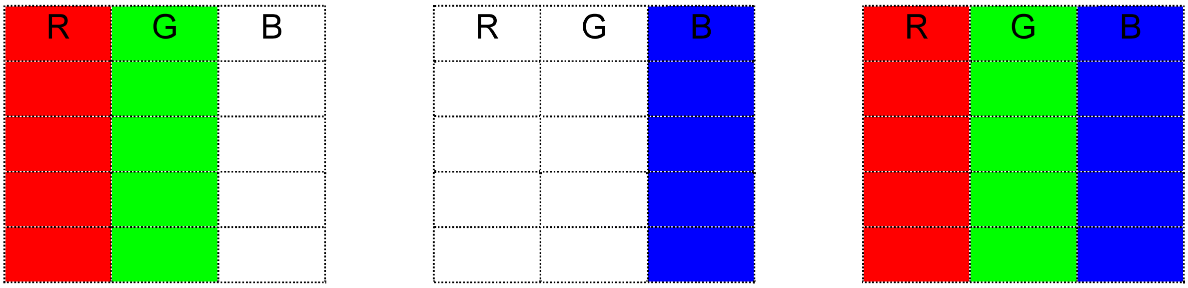

Table 9. Complementary yellow and blue.

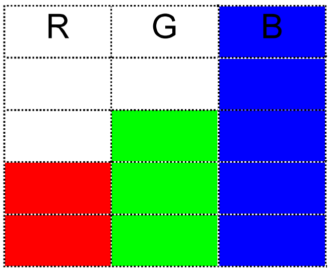

Table 10. What color is that?

W + C + B

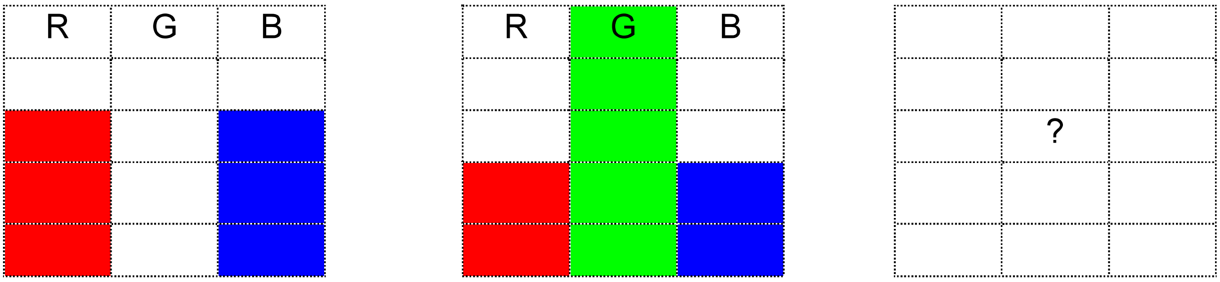

Table 11. What is the result of this synthesis?

Mixing, remember, lights from two different light sources and LEDs used in various applications like your computer or cell phone are a source of light... The first color is a dark magenta, the second is light green, we expect white as a result. Look at how one piece fits into another.

The first color is 2R+2G+2B=W, 1R+1G=Y and +1R… light amber.
The second is a light blue: 2R+2G+2B=W, 1G+1B=C and + 1B is a light blue with few green. We expect again a white as a result.

Bravo, Stanley McCandless!!! In scenic lighting we call it broken white.

24. Colored filters and SPD

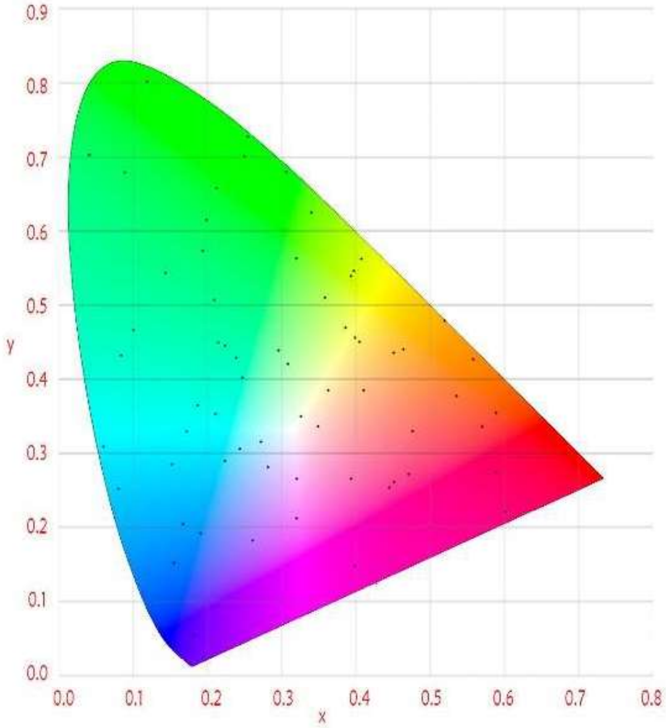

Figure 151. Distribution of some filters.

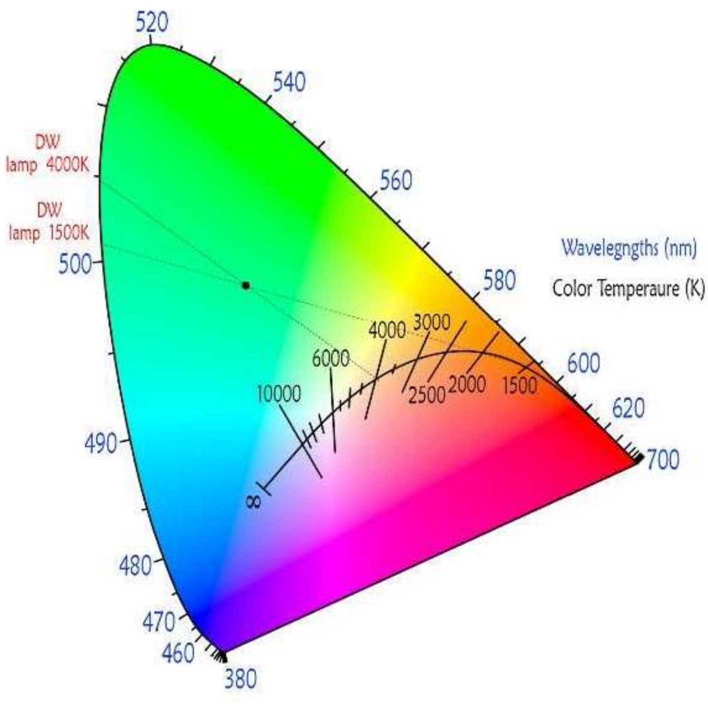

Figure 152. Dominant wavelength.

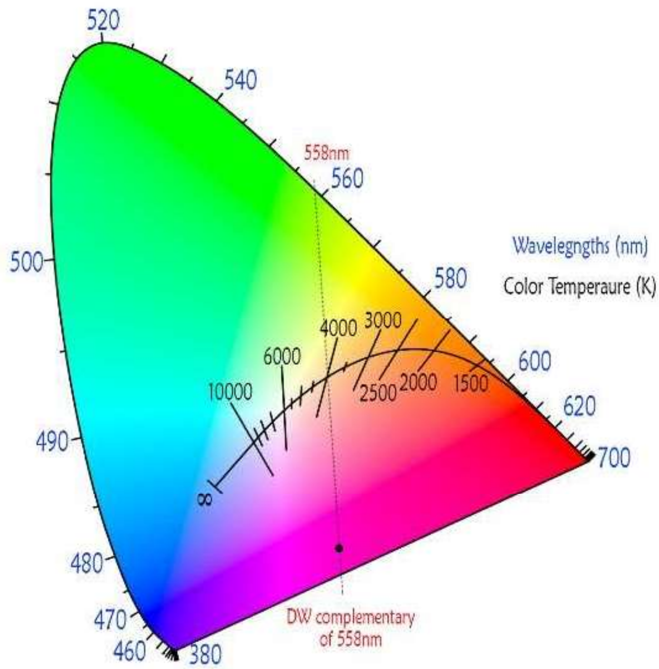

Figure 153. DW of a color that falls.

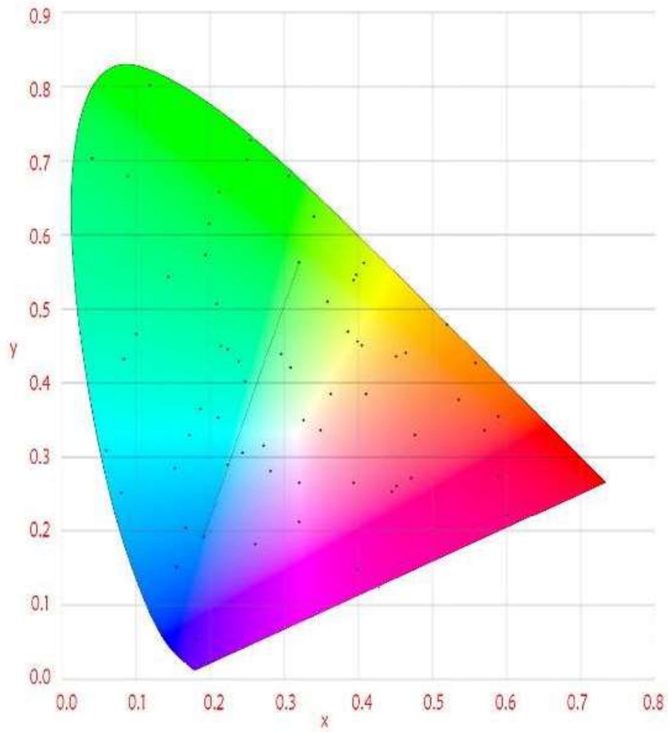

Figure 154. Mixing two lights (same characteristics) with two different filters.

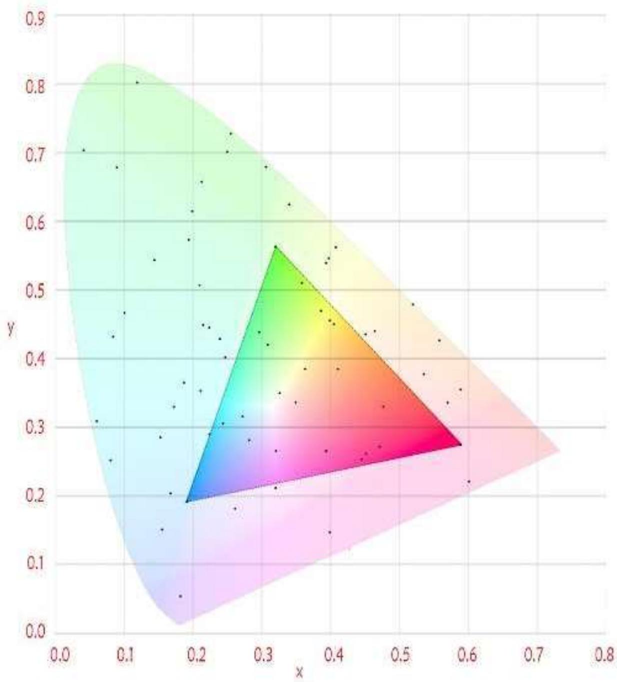

Figure 155. Three Color Mixing.

25. Light and colored objects

If you are still not convinced that red, yellow and blue are not primary colors I will try one more time.

The blue used for the painter's color mixing has a portion of green that allows the white paper to reflect beyond the blue of this green, but absorbs the red. In turn, yellow absorbs blue. If one color does not allow red reflection and the other does not allow blue reflection, we will see only green.

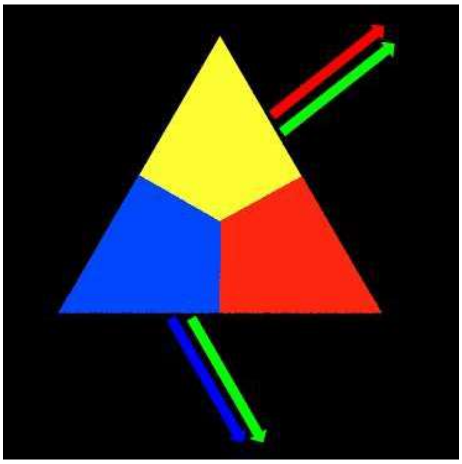

Figure 156. Why Y + B = G.

The objects do not have a defined color, they only have the possibility to reflect, absorb and transmit / refract portions of the light.
Just be in a dark place and choose any colored object. Then illuminate each of the rectangles on the following pages with a flashlight and make that light reflect off the object.
First use the first three rectangles in Figures 156, 157 and 158 as reflectors and you will see the object more or less illuminated, you are changing the intensity of the illumination because the colors of the paper are absorbing the incident light. Then use the rectangles in Figures 159, 160 and 161, with the secondary colors, in each of them you will be decreasing approximately 1/3 of the luminous intensity and avoiding the reflection of one of the three primary colors.
Finally use the rectangles in Figures 162, 163 and 164 which decrease about 2/3 of the incident light and only allow one color to reflect.

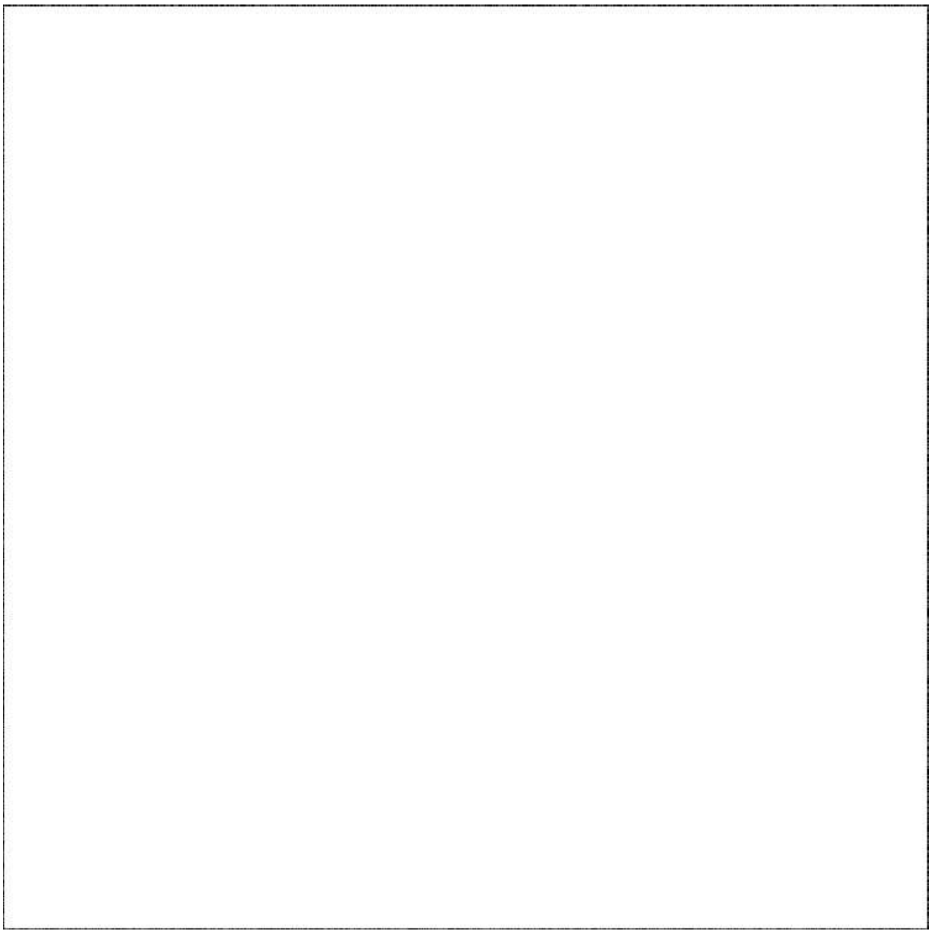

Figure 157. Color for reflexion.

Better a flashlight but you may use the light of your mobile.

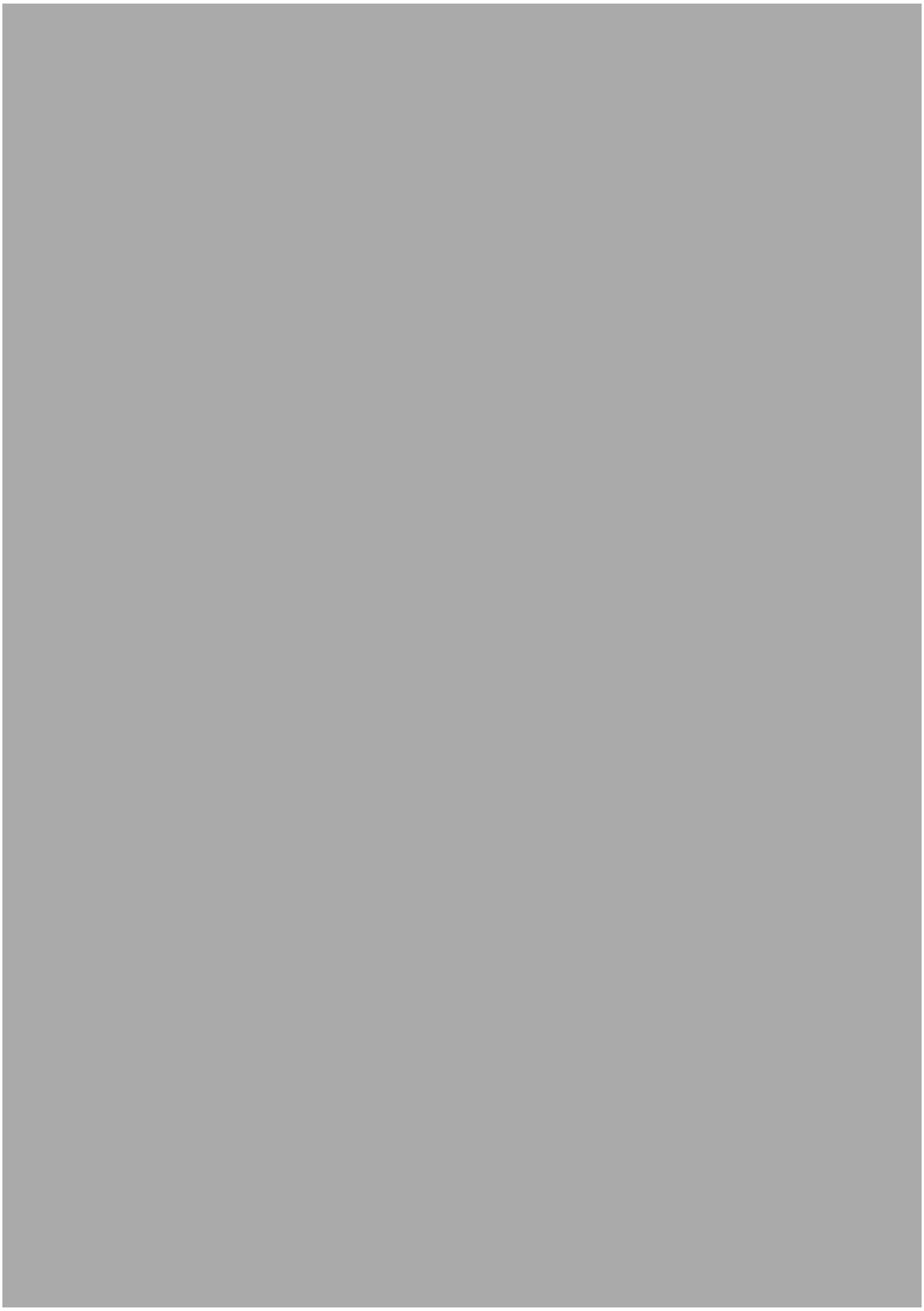

Figure 158. Color for reflexion.

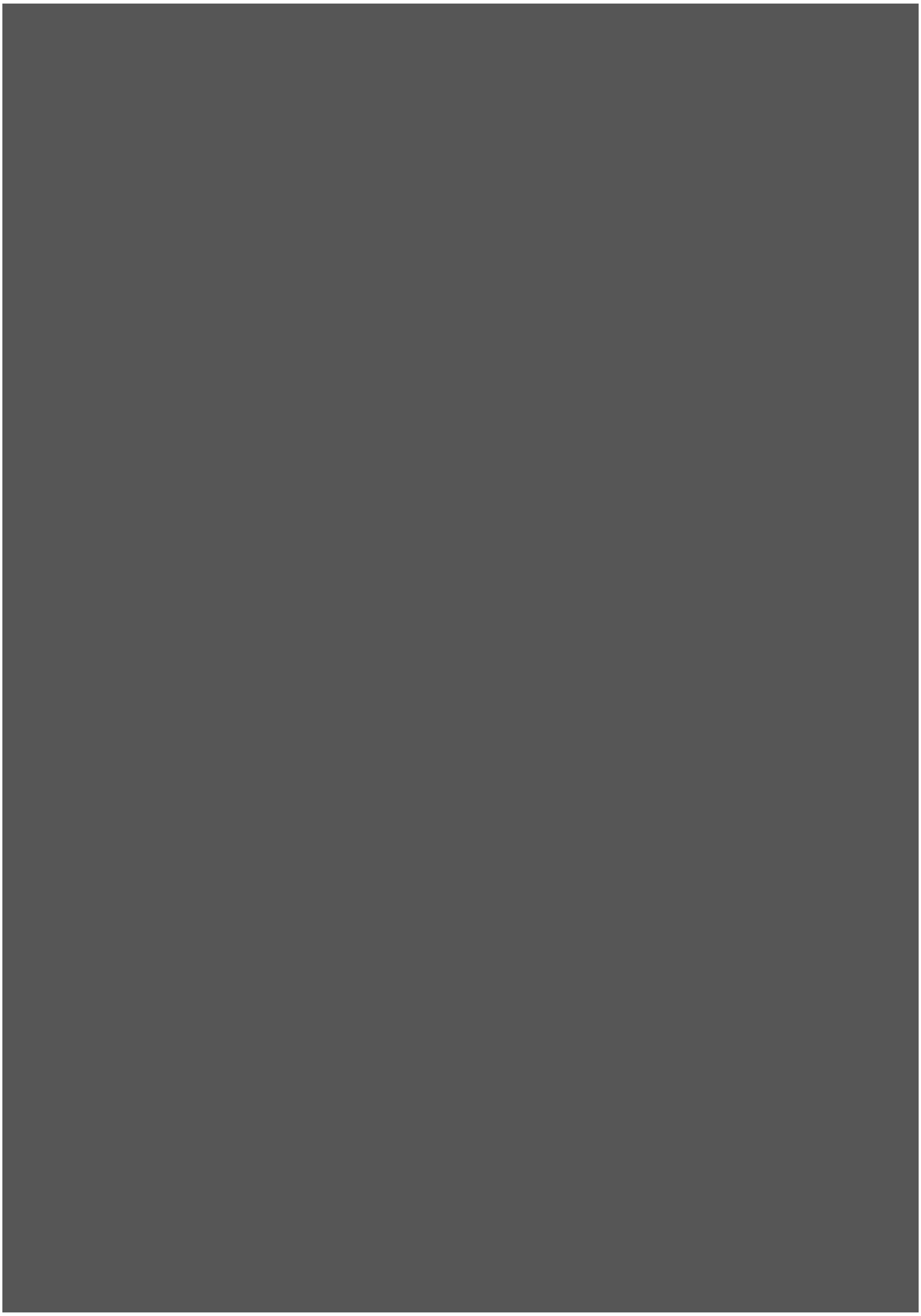

Figure 159. Color for reflexion.

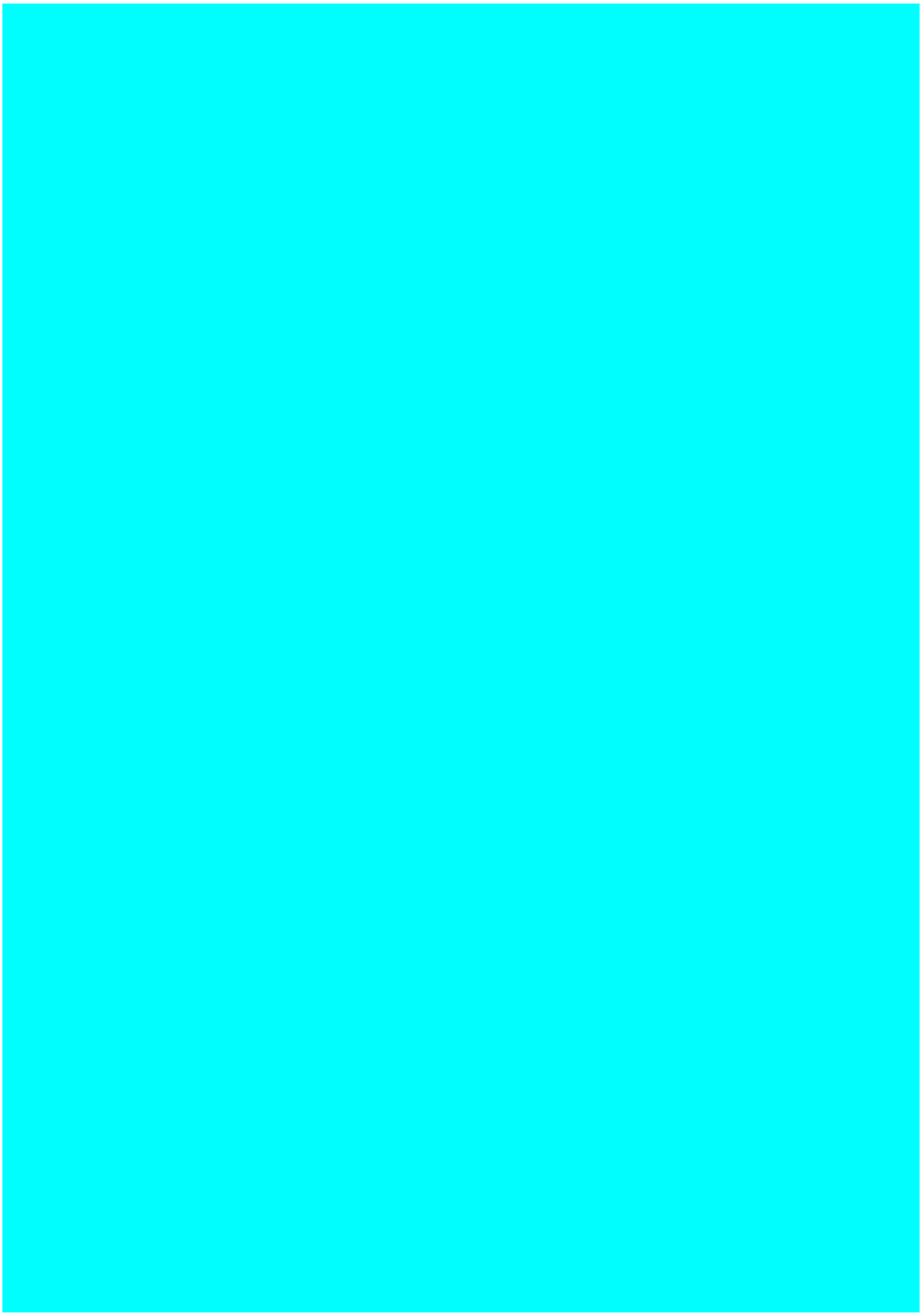

Figure 160. Color for reflexion.

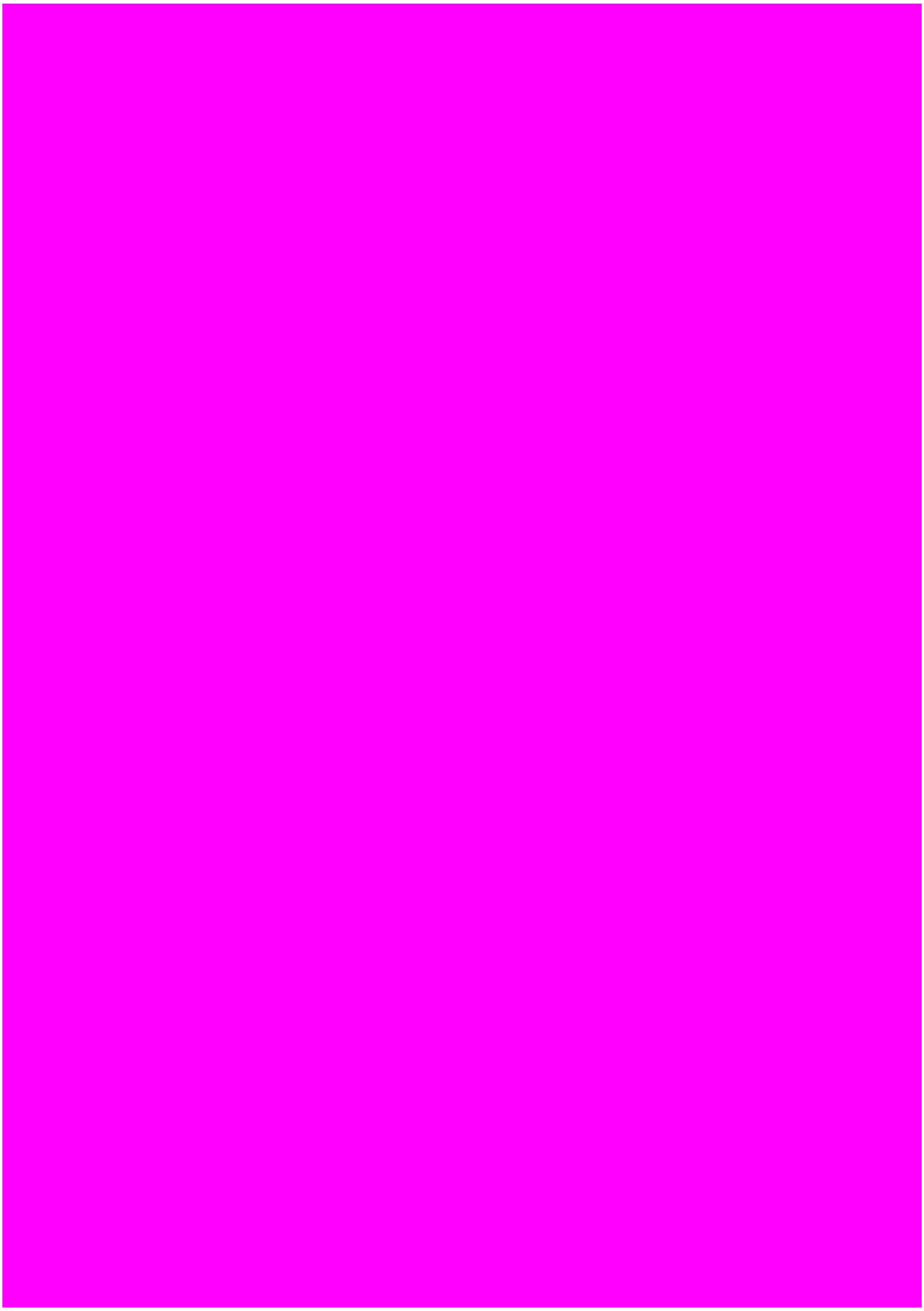

Figure 161. Color for reflexion.

Figure 162. Color for reflexion.

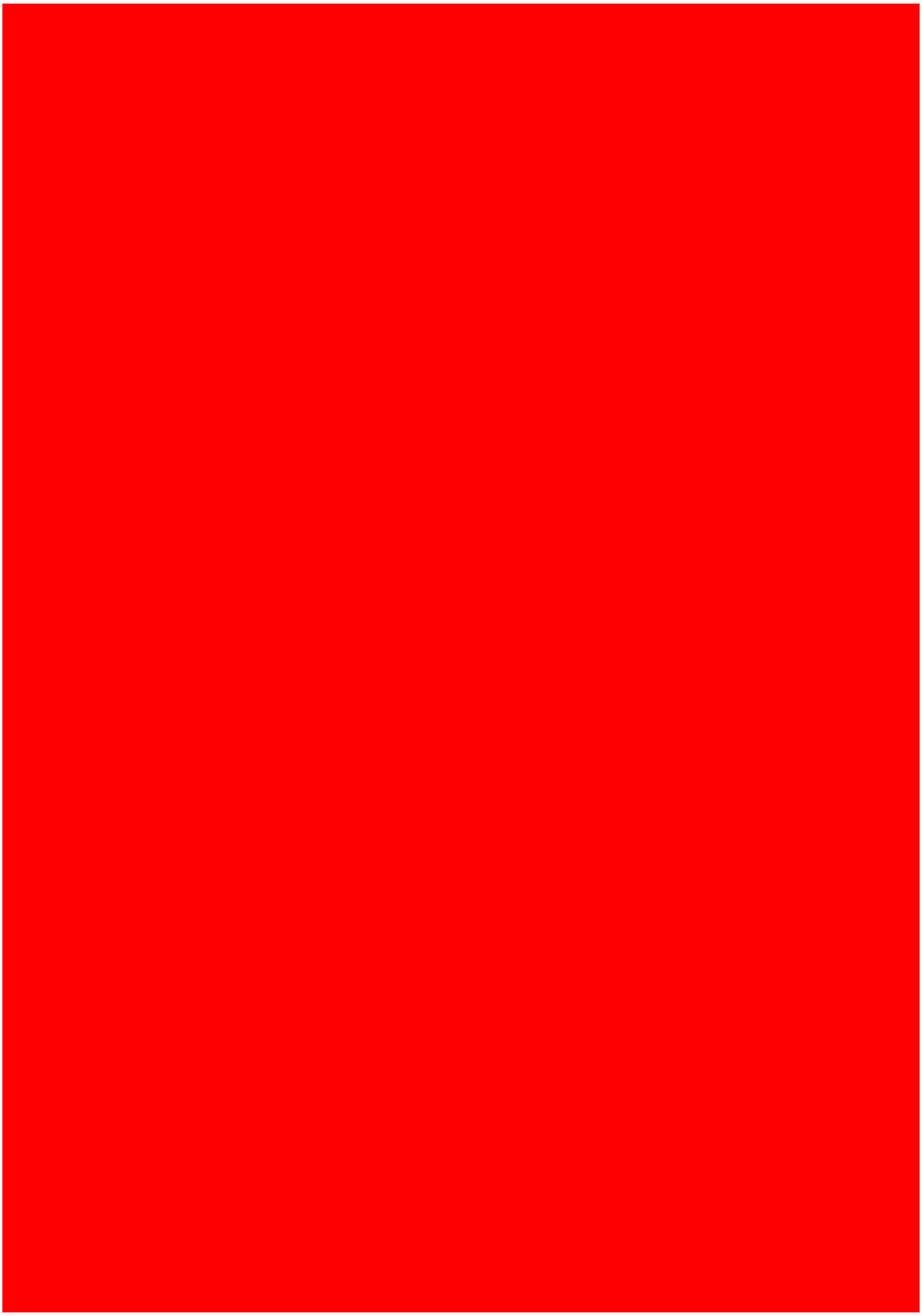

Figure 163. Color for reflexion.

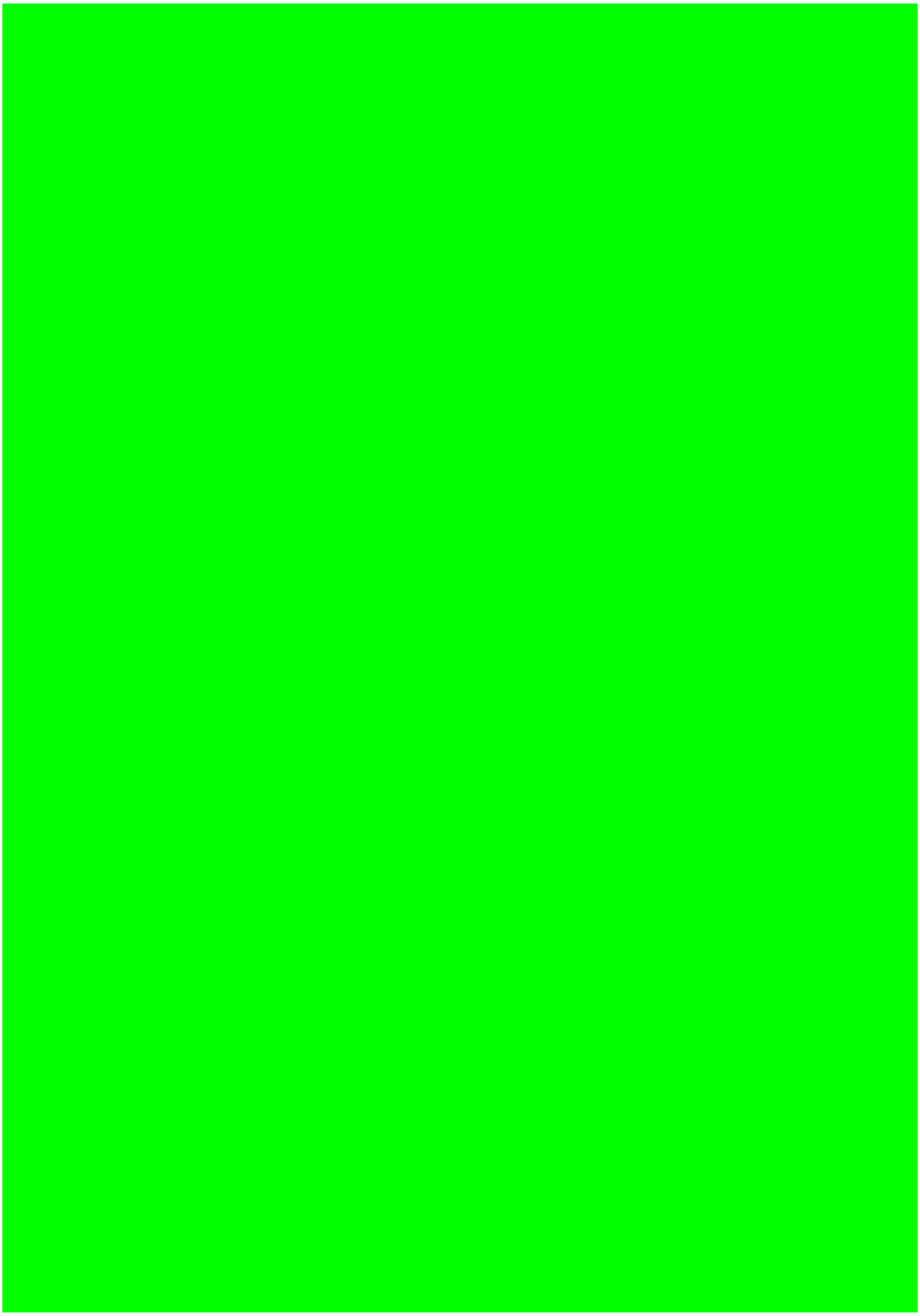

Figure 164. Color for reflexion.

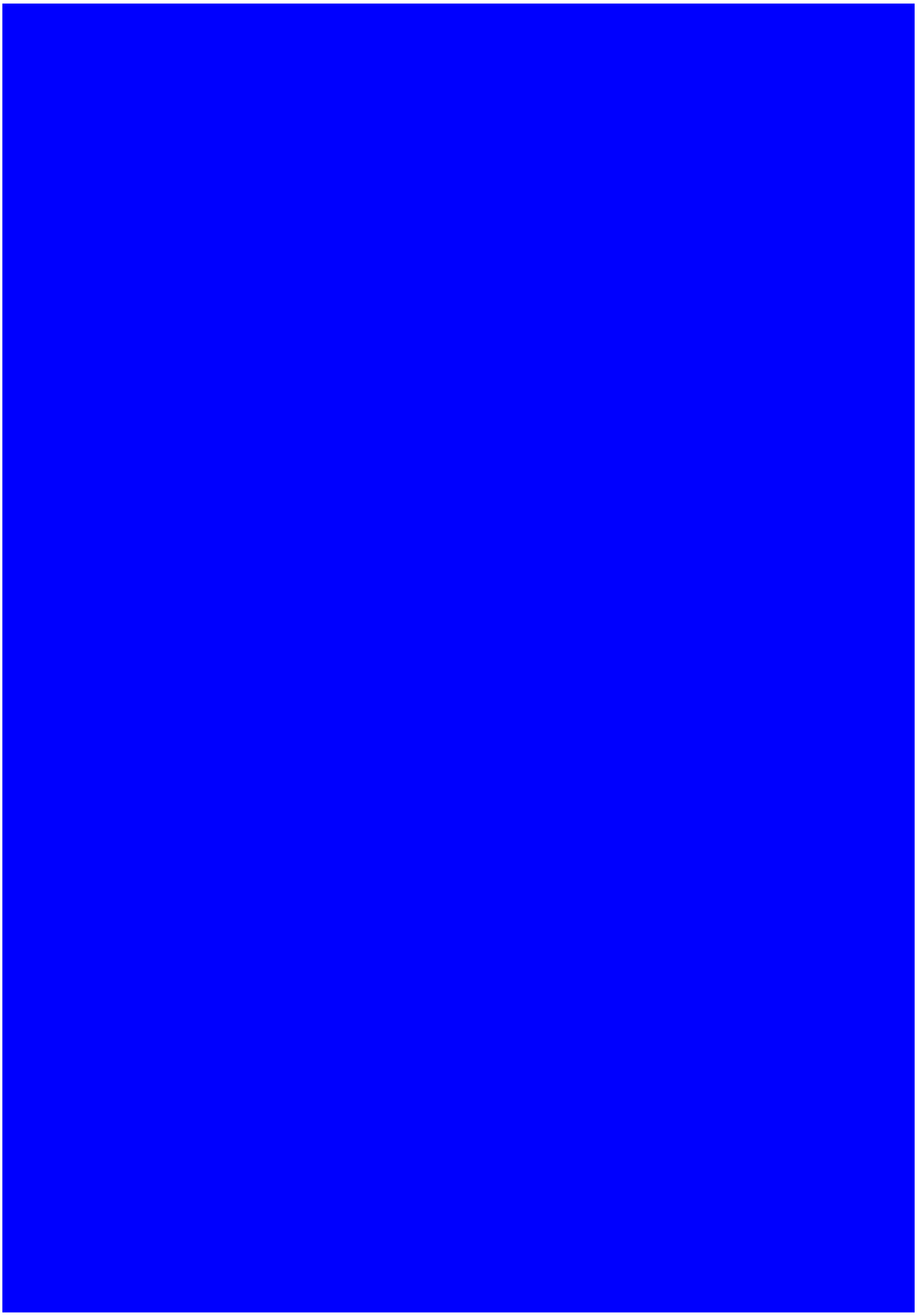

Figure 165. Color for reflexion.

26. Colored shadows

The shadow is an absence of light, it ceases to be a shadow when it is colored by the light that falls on it.
In the images below we have a simulation with three different luminaires, one with a red filter, another with a green filter and a third with a blue filter, very close to the primary colors.

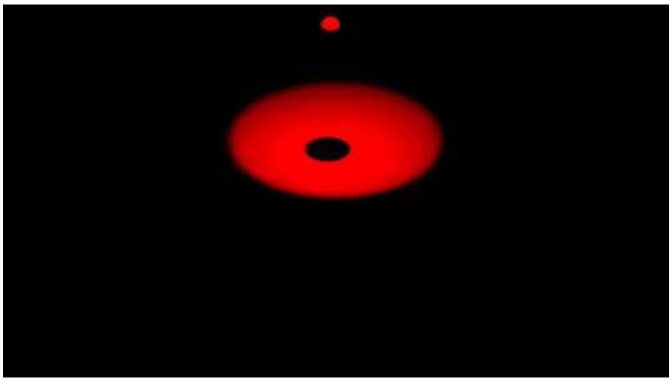

Figure 166. Only R on.

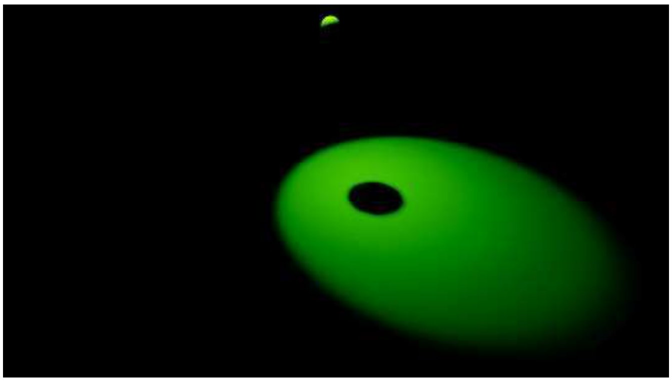

Figure 167. Only G on.

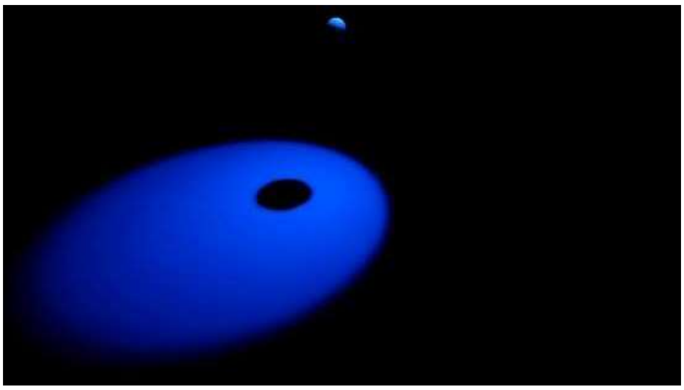

Figure 168. Only B on.

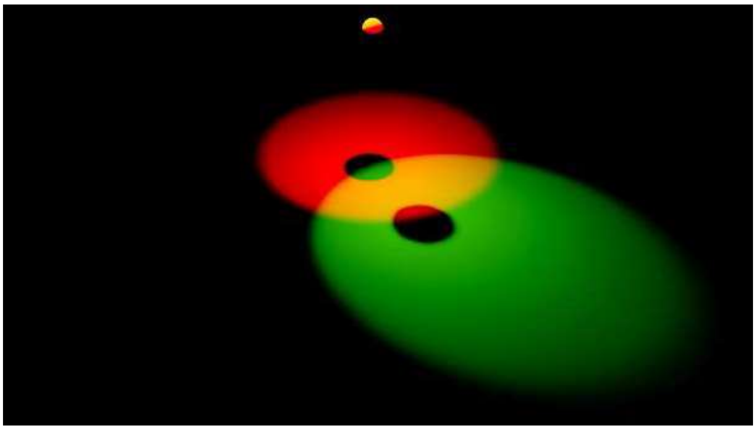

Figure 169. RG (Y) on.

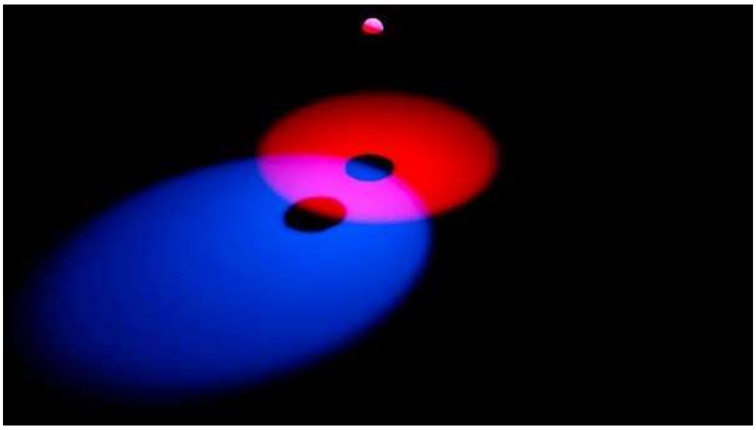

Figure 170. RB (M) on.

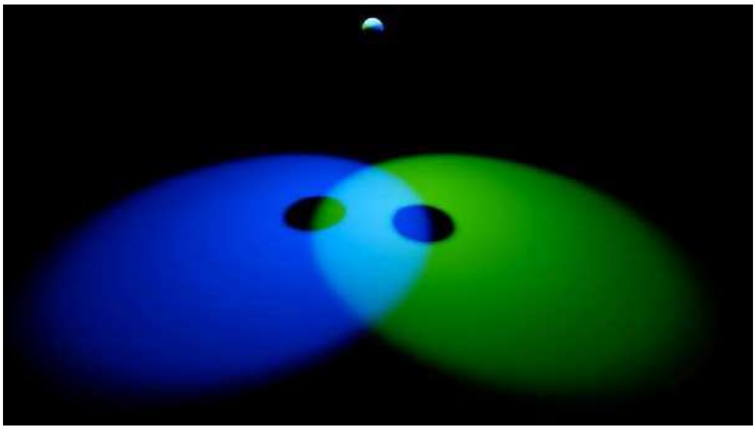

Figure 171. GB (C) on.

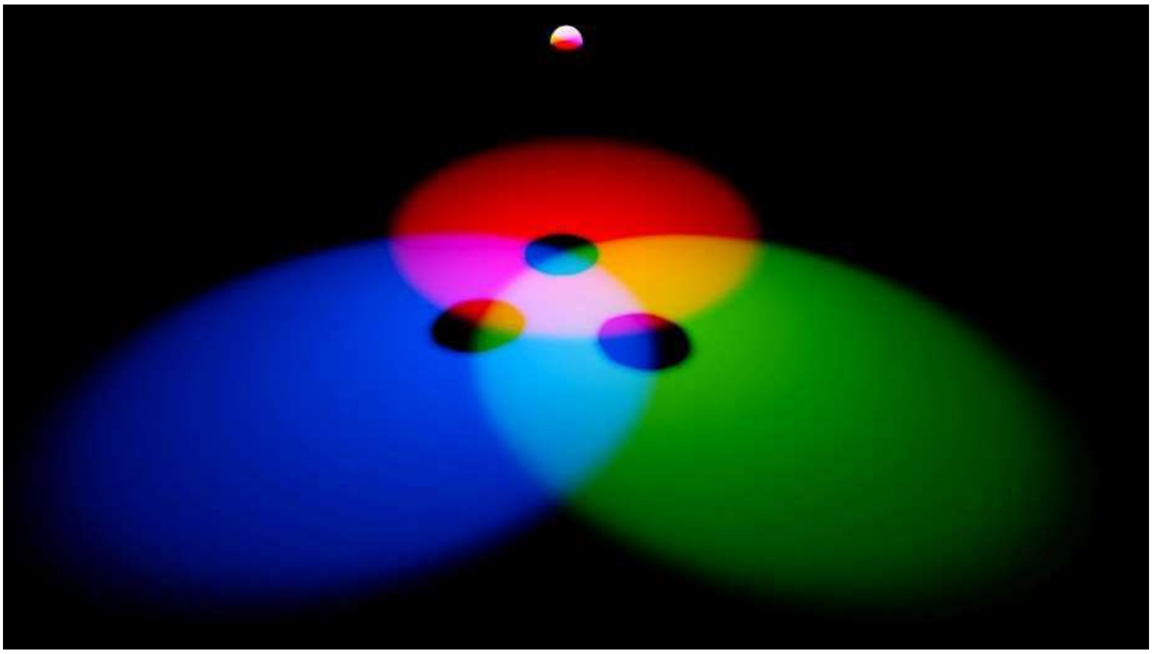

Figure 172. RGB on.

27. Negative afterimage

When we look at a color our eyes are impregnated by the complement of that color, even after the stimulus ceased, we still see this complementary for some time.
Separate a white sheet of paper for the following test and proof.
Again be in a dark environment.

Look at the Figures 172, 173, 174, 175, 176 and 177 for thirty seconds thinking about its complementary, after this look at the blank white sheet.

Give your eyes and brain thirty seconds to rest and then move on to the next color. Repeat this action for the six hues, always thinking about the color you want or expect to see.

Do the same with the Monalisa but look at the same spot on your nose for about a minute, then look at the white paper.

It will be a very beautiful experience.

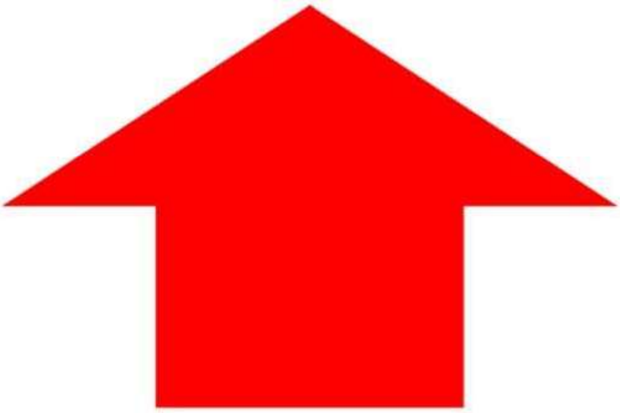

Figure 173. R/C.

Figure 174. G/M.

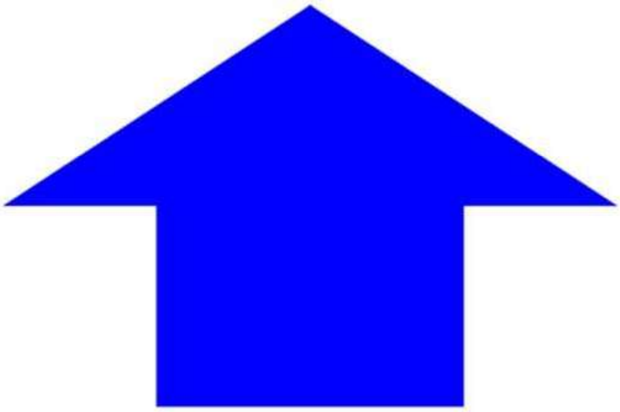

Figure 175. B/Y.

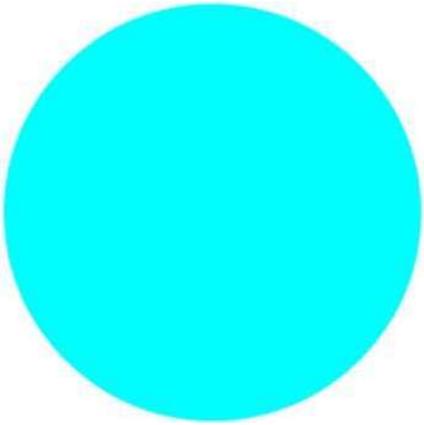

Figure 176. C/R.

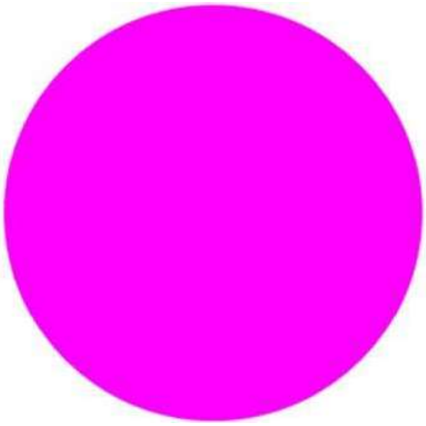

Figure 177. M/G.

Figure 178. Y/B.

Figure 179. Leonardo da Vinci – Monalisa, La Gioconda.

28. Dimension and dynamics of color and light

Differences in paint color and lighting level will cause changes in the visualization of the space.

If we apply the same painting to two walls and make light with different intensities, the wall under the effect of more light will appear lighter, the other darker.

28.1 Perception of space

Figure 180. Perception of Space.

28.2 Distance

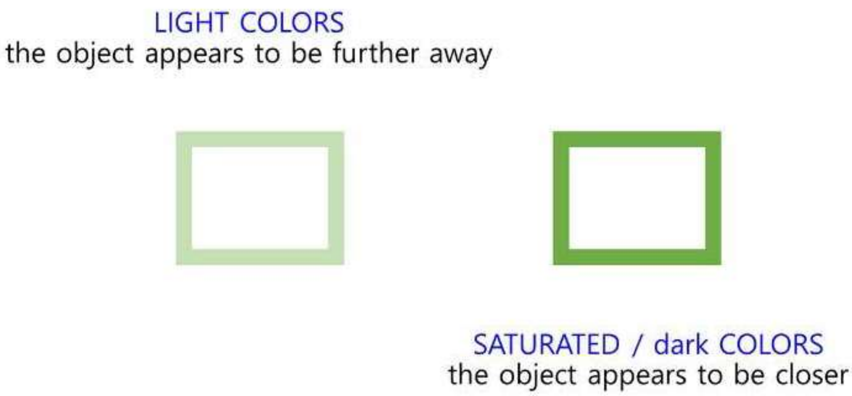

Figure 181. Distance.

28.3 Dimension

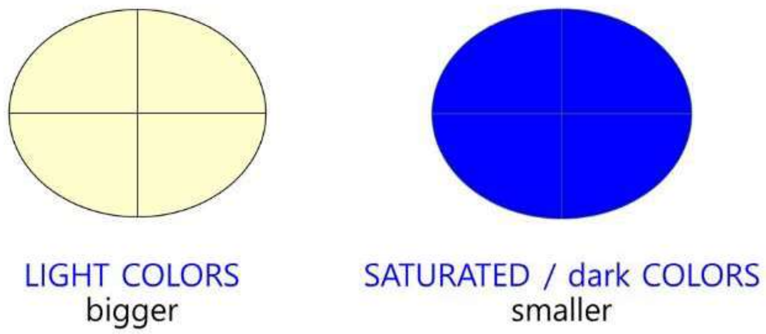

Figure 182. Dimension.

28.4 Weight

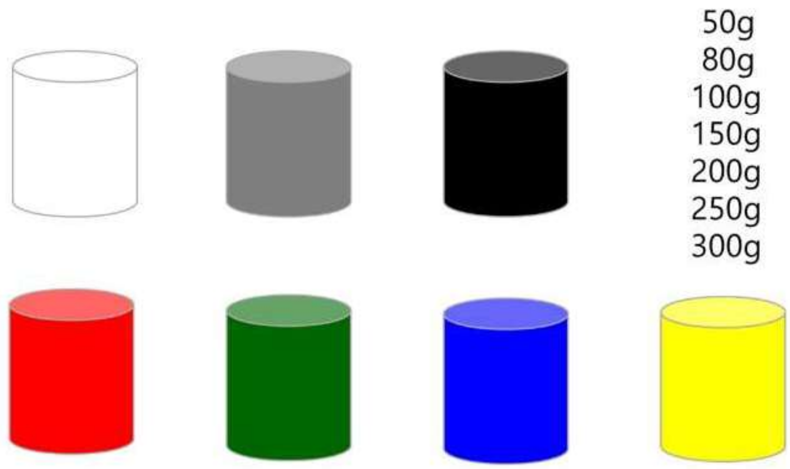

Figure 183. Weights.

Put the containers and their respective weights in order, write down the colors and weights on the blank sheet, do not look at the result on the next page.

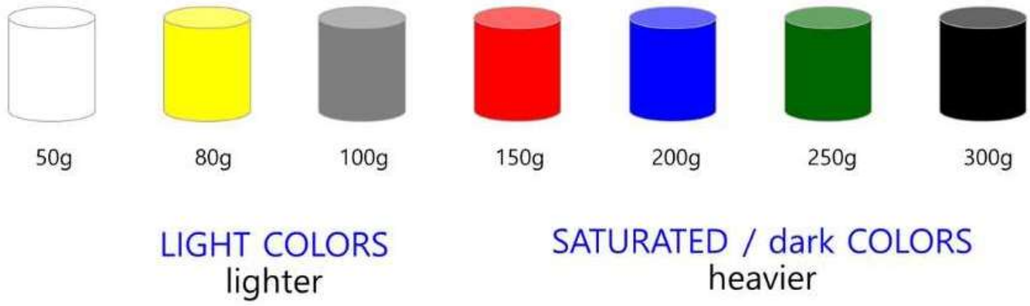

Figure 184. Results.

28.5 Temperature

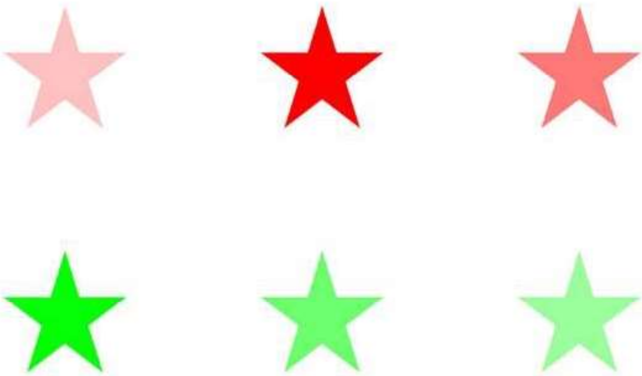

Figure 185. Temperature.

Which red star looks the hottest? And which green?
Wow, the warmest green for a cool color.

Figure 186. Results.

29. Chromatic project

You can think of the next items in order or without the obligation to follow the sequence, but they will be good guidelines.

Capture attention.

Evoke an atmosphere.

Communicate a style.

Tell stories.

Show the morphological characteristics of the space / object.

Provide rhythm.

Now is the time to define hues and use them by alternating their luminance and chroma characteristics.

You must decide on the dominant, accentuated and intermediate colors.
The dominant is the one who will be present in the largest area; the accent will be the one that will create some kind of contrast with this dominant and the intermediary, in turn, will make the connection between the previous two colors.

30. The past, nowadays and the future, no order

30.1 Optic fiber

Narinder Singh Kapany, 1952. Jean Daniel Colladon, 1841.
The light source and energy are far from the fiber.
The quality of the lighting depends on the light source.

Figure 187. End glow.[36]

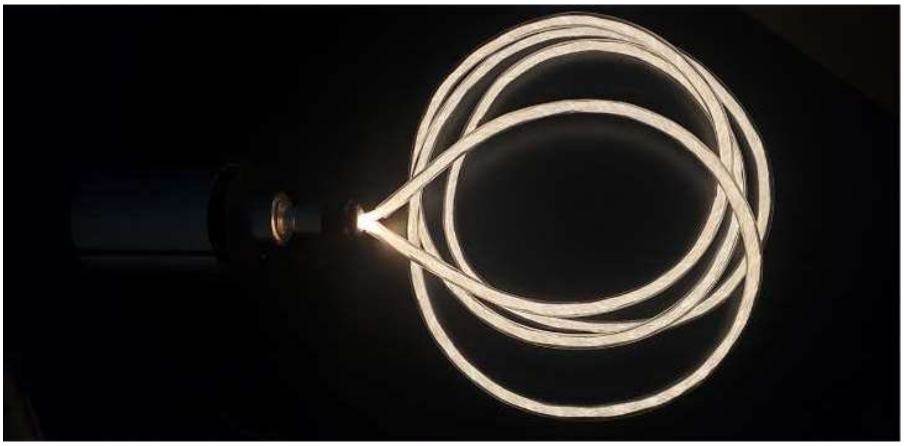

Figure 188. Side Glow.[37]

Figure 189. Crystal tip.[38]

[36] Endlight set of 36 W LED light source and different diameters of end emiting fiber optic cables, designed and manufactured by FASA Fiber Optics. Photo: FASA Fibra Ótica.

[37] Side emitting Fiber Optic – FASA Fibra Ótica. Photo: FASA Fibra Ótica.

[38] Crystal 12 mm end piece for use with FASA optical fibers .Photo: FASA Fibra Ótica.

Figure 190. Starry effect with crystals.[39]

Figure 191. Work in progress, luminous fabric.[40]

[39] Starry effect with crystals - Espaço Imperatriz 23 - FASA Fibra Ótica – Lighting Project: Scene Lighing Design. Photo: Rubens Campo.

[40] DreamLux® by Samsara S.r.l.

Figure 192. Luminous fabric.[41]

30.2 Holography

Holograms are 3D images generated by techniques for recording light interference patterns. Dennis Gabor, 1948.

Internet

Museum of Holography.

Magic Leap.

30.3 LiFi

Technology for wireless communication between devices that use LIGHT (currently the LED) to transmit data. Harald Haas lecture in 2011 at TEDGlobal (ideas worthwhile) in Edinburgh.

Internet

LiFi.

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[41] DreamLux® by Samsara S.r.l.

30.4 Graphene

Massachusetts Institute of Technology (MIT) researchers realized that by illuminating graphene, on a sheet of carbon the thickness of one atom, it is possible to let electricity flow.

Internet

Graphene.

30.5 Incandescence

That was the starting point, the light emitted by an incandescent object.

Figure 193. Incandescence.[42]

Over time, the need for a portable light emerged, so that we could move more accurately at night, the solution was torches. Then ancient oil lamps and so on. Various materials and oxidizers were used to make light.

[42] CCO from Pixabay

The advent of electricity was extremely important for us to abandon combustion, but we were still burning tungsten.

Figure 194. Gas lamp refurbished - Newark, USA.

Figure 195. Halogen lamp with diffuser bulb.

Internet
Research each of the ways to generate light more deeply.

30.6 Luminescence

The spontaneous emission of light by a substance not deriving directly from heat.

30.6.1 Chemiluminescence

The emission of electromagnetic radiation, particularly in the visible and near infrared; which can accompany a chemical reaction.
Those glowsticks they use at parties, you know?

30.6.2 Photoluminescence

The set of processes by which certain substances absorb photons, under the effect of the incident electromagnetic radiation, and then re-emit them in all directions.

30.6.2.1 Fluorescence

An energy source, usually composed of visible light or ultraviolet radiation, excites the atoms, causing some electrons to jump to an outermost orbit, when they return to the inner orbit they emit light.

30.6.2.2 Phosphorescence

It differs from fluorescence because in the latter the effect is immediate and ceases as soon as the energy source is interrupted, while in phosphorescence the effect continues even after.
Do you remember the little stars and spaceships that we used to put on the roof of the house and, when the light was turned off, we could see shining?

30.6.3 Radioluminescence

The phenomenon whereby light is produced in a material by bombardment with ionizing radiation such as beta particles.
For example some car panels and clocks.

30.6.4 Sonoluminescence

Emitting short flashes of light from bubbles that implode in a liquid when excited by sound.
It is a physical phenomenon in which sound energy is transformed into light, it has been known since the early 1930s.

30.6.5 Thermoluminescence

It is a physical phenomenon of light emission by some crystals when heated with boiling water.

30.6.6 Cathodoluminescence

We mean the light emitted by a sample as a result of the excitation of the electron beam and observed in a scanning electron microscope.

30.6.7 Triboluminescence

A particular type of luminescence that occurs in some materials which, subjected to mechanical stress, emit part of the absorbed energy in the form of electromagnetic waves.
A famous experience with images is a shot that hits a life safer.

30.6.8 Electroluminescence

It is a particular type of luminescence that characterizes some materials capable of emitting light under the action of an electric field when crossed by an electric current.

30.7 LED - Light Emitting Diode

30.7.1 Enhancement of architecture: point, line and surface

With the advent of LED we can use this light source punctually, forming lines or participating in light plans.

Internet

Luminaire de Cagna – Ghent.

30.7.2 Integration and discretion of the source

One of the biggest aesthetic advantages of LED, in addition to miniaturization, is clean mounting.

30.7.3 Individual control of the single LED

The material used in the semiconductor element of an LED determines its color. LED voltages: R - 2.18V, G - 3.70V, B - 4.00V. If we set the voltage to red the blue will look dark, if we set the proper voltage to blue the red led will burn out first.
Average lifespan x luminous flux.
The “pure” white LED is achieved by using several layers of yellow phosphor above a blue LED.

30.7.4 Very good luminous efficacy

Longer lifespan than incandescent, halogen and fluorescent lamps.
This concerns the LED but the electronic circuit will be damaged first...

30.8 OLED and QLED

Organic Light Emitting Diode (OLED), an organic film is the electroluminescent layer that emits light in response to an electric current.
It permits curved panels.

Figure 196. OLED Panel.

Figure 197. OLED panel seen up close.

Quantum Dots Light Emitting Diode (QLED) consisting of cadmium selenide nanocrystals that absorb light and re-emit it in a specific wave.
Cheaper than OLEDs as they do not require the complexity of organic chemistry.
Probably in the future, air transport vehicles will no longer have windows, they will have external cameras that transmit images to the interior of the aircraft, then we saw all the sky! Maybe the floor will be made by screens?
I have one more atrocious doubt. If your TV has a lower quality how can you watch the demonstration in an advertisement that the 4K picture is better if your TV is not 4K???

30.9 Bioluminescence

Study the processes used by animals to emit their own light.

Internet
Glowee.

By tinkering with the chemical composition of luciferase (a bioluminescent enzyme), the Japanese research team managed to change the emission color from its normal greenish yellow to orange and red.
Researchers from Institute of Physical and Chemical Research (RIKEN) and Kyoto University are now attempting to recreate the blue glow of the sea firefly (*Vargula hilgendorfii*) and firefly squid (*Watasenia scintillans*) so that they have all three primary colors at hand.

Figure 198. BIO RGBWAUV? [43]

There is a modernity for each era of humanity, the here and now.
Lasers are starting to be used in place of LEDs.
The future is the tomorrow of the time we witness now, but it is the yesterday of an even more distant future.

[43] Photo: Camila Perrenoud

Figure 199. Dark and light. [44]

YES, WE CAN DRESS SOMEONE WITH DARK AND LIGHT.

[44] Model: Nicole Curtinovi Martins. Photo: Camila Perrenoud.

31. Conflict of interest declaration
The authors declare no conflict of interest.

32. Funding source declaration
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33. Acknowledgment
First of all, thank you to my family, my kids Camila and Felipe for always being so helpful. My wife Simone Lopes, for following my divergent thoughts. I dedicate this chapter to my mother, Lia, who is so dedicated to our family and to my brother Gastão, who is so dedicated to her.
I would like to express my special thanks to professors Maurizio Rossi and Alessandro Rizzi for the invitation to participate in this project so beautiful and so important for the academic world and for society as a whole, I hope I have fulfilled the task of contributing to the perpetuation of the study and the knowledge for future generations of students and those interested in Color and Lighting Design.

34. Short biography of the author
Osvaldo Perrenoud was born in Rio de Janeiro, Brasil. He received the Master Degree in Color Design & Technology from Politecnico di Milano, Italy, in 2018. Previously he did a Master in Methodology of University Education at Instituto Porto Alegre (IPA), Brasil in 1986 and a Master in Lighting and Interior Design at Instituto de Pós Graduação (IPOG), Brasil in 2010. He is a COLOR AND LIGHTING DESIGNER, working in this area since 1979; he works as a DIRECTOR OF PHOTOGRAPHY at the company Desenhos de Luz located in Brasil.
Mr. Perrenoud currently lives in Genova, Italy, is an external researcher at MIPS (Department of Computer Science) at Università Degli Studi di Milano and teaches as a guest professor at Politecnico di Milano and Fondazione Luigi Clerici, both in Milan, Italy.