Chapter 4
Color and Design for Textiles

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4.1 Introduction

In today's modern world, color plays a vital role, for a commercial success of the product, and in the production of materials, color is a preponderant factor. The importance of color depends on many aspects (Ohta & Robertson, 2006). Generally, color is important parts of perception of nature beauty (see Fig. 4.1).

For textile designers, it is usually first color and then other factors as style, shape, texture drape, and hand. Color effect can be obtained by special techniques as is local destruction by laser (Fig. 4.2).

Color has major commercial importance. It has importance, for example, for selection of cars (see Fig. 4.3). There is little doubt that customers pay a great deal of attention to the appearance of their favorite products.

All this shows that people perceive color even in the context of expressing their position and the role they have in society (priests, brides, mourners). Light of object is dependent on the so-called visual triple, i.e., light source illumination, object optical properties (reflectance, gloss, surface texture), and the quality of the observer's eye (see Fig. 4.4).

A standard system for measuring and characterizing color is much desirable. Lighting, geometry of sample, and background and surrounding colors are the major

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Fig. 4.1 Beauty of nature

Fig. 4.2 Changes of color by laser local destruction

factors that determine the color of an object. Texture and gloss are the important parameter besides color for an appearance of an object. The International Commission on Illumination (CIE) standard of color specification is used in almost all current color measurement. The system is empirical, meaning it is based on actual observations rather than color vision theory (Schanda, 2007).

Color has various meanings among the diversity of people. For instance, for a chemist, it is a chemical compound, a dye, or a pigment; to a physicist, it could be light scattering and absorbance or objects reflectance spectra; to a physiologist, it is a measurement of nerve activity; to a psychologist, it could be a complex process in the brain that interprets the nerve signal. For an artist and others, it is a way to generate sensation in the mind of the viewer. For example, the red and yellow colors create a warm sensation. Green and blue are coupled with feelings of coolness. Color harmony and color theme in the wall paints, curtains, and furniture in a room make joyful and comfortable. The source of light, the illuminant object, and the eye and

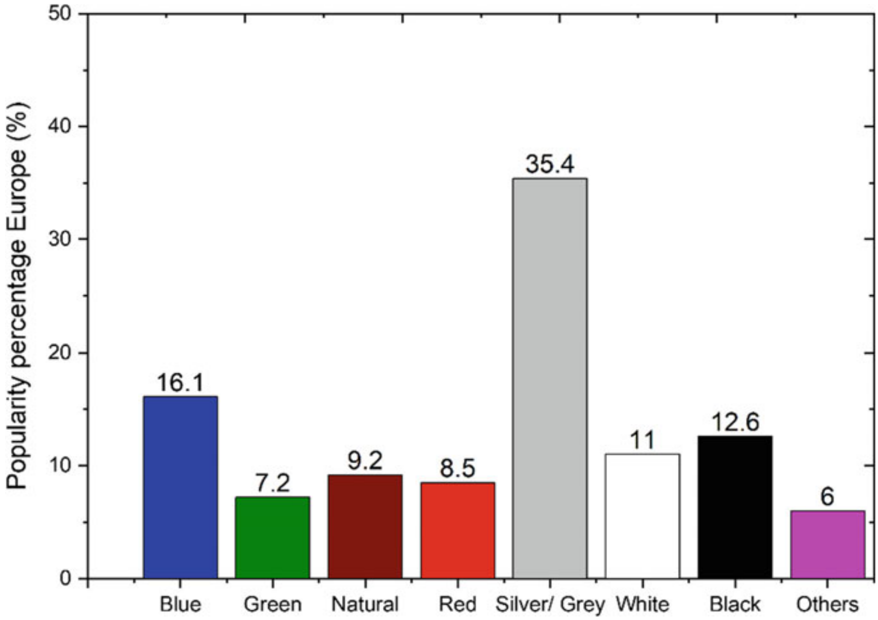
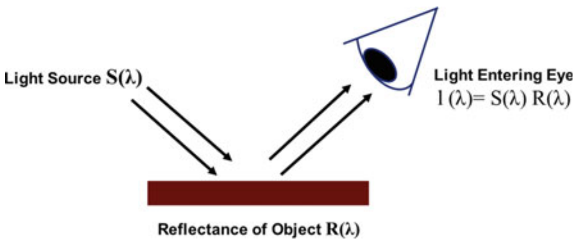


Fig. 4.3 Car colors popularity

Fig. 4.4 Visual triplet



brain that sense the color all contribute to color perception. The energy emitted at different wavelengths, i.e., the spectral power distribution, characterizes a light source (Klein, 2010).

4.1.1 Light

Color is the consequence of colorants that physically altering light and being recognized (called a response process) by the human eye and processed by perceptual process in the brain. The existence of color necessitates the presence of a light source, an object, and a person who can perceive the light. The wavelength of reflected light from an opaque object is used to characterize an item's hue. The color of a textile material is usually one of its most important characteristics. Color is a subjective perception (individual/personal), and objectivity is very important in an industrial environment where color is used (Klein, 2010; Springsteen, 1999). The color of a textile material is usually one of its most important characteristics. One of the most important aspects of a textile material is its color, and it is a subjective (individual/personal) perception; therefore, objectivity is very important in an industrial environment where color is used (Klein, 2010; Springsteen, 1999).

Light is the electromagnetic radiation (radiant energy) that creates visual sensation. In the electromagnetic spectrum, the visible light lies between 380 and 780 nm in wavelength. Nowadays, the light is defined as 'It is a kind of energy that exhibits as particle or wave in nature, which is identified through its spectrum of colors.' Simple or monochromatic light (light of defined wavelength) can be thought as electric and magnetic vectors that propagate at a certain speed. As seen in Fig. 4.5, both vectors are in rectangular proportion to each other and to the motion of direction (Klein, 2010).

Light is therefore in fact stream of photons having different energies). Visible light is in the range of wavelengths 400–760 nm (see Fig. 4.6).

Monochromatic light can be described by wavelength λ (m), frequency ν (s^{-1}), and/energy E (J). These terms are linked by the well-known equations:

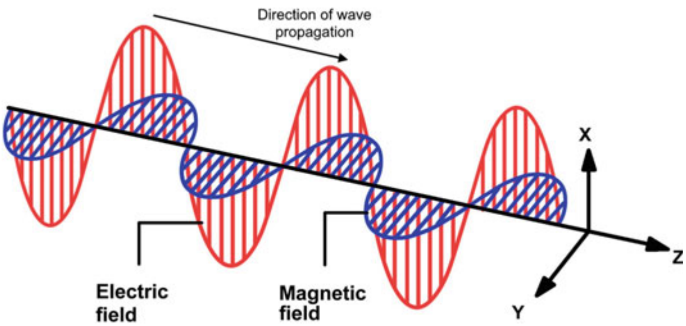


Fig. 4.5 Representation of electric E and magnetic B vectors of light

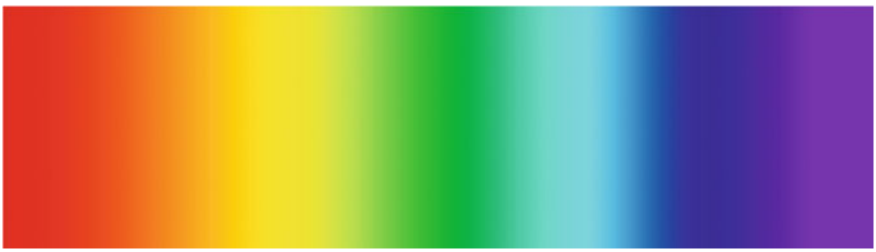


Fig. 4.6 Spectrum of visible lights

Table 4.1 Efficacy of different light sources

Types of light source	Efficiency (%)	Efficiency (lm W−1)
Incandescent light bulb	5	16
Long fluroscent tube	25	80
Compact fluroscent lamp (CFL)	20	60
Sodium lamp (High pressure)	45	130
High power white LEDs (350 mA drive current at 25 °C)	30	132 (cool white) 83 (warm white)
Low power white LEDs (20 mA drive current at 25 °C)	55	170
High power white LEDs (5 year target)	55	188 (cool white) 138 (warm white)

$$E = hv = h\frac{c}{\lambda} = kT \tag{4.1}$$

where Planck's constant $h = 6.626176 \times 10^{-34}$ J s, Boltzmann constant $k = 1.381 \times 10^{-23}$ (J/K), temperature T(K) and the velocity of light $c = 2.9979245 \times 10^8$ m s^{-1}. Selective absorption of photons of a specific wavelength causes color. The light perception is then the relation between wavelength of absorbed photons and visible color (see Table 4.1).

There are two specific lights white light the intensity of all wavelengths is the same and backlight—all wave lengths are absorbed. All kinds of light, i.e., both the visible and not visible, to the human eye are defined in the electromagnetic spectrum. Generally, humans can see only in the narrow region in the electromagnetic spectrum and this visible light is composed of the individual color of the rainbow, other the visible light most of the light is invisible in the universe (Klein, 2010). The lights which are invisible include radio waves, microwaves, infrared radiation, ultraviolet rays, X-rays, and gamma rays (Klein, 2010).

The electromagnetic spectrum covers a wide range of wavelength λ; for example, it covers cosmic radiation of $\lambda \approx 1$ fm (1 fm is equivalent to 10–15 m) to the radio waves of $\lambda = 10$ km, hence a range of around 19 orders of magnitude (Fig. 4.7). But a small part of the spectrum of electromagnetic waves is visible to humans. Ultraviolet wavelengths are those between 380 and 440 nm on the left end of the spectrum. The color impression shifts from blue to green to yellow to orange to red as the wavelength increases. At wavelengths greater than 600 nm, red is perceived. Individual differences in color perception affect the corresponding wavelengths (MacAdam, 1985; White et al., 2016).

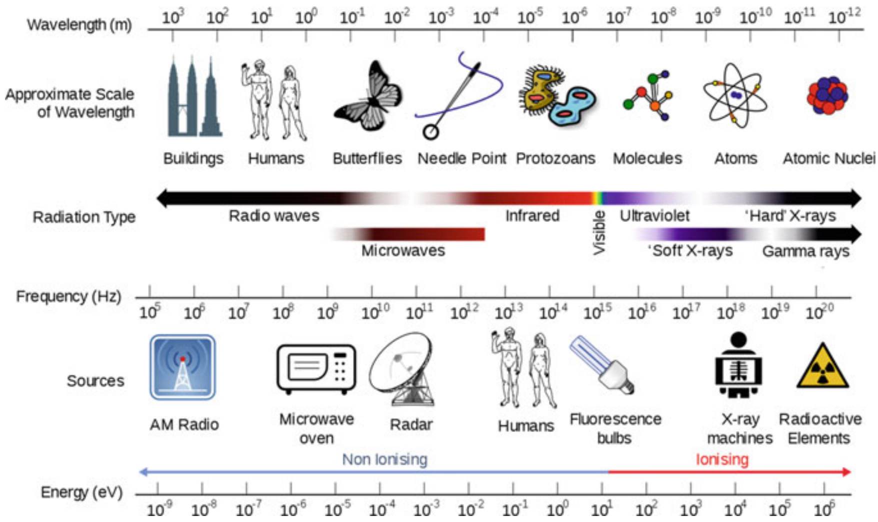


Fig. 4.7 Overview of electromagnetic spectrum

4.2 Illuminants and Sources

There are a variety of light sources by which we can visualize the objects, where the daylight is preponderant.

Luminous efficacy is a measure of how well a light source produces visible light. The maximum possible theoretical efficacy of a light source is 683 lm W^{-1}, for the case of monochromatic 555 nm green light (see Fig. 4.8). The measure of amount of visible light that is produced from the light source is called luminous efficiency. For instance, 683 lm W^{-1} is the maximum possible theoretical efficiency of a light source monochromatic 555 nm green light (see Fig. 4.8). Efficacy of different light sources is given in Table 4.1.

The $V(\lambda)$ is the eye-sensitivity function; it is defined as the function of wavelength and luminous efficiency of the sensitivity of human eye. The luminous efficiency of an optical radiation is defined as the luminous flux (lm) per unit optical power (W), where the lumen (lm) is the unit of light intensity which has been perceived by human eye. By this definition, the sensitivity of human eye considers the green light contributes more efficiency than the red or blue light. The wavelengths of ultraviolet (UV) and infrared (IR) have no effect to the luminous efficiency. The luminous efficiency of a light source is the ratio of the light power output (measured in lumens) to the electrical input power (measured in watts) (Klein, 2010).

Coupled with daylight, incandescent lamps and fluorescent lamps are man-made sources that help to view the objects. Measuring color under these conditions is impossible. However, color measurement under one source is sufficient. Yet, distinction between light source and the luminous body is paramount. While source is

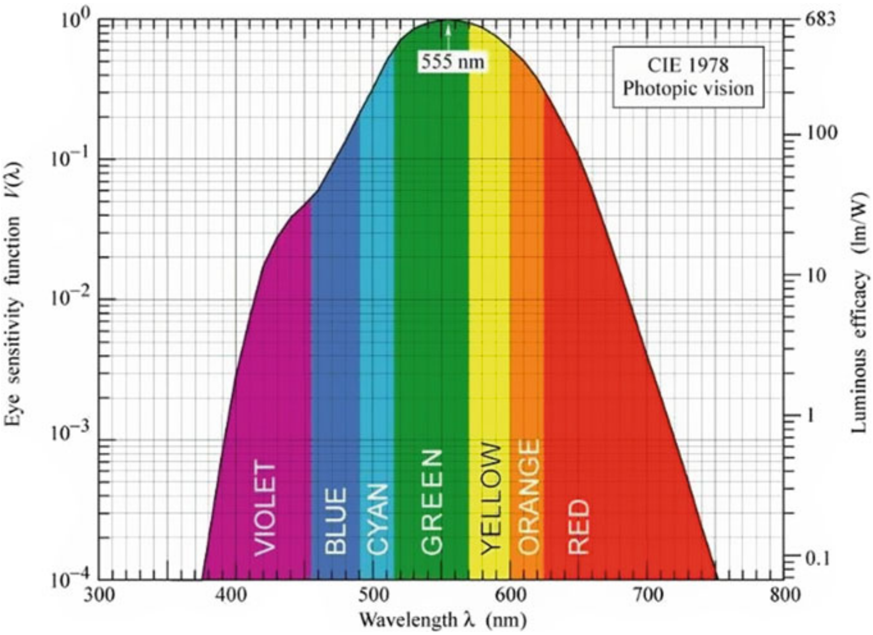


Fig. 4.8 Dependence of luminous efficacy on light wavelength

defined as the physical emitter of radiant energy, the sun, lamp, and the sky are some examples of source, and the term illuminant is referred as the incident of spectral power distribution on an object that perceived by an observer. An illuminant is determined by the source's spectral power distribution which may not be perfectly realizable. For instance, the illuminant A can be produced from the laboratory, whereas there is no standard method for producing D65 in laboratory. More than one illuminant can be created using just a single source, such as a xenon flash tube since illuminants relate to energy distribution (White et al., 2016). A 'warm' color light source (temperature less 3300 K) has a lower color temperature. The intermediate color light source temperature is in the range 3300–5300 K, and cool color light sources temperature is above 5300 K. For example, at the color temperature around 4100 K, the cool-white, fluorescent lamp exhibits bluish color, whereas a warm fluorescent lamp at the color temperature of around 3000 K exhibits yellowish in color (Klein, 2010).

CIE directed the usage of different illuminants that were derived basically from the spectral energies of various sources of light through the years. The CIE illuminant D65 has a spectral energy distribution (SED) that is a reasonable approximation of typical daylight, with an estimated correlated color temperature (CCT) of 6500 K (Kelvin). Color measurement applications use D65 as the principal illuminant. CIE illuminant A was created to define light similar to that produced by a gas-filled tungsten filament lamp, with an estimated associated color temperature of 2856 K.

The quantity of energy emitted at longer wavelengths is significantly larger than at shorter wavelengths. At the longer wavelengths, the amount of energy emitted is greater than at shorter wavelength. TL84 which is commercially known, F11 (fluorescent illuminant), has an approximate color temperature of 4000 K and a spectral energy distribution that is a good representation to store lighting. Fluorescent illuminants have extraordinarily high SED (s) at narrow bandwidth (White et al., 2016).

Artificial lighting tries to imitate natural light by producing multiple wavelengths with varying degrees of warmth and coolness. In ever-changing surroundings, this has a growing impact on our sense of color. Incandescent bulbs, for example, produce a warmer light with a strong yellow to red spectrum, which is favored for indoor usage since it mimics the warmth of the sun and is more soothing. Cooler blue and green frequencies are emitted by fluorescent lights, making cold colors look brighter and warm colors appear duller. Improved technology is being used to reproduce the warmth of incandescent light as incandescent bulbs are progressively phased out and replaced by energy-efficient lighting, matching customer preferences (White et al., 2016).

Standard illuminant for color matching (White et al., 2016).

- *CIE Standard Illuminant A:* Tungsten halogen light with the correlated color temperature of 2856 K.
- *CIE Standard Illuminant D65*: Mathematical representation of average noon sky daylight with the correlated color temperature of 6500 K. It is used in the color assessment, metamerism testing, visual correlation with spectrophotometric equipment results.
- *CIE Illuminant D50:* Mathematical illustration of ‘horizon’ sunshine in the early morning or late afternoon with the corresponding color temperature of 5000 K.
- *CIE Illuminant F2 (CWF-2):* Commercial wide-band fluorescent lights are utilized in developing nations and less commonly in the USA (cool white fluorescent). 4200 K is the color temperature. Metamerism testing is one of the applications. Due to the low initial cost but poor effectiveness, it simulates minimal commercial lighting in the USA.
- *Illuminant TL84:* Commercial light used in most of the shop with the CCT of 4100 K.
- *CIE Illuminant F12 (U30):* Mathematical representation of commercial fluorescent lights with the CCT of 3000 K.

4.2.1 Light Sources in the Shops

The TL84 (F11) light source, which is often used in shops and supermarkets, has a wavelength range of 380–750 nm, a tiny UV peak at approximately 370 nm, and a color temperature of roughly 4100 K. The CIE Standard Illuminant D65 has a color temperature of around 6500 K and emits light with a wavelength range of =

300–750 nm (UV–Vis to near-IR). At a wavelength of around 365 nm, the UV light source has a high peak (Roy Choudhury, 2015).

TL84—this illuminant simulates the CIE standard illuminant F11. A tri-phosphor fluorescent source with a narrow band of light was initially developed for commercial lighting applications outside of North America. It is distinguished by the large quantity of green light it emits, with a color temperature of around 4100 K. It has a color rendering index (CRI) of around 86. It simulates CIE standard illuminant F12 with TL830. A tri-phosphor fluorescent source with a narrow band of light that was initially developed for commercial lighting applications outside of North America. It is distinguished by the large quantity of yellowish red energy it emits, with a color temperature of over 3000 K. It has a color rendering index (CRI) of around 86. TL835—a tri-phosphor fluorescent source with a narrow band that was initially developed for commercial lighting uses outside of North America. It is distinguished by the large quantity of reddish yellow energy it emits, with a color temperature of around 3500 K. It has a color rendering index (CRI) of around 86 (Roy Choudhury, 2015).

4.2.2 Blackbody Radiation

Blackbody radiation is the radiant energy emitted by a perfect black surface (blackbody) whose spectral power distribution is solely controlled by its own temperature. Blackbody color is the temperature of a true blackbody emitter which to the human eye is a close match to the color of an incandescent object, which is not a blackbody. Planck's law often known as black body radiation states the amount of power released by a blackbody in equilibrium at temperature T to (Ohta & Robertson, 2006):

$$M_e(\lambda, T) = \frac{c_1}{\lambda^5}\left(\frac{1}{e^{c_2/\lambda T} - 1}\right) \tag{4.2}$$

where M_e (λ, T) denotes the spectral radiant existence (power per unit area per unit wavelength interval), λ denotes wavelength in meters, and T denotes the absolute temperature in kelvins. The c_1 and c_2 are the Planck's radiation constants, and the values are $c_1 = 2\,\pi hc^2 = 3.7415 \times 10^{-16}$ W m^2; $c_2 = hc/k = 1.4388 \times 10^{-2}$ m K, where Planck's constant is h, speed of light in a vacuum is c, and the Boltzmann's constant k.

Figure 4.9 displays the spectral power distributions of blackbody radiators *i*th rising temperature; the apex of the blackbody radiation curve changes to a shorter wavelength and greater energy. The apex of the curve is around 10 mm at ambient temperature (300 K), and the emission is mostly thermal in the infrared band. As previously stated, this blackbody at ambient temperature appears black because it emits virtually little visible light. However, when the blackbody source's temperature climbs across the range depicted, it emits more in the visible area, and its color changes from black to red, orange and yellow, white, and eventually a bluish-white

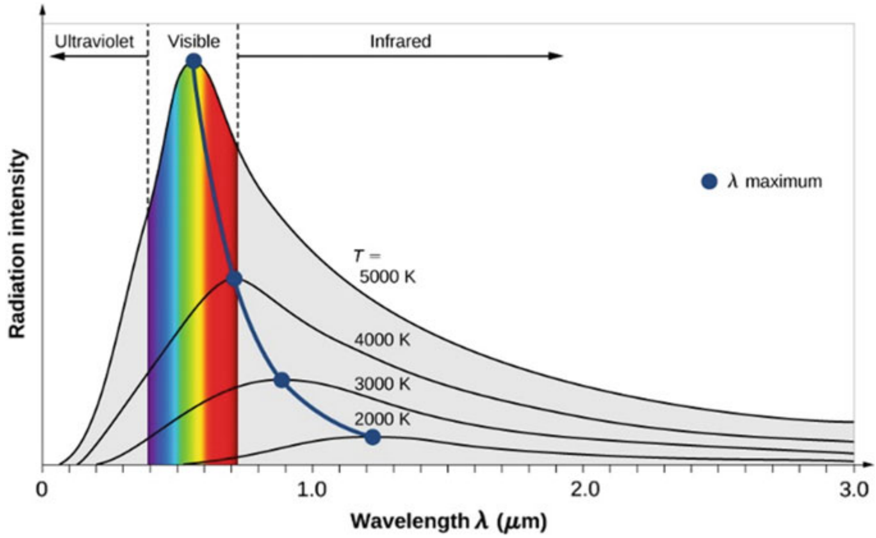


Fig. 4.9 Blackbody spectral existence curves for several temperatures

(Ohta & Robertson, 2006). In general, radiation released by materials follows the blackbody radiation curve only roughly (Fig. 4.3); however, the spectra of typical stars nearly match the blackbody radiation curve. The wavelength of emitted radiation versus the intensity of blackbody radiation. Each curve corresponds to a distinct blackbody temperature, from the low temperature (lowest curve) to the high temperature (highest curve) (Ohta & Robertson, 2006).

4.3 Interaction of Materials with Radiation

When light interact with the object, the different phenomena occur in dependence on surface texture and nature of objects (see Fig. 4.10). The materials that reflect most of the incident light are opaque materials.

The diffuse reflection which shows color, and the specular reflection shows gloss. At any angle, the amount of light reflected at specular angle is greatest. However, specular reflection accounts for just around 4% of total reflected light. The diffuse reflection contains the remaining reflection. For opaque objects, there is relation between absorbed rays and reflected complementary rays (perception of object color) as shown in Table 4.2. Surface spectral reflectance corresponding to different colors is shown in Fig. 4.11.

Instrumentation to measure color offers a subjective and reliable technique of color quality control since visual color judgments can be impacted by a multitude of factors ranging from plant lighting conditions and angle of view to individual

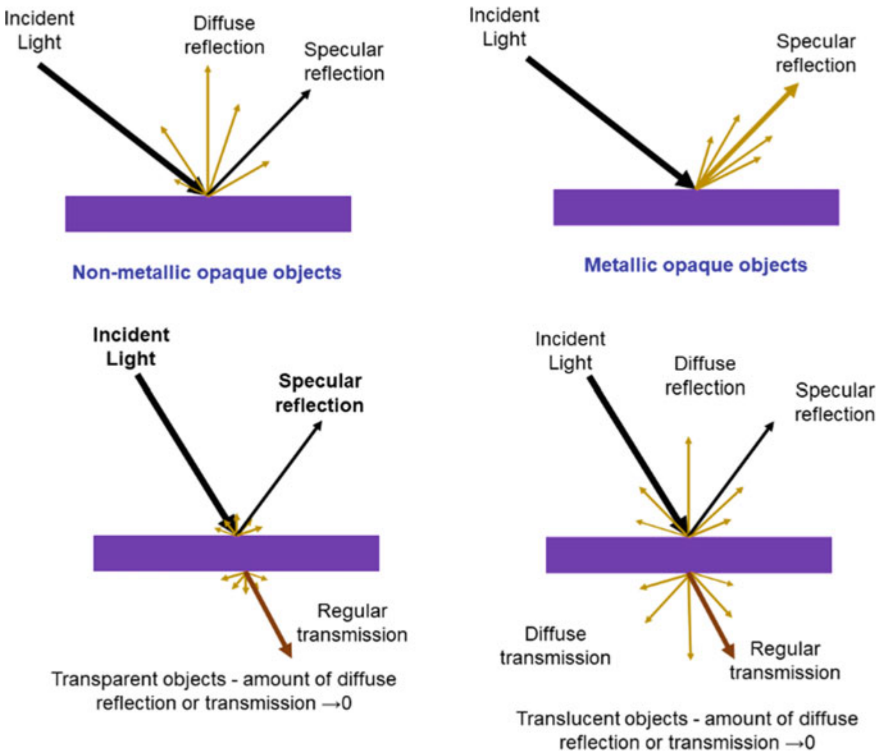


Fig. 4.10 Interaction of light with object

variances in color perception. It is critical to recognize that the total color impression is made up of at least two elements: light interactions in the volume and at the colored sample's border surface (see Fig. 4.12). In other words, the volume's reflection or transmission is overlaid on the reflection of the border surface. This reflection is caused by different refractive indices at the border surface. Boundary surfaces like these can be found in paints, coatings, polymeric materials, emulsion paints, and ceramics. Undefined surfaces, such as fabrics, uncoated papers, plasters, or suede leather, cannot be distinguished in this way (Ohta & Robertson, 2006).

In optics, transparency is the physical attribute of enabling light to travel through a substance without being dispersed. The photons can be said to obey Snell's law on a macroscopic scale (one where the dimensions analyzed are many, many times bigger than the wavelength of the photons in question). Glass, transparent dyestuff solutions are examples of transparent materials (Fig. 4.12a). Semi-transparent (Fig. 4.12b) and semi-translucent (Fig. 4.12c) materials have a mixture of regular and diffuse light transmission. Materials such as plastic foils with milk shade, low-concentration colloidal solutions, and so on are covered in this category. Translucent materials let light flow through it, but they disperse it in such a way that things on the other side look blurry. Frosted glass, s, certain polymers, ice, and tissue paper are examples

Table 4.2 Color spectrum

Absorbed rays		Observed (complement color)	Energy of photons
Wave (nm) lengths	Spectral color of absorbed light		
<380	UV -rays		>300000
380-435	Violet	Green Yellow	Energy
435-480	Blue	Yellow	
480-490	Green Blue	Orange	
490-500	Blue Green	Red	
500-560	Green	Purple	
560-580	Green Yellow	Violet	
580-595	Yellow	Blue	
595-605	Orange	Green Blue	
605-730	Red	Blue Green	
730-780	Purple	Green	
>780	Colorless IR- Radiation		<158000

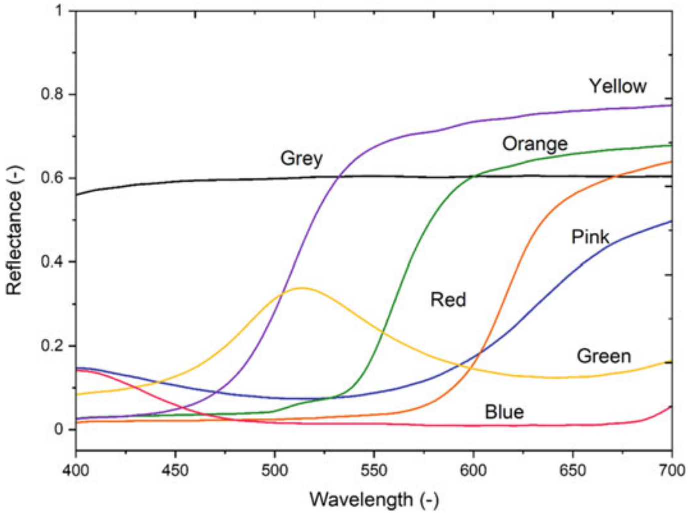


Fig. 4.11 Surface spectral reflectance

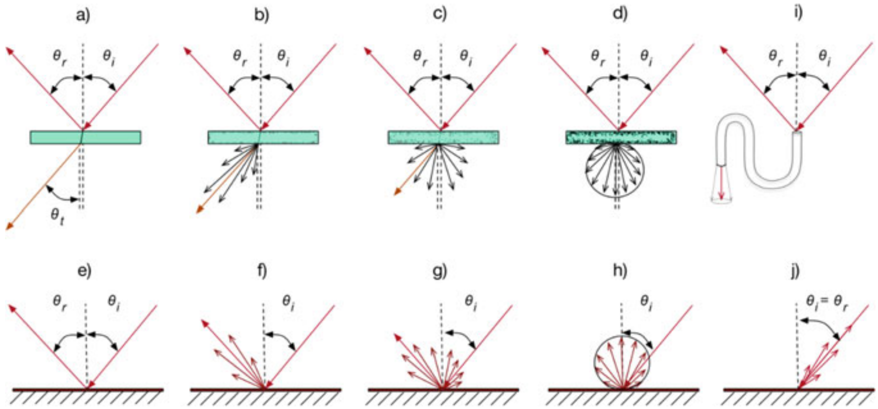


Fig. 4.12 Scheme of interaction radiation with materials (Vik, 2017)

of transparent materials (Fig. 4.12d). Specular reflection occurs at glossy surfaces between two materials with different dielectric characteristics (Fig. 4.12e). The incident ray's direction, the reflected ray's direction, and the surface normal vector span the plane of incidence perpendicular to the reflective surface. The incidence and reflection angles are the same. Pure specular surface reflection is only found in a few materials (Fig. 4.12f). Most surfaces have a combination of specular and matte reflections (Fig. 4.12g). These surfaces exhibit a wide range of reflectivity distributions, ranging from isotropic (Lambertian) to high forward reflection, depending on the size and slope distribution of the micro-roughness. The key direction is still the angle of specular reflection. Alumina, satin, and other similar materials are examples of such materials (Vik, 2017).

Matte surfaces (Fig. 4.12h) reflect light with a strong diffuse reflection and a weak specular reflection, resulting in a less saturated, duller color. The Lambertian surface is the surface that has perfectly matte properties that means it follows Lambert's cosine law. According to Lambert's cosine law, the light intensity reflected or transmitted in any direction from an element of fully diffusing surface changes as the cosine of the angle between that direction and the surface's normal vector. Barium sulfate pellets, chalk, and other matte surfaces are examples.

A physical structure that channels electromagnetic waves in the optical spectrum is called an optical waveguide (Fig. 4.12i). Optical fiber and rectangular waveguides are two common forms of optical waveguides. Optical fibers are made up of a light-carrying core and a cladding that surrounds them. Glass core/cladding, glass core with plastic cladding, and all-plastic fiber are the three most common methods of construction. Optical fibers usually have an extra coating on the exterior that protects and surrounds the fiber. Warning clothes, road signs, and other items with retroreflective surfaces are common. As shown in Fig. 4.12j, retroreflection is defined as the reflection in which radiation is returned in directions that are near the direction of the incoming radiation. Corner reflectors or glass spheres are used in such materials.

4.3.1 Color and Design for Textiles

When checking up the meaning of color in dictionaries, the reader will find that it is described in general terms as 'the visual property of light that is not tied to brightness, saturation, texture, glossiness, or translucency.' Such scientific definitions obscure color's enormously beneficial importance and effect on our species. It is the key sense for identifying ripe from unripe fruit and safe from hazardous meat from a survival standpoint; it tells us the quality of beer or honey, as well as the strength of a cup of coffee or the quality of tomato puree. It gives complicated visual information, such as maps and warning signs, more depth and immediacy. Football teams, snooker balls, and political parties are all identified. It has an impact on mood and performance, and its aesthetics dominate fashion, while its symbolism may be seen in great art, national flags, and corporate branding. Color is an important part of our daily lives for humans since we are sensitive, intelligent animals that get a large amount of information about the world around us through eyesight (Vik, 2017). It is vital to remember that an object's color is determined by the light source that illuminates its surface, the observer who looks at it, and the surface's qualities (Kryštůfek et al., 2013). Obviously, the surface's character is the most significant component. Color is more often associated with chromatic hues rather than achromatic hues like white, gray, and black. Both requirements may be precisely described in a three-dimensional space, that is, by describing three properties, according to popular belief. Color is defined by three properties in terms of the observer (Kryštůfek et al., 2013; Vik, 2017) (see Fig. 4.12):

Hue λ (dominant color seen)

- Signal's pure color wavelength.
- Identifies red, yellow, green, and other colors.
- The human eye can detect around 400 different colors.

Saturation or chroma or purity—P (degree of dilution)

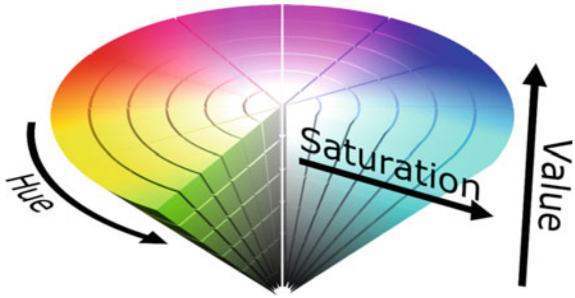
- Inverse of the signal's 'white' content. White and gray have 0% saturation, whereas pure colors have 100% saturation.
- Separates red from pink, marine blue from royal blue, and so on.
- Each color has about 20 different saturation levels.

Brightness (lightness)—L

- The quantity of light that is emitted or reflected.
- The gray levels are distinguished.
- About 100 levels are seen by the human eye (Fig. 4.13).

For quantitative description of color, the CIE model was developed (Kryštůfek et al., 2013; Vik, 2017). The CIE color model is completely independent of any device or other means of emission or reproduction and is based as closely as possible on how humans perceive color. The key elements of this model are the definitions of standard sources and the specifications for a standard observer. The tristimulus values

Fig. 4.13 Color components



X, Y, and Z are calculated at the core as integrals of spectral power distribution S_i, reflectance R_i and color matching functions of standard observer (2° or 10°) $\overline{x}$, $\overline{y}$, $\overline{z}$ over whole visible range of wavelengths (Kryštůfek et al., 2013; Vik, 2017). The use of a two-dimensional scale, known as chromaticity coordinates, is a handy approach to describe the tristimulus values of object colors in a mathematical space, x, y as relative portions of corresponding tristimulus values X, Y (Kryštůfek et al., 2013; Vik, 2017).

Chromaticity diagram in the two-dimensional space of x and y is shown in Fig. 4.14. The complete range of perceivable colors is separated into many sections that match to various color description phrases.

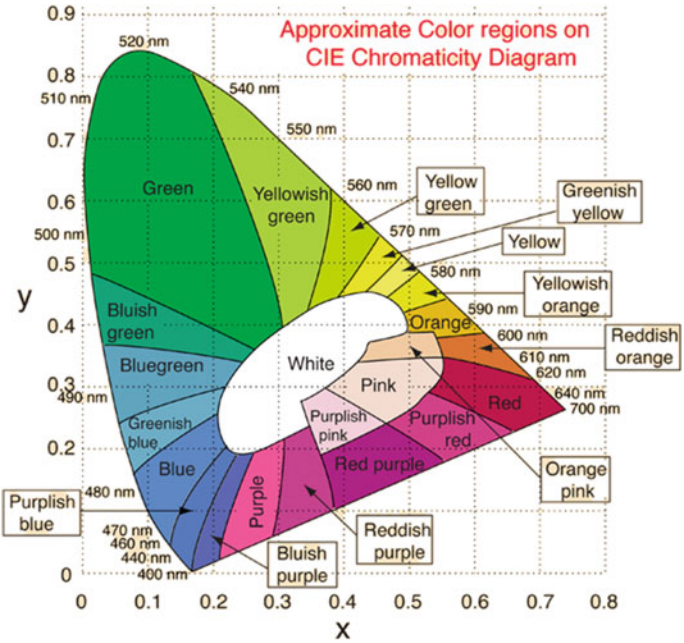


Fig. 4.14 CIE chromaticity diagram

4.3.2 Visual Color Sensation Variables

Visual color evaluation is the major technique of assessing color accuracy and control in the textile industry, retail stores, corporate offices, and residences all over the world. Several visual color sensation factors must be considered.

Metamerism

Metamerism is one of the most difficult issues for the dyers, designers, retailers, and consumer. When two things with the same color appearance but distinct spectral curves exist, this is known as metamerism. Metamerism is recognized by the layman when two things that match under one illuminant do not match under another. Metamerism occurs when the X, Y, and Z values of two specimens match under one illuminant but not the other, according to colorimetry (Vik, 2017). Even though the reflectance curves of two samples are not similar, under certain illumination circumstances, such as Illuminant D65, an observer can view the specimens as a match but not under different Illuminant, e.g., Tungsten light (Illuminant A), see Fig. 4.15.

Three types of metamerism often encountered in the textile dyeing industry include illuminant metamerism, observer metamerism, and field metamerism. Because of the many various types of illuminants used in daily living at homes and in businesses, metamerism poses a unique difficulty in evaluating color differences. The energy distribution of each illuminate is unique. As a result, the tristimulus values obtained under each illuminant differed. Color constancy is a characteristic of a single color that describes how a color appears in different lighting conditions. Metamerism requires the comparison of two distinct items. Different characteristics of objects are defined by color constancy and metamerism. Both are determined using indices, such as the metamerism index (MI) and the color constancy index (CCI), and the formulas for these indices are similar to color difference equations (Gangakhedkar, 2010).

Color Fatigue

Color fatigue is another issue in the color sensation variable. Due to the process of color vision, the nerve light receptors begin to fatigue if an individual observes a

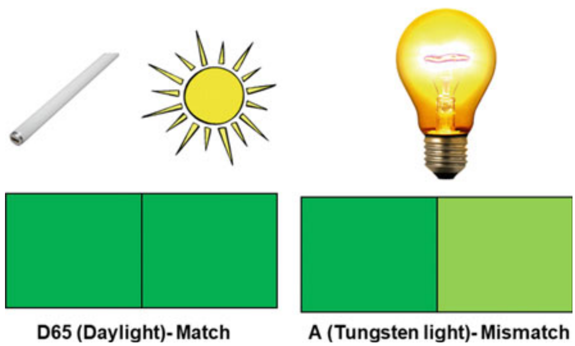


Fig. 4.15 Example of metamerism

potential color match. As an impact, the color matches gradually closer over time, often after 15–20 s after viewing. The color judgment will be affected if viewing bright colors before viewing deep color; this is due to our visuals which have not get enough rest and recovery. Many people referred that color vision must recover for at least 1–2 min after perceived divergent colors.

4.4 Textile Design

The design of a textile is good when it is seamed, darted, gathered, and wrapped over a body rather than seen as a plain piece of fabric. The more contrast in the design, and the larger and bolder the patterns, the more difficult it is to use the cloth effectively. If the motifs are added as prints after the fabric is produced, the garment will be unsatisfactory if there is mismatch in the alignment with fabric strands. The eye is drawn to geometric designs. If the geometric design fails to consistent across the garment it leads to evident of high shoulder and uneven waistline. The scale of the motif, the contrast between the motif and the background, and whether the design is multiple direction or one-way, realistic, stylized are the factors that determine the usage of abstract motifs to be simple or hard. Smaller motifs, softer shadings, and patterns with numerous directions are simpler to make and wear.

4.4.1 Texture: Visual and Hand

Texture, which encompasses the visual look and feel of materials, is another component of textile design. ‘Hand’ refers to the experience of touching, gripping, or squeezing textiles. Textural overlap between the visual surface appearance and the hand is described using adjectives such as clingy–rigid, cold–warm, crisp–limp, dry–moist, firm–flexible, heavy–light, opaque–transparent, pliable–stiff, rough–smooth, shiny–dull, stretchy–stable, and thick–thin. The texture of fabric is influenced by the fiber, yarn, structure (weave, knit, etc.). Albeit fibers are the tiniest components of a fabric, their properties have a significant impact on texture. For instance, wool produces soft textures, whereas linen produces sharp textures. Yarns are made by twisting short pieces of staple fiber or long continuous filament fibers. To generate diverse textures of yarn, the kind of fiber, the process of connecting the fibers into yarn, and the quantity of yarn twist may all be changed. Fabric structure can be woven (the yarn that held taut when one set of yarn inserted perpendicular to another set), knit (stitches of serially interlocked loop), non-woven (a web of man-made fibers held together by a resin, heat and pressure, or needle punching), or other structures like felt or lace. The joining of yarns together to form a fabric structure determines the weight, flexibility, hardness or compressibility, and stability or stretchiness properties of the fabric. The looseness or tightness of yarn twist, yarn size, and the closeness or openness of the fabric structure significantly influences the texture’s lifespan. Fabrics made of tightly twisted smooth threads that are densely woven or knit are often the most durable (such as woven gingham, gabardine, and smooth double knits). Clothing for everyday use is often made of sturdy textures, but clothing for special occasions is typically made of less durable textures. The silhouette and contouring of the cloth to the body are determined by the weight and flexibility or stiffness of the fabric. Many designs specify the sort of cloth that will work best with that pattern. Fabrics may be labeled according to the sort of garment suggested at over-the-counter fabric stores, but you must often decide whether or not they are suitable for a garment or item (Lusia, 2008; Zheng et al., 2012).

The stability or stretchiness of a cloth is another textural aspect in its appropriateness for a certain purpose. Although most knits have some stretch, not all knits have the same amount. Woven textiles with stretch are also being produced; do not assume that a knit fabric is flexible or that a woven fabric is stable just because it is woven. The pins and a ruler or the stretch gauge on the pattern envelope are used to determine the stretchability of a fiber. The more macro-porous and open textile macrostructures give more opportunities for a complicated trajectory of a light. The absorption of light by contact with a dye particle inside the fibers is more frequent before the remaining rays are reflected out to the observer. The surface of textiles with more open weave seems to be darker by the same dye content and by the same finishing, although the difference is not high.

On the contrary, lustrous, smooth, and enclosed surfaces appear lighter. Brushing, grinding, and similar operation eroding the surface of textile lead to the shade changes. Considering pile textiles, the position and the angle of the pile toward the direction of observation are essential. The necessity of the exact defined angle of incident light and observation is well known by color measuring of these textiles.

Form practical point of view:

- Wet textiles appear darker,
- It is difficult to reach of the deep, dark, and above all the black shades on polyester fibers. When this problem occurs with fine fibers (polyester microfibers), then it is difficult to reach the black and dark shades.
- The silicon-finishing agents increase the shade. The final shade can be 'optically' strengthened with the special silicon dispersions (so-called black improver) due to the lower refraction index of silicon.

It is advantageous to combine these effects with obvious silicon handle and elastic finishing.

4.4.2 Culture

Textile color has aided and facilitated the expression of cultural identity. Global merchants recognize the unique qualities and variances in consumer color preferences, and they try to produce totally distinct palette types for comparable items in different nations. This highlights where tradition, climate, and technologies have formed a society's particular color choice and underlies culture via color. A strong cultural identity may exist in remote communities. However, as a result of globalization, greater travel demand, and higher media exposure, the typical consumer worldwide is much more aware of and affected by a variety of color palettes associated with different nations, as well as the new brand culture. Color association has different meanings in different countries; however, this is eroding and evidence is expressing change. For instance, in China white is historically associated with funerals, but in the West, it is associated with weddings. As a result of global influences, there is a shift away from red, which is said to bring good luck since it is a powerful color that wards off evil spirits, to white, which is now becoming a popular color option for wedding gowns in China. The concept of a worldwide homogenized color palette is difficult to embrace, especially since museums and galleries' old and conventional collections may become the only physical cultural references accessible. The retro element of design is well established at the time to deal with consumer interest in valuing historical identity, although there may be less instances of ethnical originality to reference in the future. Yinka Shonibare, a modern artist, employs color in his work to portray an African identity as an expression of belonging. Pastel colors would not convey the same ethnic message as the brightly colored batik textiles. This is a clear allusion to the concept of cultural authenticity. The work is represented through the wonderfully colored textiles; rich vivid earth colors and patterns that we identify with Africa, despite the fact that it is socially and politically driven. Color is often used by designers to imply tradition and cultural allusions.

4.5 Functional Colors for Textiles

The first thing that catches your sight is color, which creates a visual impression. A person's preference for a specific color is influenced by a number of variables. These criteria will determine the final success of a color and, more importantly, the product. Color harmony adds aesthetic appeal as well as a feeling of order to a space. Color has a significant part in this scenario.

Most photochromic pigments are used to generate novelty fabrics such as T-shirts, ski suits, baseball hats, lampshades, and stylish objects because of their dynamic color shifting properties, which have a tremendous impact on the fashion industry. Photochromic dyes have the potential to start a new fashion trend (Periyasamy et al., 2016; Periyasamy et al., 2017; Periyasamy et al., 2019b, 2020a; 2020b; Seipel et al., 2017, 2018). It will be of great aid to apparel manufacturers by providing novel marketing opportunities. Outfits with changing motifs, letters, and patterns that are visible in the sunlight and fades in the shadow will clearly make a fashion statement and a revolution in the apparel industry.

Photochromic dyes have the potential to start a new fashion trend. Photochromic fabrics have been utilized in the fashion industry for innovative aesthetical uses like color-changing clothing, but its capacity to signal light exposure has also been used as a sun exposure indicator (Vikova et al., 2021). It will be extremely beneficial to garment producers since it would provide new marketing options. Outfits with shifting themes, lettering, and patterns that are visible in the sun and fade in the dark will undoubtedly create a fashion statement and revolutionize the apparel industry (Suhag & Singh, 2015). Various photochromic colorants were combined together to create a variety of colors (Periyasamy et al., 2020). Aside from that, photochromic colorants may be used to print company names or logos on clothes to prevent copying, as well as to create stylish materials such as footwear and furniture.

4.6 Textile Color Measurements

The technique of color measuring allows us to quantify color in numerical terms. The requirement for a numerical pass/fail system stems from the fact that visual assessments of shade differences are inconsistent when determining the narrow line between acceptable and unsuitable dyeing. In this chapter, we will look at color measuring methodologies, pass/fail acceptability limits, the relevance of spectral match, online and non-contact color measurement devices, color of dry and wet textiles, and color inspection of completed fabrics.

4.6.1 Measuring Functional Colors

Photochromism is the reversible color change that occurs when a substance is exposed to UV light; the rate of coloring and decoloration is determined by the UV irradiation index (Periyasamy & Vik, 2018). Photochromic materials have substantial color change or reversible color-changing characteristics, necessitating the use of a spectrophotometer to determine their optical properties (Little & Christie, 2010). Often the commercial spectrophotometer is the relatively long period of time between the individual measurement which is due to the less speed of sensor (photomultiplayer, CCD, CMOS, or another type of sensors), as we are aware that the molecular vibrational states, vibrational energy transfer, specific lifetimes during photochemical reactions and ring-opening/closure processes are occurring on the *ps* time scale (Mitra & Tamai, 2003). So, this system can be allowed to study the photochromic systems with their half-time color change is more than 50 ms time scale (Paramonov et al., 2011; Periyasamy et al., 2017).

To remedy this difficulty, the spectrophotometer's sphere must be integrated, which has been changed to contain an additional aperture for UV irradiation. Michal Vik and Martina Vikova (Vik & Vikova, 2007; Viková, 2011; Viková & Vik, 2015; Vikova et al., 2014) of the Laboratory of Color and Appearance Measurement (LCAM) of the Technical University of Liberec have created a new spectrophotometer (Figs. 4.16 and 4.17) that aids in the resolution of the aforesaid difficulties. These setups can aid in determining the color development during continuous

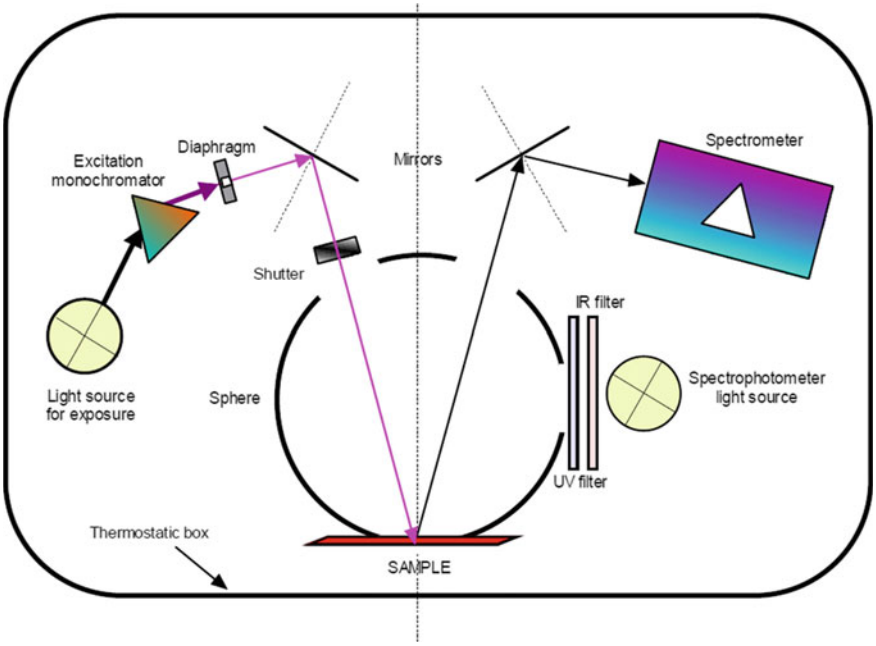


Fig. 4.16 Scheme of LCAM designed spectrophotometer (Vik & Vikova, 2007)

irradiation, as well as measuring the photochromic behavior of textiles or other substrates (Christie, 2013). The use of a shutter over an excitation light source in the spectrophotometer allows for continued monitoring of photochromic color change during reversion after the excitation light source has been switched off (Vikova & Vik, 2015; Vikova et al., 2014). It is possible to photochromic characteristics of materials with regard to one or many cycles due to the control excitation of light sources employing the shutter. This instrument's main feature is that it can measure continuously (automated), making measurement easy. It also allows for the study of photochromic kinetics color changes, the influence of exposure time, thermal and spectral sensitivities of photochromic samples, and it can be used as a fatigue tester. Most photochromic materials (mainly P-type) are temperature sensitive; this device has temperature control during measurement (Vikova & Vik, 2015; Vikova et al., 2014).

4.7 Sustainable Color and Design for Textiles

For creation of color of textile materials, a dyeing by various kinds of dyes is frequently used. A dye is a chemical that may give a certain (fibrous) material its color.

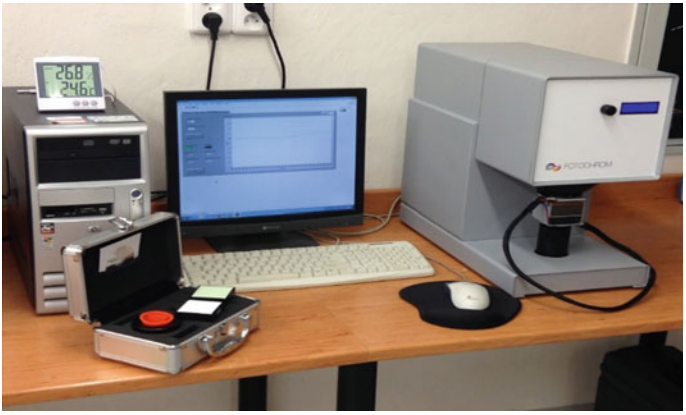


Fig. 4.17 FOTOCHROM, which was developed at the Laboratory of Color and Appearance Measurement (LCAM), faculty of textile engineering, technical university of Liberec

Compared with most typical organic compounds, dye molecules have more complicated structures. Dye structures have a lot of characteristics despite their complexity. Most dye compounds have a completely conjugated structure with many aromatic rings, such as benzene or naphthalene. This indicates that the majority of the structure is made up of a lengthy series of alternating single and double bonds between carbon and other atoms. The chromophore, or color-donating unit, is a name for this sort of arrangement. Dyes are applied to textile fabrics in four different ways (Kryštůfek et al., 2013):

a. Textile absorbs dyes in the aqueous solution (direct dyed).
b. Water-insoluble dyes can be applied to textile by water soluble form; then, it is converted to original form (insoluble) (e.g., vat dyes, sulfur dyes dyes).
c. Reactive type of dyeing, for example reactive dyes on cellulosic materials form covalent bond.
d. Mass coloring or gel dyeing is used to integrate it into the polymer.

The most often used coloring medium is water. The vapor-phase dyeing of hydrophobic textiles with dispersion colors (thermosol dyeing) uses air, while dyeing with liquid non-aqueous solvents and non-aqueous supercritical fluids has gotten a lot of interest but has not yet found a practical use. Application of dyes for coloration of textile is accompanied by serious pollutions. Textile industry remains the second worst polluting industry in the world due to the usage of hazardous and toxic chemicals and water (Periyasamy & Militký, 2020a). Usage of natural colors does not mean sustainability; real sustainability deals the entire chemical processing should be environmentally friendly. Tirupur is one of the largest textile hubs in India; meantime (Sachidhanandham & Periyasamy, 2020), it generates highest quantities of pollutant, and it is mixed in the river Noyyal (Fig. 4.18).

Fig. 4.18 Water streams in Tirupur, located in India

4.7.1 Natural Dyes

Natural dyes have been used to color food, leather, wood, and natural fibers such as wool, silk, cotton, and flax since antiquity. Natural dyes occur in a variety of colors and can be taken from roots, barks, leaves, flowers, and fruit (Fig. 4.19). Nevertheless, the environmental awareness has been increased in nascent years that puts the amelioration of interest on the application of natural dyes on natural fibers. Because of the growing environmental consciousness to avoid some harmful synthetic dyes, the use of non-toxic and eco-friendly natural dyes on textiles has become noticeable. Most natural dyes have no substantivity on cellulose or other textile fibers without the addition of a mordant. Most natural dyes require a mordanting reagent to create an affinity between the fiber and the dye or pigment molecules of natural colorants (preferably metal salt or suitably coordinating complex forming agents). Natural dyes are environmentally beneficial since they are renewable and biodegradable, as well as being skin-friendly and perhaps providing health advantages to the wearer (Singh & Bharati, 2014). Elsie and Emma were working on natural dyes to develop wide range of colorful fabrics; it can be seen Fig. 4.20.

Probably the best-known example of natural des is indigo, which is a blue dye originally obtained from the plant of the same name (see Fig. 4.21). The association of India with indigo is reflected in the Greek word for the dye, *indikón* (ινδικόν, Indian).

Indigo is a dark blue crystalline powder that reaches its peak temperature of 390 °C. Water, ethanol, and ether are insoluble; however, DMSO, chloroform, nitrobenzene, and strong sulfuric acid are all soluble. The molecule absorbs light around 470–620 nm of spectrum ($\lambda_{max} = 613$ nm) to be dissolved, and it must undergo a reduction to leuco form. On the air, leuco form combines with oxygen and reverts to the insoluble, intensely colored indigo (see Fig. 4.22).

Very important in medieval time was dibromo indigo obtained from algae, shells, and some other sea life known as Tyrian purple (see Fig. 4.23). Tyrian purple may first have been used as early as 1570 BC. The dye was treasured in antiquity because

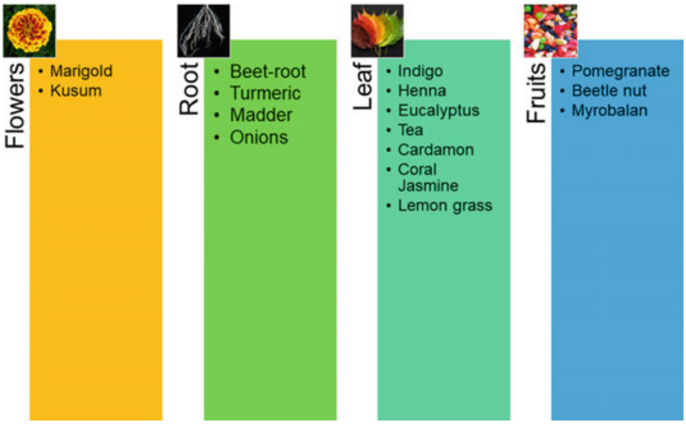


Fig. 4.19 Common natural dyestuff obtained from different vegetable regions

Fig. 4.20 Different ranges of natural dyes and their designs (Larson & Chapman, n.d.)

it did not fade quickly and instead got brighter with exposure to the elements and sunshine.

Using Tyrian purple as a dye, the hue changes from blue to reddish-purple (peak absorption at 590 nm, which is yellow-orange) to green (highest absorption at 520 nm). It has thought that as the dyed material aged the purple tint intensified rather than faded.

Fig. 4.21 Indigo dyes and their application on yarn

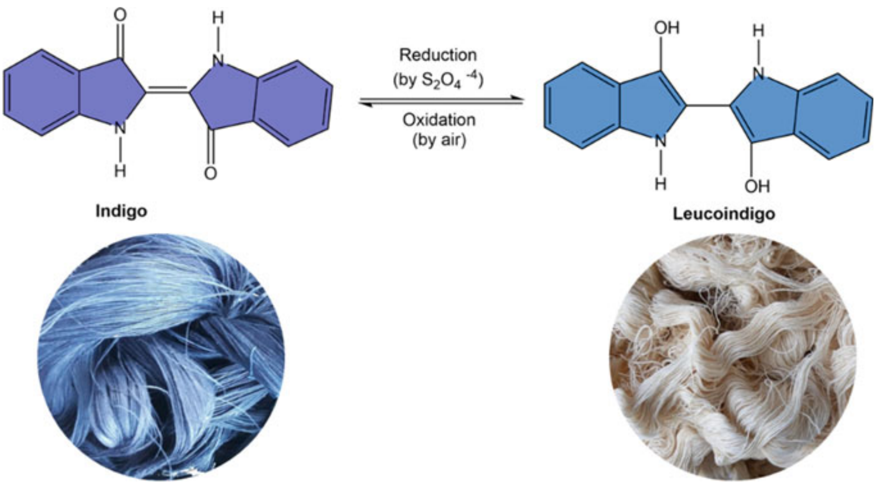


Fig. 4.22 Standard and leuco form of indigo

4.7.2 Sustainable Designs

Sustainable design suggests the design of products with less impact on the environment. It is a method of product design that considers the product's environmental effect over its entire life cycle, as the resources and materials utilized in the development of a product are considered while mitigating negative environmental consequences. These designs also raise the aesthetic and functional properties of a product.

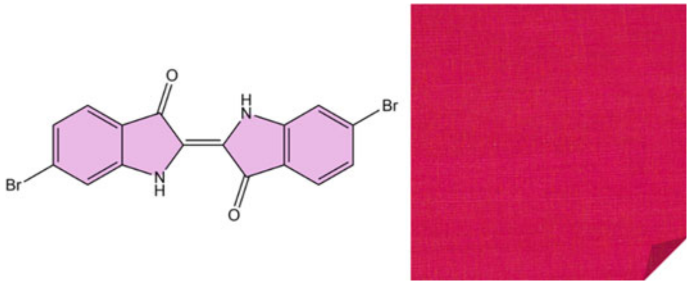


Fig. 4.23 Tyrian purple

Life cycle assessment is a method which is used to measure the effect on environment and resource of a product. It starts with the raw materials and ends with the product maintenance and disposal. Life cycle assessment is regarded as a technique for assisting in the development of sustainable designs by providing designers with sustainable options. Eco-design principles involve making a choice for,

- Materials: ecological, reusable, recyclable and non-toxic for environment, recoverable.
- Environment-friendly technologies require little energy consumption, material.
- Dimensions and shape of the products corresponding to optimal and aesthetic functions.
- Color variants not being harmful to the users and the environment.
- Materials and accessories that are subjected to the ratio price or quality.

The key aspects of going eco-friendly are:

- *Social responsibility:* Use of chemicals and pesticides pollutes drinking and groundwater, fishes, and even humans who consume it. Therefore, organic, and sustainable colors are produced without addition of hazard and toxic chemicals.
- *Biodegradable:* Natural colors are degrading gradually and naturally, whereas synthetic dyes become waste and release a lot of toxins during degradation.
- *Health:* Most of synthetic dyes cause the health impacts on living organisms.
- *Popularity:* Due to evolution, organic and eco-friendly dyes have gained popularity and become an alternative entering mainstream fashion.

4.7.3 Environmental and Commercial Issues

For consumers, the focus on social, economic, and ethical of sustainable production is an overwhelming alarm and further the prime concern of numerous global companies and designers. Becky early textile and fashion designer with radical approach has a wide range of projects questioning sustainable design and their impact on the environment (Muthusamy et al., 2021; Periyasamy, 2021; Periyasamy & Tehrani-Bagha, 2022). There are possibilities to manufacture the low-quality or single-end usage products by simple recycling; for example, the waste from dyeing and printed (i.e., colored fabric) fabric can utilize to spin again to form fabric, and these fabrics can utilize to produce the scarves, socks, etc. A new outlook is given to recycling field by the 'no waste' consecutive results of this technique together leap a forward in design. In general, a designer has more obligation in researching considering social behavior and their views on post-consumer waste which values are not spotlighted. Similarly, heap amount of pre-consumer waste emitted from cutting process must also be considered.

In the fashion and interior industry, silk and wool were predominantly occupied until twentieth century where cotton hit the top again. The properties of cotton like cool, crisp qualities, comfort usage resurrected denim and prevailing the world market in turn creating environmental problems. For production, cotton requires high-grade land, excessive amounts of water and chemicals, and for dyeing, it requires pure water equivalent to drinking water. The futuristic materials are formed utilizing range of cellulose, plant-based fibers from trees, hemp, bamboo, and nettles retrieving cotton. The cotton quality is confronted by a cellulosic fabric Lyocell, trade name 'Tencel' (Fig. 4.24).

The structure and properties of Lyocell fibers are considerably different from regenerated cellulose fibers. Crystallinity of Lyocell is about 42%. Crystallites are longer (15–45 nm) in comparison with viscose (11–25 nm) abd thinner. These long crystallites (91%) are joined only by small, well-oriented amorphous region. The radically different structures are suppressed, and cross section is oval (Fig. 4.24).

Crystallites are organized into fibrils between which are numerous systems of pores typical with by short diffusion path inside the fiber. Lyocell fibers porosity is radially homogeneous (pore diameter is 5–10 nm). Near surface is small dense layer.

Wide application of Tencel includes interior and home ware, the fashion industry, and the predominantly denim market (Periyasamy et al., 2017; Periyasamy et al., 2019a). Lenzing, Austria established to become totally sustainable where its fiber manufactured from eucalyptus trees which requires only a fifth of the cotton land and a twentieth of the water, using natural irrigation (Periyasamy & Venkatesan, 2019;

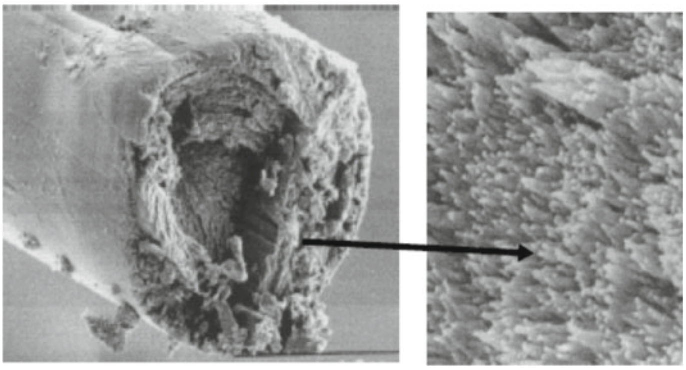


Fig. 4.24 Cross section of Lyocell fiber

Venkatesan & Periyasamy, 2019). Marginal land is sufficient for trees which does not require agriculture land, pesticides, or insecticides. Bleaching is not required for Tencel due to its white nature and consumes minimum dye to reach optimum color at lower temperature exemplarily supplanting cotton (Periyasamy & Militký, 2020b). Indigenous naturally pigmented cotton plants were developed by Sally Fox, USA, to produce Fox fiber. The company's developed success color range to include greens, browns, and beige but diminished its success due to prolonged years of researching to acquire optimum color. The importance was not appreciated due to its pioneering work at a time and in a culture.

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