CHAPTER 2
THEORETICAL CONSIDERATION AND LITERATURE REVIEWS

2.1 Elements in corundum

Corundum consists of a ratio of two atoms of aluminum and three atoms of oxygen. In its purest form, corundum is colorless. It is rare in nature. When corundums contain color-bearing elements, known as *chromophores*, some color is produced. Other non-color bearing elements may be found in corundum that have no influence on color.

2.1.1 Chromophoric elements

Most minerals are inherently colorless, with their colors resulting from minor impurities. These are termed *allochromatic* mineral, owing its color to one or more chromophoric transition metal elements that can absorb some visible light, causing distortion and producing electromagnetic energies. Some of these chromophoric elements may be present in corundum as impurities, replacing some aluminum atoms. The chromophoric ions may be present in the corundum substance in various valences and configurations : as single or multiple ions of the same atom, and/or in combination with other ions from other atoms, often in a multi-valent state, and where mixed valences occur, a great variety of colors are produced. The color on corundum is caused mainly by one or a combination of the following mechanisms.

2.1.1.1 Single metal ions.

These are individual chromophoric ions that are isolated/dispersed from other are types of atoms without any significant reaction with each other, and are called dispersed metal ions. Electrons of these ions may undergo transitions between atomic sub-energy levels in the single ion within the electronic cloud of the same atom. Therefore, certain single, dispersed metal ions in corundum are responsible for the coloration of rubies and some sapphires. For example, Cr^{+3} produces the red color in ruby; Fe^{+3}, as a single dispersed ion, may produce a yellow color in some sapphires.

2.1.1.2 Dual metal ion pairs.

This process refers to electron transitions simultaneously involving two single and isolated ions found in pairs. For example, they may almost produce a yellow color in sapphire.

2.1.1.3 Multiple metal ions.

When certain valence electrons of an atom are transferred to another atom, then charge transfer phenomena colors occur, resulting in color development. For example, when electrons are transferred from the ions of a metal atom (Fe^{+2}) to a different metal atom (Ti^{+4}), this may cause an Fe^{+2}- O - Ti^{+4} *intervalence charge transfer process*, producing the blue color in sapphire.⁽²⁾

2.1.2 Non-chromophoric elements

Non-chromophoric elements in the form of impurities are always represented in natural corundums. Their concentration may vary from a few parts per million to considerable amounts. These non-chromophoric impurities, usually, do not have any direct involvement in the coloration of ruby and sapphire. Sometimes it is present in corundum as mineral inclusions, which may greatly influence the coloration process in ruby and sapphire. Furthermore, non-chromophoric is termed *idochromatic* (self-colored) because the coloring agent is a basic component of its chemical composition.(3)

Table 2-1 Chromophoric impurities in corundum

Impurities	Valence atom	Coordination	Notes
Cr_2O_3	Cr^{+3}	Octahedral	In ruby/pink sapphires; partly in orange and yellow-orange sapphires, as a color modifier in purple/violet, blue, color change and other sapphires.
FeO	Fe^{+2}	Octahedral	Often in negligible or in minute amounts in ruby/pink sapphires.
Fe_2O_3	Fe^{+3}	Octahedral	Commonly found in rubies and sapphires. It consists of a multitude of iron impurites producing pale bluish to a brownish milky-white effect.
	Ti^{+2}	Octahedral	Often in rubies and sapphires. It consists of a multitude of needle-like crystals of TiO_2, these impurities often impart a so-called *silky* appearance.
Ti_2O_3	Ti^{+3}	Octahedral	It exists only in synthetic corundum.
V_2O_3	V^{+3}	Octahedral	Present as a chromophoric impurity in ruby and usually on color-change sapphires.
Mn_2O_3	Mn^{+3}	Octahedral	Present as a trace in some purplish/red rubies.

2.2 Cause of color in corundum

2.2.1 Introduction to color in corundum

The first examination of the mechanism of color is in corundum. White light, or sunlight, is composed of a balanced mixture of the spectral colors such as violet, blue, green, orange and red. It is certainly a perception based upon interaction between the light source, object and eye.

White and black are not colors in the scientific sense of the word. Instead, the sensation of white is created by relatively balanced amounts of all the wavelengths of colored light (400-700 nm.) striking the eye. An object appears colored because of selective absorption of visible light. Some colors (wavelengths) are absorbed, while transmitting or reflecting others. The actual color seen depends on the human eyes' interaction with the wavelengths which strike the eye and is the *complementary* color of the light absorbed. With this description the next part will examine the specific situations in corundum.(4)

2.2.2 Color distribution in corundum

The color of ruby and sapphire is a result of various chromophoric elements in the form of impurities present in the corundum substance in various amounts, ratio and configurations. These color-bearing impurities have been activated by the color perceived.

Rarely are the chromophoric impurities present in the corundum substance in perfect homogenously and dosology distributed throughout the substance to produce the beautiful colors of fine quality rubies and sapphires. An unbalanced configuration of the chromophoric elements results in less desirable coloration. For example, excessive amounts of iron or titanium in the blue sapphire produce a dark blue appearance. On the contrary, insufficient amounts of these chromophoric impurities produce light coloration. At other times, chromophores acting as color-modifiers may be present in the corundum, producing an indeterminate color appearance or indesirable overcastted secondary coloration (brownish, purplish, purplish/bluish), and occasionally, appear as color-patches.(5)

2.2.2.1 Cause of the color of ruby

The coloration of the ruby is due to trivalent chromium (Cr^{+3}) present in the alumina substance in isomorphous replacement as chromium oxide (Cr_2O_3) impurities.

In order for an atom to absorb visible light, its electron energy levels must correspond to the energy of visible light. With ruby, two absorption mechanisms occur when white light passes through it. One involves an electron transition from the ground state $^4A_2$ to the $^4T_2$ level, given in 2.2 electron volts radiation such absorbed that corresponding to yellow-green light. The second involves a transition to the $^4T_1$ level, absorbing 3.0 eV radiation, or violet light. These absorption areas are actually bands rather than narrow lines and overlap somewhat. As a result, there is only slight transmission in the blue, but strong transmission in the red, giving ruby its rich red color with slight purplish overtones.(6)

2.2.2.1.1 Characteristics by country of origin of ruby
(Quality ranking of rubies by country)

a) Myanmar : while Mogok is the traditional source of the world's finest rubies. Pigeon's blood was the term used to describe the finest Mogok stones, but it has little meaning today, as so few people have seen this pigeon's blood. Mogok-type ruby possess not just a red body color, but emits a strong fluorescence. This characteristic gives Mogok ruby a soft, slightly purplish hue not seen in stones from other sources. In addition, the best stones contain tiny amounts of light-scattering rutile silk. It is this combination of features which gives these rubies their incomparable crimson glow. In 1992, the Mong Hsu mine began producing good material, but most cut stones are under 2 cts.

b) Vietnam : Vietnamese rubies are striking in their similarity to those from Myanmar. Vietnam's ruby originates from two different mines (Luc Yen and Quy Chau), both sources display similar characteristics. Each source produces rubies with small blue patches and zones, similar to rubies from Jagdalek, Afghanistan. At Luc Yen rubies are found ranging from the lightest pink to a rich intense-red.

c) Sri Lanka : Some of the world's finest rubies have come from Sri Lanka's gem grovels. Most Sri Lanka rubies are often light in color such as pink or purple. Sri Lanka sapphires, color accumulates in large stones and so they can be quite magnificent in sizes of five carats of more. Due to the rough shape, many stones are cut with overly deep pavilions. This material is strongly fluorescent.

d) Africa, Kenya : In the year 1973, American geologists discovered ruby in Kenya's Tasvo West National Park. Although material clean enough to facet was rare, the color of the material was excellent. And today's rubies continue to produce good cabochon-grade material, with some faceted stones. Much of the material is brought to Bangkok for cutting and heat treatment.

Tanzania : Rubies of Tanzania occur in various colors including reds, oranges, yellows and mixtures of these colors. Mostly cabachon-grade material is produced here, including star material.

e) Afghanistan : There is a small deposit of rubies at Jagdalek, it has produced rubies which rank with the best of Mogok. Similar to Vietnamese rubies, many of these stones contain small areas of color. Strongly flurescent.

f) Thailand/Cambodia : The ruby deposits occur along the Thailand/Cambodia border in Chanthaburi and Trat province in Thailand, and neighbouring Battambang province in Cambodia. The rubies tend to be brownish-red or somewhat dark in color or lacking in transparency. In Thai rubies, only those facets where light is totally internally reflected will be a rich red. Thai stones are actually less purple than most Burmese rubies.(7)

2.2.2.1.2 Color modifiers of ruby

Various chromophhoric impurities may alter the overall appearance of the ruby. Certain amounts or traces of iron may produce brownish overcasted coloration, while concentrated amounts of iron impurities may form orange/brownish stains. When titanium and iron are present in ruby under certain circumstances, an overcasted bluish, violet/blue, or purplish coloration may by produced. Traces of multi-valence vanadium may modify the overall appearance, producing a purplish-violetish overcasted coloration. Certain non-chromophoric impurties present in corundum may influence its final color appearance when heated. For example, sfficient amounts of CaO in ruby may considerably alter their red/pink color, producing white stripes and increased opacity.(8)

2.2.2.2 Cause of color of blue sapphire

The blue of sapphire results from an entirely different mechanism than ruby *intervalence charge transfer*. Its mystery was not discovered until fairly recent times. Auguste Verneuil, father of the synthetic ruby, was the first to discover that titanium and iron were responsible for the blue color. By itself, a few hundredths of a percent of titanium in corundum produces no color, while the same amount of iron alone imparts only a pale yellow color. But if both are together, a rich blue results. Iron and titanium both subsititute for aluminum in the corundum structure. Iron resides either in a ferrous as Ti^{4+}. If both Fe^{2+} and Ti^{4+} lie in close proximity, a blue color results. When stimulated by light, a single electron hops from iron to the titanium ion. This is illustrated by the following equation.

$$Fe^{2+} + Ti^{4+} \rightarrow Fe^{3+} + Ti^{3+}$$

The intervalence charge transfer mechanism which produces a blue color in sapphire is far more efficient. Many sapphires possess the necessary iron and titanium for a deep blue color, but the iron is in the wrong state. Heat treatment under reducing conditions changes Fe^{3+} to the necessary Fe^{2+}. At the same time, heating may cause diffusion of titanium from rutile silk into the surrounding corundum. Now both the Fe^{2+} and Ti^{4+} needed are present. Thus, a pale and cloudy stone becomes clear, with a deep blue color.(9)

2.2.2.2.1 Characteristics by country of origin of blue sapphire (Quality ranking of blue sapphires by country)

a) Kashmir : In the world of blue sapphire, Kashmir is the peak. Kashmir sapphires are noted for their rich blue hue and distinctive “velvety” luster, caused by the presence of minute exsolved inclusions.

b) Myanmar : Myanmese stones are of a deeper, richer color, with there being simply more color inside those from Mogok. Moreover, the Mogok stones do not require heat treatment for their beauty, but come out of the ground in living color.

c) Sri Lanka : Blue sapphires from Sri Lanka have a unique beauty of color. Sri Lanka sapphires commonly reached the richer blues only in stones of ten carats or more. Today deep blues of all common. Sri Lanka is the world's most prolific producer of sapphire. Sri Lanka sapphire is typically a brighter, cornflower blue, due to less color in the stone.

d) Australia : Australia is one of the biggest producers of faceted sapphire, but most are dark and inky in color and require heat treatment. The mines of New South Wales produce the better stones, while the Queensland production consists mostly of darker blues.

e) Cambodia (Pailin) : The Pailin mine in Cambodia has produced a number of fine stones over the past 100 years, although today production is limited, due to political problems, Pailin stones, however, tend to be on the dark side and faceted stones larger than five carats are rare. Sapphires are generally dark blue.

f) Thailand : In Thailand, the occasional fine stone is produced, particularly from the mines of Bo ploi stones may be of a fine color, but sapphires from Chanthaburi province to be overly dark.(10)

2.2.2.2.2 Color modifiers of blue sapphire

Varying ratios of Cr^{3+} and/or Fr^{+3} acting as color modifiers may produce lilac/violet overcasted coloration. Certain amounts of Fe^{+3}, with Fe^{+2}/Ti^{+4}, produce blue/green, green/blue to green and similarly appearing colors.(11)

2.3 Color description of ruby and blue sapphire

2.3.1 Color description of ruby

For centuries, people described the color of the ruby in various ways. In Myanmar, the red color of the preferred rubies,called pigeon blood red, is described as resembling the color of the first few droplets of a freshly killed pigeon. Similar descriptions such as, rabbit-blood red, chicken-blood red, etc., are secondary preferred colors in Thailand, *ploy-daeng* (meaning red stone) describes rubies which have pure red hue with slight overcasted purplish or brownish coloration ; *lai-thai* (meaning design) refers to slightly yellowish red coloration charaterized by numerous fingerprint liquid inclusion. Appropriate designations are given to other corundum colors. The color of ruby is described on the basis of its overall appearance when positioned face-up. Ruby ranges in hue from reddish/orange to red to violet/red ; the saturation ranges from dull to vivid ; the tone very critical attribute-varies from very light to very dark. The phenomenon causes some fine quality rubies, noted from Burma, to show flurescence in the visible light, thus intensifying their already vibrant red coloration.

2.3.2 Color description of blue sapphire

Some external color descriptions and their corresponding localities for the blue sapphire are as follows: Blue with slight violetish (not inky) tinted coloration (Myanma, Thai); In Sri Lanka, fine blue sapphires characterized by slight violetish overcasted color is known as *rabuka*.(12)

2.4 Theoretical considerations

Evaluating the color of an object such as a faceted gem by visual means requies some appreciation of that it is actually in voloed in both observing and describing color.

2.4.1 Observing and comparing the color of an object

Whenever a person tries to establish the color of an object, or compare the colors of two objects side-by-side, several factors must be considered. Color science methodology indicates the following.

2.4.1.1One should use a consistent, standard source of light with known illumination characteristics.

2.4.1.2 The observation should take place in an appropriate surrounding environment that is neutral in its color appearance.

2.4.1.3 A rigorously defined geometry should be used between the light source, the object and the observer.

2.4.1.4 If the object of the color is to be compared to that of another object, the latter should ideally be a standard color reference material.

2.4.1.5 Observations must be made by a person with normal color vision. Because any of these factors can influence the visual perception of an object of the color, they all must be controlled if accurate and consistent results are to be obtained.(13)

The systematic observation of color in a faceted, transparent object also presents challenges in viewing geometry and color comparison that are not typically encountered in other fields of color science. When looking at a faceted gemstone, one sees a mosaic of color sensations, depending on the orientation of the stone and the relative positions of both the light source and the viewer's eyes. In addition the pattern and relative size of these sensations varies from one stone to another. Typical manufacture for brilliance and precise cutting all affect the patch of light through a stone and thus its color appearance. The size and cut also affect the total path length of light travel within the stone and the amount of light absorption. Likewise, both factors influence the overall distribution of color sensations seen by the eye. It is the need to determine from this mix of sensations, which color best represents that of the entire gemstone that most clearly distinguishes the evaluation of color, which prefer to present a more uniform color appearance. When observing the colors of several objects one at a time, it is natural to rely on color memory to help distinguish one from another. However, a person's visual color memory cannot provide the degree of repeatability that is necessary to describe color consistently. Therefore, color comparators that is, objects of established color in a chosen color system are used as standard references.

2.4.2 The Munsell Color system

Munsell divided three-dimensional color space into dimansions of hue, lightness, and chroma referred to as *Munsell hue, Munsell value, and Munsell chroma,*repectively.

In Figure 2-1(14), the lightness scale is represented by the Munsell value scale on the horizontal lines with black denoted by 0/ and white by 10/. There are grays placed uniformly in between.

The spacing of the hues around the gray scale axis is also intended to represent uniform differences in perceived hue between neighbouring hue pages. There are five principle hues, red (R), yellow (Y), green (G), blue (B), and purple (P). The intermediate hues are designated : yellow-red (YR), green-yellow (GY), blue-green (BG), purple-blue (PB), and red purple (RP). These are arranged in a circle. Finer divisions between 10R and 10YR are designated : 1YR, 2YR, ... , 9YR, and 10YR. Once again, finer divisions are represented by decimals: for example, a Munsell hue of 2.5YR is intended to be perceptually midway between samples having Munsell hues of 2YR and 3 YR ; as shown on Figure 2-2

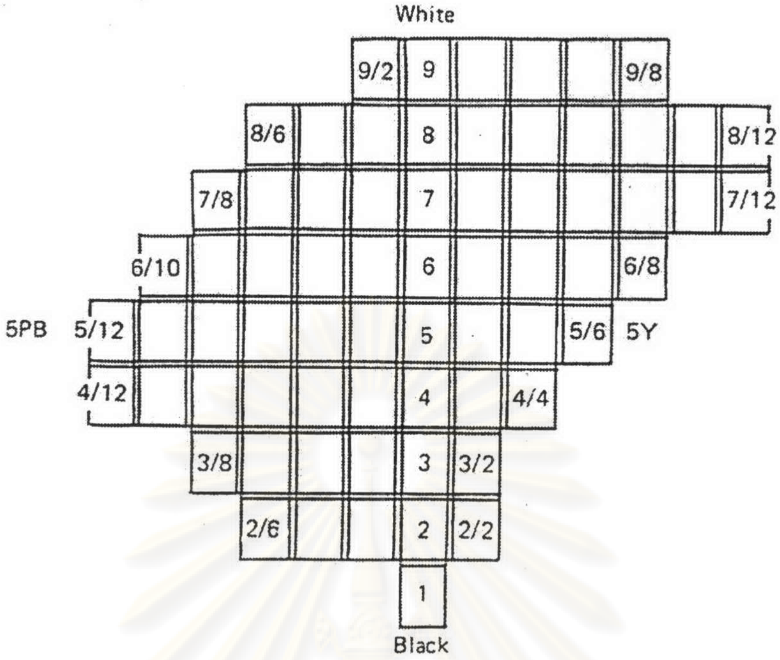

Figure 2-1 Arrangement of colors of constant Hue in the Munsell system one of the most widely used color order systems is the Munsell system; In part of investigation. It was determined that the opaque color chips provided as part of the Munsell system are best suited in this experiment.

The distances of the samples from the gray scale axis are intended to represent uniform differences in perceived chroma and are given numbers that are typically as small as 4 or less for weak colors and 10 or more for strong colors. Munsell chroma is indicated by an oblique line preceding the numerical value, for example, /8. In Figure 1-2 the dots represent samples having a Munsell chroma of /2, /4, /6, /8, and /10.(15)

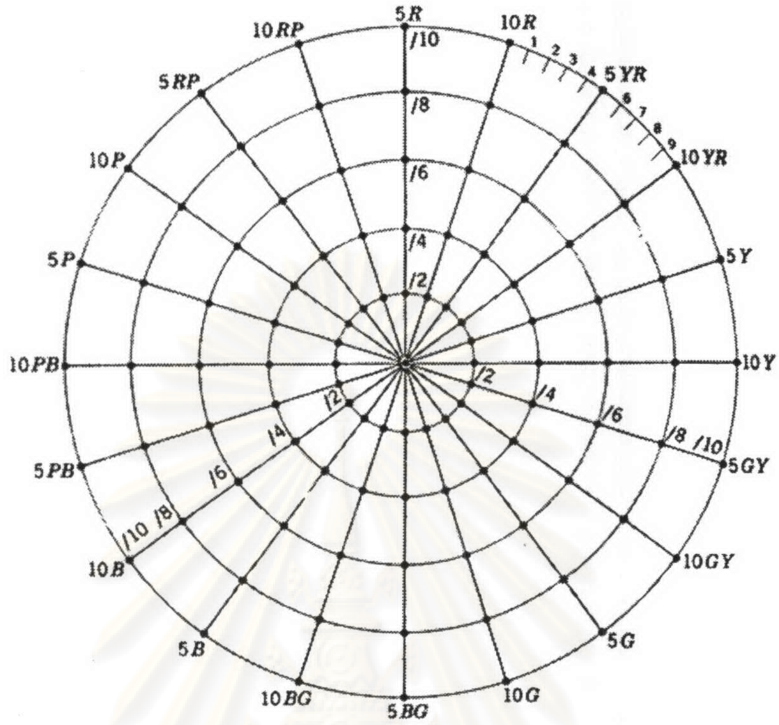

Figure 2-2 Arrangement of Hue circle in the Munsell system

2.4.3 The CIE Color Measurement system

2.4.3.1 The 1964 CIE Standard Observer

The CIE Standard Observer, the experiment leading to the 1931 CIE standard observer were performed using only the fovea, which covers only about a 2° angle of vision. The CIE removed the effects of rod intrusion, resulting in the 1964 CIE supplementary standard observer or the 10° observer. Its color-matching functions are notated. The corresponding tristimulus value Y_{10} does not directly represent a color's luminance. Its use is recommended whenever color-matching conditions exceed a 4° field of view.

2.4.3.2 Calculating tristimulus values for materials

It now describe how to calculate CIE tristimulus values from the spectral data of an object, a CIE standard illuminant and one of the CIE standard observers. The figures on this and the facing page illustrate the method. The color matching functions x, y, z of the 1931 CIE standard observer and x_{10}, y_{10}, z_{10} of the 1964 CIE supplementary standard observer are shown in Figure 2-3. These sets of tristimulus values of the spectrum colors.

The values of S, at each of many equally spaced wavelengths across the spectrum, are multiplied together with R and x, y or z to give products at each wavelength (SRx), (SRy) and (SRz). These are summed up (matchematically equivalent to finding the areas under the curves) to give the tristimulus values X, Y and Z.

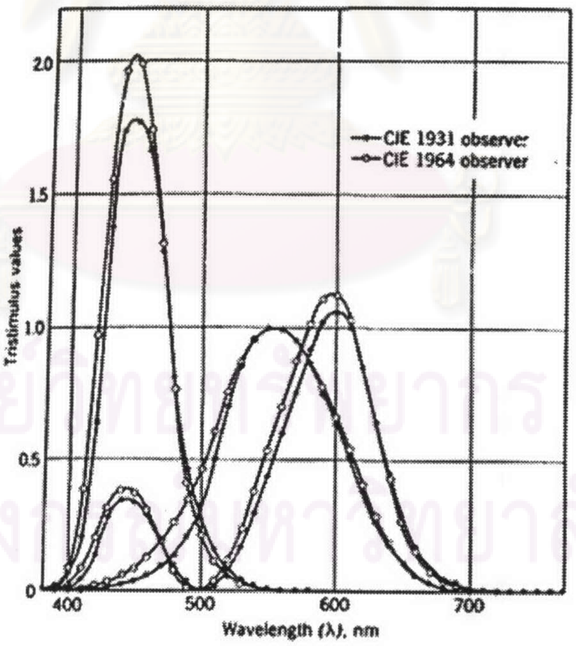

Figure 2-3 Comparison of the color – matching functions of the CIE 1931 standard colorimetric observer with those of the CIE 1964 supplementary standard colorimetric observer

Tristimulus Intergration for reflecting objects is shown here:

$$X = k\Sigma S_\lambda R_\lambda x_\lambda \Delta\lambda \quad (2\text{-}1)$$

$$Y = k\Sigma S_\lambda R_\lambda y_\lambda \Delta\lambda \quad (2\text{-}2)$$

$$Z = k\Sigma S_\lambda R_\lambda z_\lambda \Delta\lambda \quad (2\text{-}3)$$

$$k = 100/\Sigma S_\lambda y_\lambda \Delta\lambda \quad (2\text{-}4)$$

Where S is a CIE illuminant

R is the object's spectral reflectance factor

x_λ, y_λ, z_λ are the CIE standard observer color-matching functions

Σ_λ represents summation across wavelength

k is a normalizing constant

$\Delta\lambda$ is the measurement wavelength interval (for objects it is usually either 10 or 20nm)

These equations, in fact, are an approximation of the mathematical operation of integration.

2.4.3.3 Chromaticity coordinates and the chromaticity diagram

The chromaticity coordinates x, y and z are obtained by taking the ratios of the tristimulus values to their sum, X + Y + Z. Because the sum of the chromaticity coordinates is 1, chromaticities provide only two of the three coordinates needed to describe the color. One of the tristimulus values, usually Y must also be specified.

Color as described in the CIE system can be plotted on a chromaticity diagram, usually a plot of the chromaticity coordinates x and y. Perhaps the most familiar feature of the chromaticity diagram is the horseshoe-shaped spectrum locus.

$$x = X/(X + Y + Z) \qquad (2\text{-}5)$$

$$y = Y/(X + Y + Z) \qquad (2\text{-}6)$$

$$z = Z/(X + Y + Z) \qquad (2\text{-}7)$$

$$X = (x/y)\,Y \qquad (2\text{-}8)$$

$$Z = (z/y)\,Y \qquad (2\text{-}9)$$

By convention, lowercase letters are used to designate chromaticity coordinates (such as x, y) and capital letters are used to designate tristimulus values (such as X, Y, Z) except that the tristimulus values of the spectrum colors defining the standard are designated X, Y and Z.

2.4.3.4 Uniform chromaticity scale diagrams

In considering how to transform the CIE X, Y, Z space to improve its perceptual uniformity. It is enough that linear transformations preserve some important features of tristimulus values associated with additive color mixing, which are important for color imaging applications. *CIE 1976 uniform chromaticity scale diagram* or the *CIE 1976 UCS diagram,* commonly referred to as the u' v' diagram. It is obtained by plotting v' against u', where :

$$u' = \frac{4X}{X+15Y+3Z} = \frac{4x}{-2x+12y+3} \tag{2-10}$$

$$v' = \frac{9Y}{X+15Y+3Z} = \frac{9y}{-2x+12y+3} \tag{2-11}$$

To obtain x,y from u' v' the following equations can be used:

$$x = \frac{27u'}{18u'-48v'+36} = \frac{9u'}{6u'-16v'+12} \tag{2-12}$$

$$y = \frac{12v'}{18u'-48v'+36} = \frac{4v'}{6u'-16v'+12} \tag{2-13}$$

The u' v' diagram was recommended by the CIE in 1976; prior to that a similar diagram, the *u v diagram* was used in which *u=u' and v=2/3v'.* All chromaticity diagrms, whether x,y or u, v, have the property that additive mixtures of colors are represented by points lying on the straight line joining the points representing the constituent colors. The L or Y is the luminance. (16)

CIELAB is a rectangular coordinate system with axes of L*, a* and b*.

$$L^* = 116(Y/Yn)^{1/3} - 16 \qquad Y/Yn > 0.008856$$
$$a^* = 500[(X/Xn)^{1/3} - (Y/Yn)^{1/3}] \qquad X/Xn > 0.008856$$
$$b^* = 200[(Y/Yn)^{1/3} - (Z/Zn)^{1/3}] \qquad Z/Zn > 0.008856$$

Where ; Xn, Yn and Zn are the tristimulus values of the perfect reflecting siffuser

The experiment defines precision in a manner that relates to tolerances using on approximately uniform color-difference space as CIELAB. The standard deviation expands to three dimensions and when plotted, is equivalent to a CIELAB diagram.

2.4.4 Munsell Color solid

Munsell planned on sampling three-dimensional color space with a sphere. However, limiting the range of colors to a sphere wolud be misleading because for different pigments, different maximum chromas occur at different lightness. This led to the *Munsell color solid*, in which each hue was extened to its maximum chroma at each value

A subcommittee of the Optical Society of America performed further visual experiments totaling over three million observations using more sophisticated experimental techniques. The final specifications are colorimetric specifications. Because the specification is based on color matching rather than spectral properties, it is possible to produce the Munsell System using a variety of materials. However, the rules governing an exemplification must be followed. In particular, the equality of visual spacing is only expected to apply for specimens illuminated by daylight and viewed against a middle-gray background.(17)

As part of its 1976 recommendation, the CIE also defined cylindrical polar coordinates in both CIELAB and CIELUV as correlates of lightness, hue, and chroma. In addition, CIELUV has a correlate of saturation, but not CIELAB. The reason for this is that saturation, as defined by the CIE, is derived from a chromaticity diagram and thus is defined only for CIELUV. Finally, all of these color difference spaces used the Munsell system in either their development or as a data set when optimizing constant. However, the Munsell system is defined only for the 1931 standard observer and illuminant C. Hunter (1966) recognized this limitation and generalized his equations in an effort to accommodate any illuminant and observer combination.(18)

In Figure 2-5 the *u'*, *v'* chromaticties corresponding to Munsell Notation are shown for Munsell Value 5, at Munsell Hue intervals of 2.5 and at Munsell Chroma. Intervals of 2, only the colours plotting within the unbroken inrregular line inside the spectral locus are included in the *Munsell Book of Color* (matt version); those lying outside have been extrapolated and are not based on perceptual experiments on actual chips. If the spacing of the colours in the u' v' diagram were the same as that in the Munsell system at Munsell Value 5 and then in Figure 2-5 the Munsell Hues would lie on straight lines radiating from the illuminant point, separated by equal angles all round the hue circuit and the Munsell Chromas would lie on concentric circles, centred on the illuminant point and separated by equal distances, so as to form a grid of the same general shape as that of Figure 2-1.

It is clear from Figure 2-5 that there is a tendency for this to be the case representing single Munsell Hues lie on lines that are slightly curved, especially for some hues; the points representing single Munsell Chromas lie on roughly circular contours which are stretched in the yellow and blue directions and also for the higher Chromas, in the red direction.

The CIELUV system has a general similarity to the Munsell system because they were designed with this intention. However, it is known that the Munsell system is not perfectly uniform, so that Figure 2-5 can only be used with caution to estimate the uniformity of the CIELUV system.(19)

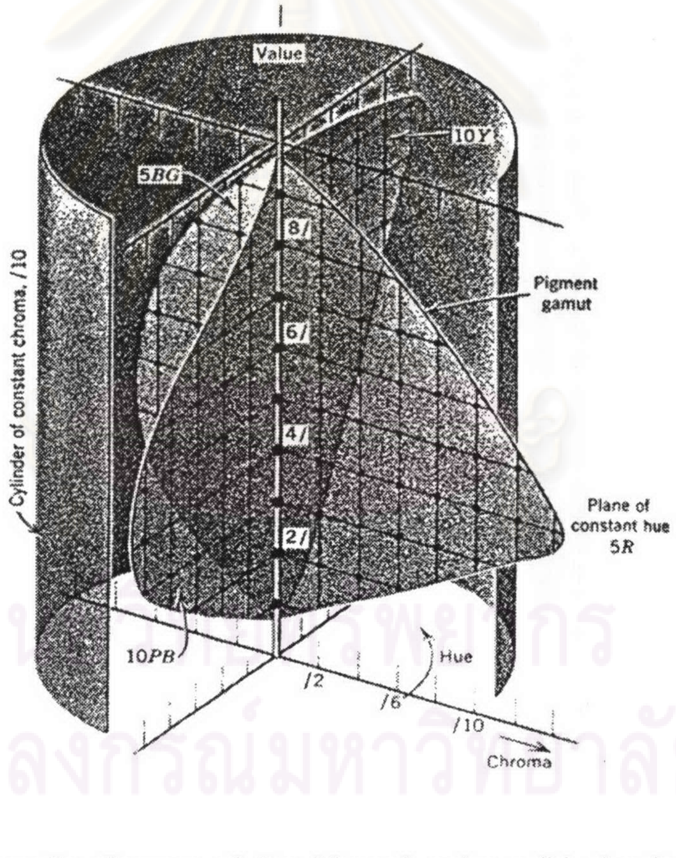

Figure 2-4 Schematic diagram of the Munsell color solid showing four planes of constant Munsell hue, a cylinder representing constant Munsell chroma and planes of constant Munsell value intersect the axis perpendicularly

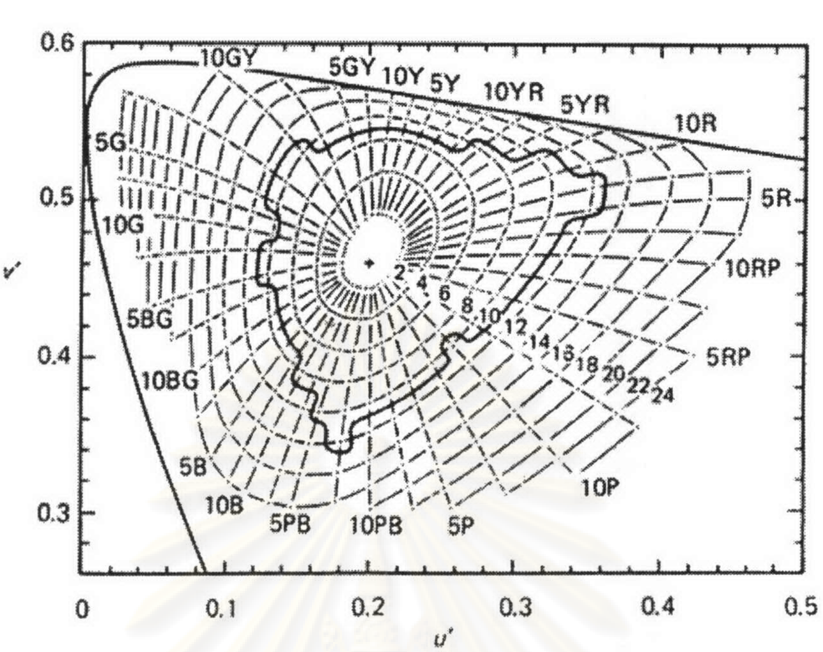

Figure 2-5 Chromaticities of colors of Munsell value 5 shown on the u' v' diagram, for Standard Illuminant C [shown as +]

2.5 Literature Reviews

A Gems Color Communication System $^{(20)}$ The objective of this research project is to construct a gem color communication system which color characteristics of gems in the form of numbers a*, b* measured through a spectrophotometer and U', V' converted from a*, b* can be correlated to the color systems giving the color characteristics of gems through the visual sensation. The conversion tables of x, y of each color chip of the Munsell System to a*, b* and to U', V' are obtained by using computer programming. The Munsell's color chips of the same value were systematically located in the U', V' diagram and also in the L* a* b* color chart according to their color coordinates. The conversion tables, the adapted U', V' diagram and the adapted L* a* b* charts can be used as communication tools which color characteristics of gems in form of numbers measured through a spectrophotometer can be correlated to the systems giving the color characteristics of gems through the visual sensation. The outcome of this research allows the manufacturers and distributors to add this gem color communication system into the certificate of guarantee issued by the jewelers for increased liability. In addition, the numerical color data can be used in inventory, customers' selling and purchasing, repairs, appraisals and for communication between jewelry traders or between retailers and customers, through information technology which will become an important medium of sales promotion and the world's gems market in the future. Moreover, researchers on gems heat treatment and radiation can use L* a* b* color chart for evaluation of their research works.

GIA (21) Colored stone grading system used as its color comparison standard an instrument called the Color Master. It produces up to one million different color images of gems with a set of built in filters that generate calibrated mixtures of red, green and blue light. The Color Master which the GIA introduced sets of colored plastic stones as color reference points for their gems.

Gem Dialogue (22) The GemDialogue system colors are offered as a master set of colors into which virtually any gem can fit. It has a color chart manual containing 21 loose-leaf color charts on transparent acetate, each showing ten different saturation levels for each color. This makes if easy to compare the strong and weak colors which show up in a stone at the same time. If a stone is cut shallow, the strongest color will be on the same chart in such cases. The degree to which colors are masked by brown or gray is determined by placing acetate overlays on the color charts. One of the overlays ranges from black to gray and the other one from brown to light brown. In all, the system gives you over 60,000 reference points in a very portable 4" x 8 ½ " manual. Also included are an instruction manual which explains the system in plain language and a grading and pricing manual which explains the pricing patterns of colored stones. The GemDialogue system is easy to learn and convenient to use when shopping for gems.

Gemstones Quality and Value (23) The value of a gemstone is established by the rate of occurrence for its quality level and by demand. Strictly speaking, each gemstone has a different quality, so it follows that each gem would have a different value. In this book, gemstones are arranged in Quality Scales by their species, source and consideration of treatments and quality and value are judged by grouping them into three zones the especially beautiful and rare stones that are commonly used in jewelry; and *accessory-quality* stones that lack beauty but can be used in accessories. Because refractive index and hardness differ between the various gemstones and each species has its characteristic beauty, the arrangement of the three zones will vary. It goes without saying that gem and jewelry-quality gemstones cannot contain imperfections that threaten durability and that the stones must be of appropriate size. Furthermore, when using the quality zones as a reference for value judgement, one must fully understand that the three zones may vary according to regional differences in perception of beauty and preference in tone, that their positions move over time and that there are different optimal tone levels depending on the size of the stone. The relative quantities of gem quality, jewelry quality and accessory quality produced for each gemstone have seen arranged in a chart. (In principle, these represent the number of stones in each zone as a percentage of the total number of stones polished to a size of approximately three carats.) In terms of total numbers produced, accessory quality is by far the highest, but in terms of value, gem quality and jewelry quality represent a larger amount. Supply and demand determines whether or not low-quality rough is polished and actual quantities produced will vary. The percentage shown is best viewed as a rough rough estimate.

AGL (Color/Scan)(24) The AGL color grading system used a set of color-comparison cards. (Color/Scan) each of which has six oval holes. The holes are filled with layers of colored filters and a patterned foil that simulates the three-dimensional appearance of a gemstone color. The Color/Scan allows the user to view several samples simultaneously, like a set of diamond-color master stones. This ability enables the eye to utilize one of its most important features to compare rather than remember color. The Color/Scan grading system is easy to use when shopping for gems and is explained in *The Color/Scan Training Manual*. Unlike the other two systems, AGL's is being used on an internationally-recognized colored-stone grading document the AGL colored stone certificate. Besides being an impartial report about gem quality and identity, this certificate helps Color/Scan users verify if they are grading stones according to AGL standards.