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Cesia: Its Relation to Color in Terms of the Trichromatic Theory

The word "cesia" has been coined to refer to the visual sensations aroused by different spatial distributions of light: sensations of transparency, translucency, matte opacity, specularity, gloss, darkness, etc. The trichromatic theory holds that the perception of colors is possible through three kinds of receptors in the retina, sensitive to specific portions of the visible radiation: long wavelength, medium wavelength, and short wavelength; and the science of color has proved that by mixing appropriate amounts of three primary lights all the other colors can be produced. But color sensations are always accompanied by sensations of cesia; the same opaque color may have a glossy or matte aspect, a specular reflectance (mirrorlike appearance) may be colorless or colored, and we can also see color in transparency. Cesia stimuli appear associated with color due to the fact that all the spatial modalities of light transfer may be selective as regards wavelength; if they are nonselective, then we have achromatic or colorless cesias. The explanation arises from the analysis of the possibilities of transmission and reflection (whether they are diffuse or regular), as well as absorption of light, splitting the light stimuli into each primary component.

Le mot «césie» a été créé pour se référer aux sensations visuelles produites par différentes distributions spatiales de lumière: sensations de transparence, de translucidité, d'opacité mate, de spécularité, d'éclat, d'obscurité, etc. La théorie trichromatique affirme que la perception des couleurs est possible à travers trois types de récepteurs dans la rétine, sensibles aux portions spécifiques de la radiation visible: longueur d'onde longue, longueur d'onde moyenne, et longueur d'onde courte; et la science de la couleur a prouvé que mélangeant la quantité appropriée de trois lumières primaires on peut produire toutes les autres couleurs. Mais les sensations de couleur sont toujours accompagnées de sensations de césie: la même couleur opaque peut avoir un aspect brillant ou mat, la réflexion spéculaire peut être incolore ou colorée, et nous pouvons voir aussi de la couleur dans la transparence. Les stimuli de césie apparaissent associés à la couleur par le fait que toutes les modalités spatiales de transfert de lumière peuvent être sélectives par rapport à la longueur d'onde; si elles ne sont pas sélectives nous aurons alors des césies achromatiques ou incolores. L'explication de ce phénomène émane de l'analyse des possibilités de transmission et de réflexion (qu'elles soient diffuses ou régulières), ainsi que de l'absorption de la lumière, séparant le stimulus lumineux dans chacun des composants primaires.

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Der Ausdruck „Cesia" wurde geprägt, um die Sinneseindrücke des Gesichtsfeldes zu benennen, die durch Unterschiede der Beleuchtungswahrnehmung im Raum hervorgerufen werden: Durchsichtigkeit, Durchscheinen, mattierte Opazität, Rückstrahlung, Glanz, Dunkelheit usw. Die Trichromatische Theorie behauptet, daß, die Wahrnehmung der Farben durch drei verschiedene Arten von Empfängern in der Netzhaut möglich ist: diese sind empfindlich gegenüber spezifischen Teilen der sichtbaren Strahlung: lange Wellenlängen, mittlere Wellenlängen, kurze Wellenlängen. Die Farbwissenschaft hat bewiesen, daß, beim Mischen entsprechender Mengen der drei primären Beleuchtungen alle anderen Farben erzeugt werden können. Aber die Farbsinneseindrücke werden immer von Cesia-Sinneseindrücken begleitet. Dieselbe undurchsichtige Farbe kann einen glänzenden oder matten Eindruck aufweisen, die Rückstrahlung kann farblos oder bunt sein, und auch in der Durchsichtigkeit können wir Farbe wahrnehmen. Die Cesia-Reize scheinen mit Farbe verbunden zu sein, da alle Lichttransferenzen innerhalb verschiedener Raumgegebenheiten selektiv gegenüber der Wellenlänge sein können. Sind sie nicht selektiv, so haben wir achromatische oder farblose Cesias. Die Erklärung hierfür geht aus der Analyse der verschiedenen Übertragungs- und Rückstrahlungsmöglichkeiten hervor, (diffus oder gerichtet) sowie auch die der Lichtabsorption, durch Aufspaltung des Lichtreizes in die einzelnen Primärkomponenten.

1. Generalities on color and color order systems

There is more than one hypothesis about how color vision is produced. The trichromatic theory puts forth that the perception of colors by humans and by some other mammals occurs through three types of receptors in the retina, which are sensitive to specific bands of wavelength of visible radiation: long wavelength, medium wavelength, and short wavelength. The science of color has proved that by means of mixing three more or less arbitrarily chosen primary lights in different proportions – usually a red, a green, and a blue one (mixture known as additive synthesis) – all possible color sensations can be produced. These lights have to be chosen so that no one of them can be matched by mixing the other two.

Regardless of the question about which is the physiological mechanism that better explains color vision, there is a certain agreement on the fact that in the differentiation of color three perceptual categories are at play: (1) *hue,* with its physical correlate in the *dominant wavelength* of visible radiation, (2) *saturation,* with its physical correlate given by the *purity* of the stimulus, and (3) *luminosity* – usually applied to primary sources, i. e. lights – or *lightness* – usually applied to secondary sources, i. e. objects –, with its physical correlate in the *luminance* – if we are dealing with objects that emit light – or *reflectance* and *transmittance* – if we refer to objects that reflect or transmit the light incident upon them (Figure 1). It is usual to consider that the first two categories define the *chromaticity* of a color. Thus, the CIE triangle is called chromaticity diagram; being a two-dimensional scheme, it excludes the dimension of luminance. However, this last dimension is included in the concept of color, even if sometimes it can be considered separately; this is the variable that GREEN-ARMYTAGE has called "colour's third dimension" [1]. Likewise, in chromatic circles, the most habitual representations of the arrangement of color, the dimension of luminosity or lightness is excluded and only hue and saturation are specified. We will see how all this is related with cesia; let us make first an overview about what cesia is.

2. The notion of cesia and the order system for cesias

The word "cesia" has been coined to refer to the visual sensations produced by the different *spatial* distributions of light (sensations of transparency, translucency, matteness, specular reflection, glossiness, etc.), establishing a different domain with respect to the term "color", which designates all that has to do with the sensations originated by differences in the *spectral* distribution of light [2; 3; 4]. In the publications of reference (especially in [2] and [4]), antecedents on the study of related questions by authors such as KATZ, EVANS, POPE, HESSELGREN, HUNTER, and others are discussed. There, the interested reader can also find an explanation of how the word "cesia" was conceived.

In the model developed for the arrangement of the sensations of cesia, we have five vertices occupied by what has been defined as primary cesias: *specularity* (mirrorlike appearance, produced by a regular or specular reflection), the quality of *matte* (produced by a diffuse

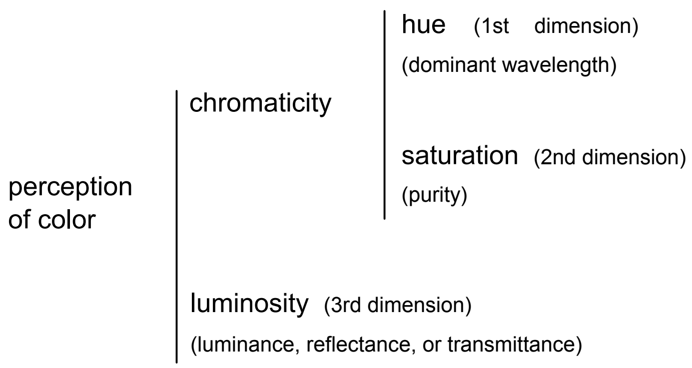

Fig. 1: Categories in the perception of color.

reflection), *transparency* (produced by a regular transmission), *translucency* (produced by a diffuse transmission), and the sensation of *black* (produced by a relatively high absorption of visible radiation). The first four sensations are placed in the vertices of a square surface at the top of the model, and the last one in a vertex at the bottom, in which lines traced from the four previous ones converge, making a kind of inverted pyramid (Figure 2).

We can note a difference between the first four cesias and the last one, either if we talk in terms of visual sensation or physical stimulus. Among the first four stimuli of cesia, placed on the upper plane, what varies is specifically the way in which light is spatially distributed, while in the absorption, placed in the lower vertex, light has completely disappeared. Specularity, matteness, transparency, and translucency are equivalent as categories, because they are defined by an interplay of mutual oppositions (reflection versus transmission, and regular versus diffuse); the sensation of black, on the contrary, is an independent category. The first four categories refer to the spatial quality of the perceived light, the last one to the quantity of perceived light. Among the first four cesias the variations of *permeability* and *diffusivity* occur (first and second

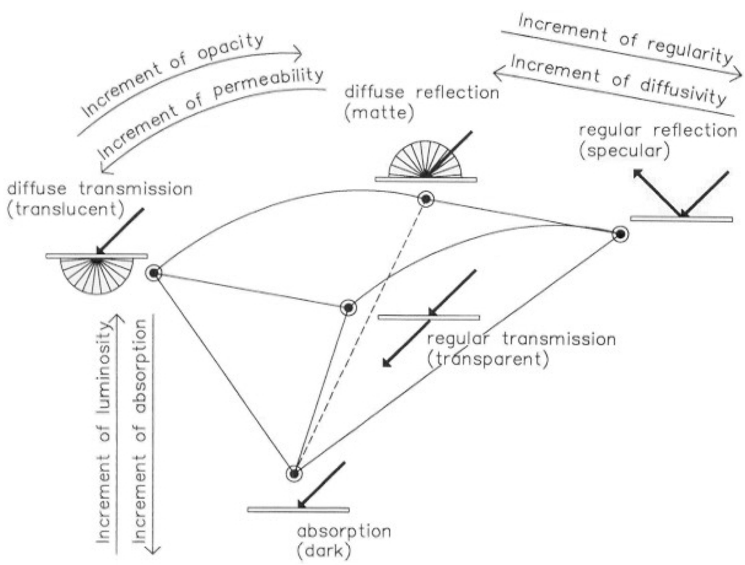

Fig. 2: The solid of cesias with the five primary sensations and the three kinds of variation.

dimensions of cesia). On any horizontal section of the solid, we find the same pattern of variation in the spatial distribution of light than in the upper plane, except that it shows a lower intensity, because a certain absorption has occurred.

Thus, similarly to what occurs with the notion of *chromaticity* in color, by which the purely chromatic relations are defined (hue and saturation of the color sensation, or dominant wavelength and purity of the stimulus), independently of the sensation of luminosity or lightness or the luminance, reflectance, or transmittance of the stimulus, we can give also a name to the interplay of relations that occur in any horizontal section of the model of cesias, where abstraction is made of the absorption. In absence of another term, we can perhaps use the word *cesity* for this concept (Figure 3).

3. The relation between color and cesia

It is not by chance that the variable of luminosity or lightness in color and the variable of absorption in cesia can be regarded as the “third dimensions”, somewhat separable from the most specific variables that define the chromaticity and the cesity. There is a strong logic underlying this matter. These are the dimensions that relate color with cesia. In fact, these variables are the only shared point between color order systems and the order system proposed for cesias, what leads us to the point that in reality we are talking not of two but of one and the same variable shared by color and cesia. The lightness of a matte surface color, for instance, is

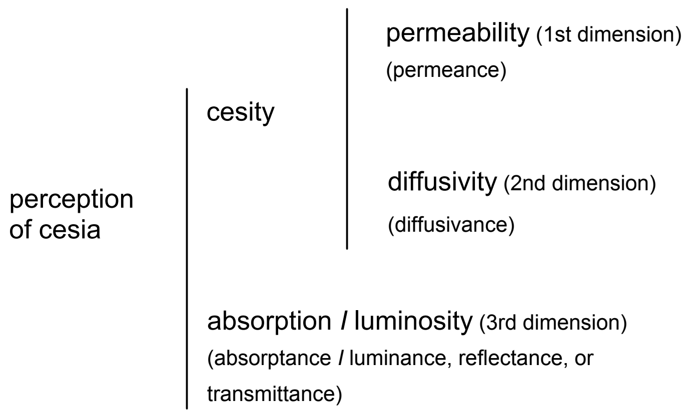

Fig. 3: Categories in the perception of cesia.

the key to place it in the model of cesias, along the line going from the point of total absorption to the point of total diffuse reflection. If we were to devise an order system for color with all their possible modes of appearance (an order system for color and cesia, more properly speaking) we would need just a five dimensional space, *not* a six dimensional one.

Now on, color sensations always appear associated to sensations of cesia. Except in the few occasions in which we look directly to a luminous source, in most of our daily visual perceptions we see light reflected or transmitted by nonluminous objects. It is in these cases when the sensations of cesia appear, because objects reflect or transmit light very differently depending on their physical constitution and their exterior finishing. Here we are not talking about color. An object can be seen as yellow but, at the same time, it can be seen as glossy or matte, transparent or translucent (Figure 4). The same color can look, then, with different cesias, and the same cesia can appear on different colors. We can see color in transparency (as in colored glasses or color filters) and translucency. The specular reflection can appear colorless or colored (Figure 5).

All this can be explained by reasoning that the stimuli of cesia appear associated to color because the transmission, reflection, or absorption of light may occur selectively as regards wavelength. On the other hand, if the reflection, transmission, or absorption of light on the part of the objects is nonselective, being equal for the whole spectrum of visible radiation, we obtain achromatic or colorless sensations of cesia.

If we situate ourselves within the frame of the trichromatic theory, the explanation arises from the analysis of the possibilities of either regular or diffuse reflection, transmission, and absorption, by splitting out the luminous stimuli into the primary components of long (L), middle (M), and short (8) wavelengths. An opaque matte red color is given by the absorption of the middle and short wavelengths and the diffuse reflection of the long wavelengths; a red mirror (that in which everything reflected acquires a reddish tinge) looks that way because the middle and short wavelengths are absorbed and only the long ones are reflected specularly; a transparent piece of glass will look red if it absorbs the middle and short wavelengths and transmits the long ones regularly. The same criteria is applicable to the other primary colors associated with the primary cesias, as well as to any chromatic mixture associated with any primary or intermediate cesia (Figure 6). Let us take a look at how, from these simple explanations, composite stimuli of color and cesia can be produced to match a given sample or to quantitatively specify both color and cesia altogether.

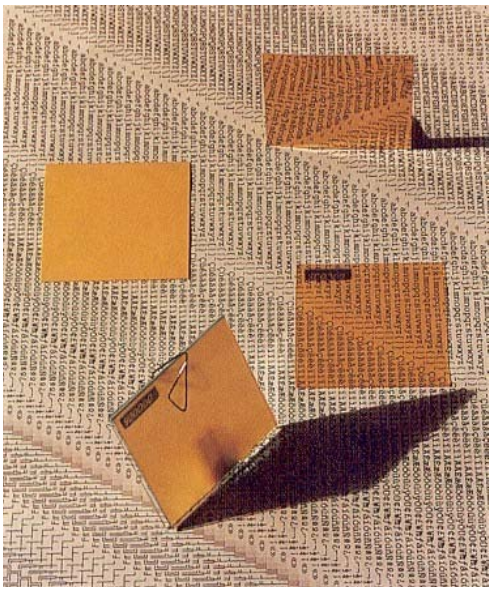

Fig. 4: Four different cesias in the same color.

Fig. 5: Nonselective and selective specular reflection.

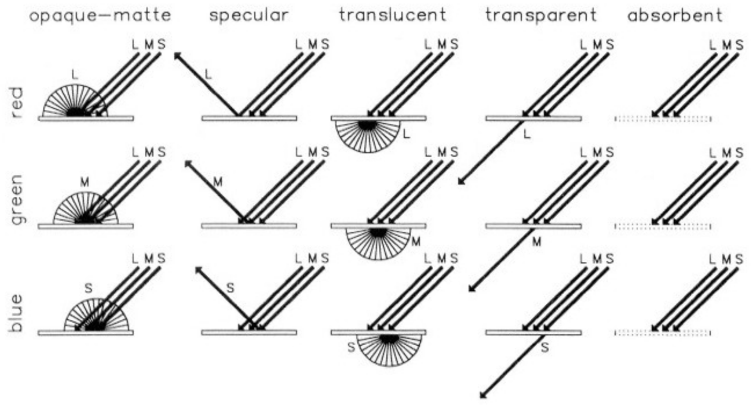

Fig. 6: The sensations of cesia and color explained by the different spatial distributions of the three primary lights (long, middle, and short wavelengths). In the example we have the explanation for the sensations of red, green, and blue, in the variants opaque matte, specular (mirrolike), translucent, and transparent, in addition to the sensations of darkness (absorption of the three components).

4. Production of cesia stimuli associated to color

A previous publication [4] explained how the intermediate sensations of cesia could be obtained starting from the combination of primary stimuli of cesia arranged in pairs in spinning disks where the visual syntheses is produced. In the scaling experiments made for that works, only achromatic or colorless samples were used, so that the chromatic aspect was placed deliberately aside. The reason for combining pairs of primary stimuli was that, at first, I only intended to produce the cesias that appear on the boundaries of the model, placed at intermediate positions between two opposite primary cesias. But, in order to produce any other stimulus for cesia it is necessary to combine three primary stimuli, by which we define two things: its projection on the plane of cesity, i.e. on the square of the inverted pyramid, and its degree of absorption, i. e. its distance from the point of total absorption.

In order to determine the combinations of stimuli that are necessary to produce a certain cesia placed at any point in the solid (let it be *X*), we begin by tracing a line from the point of total absorption *(A),* passing through the point of the cesia in question (*X*), and intersecting the upper plane, intersection that defines a point *(B)* on this plane. Already positioned in this two-dimensional plane, we trace a straight line from any of the four primary stimuli (*C*), passing through the point *B,* and intersecting the opposite border of the plane. This intersection defines a point *(D),* which represents the combination of the two primaries *(E* and *F)* that are colinear with it (Figure 7). In order to produce the stimulus for the cesia in question, we have to combine the stimuli in the reverse order, that is, the primary cesias *E* and *F,* combined in inverse ratios to their distances to point *D*, produce the stimulus *D*, which, in turn, combined with the primary cesia *C* in inverse ratios to the distances to point *B,* give the stimulus *B,* which combined with black *A* in inverse ratios to their distances to point *X* produces the stimulus *X* we were looking for. We can see that in all this process only three primary stimuli *(C, E,* and *F)* and the black *(A)* take part, the intermediate stimuli necessary to reach the stimulus for the cesia in question being obtained with them.

This sequence is similar to the process for the definition of a point in a chromaticity diagram such as the CIE triangle, starting from the three valences of the primary color stimuli, determination to which we have to add the photometric specification of luminance in order to completely define a certain color stimulus.

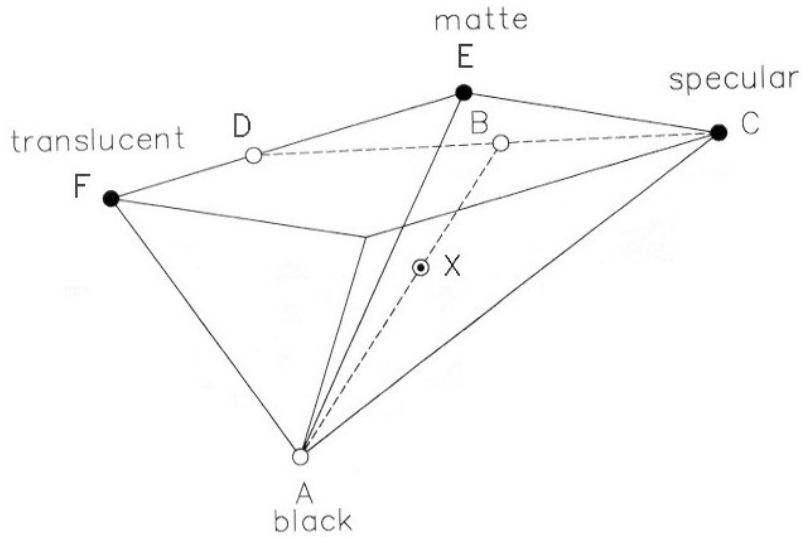

Fig. 7: Combinations of primary stimuli of cesia *(P, E, C, A)* to obtain a certain intermediate cesia (*X*). The fifth corner (transparent) is not marked here because, in this particular example, it does not enter in the composition of *X.*

From all this, it is evident that if we want to specify or match a real sample, with its color and cesia altogether, we need to use up to six valences, three for cesia and three for color, in addition to the value of reflectance or absorbance. If the technique of matching is performed by means of spinning disks, at most seven sectors on a disk should be used: three sectors to match the chromaticity, three ones to match the cesity, and a black sector to obtain the level of absorption (it should be noted that, in using spinning disks, the values of the stimulus have to be converted to proportional sectors, where the total sum is 360 degrees, as it was made in the Appendix in reference [4] while working with achromatic stimuli).

5. Metamerism in cesia

The phenomenon of metamerism can be considered as one of the pillars of the colorimetric science. Without this phenomenon it would be impossible to match colors by means of different compounds of other color stimuli. It is evident that in the field of cesia there are cases that we can also call metamerism. For certain conditions of illumination and observation there can be two identical sensations of cesia that are produced by two different combinations of stimuli, equality which will cease to be if we alter the conditions of illumination and observation. A very simple example can be mentioned: if we take two sheets of white paper, a matte one and a glossy one, under a certain angle of view and certain conditions of incidence of light they may appear identical, but as soon as the angle of observation is changed the difference between both sheets is evident.

Let us analyze an example in more detail. Suppose two materials, one that has the capacity of reflecting a great portion of the incident light in the specular direction (that is, in an angle equal and opposite to the incidence of light), and another that reflects the light in all directions in a completely diffuse way regardless of the angle of incidence. If both samples are observed under an angle that departs from the specular direction of the first sample, both materials will look matte (this is the typical way of comparing colors on different materials in order to avoid glare that impede the evaluation). Now on, if the same samples are seen under an angle of observation that coincides with the angle of specular reflection of the first sample, this one will look glossy, while the second one will continue to be seen as matte. Therefore, here the difference has been produced by a change in the angle of observation. It can also arise because of a change in the type of illumination. If the material that reflects light mainly in a specular way is illuminated with light coming from all directions, a specular reflection will be produced for each direction, the overall result being a diffuse reflection, something similar to what happens with the matte sample. In these conditions, both samples will look matte. If the illumination changes to a concentrated beam, then the difference will arise again (Figure 8).

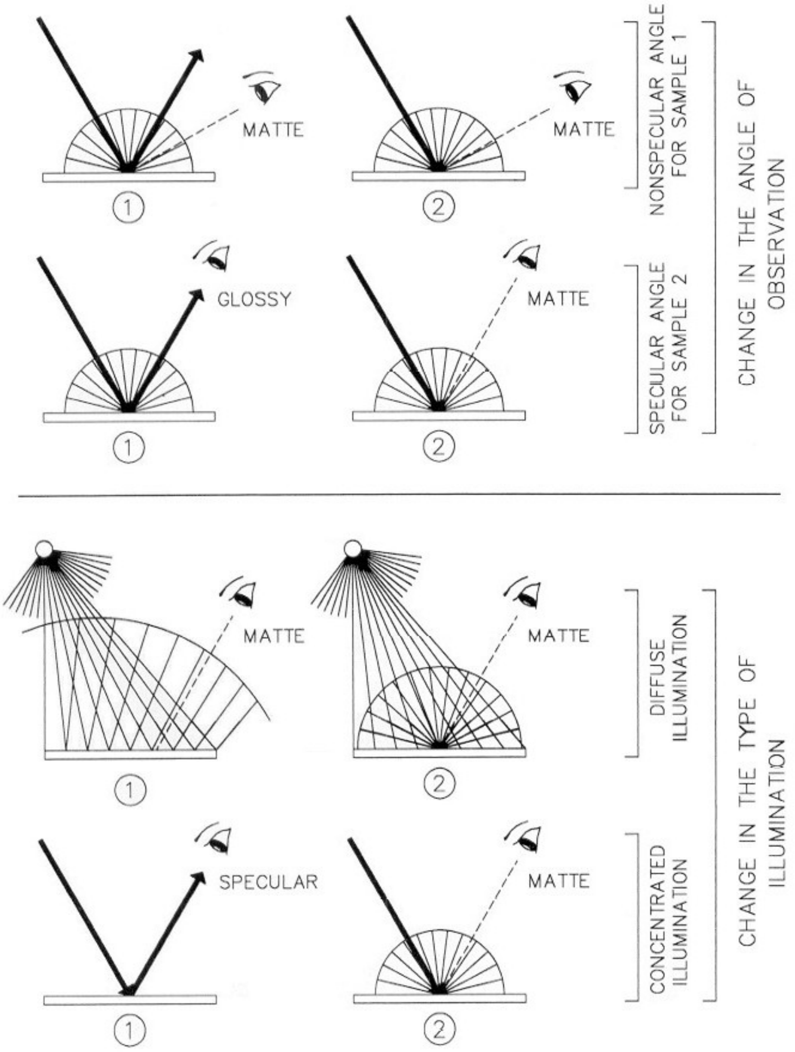

Fig. 8: “Metamerism” in cesia.

Why we say that these phenomena of cesia are equivalent to metamerism in color? Because in both cases we are dealing with materials having a different physical constitution, that produce different spectral or spatial distributions of light, but in certain circumstances elicit the same sensations of color or cesia.

6. Final considerations

The fact that this explanation of the relationship between color and cesia has here been based mainly on the trichromatic theory of color vision does not rule out the possibility of arriving at an explanation on the grounds of another hypothesis, such as the theory of opponent colors. This theory assumes that color vision is produced by a inhibitory mechanism on the basis of six elementary colors grouped in three pairs of opposite sensations: white-black (or light-dark), yellow-blue, and red-green. Each of these six primary sensations is considered as a mental or cognitive point of reference, and is defined by the absence of the others. Thus, the sensation of black appears when there is no trace of the sensation of white or of the four elementary chromatic sensations; when we perceive the elementary color yellow we do not find any trace of red, green, blue, black, or white; and so on for the other elementary color sensations. The pairs of opposite categories work as natural boundaries of the color sensations; one can perceive a yellowish green (which would be deviated towards one side of the green-red axis) or a bluish green (which would be deviated towards the other side), but the existence of a green having some resemblance to yellow and blue at the same time is impossible.

The relationship between color and cesia could also be approached through models such as those proposed in more recent theories [5], that intend to conciliate both positions, the trichromatic one and that of the opponent colors, by considering the three color valences at the level of the stimulus, the three receptors at the retinal level (where the mechanism is evidently a photochemical reaction), and the system of chromatic opposition at the level of the cerebral cortex, in a deeper stadium of the vision process.

The reason why we have chosen in this opportunity the trichromatic theory is due to the fact that it is on this basis that the whole colorimetric science has been built. There is a long tradition in this sense, and, for the moment, it seems a solid ground to erect a science of the measurement of cesias.

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