The quantitative measurement of colour in minerals

Htein, Win

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Thesis of Win Htein

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278		Antimony	76
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283		Arsenopyrite	52
280		Bismuth	62
289		Bismuthinite	50
83		Bixbyite	22
71	82	Bornite	18-24
181	182	Boulangerite	41
295		Bournonite	35
273		Braunite	21
286		Breithauptite	50
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306		Cassiterite	12
28		Cattierite	34
296		Chalcocite	33
268		Chalcophanite	27
164	178	Chalcopyrite	47
122	139	Chromite	13
298	299	Cinnabar	29
141		Clausthalite	50
19		Cobaltite	50
[illegible]	153	Coloradoite	34-38
[illegible]	41	Colusite	30
[illegible]		Copper	53
[illegible]		Coronadite	32
[illegible]	308	Covellite	0-7, E-22
[illegible]		Crednerite	34
[illegible]		Cryptomelane	26
278		Dyscrasite	64
246	257	Enargite	29
[illegible]97		Eskebornite	35
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270	272	Gallite	22
306		Geikielite	14
179	180	Geochronite	41
65	70	Germanite	22
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3		Gold	57
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THE QUANTITATIVE MEASUREMENT
OF COLOUR IN MINERALS

A THESIS SUBMITTED FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY IN THE
UNIVERSITY OF DURHAM

by

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ABSTRACT

The present study has been directed towards investigating quantitative measurements of colours in minerals, which might serve as a readily accessible means of identification and understanding related properties.

A review of the concepts of colour measurement is described in the first part of the thesis. Attention has been paid to the improvement and application of methods of colour measurement in mineralogy and gemmology. Computational procedures and all the necessary computer programmes for calculating colour values are given with examples. For this purpose appropriate measurements of spectral reflectivity for opaque minerals, and spectral transmittance for non-opaque minerals and facetted gemstones are described.

Quantitative measurements of other colour properties - colour constancy, bireflectance and reflection pleochroism - are described and defined. A study of some colour problems in ore minerals is made. Tables of colour values and spectral reflectivity data for 130 ore minerals are given, and these values are also presented in colour diagrams. The uses of quantitative colour values and colour diagrams are explained with examples.

ACKNOWLEDGEMENT

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Finally the writer is indebted to the individuals and institutions, listed in References, for permission to redraw diagrams or copy tables and photos from the sources noted.

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APPENDICES

X. Tables of Quantitative Colour Values & Spectral Reflectivity Data of some Ore Minerals

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Anistropic Minerals

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I. INTRODUCTION

The colour of a mineral is one of the simplest qualitative properties that can be used as an aid to distinguishing it from other minerals, even though the same mineral may show different colours and different minerals may have the same colour.

The quantitative measurement of colour involves several theoretical and practical difficulties. Other physical properties that can be measured more easily have therefore been used for mineral identification and it is only relatively recently that an interest in the quantitative measurement of colour in mineralogy has developed.

One branch of mineralogy in which colour is of prime importance is gemmology, where small colour differences may greatly affect the relative value of two otherwise identical specimens. Once a gemstone has been facetted, transmitted light methods of determining its spectral transmission are difficult or impossible to apply, so it was decided that an investigation of the use of reflected light methods would be made.

At the same time, the application of similar methods to the measurement of colour in opaque minerals was also investigated, since it promised to be a useful additional method for the identification of these minerals.

It was found that the use of reflected light method in non-opaque minerals including gemstones was unfavourable for purposes of quantitative colour measurement.

After a theoretical study therefore, an alternative method was developed using a matching liquid to determine the spectral transmission of a facetted gemstone for colour compatison.

Finally, it was also decided to investigate some colour problems in minerals, such as changes in the observed colour of a mineral that occur as its grain size is reduced.

II. LITERATURE REVIEW ON THEORY OF COLOUR MEASUREMENT

II.1. INTRODUCTION

The art of coloring started many thousands of years ago, but the science of colour began in the last centuries. It was founded by Isaac Newton (1866) hwo separated the components of homogeneous white light (the sun light) into a sequence of coloured rays. In recent years modern methods of colour measurement have been developed. Concepts , methods and quantitative data have become standardized and used by colorimetrists and research workers.

Despite the fact that colour is an important physical property made use of in mineralogy, and particularly in gemmology, in various ways (e.g. specimen colour, colours seen under the microscope in polarised light, etc.), there has been comparatively little use or understanding of the concepts of quantitative colour measurement.

A summary of the necessary basic information has therefore been prepared from the literature, which is abundant. Further details if required may be found in the following useful books, and periodical papers listed in the reference section.

(1) 'The Science of Color'	by the Committee on Colorimetry of the Optical Society of America,1968.
(2) ' Color Science '	by Gunter Wyszecki and W.S.Stiles, 1967.
(3) 'The Measurement of Colour'	by W.D.Wright, 1969.
(4) ' Physical Aspects of Colour'	by Dr. P.J.Bouma, 1947.

(5) 'Color in Business, Science and Industry' by D.B. Judd & G. Wyszecki, 1963.

(6) 'Sources of Color Science' selected and edited by D.L. MacAdam, 1970.

In 1931 the Commission Internationale de l'Eclairage (C.I.E.) first adopted a set of data to define the colour- matching characteristics of standard observers (that is of the average eye) and established a reference framework for the specifications of colours . Armed with this reference framework, specifications of various standard stimuli (light sources) and a standard chromaticity diagram were derived.

Any colour is then determined with reference to a standard stimulus or standard stimuli and expressed by three numbers termed tristimulus values. It can also be represented in the standard C.I.E. chromaticity diagram and characterised by numbers, namely dominant (or complementary) wavelength, excitation purity and relative brightness.

Since basic data representing the normal eye as standardised by the C.I.E. colour specifications are independent of the colour vision of any particular individual, they are reproducible from one laboratory to another.

II.2. PSYCHOPHYSICAL CONCEPTS OF COLOUR

Man has been aware of colour since immemorial time . Aristotle first realized that light is necessary for colour vision. It is now well known that colours are seen because of light. The phenomena of light have been explained by wave (Maxwell's electromagnetic) and quantum theories. Both theories have been accepted, as light has a dual nature, possessing both wave and corpuscular properties.

As far as the measurement of colour is concerned the concepts of light and colour need to be defined by the procedures which are precribed for their measurements.

The measurement of colour is not a purely physical practice. Physiology and in some cases (such as sensation, perception, recall , recognition, imagination, motivation, feeling, emotion, reasoning,etc.) psychology are involved in the measurement, since colour - matching experiments to obtain basic data were made by human observers.

When a beam of light strikes the retina of the eye the colour sensation is interpreted by the mind. Colour sensation which may be defined as the primary conscious response to excitation of the visual mechanism has three attributes, hue , saturation and brightness as interpreted by the eye and mind. Sensation is specifically the direct result of consciousness of the present stimulation of the sense organs, as distinguished from perception, which includes the combination of different sensations and utilization of past experience in recognizing the objects and facts from which the present stimulation arises.

Objects are very commonly recognized and classified according to the colour of the light they reflect. The colour of an object depends upon the effect of its selective absorption, upon the spectral distribution of the incident radiant energy and upon the psychophysical functions of human vision.

It is obvious that subjects of light and colour are linked to the sciences of physics, chemistry, physiology, and in some cases psychology. Light and colour, therefore, are defined as psychophysical concepts.

II 3. ATTRIBUTES OF COLOUR

Light is characterised by its frequency, velocity and wavelength. Since the velocity is constant in a given medium, the frequency and wavelength are inversely proportional. However, wavelength is usually quoted in preference to frequency, as the numbers required are smaller. Table II 1 shows the colour names given to light of certain wavelength ranges in approximate divisions.

Table II 1

Wavelength (nm)	Colour name
380 - 450	Violet
450 - 490	Blue
490 - 560	Green
560 - 590	Yellow
590 - 630	Orange
630 - 780	Red

There is, of course, a continuous series of pure colours gradually passing from the one into the others. They are known as hues and illustrated, for example, in Plate 1.

Each hue (spectrum colour) has several different colours (having the same brightness) when it becomes progressively paler till it approachswhite. The progression from a spectrum colour (retaining its hue throughout towards white is said to be one of desaturation. The aspect in which the individual members of such series differ, namely the property of being more or less white, we call their saturations. Plate 2 shows a green hue giving a gradual change of saturation. The saturation increases progressively from zero in the case of white sample (achromatic) to a maximum in the case of a highly saturated colour sample (chromatic).

A colour retaining its two properties, hue and saturation, will give rise to a slightly different sensation of colour when its brightness level is changed. In other words if two samples have the same hue and saturation but differ in brightness they will appear to be different colours.

Thus the colour sensation has three attributes, namely hue,saturation and brightness. Expressed differently, therefore, a colour sensation is completely determined by these three magnitudes .

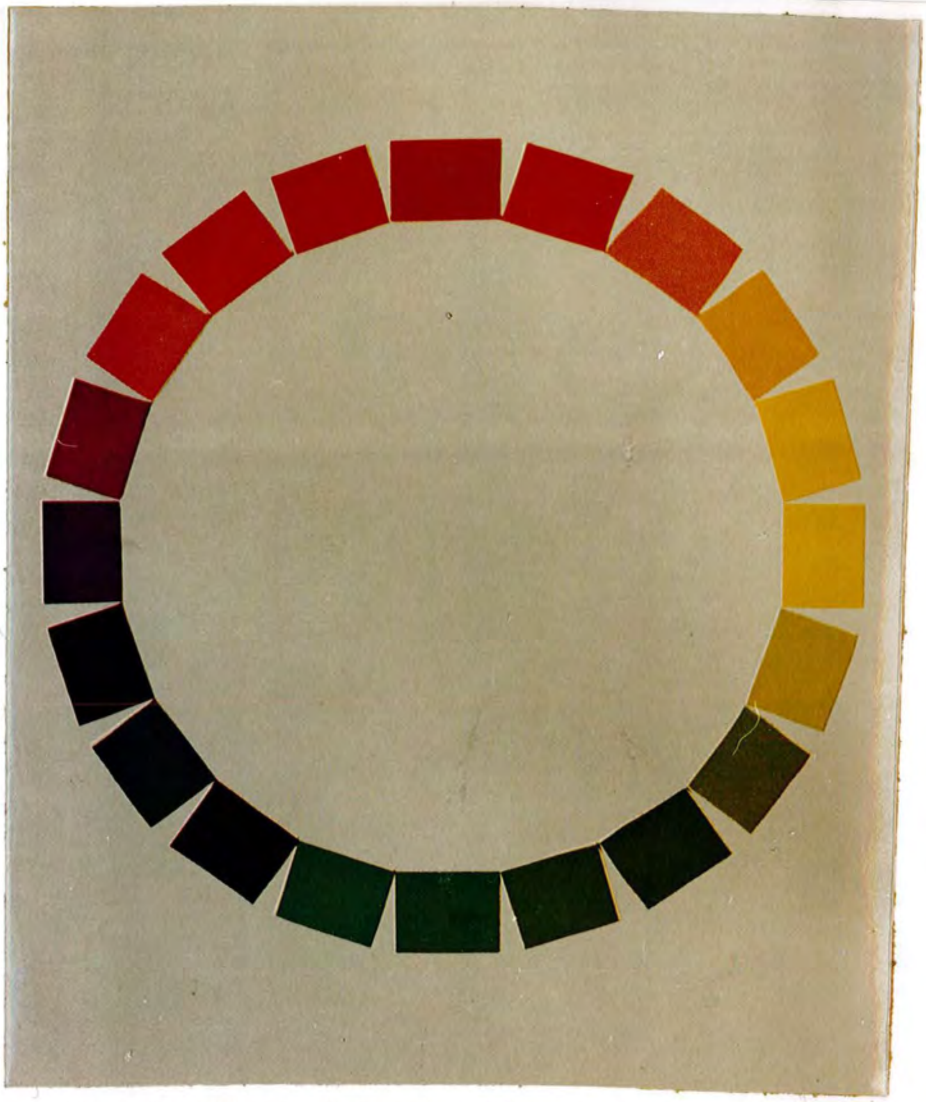

Plate 1 a. Hue circuit of high saturation, brightness varying to give the highest saturation of each hue.
(from Plate 19 in the 'Science of Color' published by the Committee on Colorimetry Optical Society of America, 1968)

Plate 1 b. Red-to-Yellow series giving approximately equal subjective intervals of hue.
(from Plate 8 facing Page 102 in the 'Measurement of Colour' by W.D.Wright, 1969)

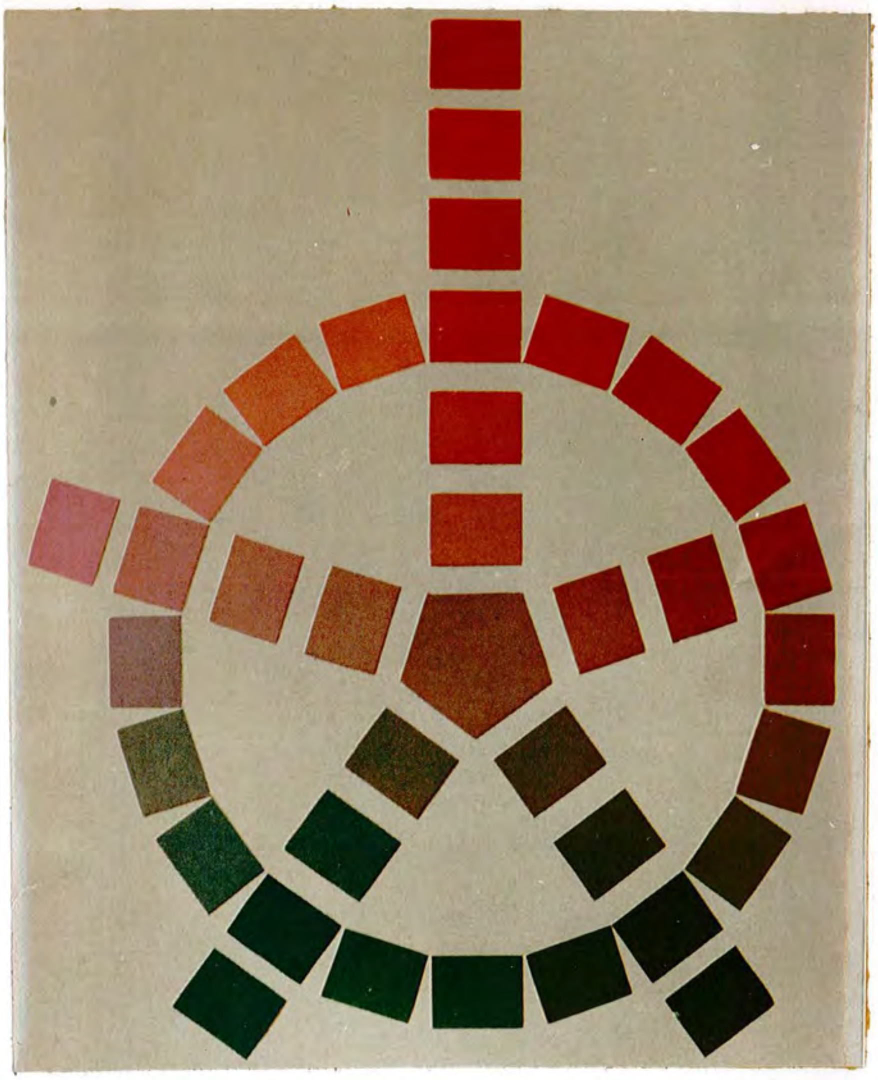

Plate 2 a. Polar arrangement of various saturations of several hues, all having the same brightness.
(from Plate 18 in the 'Science of Color' published by the Committee on Colorimetry Optical Society of America, 1968)

Plate 2b. Grey-to-Green series giving approximately equal subjective intervals of saturation.
(from Plate 8 facing Page 102 in the 'Measurement of Colour by W.D.Wright, 1969)

II.4. THE SENSITIVITY OF THE EYE

Relative Luminous Efficiency Functions

The most important natural light source is the sun. Many spectroradiometric measurements of the spectral energy distributions of the sun have been made and reported in the literature (Abbot et al 1923; Kimball 1928; Moon 1940; Taylor and Kerr 1941; MacAdam 1958 ; Henderson and Hodgkiss 1963; and Budde 1963). The significant spectral distribution data taken from Wyszecki and Stiles (1967) are shown in Figures II.1 and II.2.

Figure II.2 contains relative spectral irradiance distributions of daylight at correlated colour temperatures 5500, 6500 and 7500°K. They are considered as the most typical spectral distributions of irradiance produced by daylight at the earth's surface and are recommanded as guides in the development of sources of artificial daylight.

The above data show that the spectrum of the sun radiates approximately equal amounts of energy per unit wavelength interval throughout the visible range. But these equal amounts of energy of different wavelengths do not produce visible sensation having equal brightnesses. In other words the brightness sensitivity of the eye is not equal for all wavelengths of the visible spectrum. The sensitivity of the eye to radiant energy depends upon the wavelength.

The conversion of light energy into nervous energy takes place in the light-sensitive retina of the eye. The retina contains two kinds of light sensitive elements, rods and cones. Rods are receptors which function in the low level of illumination (scotopic vision) , whereas cones operate at high illumination levels (photopic vision). The luminance level of the normal photopic range is from about one to fifteen foot-lamberts* (Brown, 1951).

Important investigations of the spectral sensitivity of the eye were made by Gibson and Tyndall (1923), Crawford (1949), Judd and Wyszecki (1963), Wright (1946) and others. In such investigations spectral sensitivity was recorded subjectively by finding the energy required at each wavelength in the visible spectrum to produce a response of constant brightness; for cones, the observations were made under photopic conditions or by using the foveal area of the retina, while the rod sensitivity was obtained at near-threshold illumination using the extra-fovea (Wright, 1969). The sensitivity curve was then given by plotting the inverse of the energy obtained against wavelength.

Since only the relative sensitivity to the various wavelengths was of interest, all values were multiplied by a constant so that the maxima were equal to unity. These values thus obtained are termed the relative luminous efficiency functions.

Figure II.3 shows scotopic (V'_λ) and photopic (V_λ) curves as standardised in 1951 and 1924 respectively by the C.I.E. The rods have their maximum sensitivity at a wavelength of 507 nm and the cones at one of about 555 nm . The curves as a whole have been shifted with respect to each other.

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* 1 foot-lambert = 0.0003426 candle per square centimeter(CCOSA 1968).

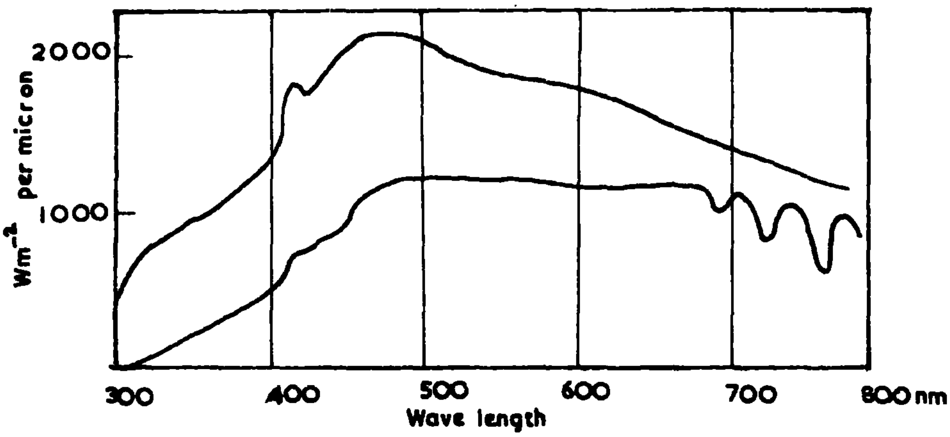

Figure II 1. Spectral distributions of irradiance of direct sunlight in absolute units (Wm^{-2} μ^{-1}).
upper curve: above atmosphere,
lower curve: at sea level. (from Moon, 1940)

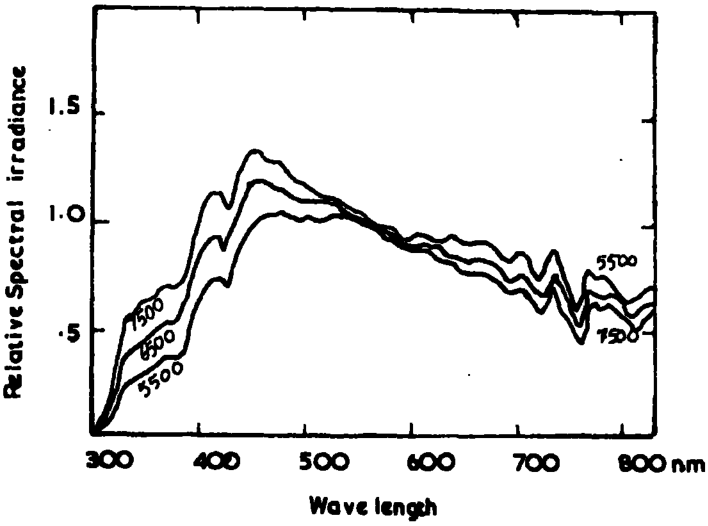

Figure II 2. Relative spectral distributions of irradiance of three phases of daylight, of correlated colour temperatures, 5500, 6500, 7500° k.
(From Judd, Wyszecki and MacAdam, 1964)

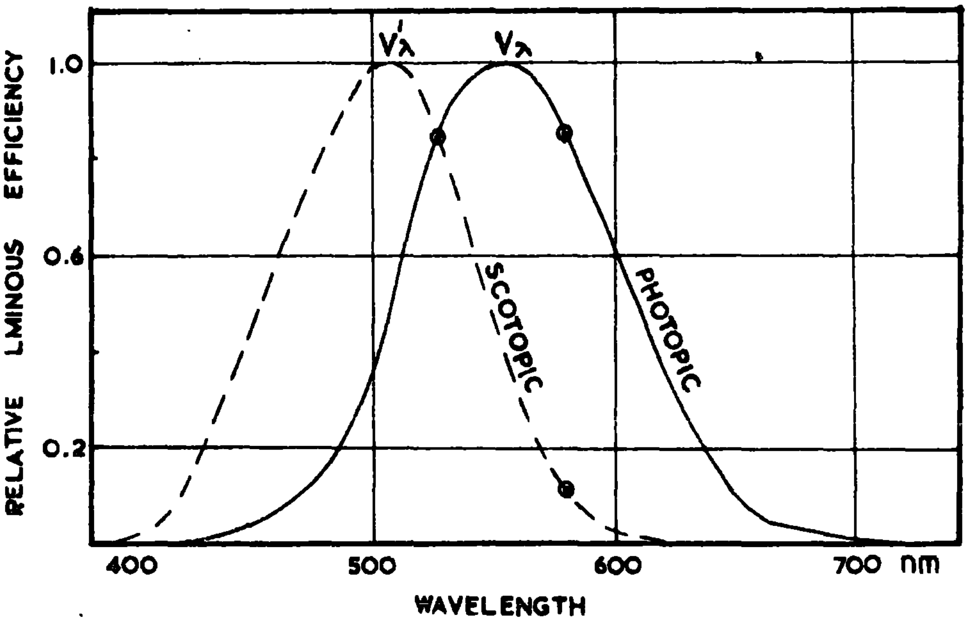

Figure II 3. Standard relative luminous efficiency functions for photopic (Vλ) and scotopic (V'λ) vision, (from Wyszecki and Stiles, 1967) and also showing the Perkinje effect.

A considerable difference between the two functions is that the relative brightness in different coloured objects alters when the quantity of light is greatly reduced. If one half of the field of vision, for instance, is strongly illuminated with yellow light of 581 nm and the other half with green light of 530 nm the eye sensitivity for these two wavelengths is equal. When the illumination levels are reduced by the same factor, the powers of the two halves have indeed remained equal but the eye sensitivity has become quite different for the two lights.

With these equal powers the green light has a much stronger apparent brightness than the yellow light (Figure II.3). This is known as the Purkinje effect. Expressed differently, in order to obtain the same apparent brightness we shall have to transmit much more energy per second of violet or red light to the eye than the green light.

It became necessary to select one of the relative efficiency functions to be used to obtain standard data specifying visual sensitivity for colour differences. When colours are observed at low luminance levels such as under twilight conditions or in areas of high density in colour transparencies, the scotopic function (V'_λ) would be useful to obtain data.

Normally, colour differences are observed under high illumination levels (i.e., higher than one foot-lambert) and therefore the photopic (V_λ) function was selected by the C.I.E. and used to derive the basic colour-matching functions for general purposes of colour measurements.

It was later verified from the experimental data by Brown (1951) that sensitivity to colour differences remains constant for a normal observer until the field luminance drops below about one foot-lambert. Below this level the colour discrimination becomes poorer , slowly at first, and then rapidly.

Sensitivity To Differences Of Hue And Saturation

In the same way that the sensitivity of the eye to small differences of brightness varies, so there are sensitivities to small differences of hue (wavelength) and saturation (purity).

Hue discrimination was measured by setting just-noticeable differences of wavelengths. Starting with the two halves of the photometric field illuminated by light of the same wavelength λ and luminance (brightness), the wavelength of one half of the field was then gradually changed to $\lambda \pm d\lambda$, at the same time maintaining the brightness match between the two halves, until a just-noticeable chromaticness* difference was detected (Wright and Pitt, 1934; Bedford and Wyszecki, 1958). The average difference $d\lambda = \left[(+d\lambda) + (-d\lambda)\right]/2$ was obtained from several repeated measurements for each comparison wavelength and plotted against λ .

All curves have the same general appearance as shown in Figure II.4. It is regarded only as typical , since the differences between individuals are fairly large.

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* Chromaticness = hue and saturation, taken together, expressive of the quality of colour sensation as distinguished from its intensity (CCOSA 1968).

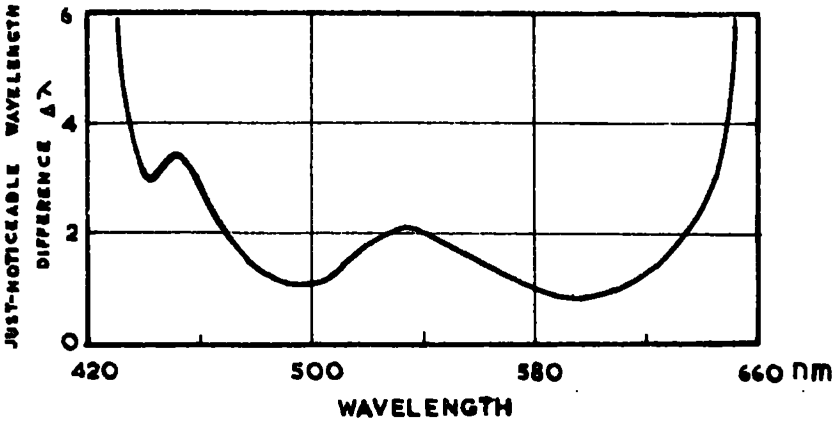


Figure II 4. Typical wavelength discrimination for a normal observer using a 2°field of view. (Wright and Pitt, 1934)

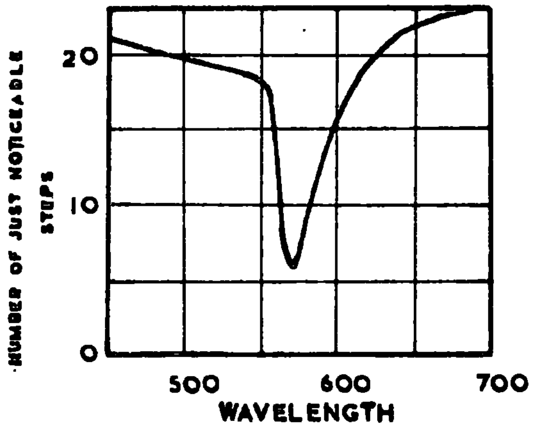


Figure II 5. Average purity discrimination as a function of wavelength (Martin et al, 1933,and Jones and Lowry, 1926)

Figure II.4 shows that the difference of wavelength which can just be detected by the normal eye varies irregularly from end of the spectrum to the other. A wavelength difference of about 1 nm will give rise to a just-noticeable chromaticness difference in the yellow-orange (590 nm) part of the spectrum and again in the blue-green(490 nm) under a 2-degrees field of observation. Under large field conditions small differences of wavelength might be detectable in these regions of the spectrum (Wright, 1969). Hue discrimination rapidly becomes poor at both ends of the visible spectrum.

The sensitivity of the eye to differences of saturation is expressed by the number of just-noticeably different mixtures of white with light of any given wavelength. In the experiments additive mixtures of a monochromatic light of a given wavelength and a given achromatic (white) light were produced in two halves of a photometric field. The luminance of the both lights can be varied independently, thus providing a series of colours ranging from a pure white to a spectrum colour.

The observer was required to determine just-noticeable differences or equally differences of saturation by changing the colour of one half of the photometric field (Martin et al , 1933).

An alternative method was to make repeated colour matches and deduce the just-noticeable difference from the standard deviation of the matches (MacAdam , 1942).

In both cases it was found that the sensitivity to saturation was least (i.e. the number of steps between white and the spectral radiation was least) for wavelength in the yellow part (570 nm) of the spectrum, as shown in Figure II.5 (taken from Wyszecki and Stiles, 1967). This implies that a monochromatic light of wavelength 570 nm is in some sense less saturated than light of any other wavelength.

In conclusion, the photopic luminous efficiency functions V λ play an important part in the derivation of colour-matching functions. The sensitivity of the eye to small differences of hue (wavelength) and saturation (purity) are of special interest and are major problems in measurements of colour discrimination, and are described in the later sections.

II.5. SPECTRAL ENERGY DISTRIBUTION AND COLOUR SENSATION

Experiments on radiant energy distribution of light sources showed that there is a relation between spectral composition of light and colour sensation. A white light sources, such as the sun, radiates more or less equal energy throughout the visible spectrum . In other words when the integrated white light is dispersed into distinguishable components an equal distribution of energy over the spectrum will result. If its spectral energies were plotted against wavelength a flat curve will be obtained. There is no region in which the energy is greater over other regions of the spectrum.

When the energy distribution at some wavelengths is lower the light in general appears coloured . A yellow stimulus of a source, for instance, is due to a high energy distribution at long wavelengths and low energy distribution in the shorter wavelength regions.

The spectral energy distribution ($P\lambda$) is a purely numerical series as a function of wavelength. Wavelength and intensity of light are characteristics of the appropriate colour response. This is known as the colour stimulus (Q).

For object colours the same principle applies, because they act as secondary light sources. When radiant energy falls onto a surface of an object the spectral energy distribution ($P\lambda$) of the incident light is altered after reflection by the surface of the object. The spectral energy distribution, the resultant of the combined action of the incident light (P_λ) and reflection power (R_λ) of the object is equal to the colour stimulus of that object. that is,

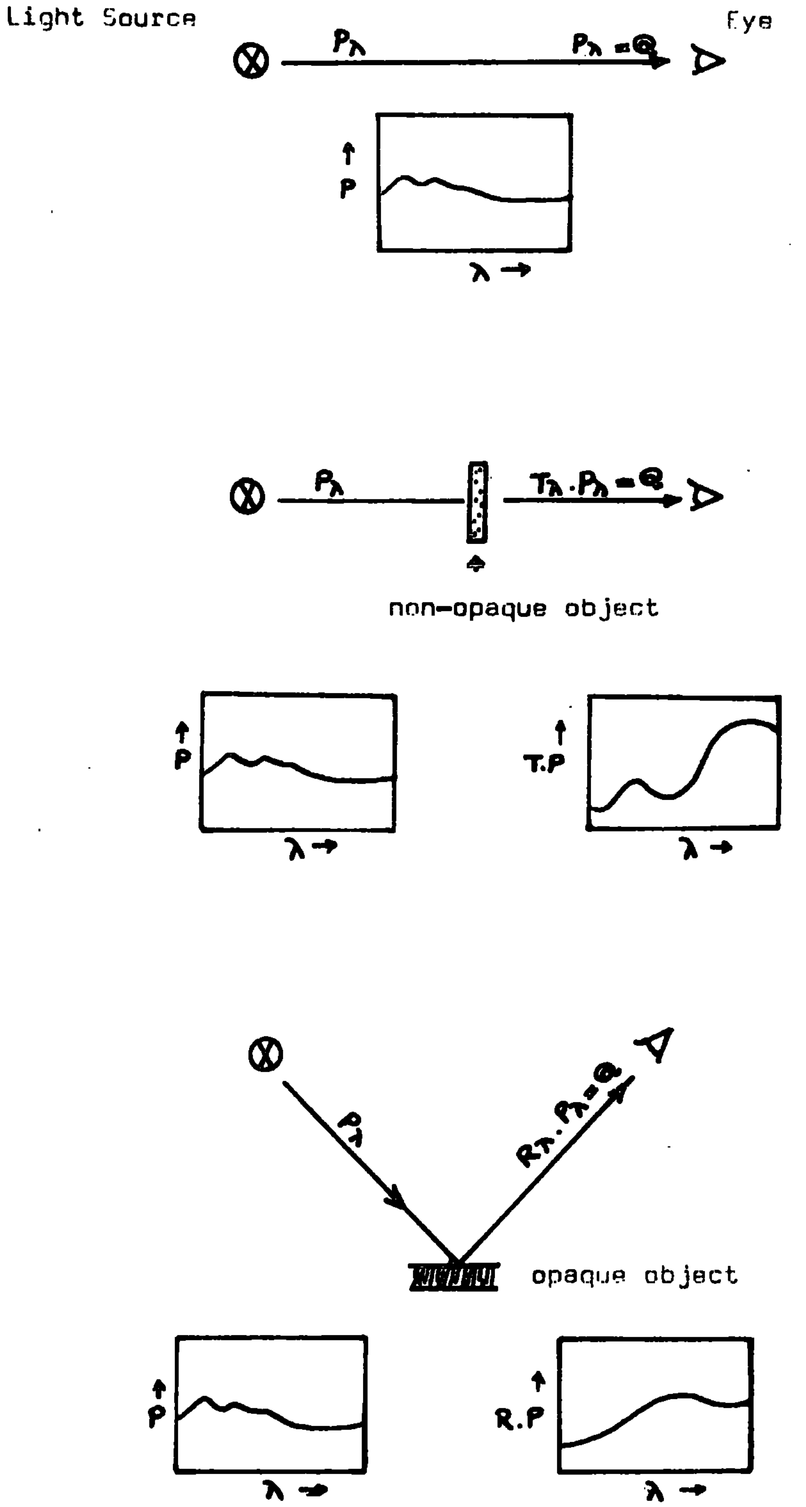
$$P_\lambda \cdot R_\lambda = Q.$$

This interrelations are the fundamental facts to define object colours and are illustrated in Figure II.6. Light sources in general having different energy distributions cause different colour response. It appears that different colour stimuli from an object caused by different light sources can be measured using the above general expression.

It can be assumed that the retina (cone) possesses three dufferent types of light sensitive photo cells which are distinguished from one another by their spectral sensitivities. It can also be assumed that the first cell has its maximum sensitivity in the red part of the spectrum, the second in the green and the third in the blue. When a light beam stimulates the eye the three photo cells operate together simultaneously and form three magnitudes by which a colour sensation is determined.

The above assumption makes quantitative colour measurement possible by means of a photo-electric device functioning exactly the same as those of the retina. With such apparatus measurements of spectral reflectivity (or transmittance) on an object surface can be made and followed by appropriate calculation to derive the three magnitudes which will represent the attributes of colour sensation.

Figure II 6. Relation between spectral distribution and colour sensation.



II.6. PRINCIPLES OF COLOUR MEASUREMENT

By experiments it was found that any colour could be produced by varying appropriate amounts of three suitable radiations (colours). The fundamental principles of colour measurement were first postulated by Grassmann (1854) and were familiar to Maxwell (1860 & 1872), Helmholtz (1866) and others.

Experimental checks were carried out later by Blottian (1947), Trezona (1954) and recently by Stiles (1963). Two significant investigations were made by Guild (1924 & 1931) and Wright (1928–1929) to determine the relative amounts of three specified radiations required to match the colours in the spectrum.

Their colour mixture data were used in 1931 by the Commission Internationale de l'Eclairage (C.I.E.) to standardize the colour-matching functions of a normal observer and to adopt a standard framework for colour specification.

One of the basic laws of colour theory would be expressed thus: By mixing three selected spectral colours in definite proportions any given colour sensation can be matched.

Grassmann's first law states that three primary colours can be selected so that it is impossible to match one of them by any mixture of the other two.

The primary colour stimuli employed in the colour-matching experiments were saturated red, green and blue, thus satisfying the above law none of them can be produced by a mixture of the rest of two radiations. But with these primary colours a yellow can be produced by mixing the red and green, and a purple by mixing blue and red. All intermediate hues of sucessive degrees of desaturation can be produced by combining the stimuli in appropriate definite proportions. A white is obtained by mixing the correct proportions of all three stimuli and is demonstrated in Plate 3.

For a given colour Q , the colour equation can be conveniently expressed as

$$R(R) + G(G) + B(B) \equiv Q(Q) .$$

where R, G and B are amounts of the three primary colours (R), (G) and (B), and they are termed the tristimulus values required to produce the Q quantity of the (Q) colour. It is possible and convenient to represent colours in colour space by three dimensional vectors, and colour matches by linear equations between such vectors. The symbol Q, for instance, is a vector representing a colour and R,G,B are the vectors representing the amounts of three fixed primaries. A three dimensional vector diagram illustrating a colour space and a corresponding two dimensional colour plane are shown in Figure II.7.

Grassmann's third law says that if two colours Q_1 and Q_2 are produced by mixtures of three radiations, the colours together , when mixed additively, will be matched by the sum of the two mixtures similarly combined.

i.e., if

$$R_1\ (R) + G_1\ (G) + B_1\ (B) \equiv Q_1\ (Q) \qquad \text{and}$$

$$R_2\ (R) + G_2\ (G) + B_2\ (B) \equiv Q_2\ (Q)$$

then

$$\frac{R_1 + R_2}{2}(R) + \frac{G_1 + G_2}{2}(G) + \frac{B_1 + B_2}{2}(B) \equiv \frac{Q_1 + Q_2}{2}(Q) \equiv Q_3\ (Q)$$

The new colour Q_3 is thus obtained by the additive mixing of the two colours Q_1 and Q_2 and lies on the straight line connecting Q_1 and Q_2, as shown in Figure II.8.

If m units of Q_1 are mixed with n units of Q_2, $(m + n)$ units of a new colour Q_3 will be obtained. The colour Q_3 will lie at a distance on the line $Q_1\ Q_2$ such that $Q_1\ Q_3\ /\ Q_3\ Q_2 = n\ /\ m$.

For three or more colours the same principle applies. A convention was made to base the units of (R), (G) and (B) on a match on a white of some defined quality. For this purpose there was an assumption that white may be regarded as a colour (achromatic)* in which neither red nor green nor blue predominates. The standard white, therefore, could be defined by its colour temperature if it were a Plankian radiator (Black body), whereas the qualities of other colours (chromatic colours) could be defined by their dominant wavelength and purity corresponding, in an approximate way, to their hue and saturation respectively.

Based on such units the colour equation for the standard white (E) becomes:

$$1(E) = R(R) + G(G) + B(B)$$

---

* achromatic colour: colour that does not elicit hue.
white, grey, black are achromatic colours.

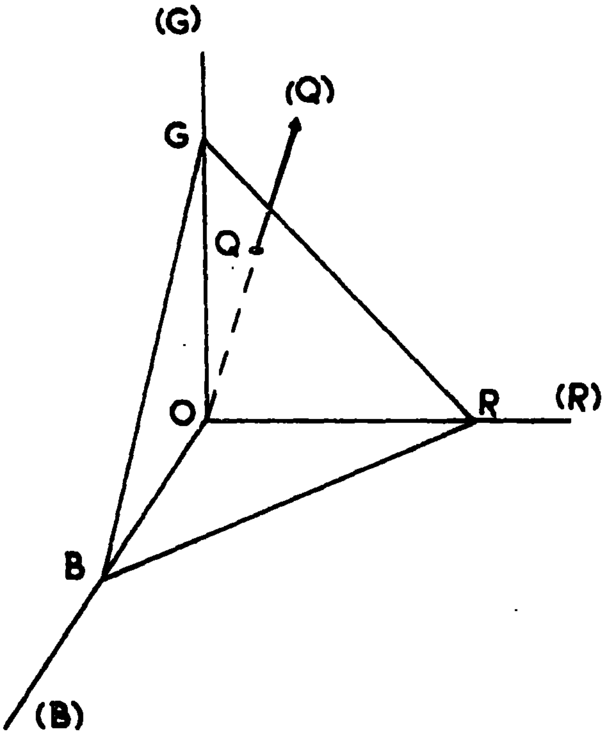


Figure II 7. A three dimensional vector diagram illustrating a colour space and a corresponding two dimensional colour plane.

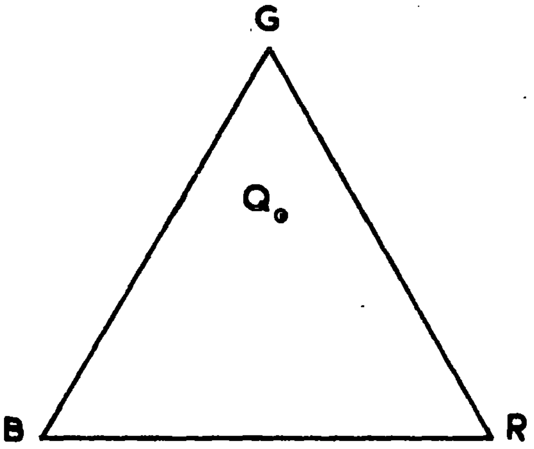


Plate 3. Additive combination of red, green and blue producing white. Partly overlapping mixture of red and green produces yellow, red and blue produces purple, blue and green produces blue-green.

(from Plate 6 in the 'Science of Color' by the Committee on Colorimetry Optical Society of America, 1968)

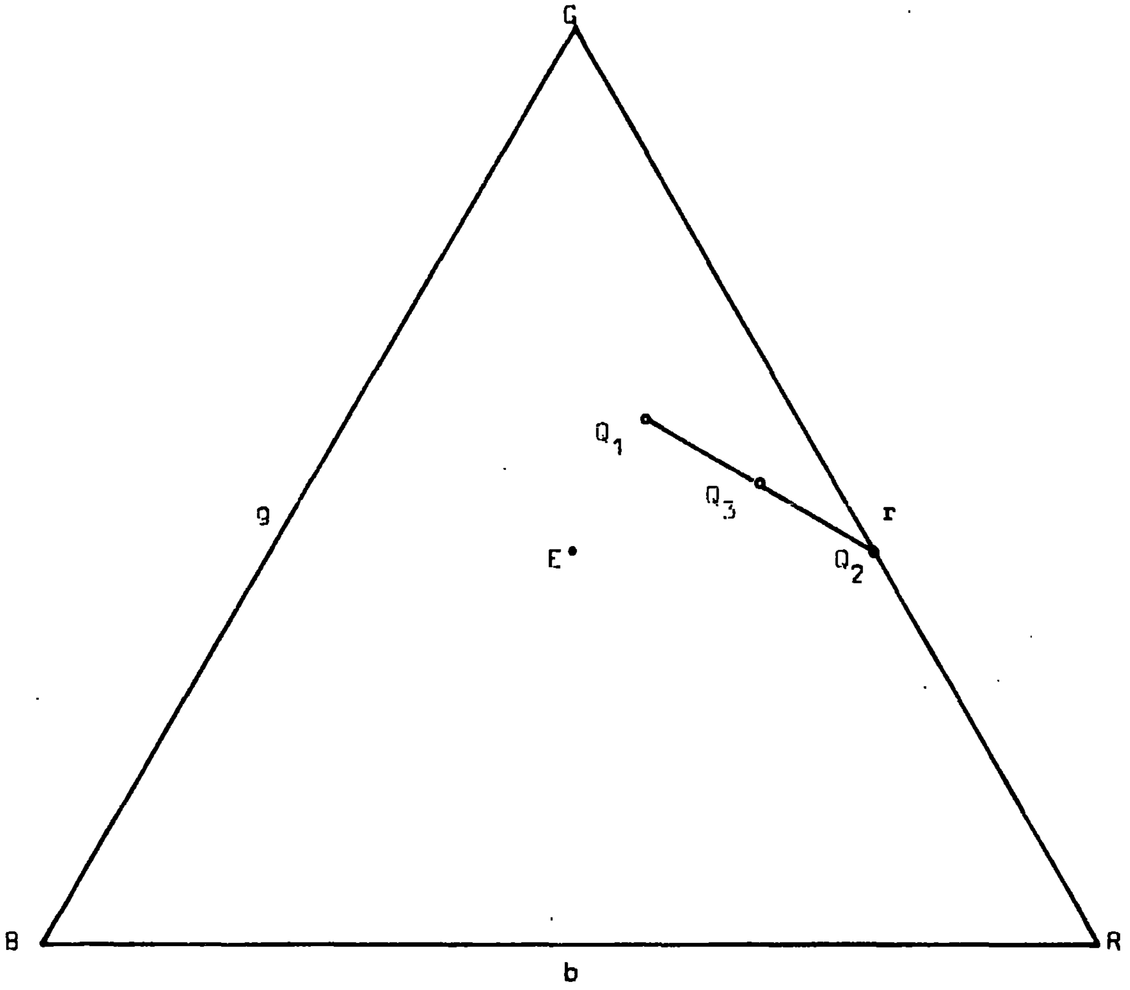


Figure II 8. Illustrating the additive mixture of the two colours Q_1 & Q_2 producing a new colour Q_3.

$$r = \frac{R}{R + G + B} = 1 / 3$$

$$g = \frac{G}{R + G + B} = 1 / 3$$

$$b = \frac{B}{R + G + B} = 1 / 3 .$$

This particular white in fact is the centroid of the colour triangle. R, G, B are called tristimulus values and r, g, b are termed the chromaticity coordinates. By definition tristimulus values are components necessary in a three-colour mixture matching a sample colour.

Grassmann's second law states that if two different light spots give the same colour sensation they continue to do so if the brightnesses of both are increased or decreased by the same factor . It means that with any change in brightnees of a colour, its tristimulus values increase proportionally.

All colours having the same hue and saturation but differing in brightness will be represented by one point in a colour plane. This is illustrated in Figure II.9. Therefore colours slightly different due to variation in brightness annot be distinguidhed by the two-dimensional plane diagram.

Although the colour sensation is defined by three magnitudes only hue and saturation are taken into account in the colour plane, the brightness is ignored. Such a colour plane is called a chromaticity diagram. It is in fact a plane of constant brightness. The chromaticity (quality of hue and saturation) of a synthesized colour may be specified in terms of the proportions of each of two of the

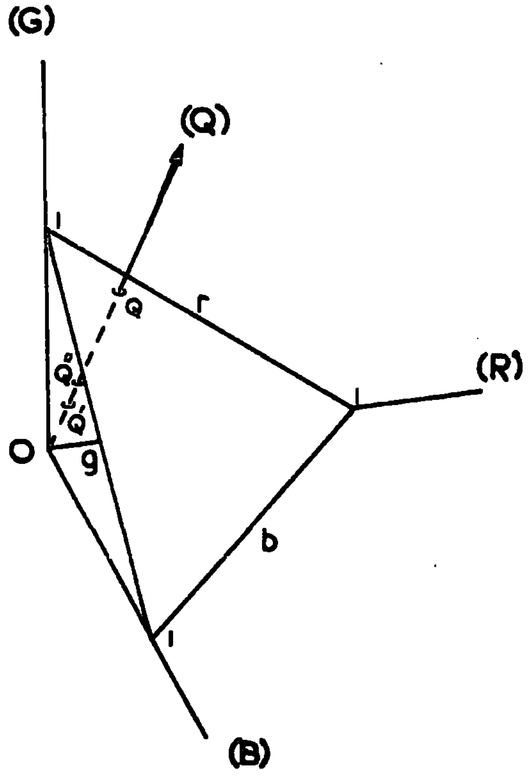


Figure II 9. A vector diagram with a colour plane of constant brightness.

components in the trichromatic mixture.

From the above laws any additive mixture of the primary colours RGB will produce a colour point lying within the colour triangle formed by three spectral radiations RGB. Practically this additive colour-mixture system does not hold the fundamental rule which states that all spectrum colours must lie inside the colour triangle. Some of the spectrum colours lie slightly beyond the triangle RGB. They cannot be produced by positive mixtures of RGB. Therefore the fundamental law of additive colour-matching has a limitation in its application.

However the exceptions were eliminated by introducing subtractive amounts in the colour-matching. For example the colour of wavelength 510 nm cannot be produced by additive mixing of RGB but it can be matched in the following way expressed algebraically thus,

$$(510) + r(R) = g(G) + b(B).$$

or

$$(510) = -r(R) + g(G) + b(B).$$

Hence the spectrum colour (510) can be produced by a negative quantity of (R) plus two positive quantities of (G) and (B). In this manner the fundamental law holds universally.

Based on these fundamental criteria of colour-mixing theory, extensive experiments were made to specify the units of reference stimuli (R), (G) and (B) and their quantities required to match each wavelength colour in turn in the equal-energy spectrum.

To fullfil the above requirements important investigations were undertaken by Wright (1928-29 & 1930) and Guild (1931) indepently, using very different instruments and with different groups of observers.

In Guild's experiment seven observers made colour matches through the spectrum. The instrumental stimuli were adjusted to be equal in a match on the N.P.L. white.

Wright used ten observers in his investigation and his reference stimuli were monochromatic radiations of wavelengths 650 (R), 530 (G) and 460 (B) nm. The units were adjusted so that equal amounts of the red and green stimuli were required in the match of a monochromatic yellow of wavelength 582.5 nm and equal amounts of the green and blue in the match on 494.0 nm.

Both sets of data obtained by Guild and Wright were transformed by the C.I.E. to the same reference stimuli, namely 700.0, 546.1 and 435.8 nm, with the units based on the N.P.L. white. The mean results of the two investigations were compared and it was found that they were in good agreement. Therefore the average values of the Guild-Wright investigations were accepted as basic data for further experiments. These data are representative of a normal eye and called the 1931 standard observer by definition.

In 1955 a redetermination of the colour-matching functions was made by Stiles (1955) and his data showed that no important errors were present in Guild-Wright data.

Figures II.10 and II.11 show the mean chromaticity coordinates of spectrum colours, obtained by Guild and Wright respectively. In both figures the coordinates add up to unity at each wavelength. But one or the other of the coordinates is always negative, because those colours indicated by negative coordinates cannot be matched by a positive mixture of three components. In such case a match was established with a mixture of the sample light and one of the components. The amount of the component which is mixed with the sample light was taken as a negative quantity. It can be explained by the following expressions thus,

$$r(R) + g(G) = Q(Q) + b(B)$$

or

$$r(R) + g(G) - b(B) = Q(Q).$$

To obtain the amounts of (R), (G) and (B) in the equal-energy spectrum the relative luminous efficiency function ($V\lambda$) was used(Figure II.3) instead of making direct colour matches on an equal-energy spectrum, because the light flux (luminance)at wavelength λ in the equal-energy spectrum is proportional to $V\lambda$.

If the luminances are written as V(R), V(G), V(B) the colour equation becomes

$$V(Q) = r.V(R) + g.V(G) + b.V(B).$$

the spectral colour with wavelength λ is

$$V(\lambda) = r \quad V(R) + g \quad V(G) + b \quad V(B).$$

Since the light flux at wavelength (λ) in the equal-energy spectrum is proportional to $V\lambda$, the unit quantities of the primaries in the equal-energy spectrum will be proportional to

$$\frac{V\lambda}{V(\lambda)} = \frac{V\lambda}{r \quad V(R) + g \quad V(G) + b \quad V(B)} = m\lambda$$

The value $V\lambda$ is already in existance(Figure II.3), the chromaticity coordinates , $r\lambda$, $g\lambda$, $b\lambda$, and the reference stimuli, V(R), V(G), V(B) are known experimentally. The colour-matching functions (also called distribution coefficients, or tristimulus values of the spectrum),

$\bar{r}_\lambda$, $\bar{g}_\lambda$, $\bar{b}_\lambda$, of the equal-energy spectrum are given by

$$\bar{r}_\lambda = m_\lambda \, r_\lambda$$
$$\bar{g}_\lambda = m_\lambda \, g_\lambda$$
$$\bar{b}_\lambda = m_\lambda \, b_\lambda \quad .$$

Since only the relative values of the colour-matching functions are of interest, the coefficients for all wavelengths were multiplied by the same factor, and thus they were finally derived to satisfy the equation

$$V_\lambda = \text{a constant} \left[\bar{r}_\lambda V(R) + \bar{g}_\lambda V(G) + \bar{b}_\lambda V(B)\right]$$

Figure II.12 which was thus derived from Figures II. 11 and II.10 shows the spectral distribution curves for the equal-energy spectrum expressed in terms of the matching stimuli 700.0 nm, 546.1 nm and 435.8 nm with their units adjusted to be equal in a match on an equal-energy white.

Thus the spectrum colours were broken down into three parameters $\bar{r}_\lambda$, $\bar{g}_\lambda$ and $\bar{b}_\lambda$ measured in terms of the tristimulus values (or distribution coefficients).

These basic data had to be used to compute specifications of a given stimulus. The spectrum locus could be drawn by plotting the spectral chromaticity coordinates, giving the chromaticities of the spectrum colours. It is clear from Figure II.13 that part of the spectrum locus, unfortunately, lie outside the RGB triangle. Therefore it is not a suitable system for colour measurement purposes. The RGB system had to be transformed into a new reference system.

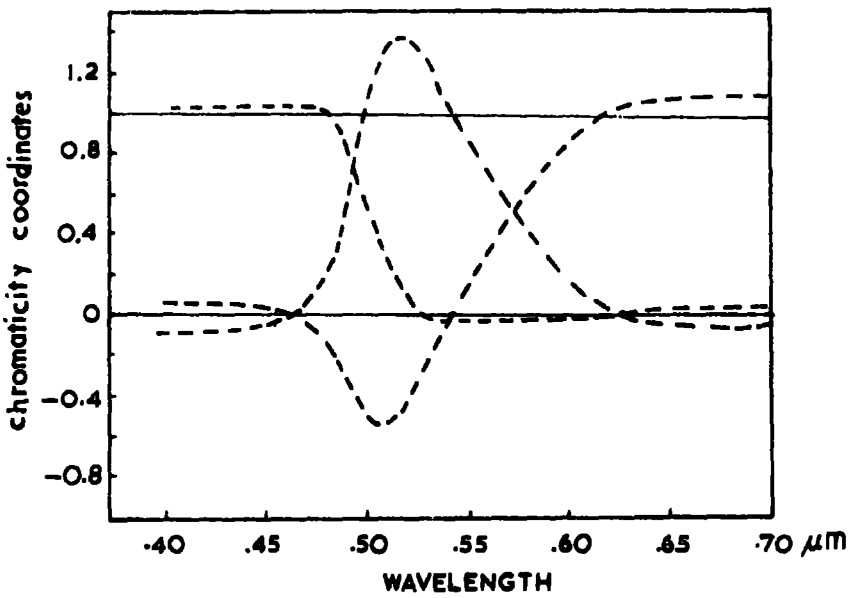


Figure II 10. Mean colour matching results obtanied by Guild.

(from Guild, Phil. Trans., 1931)

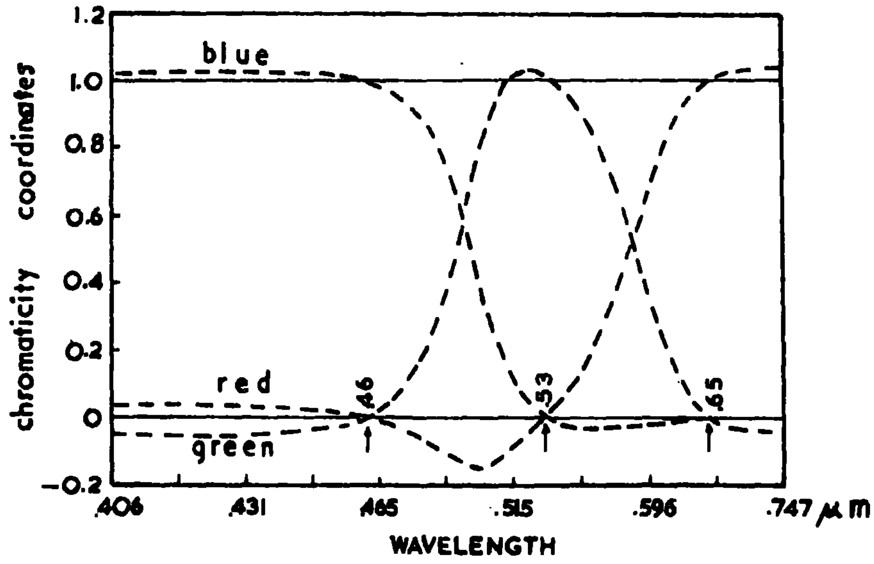


Figure II 11. Mean colour matching results obtained by Wright.

(From Wright, Trans. Opt. Soc., 1928-29)

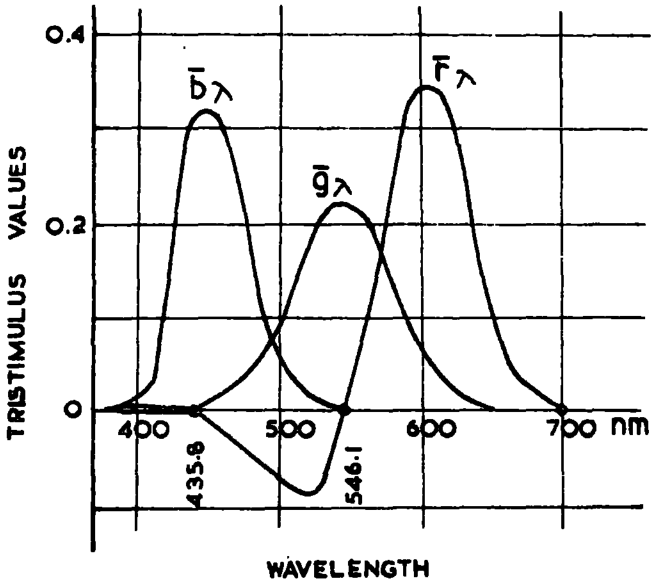


Figure II 12. Spectral distribution curves (colour-matching functions $\bar{r}_\lambda$, $\bar{g}_\lambda$, $\bar{b}_\lambda$) of equal energy spectrum in the primary system R=700.0 nm, G=546.1 nm, B=435.8 nm (from Wyszecki & Stiles,1967)

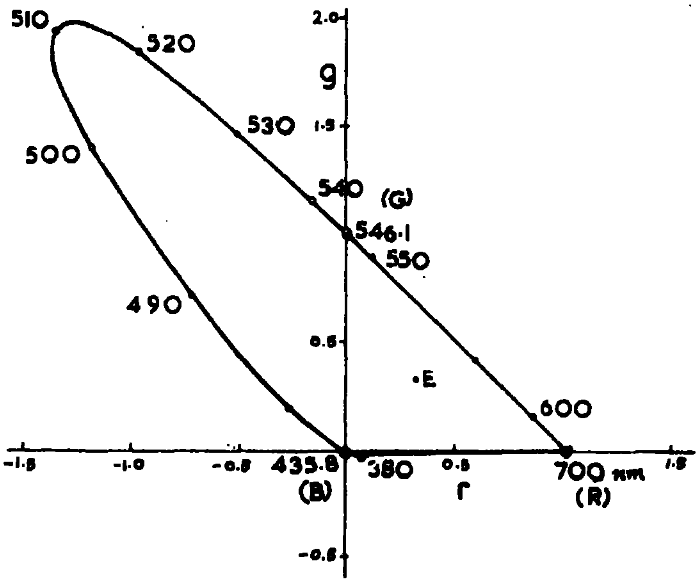


Figure II 13. Chromaticity diagram showing spectrum locus (380-700 nm) in the primary system R,G,B, equal-energy stimulus (E) (from Wyszecki & Stiles, 1967)

II.7. THE C.I.E. SYSTEM OF COLOUR MEASUREMENT

The principles of colorimetry were developed from the starting point of a colour-match with a visual trichromatic colorimeter. The whole of applied colorimetry is based on the primary RGB system. But the RGB system for the notation of colours in space and on a plane diagram is not convenient for practical use. The negative quantities of the chromaticity coordinates create difficulty in the sophisticated computations for colour specifications and cause the spectrum locus to lie outside the RGB colour triangle as shown in Figure II.13 .

The C.I.E. (Commission Internationale de l'Eclairage), a body which in 1931 took over the functions of the earlier 'Commission Internationale de Photometrie' was responsible for transforming the RGB system into one based on new primaries XYZ. This new system not only would make use of the experimental data underlying the RGB system but also would introduce changes chiefly intended to simplify computation in colorimetric calculations. Thus the new system was diveloped via a transformation of the RGB coordinates.

This is the transformation of Guild's and Wright's data by mathematical treatments into the new XYZ-CIE system so that the coordinates and tristimulus values of the spectrum are never negative. Details of the transformation equations, if required, from one system to another can be found in the text-books.

In this new system the colour-matching functions ($\bar{r}\lambda$, $\bar{g}\lambda$, $\bar{b}\lambda$ in the old RGB system) are denoted by the symbols $\bar{x}\lambda$, $\bar{y}\lambda$, $\bar{z}\lambda$.

The 1931 C.I.E. colour-matching functions based on the XYZ primaries are presented by the curves in Figure II.14. Figure II.15 shows the CIE-XYZ standard chromaticity diagram in terms of the reference stimuli (X), (Y) and (Z) with unit based on an equal-energy (E) whose coordinates in the chromaticity diagram are 1/3, 1/3 and 1/3. Table II.2 summerises the relationships between the 1931 CIE-RGB system and the 1931 CIE-XYZ system.

With the new set of reference stimuli XYZ the transformed system has the following characteristics:

(1) Tristimulus values and coordinates of all spectrum colours are now positive, so the triangle formed by the chromaticity points XYZ completely encloses the spectrum locus.

(2) The units of (X), (Y) and (Z) are adjusted, as in the RGB system , to be equal in a match of an equal-energy white, so that the equal-energy white (E) lies in the middle of the chromaticity triangle.

(3) The colour-matching function $\bar{y}_\lambda$ is set to be identical with the luminous efficiency function V_λ . It follows that the tristimulus values Y of a given colour is equal to its relative reflection or transmission factor.

(4) As in the RGB system, the areas under the curves $\bar{x}_\lambda$, $\bar{y}_\lambda$, $\bar{z}_\lambda$ of the spectrum are equal (Figure II.10).

that is, $$\int \bar{x}_\lambda \, d\lambda = \int \bar{y}_\lambda \, d\lambda = \int \bar{z}_\lambda \, d\lambda$$

(5) The reference stimuli XYZ cannot be reproduced experimentally in the laboratory. They are hypothetical stimuli, but they have real merits as reference coordinates of the C.I.E. system.

All colours will be represented by points within the spectrum locus and the purple line connecting the red and blue ends. There is no colour outside the curve.

Standard chromaticity coordinates x, y, z and the colour-matching functions $\bar{x}\lambda$, $\bar{y}\lambda$, $\bar{z}\lambda$, of the equal-energy spectrum are given in Table II.3 (from Wyszecki and Stiles, 1967).
These colour-matching functions are to be used in calculations for any light source when its spectral energy distributions are known.

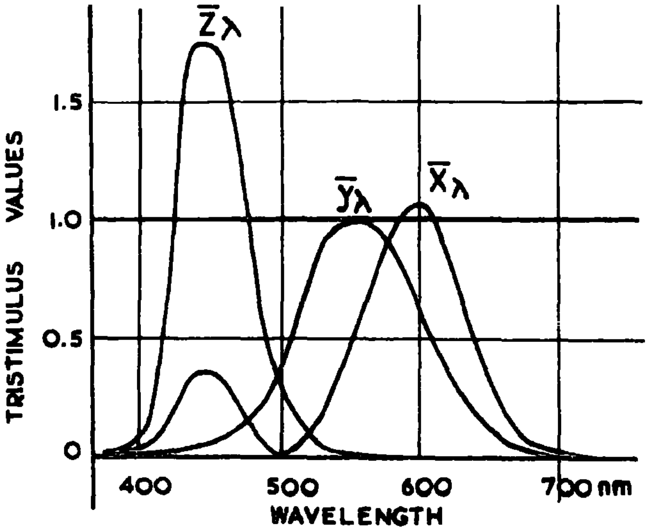


Figure II 14. 1931 C.I.E. colour matching functions $\bar{x}_\lambda$, $\bar{y}_\lambda$, $\bar{z}_\lambda$.
(from Wyszecki & Stiles, 1967)

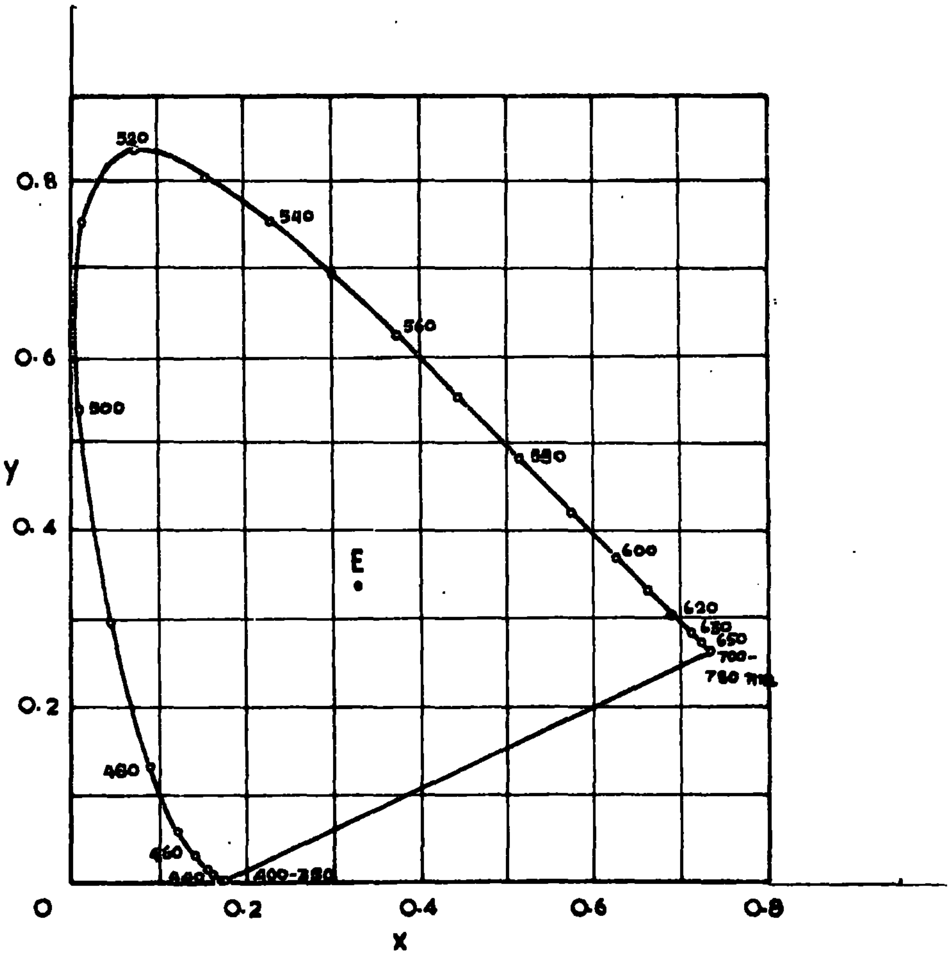


Figure II 15. 1931 C.I.E. chromaticity diagram with spectrum locus, purple line, and the chromaticity point of equal-energy stimulus E (from Wyszecki & Stiles, 1967)

Table II 2.

Relationships between the 1931 C.I.E.-(R,G,B) System and the C.I.E.-(XYZ) System of colour specification

	R,G,B System (chromaticity coordinates)			X,Y,Z System (chromaticity coordinates)		
Stimulus	r	g	b	x	y	z
(R) 700.0 nm	1	0	0	0.73467	0.26533	0.00000
(G) 546.1 nm	0	1	0	0.27376	0.71741	0.00883
(B) 435.8 nm	0	0	1	0.16658	0.00886	0.82456
Equal-energy source(E)	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$
Source A	0.55255	0.32126	0.12619	0.44757	0.40745	0.14498
Source B	0.36230	0.34305	0.29465	0.34842	0.35161	0.29997
Source C	0.28226	0.33326	0.38448	0.31006	0.31616	0.37378

(from Wyszecki & Stiles 1967).

Table II 3. Chromaticity Coordinates and Color-Matching Functions in 1931 CIE Colorimetric System (X, Y, Z)

($\lambda = 380 \cdots 780$ nm; $\Delta\lambda = 5$ nm)

Chromaticity Coordinates			Wavelength λ (nm)	Color-Matching Functions		
x_λ	y_λ	z_λ		$\bar{x}_\lambda$	$\bar{y}_\lambda$	$\bar{z}_\lambda$
0.1741	0.0050	0.8209	380	0.0014	0.0000	0.0065
0.1740	0.0050	0.8210	385	0.0022	0.0001	0.0105
0.1738	0.0049	0.8213	390	0.0042	0.0001	0.0201
0.1736	0.0049	0.8215	395	0.0076	0.0002	0.0362
0.1733	0.0048	0.8219	400	0.0143	0.0004	0.0679
0.1730	0.0048	0.8222	405	0.0232	0.0006	0.1102
0.1726	0.0048	0.8226	410	0.0435	0.0012	0.2074
0.1721	0.0048	0.8231	415	0.0776	0.0022	0.3713
0.1714	0.0051	0.8235	420	0.1344	0.0040	0.6456
0.1703	0.0058	0.8239	425	0.2148	0.0073	1.0391
0.1689	0.0069	0.8242	430	0.2839	0.0116	1.3856
0.1669	0.0086	0.8245	435	0.3285	0.0168	1.6230
0.1644	0.0109	0.8247	440	0.3483	0.0230	1.7471
0.1611	0.0138	0.8251	445	0.3481	0.0298	1.7826
0.1566	0.0177	0.8257	450	0.3362	0.0380	1.7721
0.1510	0.0227	0.8263	455	0.3187	0.0480	1.7441
0.1440	0.0297	0.8263	460	0.2908	0.0600	1.6692
0.1355	0.0399	0.8246	465	0.2511	0.0739	1.5281
0.1241	0.0578	0.8181	470	0.1954	0.0910	1.2876
0.1096	0.0868	0.8036	475	0.1421	0.1126	1.0419
0.0913	0.1327	0.7760	480	0.0956	0.1390	0.8130
0.0687	0.2007	0.7306	485	0.0580	0.1693	0.6162
0.0454	0.2950	0.6596	490	0.0320	0.2080	0.4652
0.0235	0.4127	0.5638	495	0.0147	0.2586	0.3533
0.0082	0.5384	0.4534	500	0.0049	0.3230	0.2720
0.0039	0.6548	0.3413	505	0.0024	0.4073	0.2123
0.0139	0.7502	0.2359	510	0.0093	0.5030	0.1582
0.0389	0.8120	0.1491	515	0.0291	0.6082	0.1117
0.0743	0.8338	0.0919	520	0.0633	0.7100	0.0782
0.1142	0.8262	0.0596	525	0.1096	0.7932	0.0573
0.1547	0.8059	0.0394	530	0.1655	0.8620	0.0422
0.1929	0.7816	0.0255	535	0.2257	0.9149	0.0298
0.2296	0.7543	0.0161	540	0.2904	0.9540	0.0203
0.2658	0.7243	0.0099	545	0.3597	0.9803	0.0134
0.3016	0.6923	0.0061	550	0.4334	0.9950	0.0087
0.3373	0.6589	0.0038	555	0.5121	1.0002	0.0057
0.3731	0.6245	0.0024	560	0.5945	0.9950	0.0039
0.4087	0.5896	0.0017	565	0.6784	0.9786	0.0027
0.4441	0.5547	0.0012	570	0.7621	0.9520	0.0021
0.4788	0.5202	0.0010	575	0.8425	0.9154	0.0018
0.5125	0.4866	0.0009	580	0.9163	0.8700	0.0017

Table II 3 (continued)

Chromaticity Coordinates			Wavelength λ (nm)	Color-Matching Functions		
x_λ	y_λ	z_λ		$\bar{x}_\lambda$	$\bar{y}_\lambda$	$\bar{z}_\lambda$
0.5125	0.4866	0.0009	580	0.9163	0.8700	0.0017
0.5448	0.4544	0.0008	585	0.9786	0.8163	0.0014
0.5752	0.4242	0.0006	590	1.0263	0.7570	0.0011
0.6029	0.3965	0.0006	595	1.0567	0.6949	0.0010
0.6270	0.3725	0.0005	600	1.0622	0.6310	0.0008
0.6482	0.3514	0.0004	605	1.0456	0.5668	0.0006
0.6658	0.3340	0.0002	610	1.0026	0.5030	0.0003
0.6801	0.3197	0.0002	615	0.9384	0.4412	0.0002
0.6915	0.3083	0.0002	620	0.8544	0.3810	0.0002
0.7006	0.2993	0.0001	625	0.7514	0.3210	0.0001
0.7079	0.2920	0.0001	630	0.6424	0.2650	0.0000
0.7140	0.2859	0.0001	635	0.5419	0.2170	0.0000
0.7190	0.2809	0.0001	640	0.4479	0.1750	0.0000
0.7230	0.2770	0.0000	645	0.3608	0.1382	0.0000
0.7260	0.2740	0.0000	650	0.2835	0.1070	0.0000
0.7283	0.2717	0.0000	655	0.2187	0.0816	0.0000
0.7300	0.2700	0.0000	660	0.1649	0.0610	0.0000
0.7311	0.2689	0.0000	665	0.1212	0.0446	0.0000
0.7320	0.2680	0.0000	670	0.0874	0.0320	0.0000
0.7327	0.2673	0.0000	675	0.0636	0.0232	0.0000
0.7334	0.2666	0.0000	680	0.0468	0.0170	0.0000
0.7340	0.2660	0.0000	685	0.0329	0.0119	0.0000
0.7344	0.2656	0.0000	690	0.0227	0.0082	0.0000
0.7346	0.2654	0.0000	695	0.0158	0.0057	0.0000
0.7347	0.2653	0.0000	700	0.0114	0.0041	0.0000
0.7347	0.2653	0.0000	705	0.0081	0.0029	0.0000
0.7347	0.2653	0.0000	710	0.0058	0.0021	0.0000
0.7347	0.2653	0.0000	715	0.0041	0.0015	0.0000
0.7347	0.2653	0.0000	720	0.0029	0.0010	0.0000
0.7347	0.2653	0.0000	725	0.0020	0.0007	0.0000
0.7347	0.2653	0.0000	730	0.0014	0.0005	0.0000
0.7347	0.2653	0.0000	735	0.0010	0.0004	0.0000
0.7347	0.2653	0.0000	740	0.0007	0.0003	0.0000
0.7347	0.2653	0.0000	745	0.0005	0.0002	0.0000
0.7347	0.2653	0.0000	750	0.0003	0.0001	0.0000
0.7347	0.2653	0.0000	755	0.0002	0.0001	0.0000
0.7347	0.2653	0.0000	760	0.0002	0.0001	0.0000
0.7347	0.2653	0.0000	765	0.0001	0.0000	0.0000
0.7347	0.2653	0.0000	770	0.0001	0.0000	0.0000
0.7347	0.2653	0.0000	775	0.0000	0.0000	0.0000
0.7347	0.2653	0.0000	780	0.0000	0.0000	0.0000
			Totals	21.3713	21.3714	21.3715

II.8. C.I.E. STANDARD LIGHT SOURCES

It is necessary to specify a particular kind of light source (or light sources) under which colours are observed and measured. For the purposes of general colour measurement three light sources have been recommended by the C.I.E. in 1931 since they are the most common of all kinds of light. These sources designated by the symbols A, B and C are representatives of the following types of radiant energy distribution.

A : Incandesent lamp light, at a colour temperature of 2854°K (this provides a standard illuminant similar to the average tungsten-filament lamp).

B : Artificial sun light, correlated colour temperature of 4870°K.

C : Artificial average daylight, correlated colour temperature of 6770°K.

In the visible range the spectral emittance distributions of source A is equal to that of a Planckian radiator and the spectral irradiance from source A is found from the Planck radiation law. The locus of Planckian (Black-body) radiators is useful for determining the correlated colour temperature of a source, as shown in Figure II.17.

Sources B and C were obtained by combining source A with special filters, the Davis-Gibson filters. The relative spectral distributions of sources B and C were obtained by measuring spectrophotometrically and are represented by the curves in Figure II.16. Their chromaticity coordinates are tabulated in Table II. 4 and are plotted in the C.I.E. chromaticity diagram of Figure II.17.

As a convenient and practical rule standard light sources are used as reference achromatic stimuli.

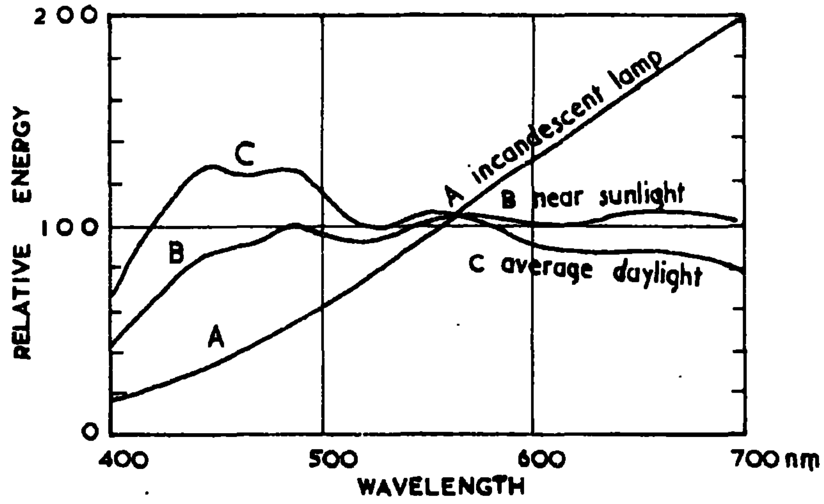


Figure II 16. Relative spectral distributions of the C.I.E. standard sources A,B and C (from Judd & Wyszecki, 1965)

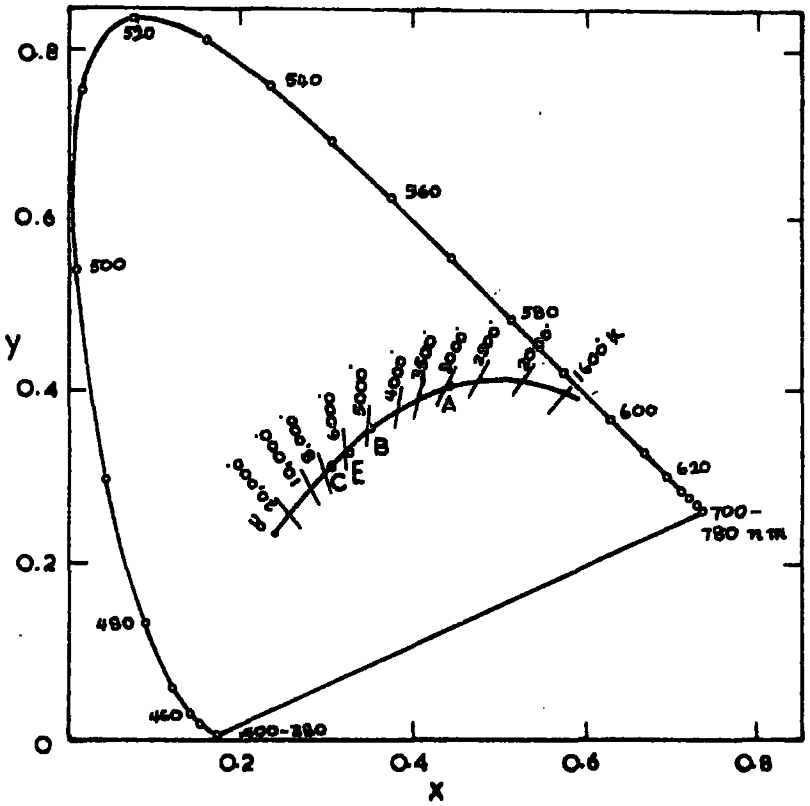


Figure II 17. C.I.E. light sources A,B,C and the locus of Planckian radiators in the C.I.E. chromaticity diagram. Absolute colour temperatures are shown against the locus (from Judd & Wyszecki, 1965)

Table II.4.

CHROMATICITY COORDINATES OF THE 1931 C.I.E. STANDARD LIGHT SOURCES

Source		x	y
A	Incandescent Lamp	0.4476	0.4075
B	Sunlight (artificial)	0.3485	0.3518
C	Average Daylight (artificial)	0.3101	0.3163
E	Equal-energy Stimulus	0.3333	0.3333

II.9. COMPUTATION OF TRISTIMULUS VALUES AND CHROMATICITY COORDINATES

The C.I.E. system of colour measurement is an internationally adopted method to specify the characteristics of a light source or an object colour in terms of its tristimulus values. For a desired light source specified by its spectral irradiance distributions ($S_\lambda\, d\lambda$) in the visible range (i.e. 380 nm to 780 nm) the tristimulus values XYZ are given by

$$
\begin{aligned}
X &= K \int S_\lambda\, \bar{x}_\lambda\, d\lambda \ , \\
Y &= K \int S_\lambda\, \bar{y}_\lambda\, d\lambda = 100.0 \qquad (1) \\
Z &= K \int S_\lambda\, \bar{z}_\lambda\, d\lambda \ .
\end{aligned}
$$

where $K = \dfrac{100.0}{S_\lambda\, \bar{y}_\lambda\, d\lambda}$, a normalizing factor and so that $Y = 100.0$;

$d\lambda$ = wavelength interval.

The chromaticity coordinates are computed therefrom thus,

$$
\begin{aligned}
x &= \frac{X}{X + Y + Z} \ , \\
y &= \frac{Y}{X + Y + Z} \ , \qquad (2) \\
z &= \frac{Z}{X + Y + Z}
\end{aligned}
$$

Spectral energy distributions, tristimulus values and chromaticity coordinates of the C.I.E. standard sources and many other sources can be found in the text-books, particularly in 'Color Science' by Wyszecki and Stiles, 1967.

To characterise an object colour irradiated by one of those sources the first requirement is to determine its spectral reflectance (r_λ) or transmittance (t_λ) by measurement, followed by calculation. Generally, spectral reflectance or transmittance is measured with a spectrophotometer and the C.I.E. tristimulus values are then calculated. Sometimes tristimulus values are measured directly with a photoelectric colorimeter.

The evaluation of the tristimulus values of an object colour with respect to a particular source can be done by either of the following methods.

(1) Weighted Ordinate Method.

This is merely a numerical method of integrating the values of spectral energy distributions ($S_\lambda \bar{x}_\lambda$, $S_\lambda \bar{y}_\lambda$, $S_\lambda \bar{z}_\lambda$) and spectral reflectance (r_λ) or transmittance (t_λ) at equal wavelength intervals.

The tristimulus values of an object colour are given by

$$X = K \int r_\lambda S_\lambda \bar{x}_\lambda \, d\lambda$$

$$Y = K \int r_\lambda S_\lambda \bar{y}_\lambda \, d\lambda \qquad (3)$$

$$Z = K \int r_\lambda S_\lambda \bar{z}_\lambda \, d\lambda \ .$$

Since the products $S_\lambda \bar{x}_\lambda d\lambda$, etc. of a source are constants for all problems of computing object colours, tables of normalized products denoted by $H_\lambda \bar{x}_\lambda d\lambda$, $H_\lambda \bar{y}_\lambda d\lambda$ and $H_\lambda \bar{z}_\lambda d\lambda$ are convenient for the Weighted Ordinate Method of evaluating the integrals.

The normalized products to be used for standard sources A, B and C are listed in Table II.5 (from Wyszecki and Stiles, 1967). Using these Tables the tristimulus values of an object colour are given by

$$X = \int R_\lambda H_\lambda \bar{x}_\lambda d\lambda \quad ,$$

$$Y = \int R_\lambda H_\lambda \bar{y}_\lambda d\lambda \quad , \qquad (4)$$

$$Z = \int R_\lambda H_\lambda \bar{z}_\lambda d\lambda \quad .$$

In the same way for a transparent object T_λ replaces R_λ. The chromaticity coordinates are then calculated by the equations (2).

(2) Selected Ordinate Method

An alternative method for computing tristimulus specification of an object colour was proposed by Hardy and Pineo (1935). Their method is called the Selected Ordinate Method and is popular in practical colorimetry because of the simpler computation to be carried out. In this method numerous multiplications involved in the Weighted Ordinate Method are avoided and only summations of reflectance are required at selected wavelengths.

The selected wavelength intervals are chosen to be inversely proportional to $H_\lambda \bar{x}_\lambda$ for X, $H_\lambda \bar{y}_\lambda$ for Y and $H_\lambda \bar{z}_\lambda$ for Z so that where the distribution coefficients are large the wavelength intervals are small, and vice versa. The essential calculations for the tristimulus values XYZ of an object colour by the Selected Ordinate Method are performed simply by

(1) adding the values of reflectance (or transmittance) at selected wavelengths , and

(2) multiplying the three sums thus obtained by appropriate factors.

The thirty ordiantes for standard sources A, B and C are listed in Table II.6 and the corresponding multiplication factors are also given at the bottom of the Table. The derivations of the tristimulus specification of an object by both methods are illustrated in Figure II. 18.

ACCURACY OF THE TWO METHODS

The methods used to compute tristimulus specifications have limits of accuracy. The accuracy, based on comparison between computed values of standard reflecting surfaces and filters, depends on the numbers of wavelength intervals employed in the Weighted Ordinate and Selected Ordinate methods (Kerf, 1957). The smaller the wavelength intervals in the computation the better the accuracy obtained.

According to Nickerson (1935) the Weighted Ordinate method with $d\lambda$ = 10 nm and Selected Ordinate with N = 30 are sufficient for accuracy. The Selected Ordinate method N = 10 is rejected. Many authors think so for most purposes.

According to Kerf (1957) the Weighted Ordinate $d\lambda$ = 10 nm and Selected Ordinate method N = 100 are equally accurate in average, but the error of both methods is greater than 1/2 jps (just perceptible steps, or = 1/10 NBS units) in some cases. Kerf concludes that the only method, which determines the tristimulus specifications of all the samples studied with an uncertainty smaller than 1/2 jps, is the Weighted Ordinate method $d\lambda = 5$ nm ; and that the Selected Ordinate method $N = 30$ may only be applied to smooth curves of samples.

It is obvious that if accuracy is of prime importance the Weighted Ordinate method is preferable. With automatic computing machines becoming increasingly available to research workers the Selected Ordinate method is of less importance.

It is also found that the Weighted Ordinate method is more convenient to be used to derive weighted spectral energy distributions of any desired illumination . Therefore computer programs for the Weighted Ordinate method were developed and used in this present work.

Using the Weighted Ordinate method $d\lambda = 5$ nm consistantly as a standard method the deviations in computed colour values would be only due to errors in measured reflectivity (or transmittance) or insufficient numbers of wavelength intervals used in the measurement of spectral reflectivity (or transmittance). Precision of colour specifications in this work is discussed in a later Chapter.

Table II 5. 1931 CIE Color-Matching Functions ($\bar{x}_\lambda, \bar{y}_\lambda, \bar{z}_\lambda$) Weighted by Relative Spectral Energy Distribution ($H_\lambda \Delta\lambda$) of CIE Source *A* (λ = 380 ··· 780 nm; $\Delta\lambda$ = 5 nm)

Wavelength λ (nm)	$\bar{x}_\lambda H_\lambda$	$\bar{y}_\lambda H_\lambda$	$\bar{z}_\lambda H_\lambda$	Wavelength λ (nm)	$\bar{x}_\lambda H_\lambda$	$\bar{y}_\lambda H_\lambda$	$\bar{z}_\lambda H_\lambda$
380	0.0006	0.0000	0.0029	580	4.8594	4.6139	0.0090
385	0.0011	0.0000	0.0053	585	5.3549	4.4668	0.0077
390	0.0024	0.0000	0.0113	590	5.7896	4.2704	0.0062
395	0.0047	0.0001	0.0224	595	6.1403	4.0379	0.0058
400	0.0097	0.0003	0.0463	600	6.3518	3.7733	0.0048
405	0.0174	0.0004	0.0825	605	6.4299	3.4855	0.0037
410	0.0356	0.0010	0.1699	610	6.3340	3.1780	0.0019
415	0.0694	0.0020	0.3319	615	6.0877	2.8622	0.0013
420	0.1308	0.0039	0.6283	620	5.6865	2.5358	0.0013
425	0.2269	0.0077	1.0974	625	5.1267	2.1901	0.0007
430	0.3246	0.0133	1.5840	630	4.4902	1.8523	0.0000
435	0.4055	0.0207	2.0036	635	3.8779	1.5529	0.0000
440	0.4632	0.0306	2.3236	640	3.2791	1.2812	0.0000
445	0.4976	0.0426	2.5484	645	2.7004	1.0344	0.0000
450	0.5155	0.0583	2.7173	650	2.1681	0.8183	0.0000
455	0.5230	0.0788	2.8621	655	1.7078	0.6372	0.0000
460	0.5097	0.1052	2.9254	660	1.3141	0.4861	0.0000
465	0.4690	0.1380	2.8539	665	0.9850	0.3625	0.0000
470	0.3882	0.1808	2.5581	670	0.7241	0.2651	0.0000
475	0.2998	0.2375	2.1979	675	0.5368	0.1958	0.0000
480	0.2138	0.3108	1.8179	680	0.4022	0.1461	0.0000
485	0.1372	0.4004	1.4575	685	0.2877	0.1041	0.0000
490	0.0799	0.5196	1.1622	690	0.2019	0.0729	0.0000
495	0.0387	0.6813	0.9308	695	0.1429	0.0515	0.0000
500	0.0136	0.8960	0.7545	700	0.1047	0.0377	0.0000
505	0.0070	1.1878	0.6191	705	0.0756	0.0271	0.0000
510	0.0285	1.5398	0.4843	710	0.0549	0.0199	0.0000
515	0.0934	1.9518	0.3585	715	0.0394	0.0144	0.0000
520	0.2127	2.3855	0.2627	720	0.0283	0.0097	0.0000
525	0.3849	2.7859	0.2012	725	0.0198	0.0069	0.0000
530	0.6069	3.1609	0.1547	730	0.0140	0.0050	0.0000
535	0.8631	3.4987	0.1140	735	0.0101	0.0041	0.0000
540	1.1567	3.7999	0.0809	740	0.0072	0.0031	0.0000
545	1.4904	4.0618	0.0555	745	0.0052	0.0021	0.0000
550	1.8660	4.2841	0.0375	750	0.0032	0.0010	0.0000
555	2.2887	4.4701	0.0255	755	0.0021	0.0010	0.0000
560	2.7550	4.6110	0.0181	760	0.0021	0.0010	0.0000
565	3.2564	4.6974	0.0130	765	0.0011	0.0000	0.0000
570	3.7853	4.7285	0.0104	770	0.0011	0.0000	0.0000
575	4.3259	4.7002	0.0092	775	0.0000	0.0000	0.0000
580	4.8594	4.6139	0.0090	780	0.0000	0.0000	0.0000
				Totals			
				(X_A, Y_A, Z_A)	109.8472	100.0000	35.5824
				(x_A, y_A, z_A)	0.4476	0.4074	0.1450

(continued)

Table II 5. 1931 CIE Color-Matching Functions ($\bar{x}_\lambda, \bar{y}_\lambda, \bar{z}_\lambda$) Weighted by Relative Spectral Energy Distribution ($H_\lambda \Delta\lambda$) of CIE Source B
($\lambda = 380 \cdots 780$ nm; $\Delta\lambda = 5$ nm)

Wavelength λ (nm)	$\bar{x}_\lambda H_\lambda$	$\bar{y}_\lambda H_\lambda$	$\bar{z}_\lambda H_\lambda$	Wavelength λ (nm)	$\bar{x}_\lambda H_\lambda$	$\bar{y}_\lambda H_\lambda$	$\bar{z}_\lambda H_\lambda$
380	0.0015	0.0000	0.0070	580	4.4218	4.1984	0.0082
385	0.0028	0.0001	0.0135	585	4.6790	3.9030	0.0067
390	0.0063	0.0001	0.0301	590	4.8644	3.5880	0.0052
395	0.0131	0.0003	0.0626	595	4.9701	3.2684	0.0047
400	0.0282	0.0008	0.1340	600	4.9736	2.9546	0.0037
405	0.0517	0.0013	0.2455	605	4.8999	2.6561	0.0028
410	0.1083	0.0030	0.5163	610	4.7185	2.3672	0.0014
415	0.2139	0.0061	1.0236	615	4.4415	2.0882	0.0009
420	0.4058	0.0121	1.9495	620	4.0700	1.8149	0.0009
425	0.7017	0.0238	3.3944	625	3.6031	1.5392	0.0005
430	0.9916	0.0405	4.8394	630	3.1000	1.2788	0.0000
435	1.2134	0.0621	5.9951	635	2.6296	1.0530	0.0000
440	1.3446	0.0888	6.7448	640	2.1871	0.8545	0.0000
445	1.3878	0.1188	7.1067	645	1.7765	0.6804	0.0000
450	1.3718	0.1551	7.2308	650	1.4074	0.5312	0.0000
455	1.3229	0.1993	7.2399	655	1.0929	0.4078	0.0000
460	1.2269	0.2531	7.0422	660	0.8273	0.3060	0.0000
465	1.0807	0.3181	6.5769	665	0.6085	0.2239	0.0000
470	0.8589	0.4000	5.6599	670	0.4381	0.1604	0.0000
475	0.6365	0.5044	4.6670	675	0.3177	0.1159	0.0000
480	0.4348	0.6323	3.6980	680	0.2323	0.0844	0.0000
485	0.2667	0.7784	2.8332	685	0.1617	0.0585	0.0000
490	0.1475	0.9590	2.1449	690	0.1102	0.0398	0.0000
495	0.0672	1.1826	1.6156	695	0.0758	0.0273	0.0000
500	0.0221	1.4538	1.2242	700	0.0540	0.0194	0.0000
505	0.0106	1.7976	0.9370	705	0.0378	0.0135	0.0000
510	0.0403	2.1798	0.6856	710	0.0267	0.0097	0.0000
515	0.1246	2.6052	0.4785	715	0.0185	0.0068	0.0000
520	0.2707	3.0361	0.3344	720	0.0129	0.0044	0.0000
525	0.4735	3.4272	0.2476	725	0.0087	0.0030	0.0000
530	0.7291	3.7973	0.1859	730	0.0060	0.0021	0.0000
535	1.0186	4.1292	0.1345	735	0.0042	0.0017	0.0000
540	1.3445	4.4168	0.0940	740	0.0029	0.0012	0.0000
545	1.7042	4.6445	0.0635	745	0.0020	0.0008	0.0000
550	2.0915	4.8016	0.0420	750	0.0012	0.0004	0.0000
555	2.5006	4.8840	0.0278	755	0.0008	0.0004	0.0000
560	2.9200	4.8872	0.0192	760	0.0008	0.0004	0.0000
565	3.3360	4.8122	0.0133	765	0.0004	0.0000	0.0000
570	3.7359	4.6669	0.0103	770	0.0004	0.0000	0.0000
575	4.1019	4.4568	0.0088	775	0.0000	0.0000	0.0000
580	4.4218	4.1984	0.0082	780	0.0000	0.0000	0.0000
				Totals			
				(X_B, Y_B, Z_B)	99.0930	100.0000	85.3125
				(x_B, y_B, z_B)	0.3484	0.3516	0.3000

(continued)

Table II 5. 1931 CIE Color-Matching Functions ($\bar{x}_\lambda, \bar{y}_\lambda, \bar{z}_\lambda$) Weighted by Relative Spectral Energy Distribution ($H_\lambda \Delta\lambda$) of CIE Source C
($\lambda = 380 \cdots 780$ nm; $\Delta\lambda = 5$ nm)

Wavelength λ (nm)	$\bar{x}_\lambda H_\lambda$	$\bar{y}_\lambda H_\lambda$	$\bar{z}_\lambda H_\lambda$	Wavelength λ (nm)	$\bar{x}_\lambda H_\lambda$	$\bar{y}_\lambda H_\lambda$	$\bar{z}_\lambda H_\lambda$
380	0.0022	0.0000	0.0101	580	4.2084	3.9958	0.0078
385	0.0041	0.0002	0.0197	585	4.3859	3.6585	0.0063
390	0.0093	0.0002	0.0447	590	4.4920	3.3133	0.0048
395	0.0197	0.0005	0.0938	595	4.5265	2.9767	0.0043
400	0.0425	0.0012	0.2018	600	4.4745	2.6581	0.0034
405	0.0782	0.0020	0.3716	605	4.3617	2.3644	0.0025
410	0.1647	0.0045	0.7850	610	4.1622	2.0882	0.0013
415	0.3263	0.0092	1.5611	615	3.8863	1.8272	0.0008
420	0.6192	0.0184	2.9743	620	3.5349	1.5763	0.0008
425	1.0672	0.0363	5.1628	625	3.1074	1.3275	0.0004
430	1.4986	0.0612	7.3139	630	2.6548	1.0952	0.0000
435	1.8165	0.0929	8.9747	635	2.2358	0.8953	0.0000
440	1.9874	0.1312	9.9687	640	1.8468	0.7216	0.0000
445	2.0182	0.1728	10.3351	645	1.4909	0.5711	0.0000
450	1.9578	0.2213	10.3194	650	1.1743	0.4432	0.0000
455	1.8499	0.2786	10.1235	655	0.9058	0.3380	0.0000
460	1.6811	0.3469	9.6497	660	0.6807	0.2518	0.0000
465	1.4539	0.4279	8.8481	665	0.4965	0.1827	0.0000
470	1.1360	0.5291	7.4860	670	0.3542	0.1297	0.0000
475	0.8281	0.6562	6.0719	675	0.2548	0.0929	0.0000
480	0.5563	0.8088	4.7305	680	0.1846	0.0671	0.0000
485	0.3348	0.9773	3.5571	685	0.1270	0.0459	0.0000
490	0.1814	1.1790	2.6369	690	0.0855	0.0309	0.0000
495	0.0807	1.4197	1.9396	695	0.0581	0.0209	0.0000
500	0.0258	1.7004	1.4319	700	0.0408	0.0147	0.0000
505	0.0121	2.0462	1.0665	705	0.0283	0.0101	0.0000
510	0.0447	2.4165	0.7600	710	0.0197	0.0071	0.0000
515	0.1350	2.8223	0.5183	715	0.0136	0.0049	0.0000
520	0.2881	3.2309	0.3559	720	0.0093	0.0032	0.0000
525	0.4982	3.6052	0.2604	725	0.0062	0.0022	0.0000
530	0.7617	3.9671	0.1942	730	0.0042	0.0015	0.0000
535	1.0593	4.2941	0.1399	735	0.0029	0.0012	0.0000
540	1.3924	4.5742	0.0973	740	0.0020	0.0009	0.0000
545	1.7559	4.7853	0.0654	745	0.0014	0.0006	0.0000
550	2.1412	4.9157	0.0430	750	0.0008	0.0003	0.0000
555	2.5414	4.9636	0.0283	755	0.0005	0.0003	0.0000
560	2.9399	4.9204	0.0193	760	0.0005	0.0003	0.0000
565	3.3167	4.7844	0.0132	765	0.0003	0.0000	0.0000
570	3.6613	4.5736	0.0101	770	0.0003	0.0000	0.0000
575	3.9623	4.3051	0.0085	775	0.0000	0.0000	0.0000
580	4.2084	3.9958	0.0078	780	0.0000	0.0000	0.0000
				Totals			
				(X_C, Y_C, Z_C)	98.0705	100.0000	118.2246
				(x_C, y_C, z_C)	0.3101	0.3162	0.3737

Table II 6.

Selected Ordinates for Computing 1931 C.I.E. Tristimulus Values of Object Colours with Respect to C.I.E. Standard Sources A,B,C

Ordinate	Source A			Source B			Source C		
Number	X	Y	Z	X	Y	Z	X	Y	Z
1	444.0	487.8	416.4	428.1	472.3	414.8	424.4	465.9	414.1
2	516.9	507.7	424.9	442.1	494.5	422.9	435.5	489.4	422.2
3	544.0	517.3	429.4	454.1	505.7	427.1	443.9	500.4	426.3
4	554.2	524.1	432.9	468.1	513.5	430.3	452.1	508.7	429.4
5	561.4	529.8	436.0	527.8	519.6	433.0	461.2	515.1	432.0
6	567.1	534.8	438.7	543.3	524.8	435.4	474.0	520.6	434.3
7	572.0	539.4	441.3	551.9	529.4	437.7	531.2	525.4	436.5
8	576.3	543.7	443.7	558.5	533.7	439.9	544.3	529.8	438.6
9	580.2	547.8	446.0	564.0	537.7	442.0	552.4	533.9	440.6
10	583.9	551.7	448.3	568.8	541.5	444.0	558.7	537.7	442.5
11	587.2	555.4	450.5	573.1	545.1	446.0	564.1	541.4	444.4
12	590.5	559.1	452.6	577.1	548.7	448.0	568.9	544.9	446.3
13	593.5	562.7	454.7	580.9	552.1	450.0	573.2	548.4	448.2
14	596.5	566.3	456.8	584.5	555.5	451.9	577.3	551.8	450.1
15	599.4	569.8	458.8	588.0	559.0	453.9	581.3	555.1	452.1
16	602.3	573.3	460.8	591.4	562.4	455.8	585.0	558.5	454.0
17	605.2	576.9	462.9	594.7	565.8	457.8	588.7	561.9	455.9
18	608.0	580.5	464.9	598.1	569.3	459.8	592.4	565.3	457.9
19	610.9	584.1	467.0	601.4	572.9	461.8	596.0	568.9	459.9
20	613.8	587.9	469.2	604.7	576.7	463.9	599.6	572.5	462.0
21	616.9	591.8	471.6	608.1	580.6	466.1	603.3	576.4	464.1
22	620.0	595.9	474.1	611.6	584.7	468.4	607.0	580.5	466.3
23	623.3	600.1	476.8	615.3	589.1	470.8	610.9	584.8	468.7
24	626.9	604.7	479.9	619.1	593.9	473.6	615.0	589.6	471.4
25	630.8	609.7	483.4	623.3	599.1	476.6	619.4	594.8	474.3
26	635.3	615.2	487.5	628.0	605.0	480.2	624.2	600.8	477.7
27	640.5	621.5	492.7	633.4	611.8	484.5	629.8	607.7	481.8

Table II 6 (continued)

Ordinate	Source A			Source B			Source C		
Number	X	Y	Z	X	Y	Z	X	Y	Z
28	646.9	629.2	499.3	640.1	619.9	490.2	636.6	616.1	487.2
29	655.9	639.7	508.4	649.2	630.9	498.6	645.9	627.3	495.2
30	673.5	659.0	526.7	666.3	650.7	515.2	663.0	647.4	511.2
Factors:	0.03661	0.03333	0.01185	0.03303	0.03333	0.02842	0.03268	0.0333	0.03938

(from Committee on Colorimetry Optical Society of America, 1968)

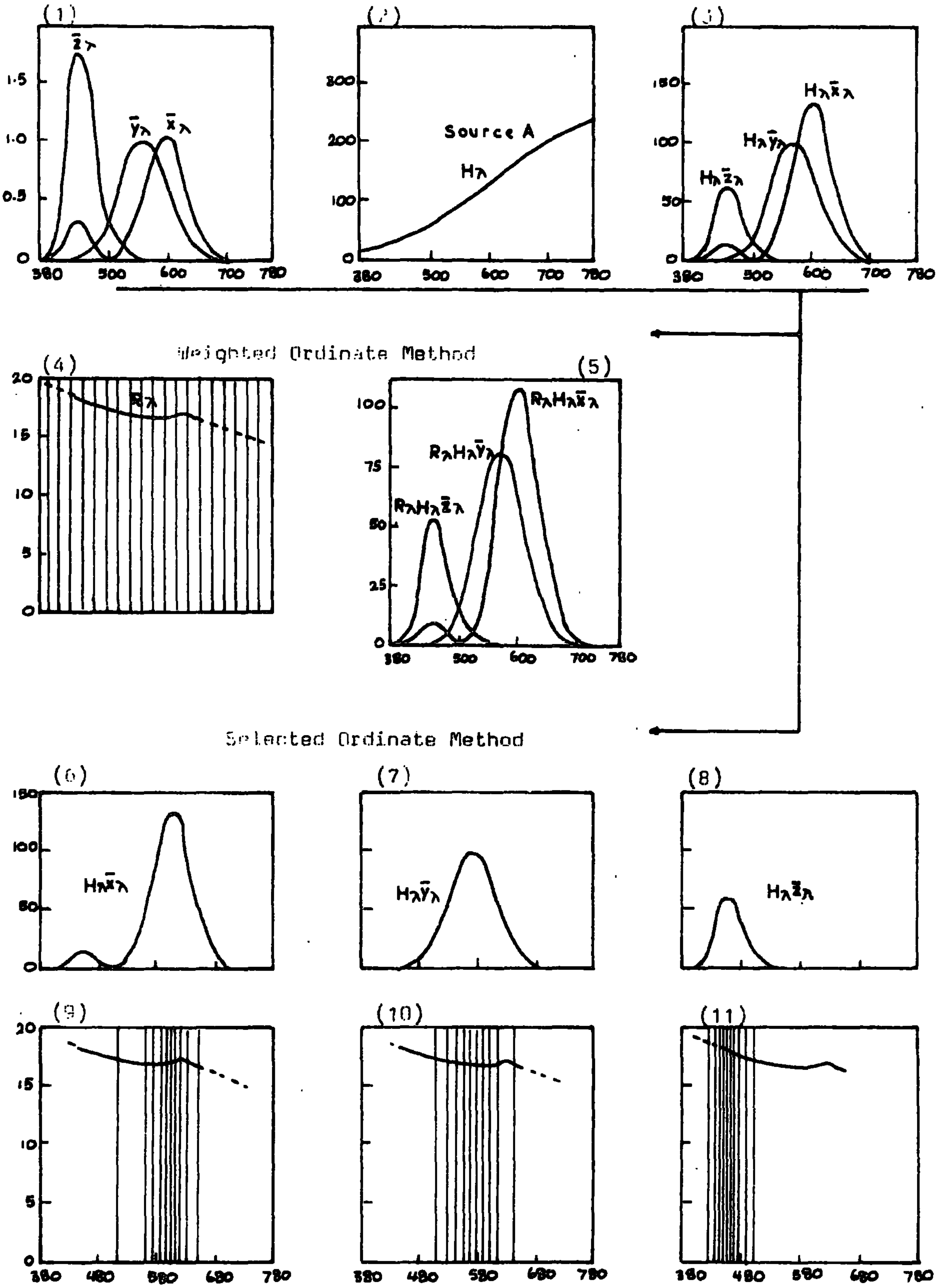


Figure II 18. Derivations of the tristimulus specifications of an object colour by Weighted Ordinate and Selected Ordinate methods.

Figure II 18. Illustration of the Computation of the Tristimulus Values of an Object Colour by the Weighted Ordinate and Selected Ordinate Methods.

(1) Colour-matching functions ($\bar{x}_\lambda$, $\bar{y}_\lambda$, $\bar{z}_\lambda$).

(2) Energy distributions of the C.I.E. source A (H_λ).

(3) Products of (2) with the colour-matching functions ($H_\lambda \bar{x}_\lambda$, $H_\lambda \bar{y}_\lambda$, $H_\lambda \bar{z}_\lambda$).

(4) Spectral reflectance (R_λ) of the object at equal wavelength intervals .

(5) Products of (3) and (4). The areas under the three curves give the tristimulus values X,Y and Z of the object by the Weighted Ordinate method .

(6)(7)(8) Selected ordinates derived from (3) for the C.I.E. source A.

(9)(10)(11) Spectral reflectance of the object at selected ordinates. Products of the sums by the appropriate factors give the tristimulus values X,Y and Z of the object by the Selected Ordinate method.

II 10. THE 1931 C.I.E. CHROMATICITY DIAGRAM

The 1931 C.I.E. chromaticity diagram with the spectral locus and the purple line is drawn on the x-y coordinates chart, as in Figure II 19. The chromaticity coordinates of the spectrum locus are included in Table II 3.

Chromaticity, the quality of a colour may be specified by a point in a plane diagram, the chromaticity diagram. This diagram represents the relative chromaticities of all colours in the same manner as a plane map represents the relative locations of various places on the earth. That is, the brightness of any colour is not taken into account in the diagram. The perfect white and black colours in fact will coincide at a poimt (achromatic point).

All colours represented by points on the spectrum locus are termed spectrum colours. All colours within the triangle defined by the points of two ends (380 nm and 780 nm) of the spectrum locus and the point of the achromatic stimulus are called non-spectral colours. Colours having chromaticities (chromatic points) represented within the curve and outside the non-spectral triangle are called spectral colours . There is no colour outside the spectrum locus and the purple line (the Science of Color by the Committee on Colorimetry of the Optical Society of America, 1968).

II 11. DOMINANT WAVELENGTH AND EXCITATION PURITY

Although the quality of a colour can be completely specified by its tristimulus values X,Y,Z (known as the trichromatic system) these numerical values do not provide a suitable way to visualize the chracter of the colour. A given colour can also be characterised by additional numerical values in terms of the dominant wavelength and excitation purity (known as the monochromatic system).

It is in practice easier to get a general picture of a colour when it is expressed in terms of its dominant wavelength, purity and tristimulus Y value (brightness) with respect to a particular light source.

The dominant wavelength of a colour is the wavelength of spectrally pure radiant energy (spectrum colour) that, when additively mixed in suitable proportions with a specified white light yields a match with the given colour. The dominant wavelength of a colour correlates in an approximate way with the general term, hue. Thus, in general, colours of constant dominant wavelength would be said to have the same hue. The derivation of the dominant wavelength of a sample colour is shown in Figure II 20. That is the wavelength at the intersection point of the spectrum locus with the straight line drawn from the achromatic point through sample point.

If a sample point lies in the non-spectral triangle then the wavelength corresponding to the intersection is the complementary wavelength (λc) of the colour. The chromaticity of a spectral colour is specified by its dominant wavelength (λd) and excitation purity (Pe), and the chromaticity of a non-spectral colour is specified by its complementary wavelength (λc) and excitation purity (Pe).

The determination of dominant wavelength from the chromaticity coordinates can also be carried out by computation,making use of tabulated ratios prepared by Judd (1933).

Radiant energy of a single wavelength is said to be spectrally pure. In terms of the chromaticity diagram, a dominant (or complementary) wavelength is constant for all points on any straight line passing through an achromatic point, whereas purity increases linearly with increasing distance from zero at the achromatic point to the maximum (1 or 100%) on the spectrum locus (or on the purple line).

The excitation purity (Pe) is defined as a ratio by the following equivalent expressions:

$$Pe = \frac{x_1 - x}{x - x} = \frac{y_1 - y}{y - y}$$

where x_1 , y_1 and x , y are coordinates of the sample point and specified achromatic point respectively ; $x\lambda$, $y\lambda$ are coordinates of the dominant or complementary wavelength at the intersection point.

When the straight line passing through the illuminant point and sample point is nearly horizontal the second formula will become less accurate and vice versa when the line is nearly vertical.

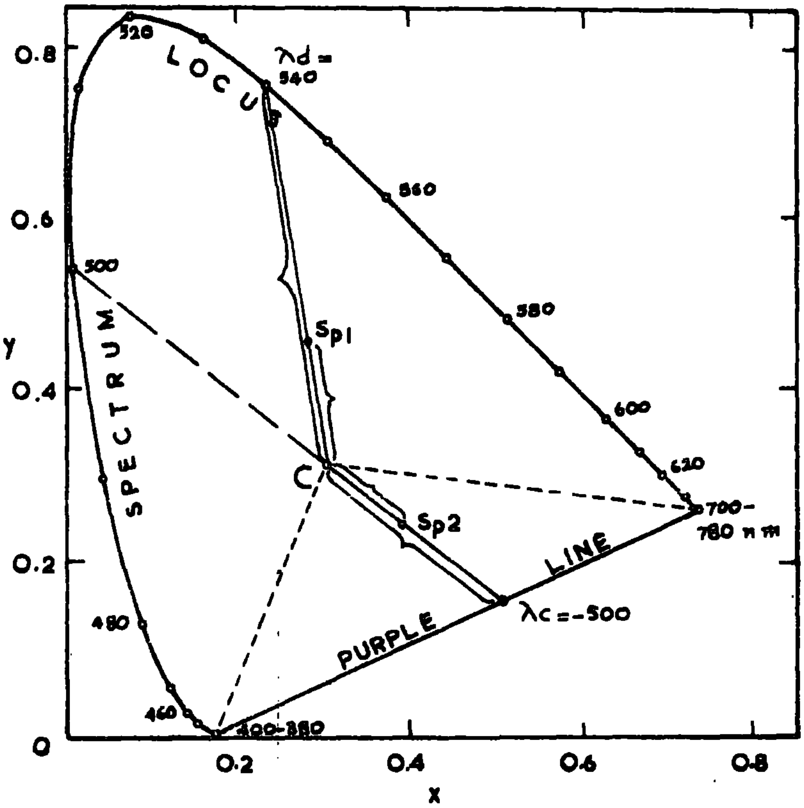


Figure II.20. Graphical determination of dominant (or complementary) wavelength and excitation purity of a sample colour in the C.I.E. chromaticity diagram.

II 12. COLOUR DISCRIMINATION

It has been shown that the standard C.I.E. system allows all colours to be specified quantitatively in terms of tristimulus specifications. As a consequence of the application of the system it is necessary to specify colour differences. The reason for this is the fact that small differences in XYZ figures do not give directly an indication of the visual effect of the colour difference.

There are limits to the precision and accuracy within which colours were matched by the standard observer, as described in previous sections, with a purely physical instrument. In other words there are limits within which colours are not discriminated to the visual sensation.

This means that the C.I.E. system is not uniform and not quite suitable for colour difference specification without additional standardization or transformation into a uniform scale. Therefore, there is need of an additional system for specifying colour differences.

A number of different methods of calculating colour differences have been tried by various workers : Judd (1935); Wright (1941); Nickerson (1944 & 1950); Balinkin (1941); Godlove (1951) ; MacAdam (1942 & 1943); and others.

All of these methods are based on measurements of intervals (distances) between colours. Three general approaches to the problem of establishing a uniform colour space have been proposed. The first of these is a linear transformation of the C.I.E. chromaticity chart into a so called Uniform Chromaticity (UCS) diagram (Judd , 1935 ; MacAdam, 1937; Hunter, 1941; Committee on Colorimetry, 1963). Combination of this transformation with a lightness scale yields a colour difference formulation of limited usefulness.

The second approach, suggested by Nickerson (1936 & 1950), Balinkin (1941) and Godlove (1951), is the transformation of C.I.E. data into a so called uniform colour spacing as laid down in the Munsell Renotation and DIN systems. A colour difference specification can be defined in terms of hue, value and chroma (Munsell) or Farbton, Sättigung and Dunkelstufe (DIN). The transformation of C.I.E. data into these units can only be made by means of graphical representation.

The third approach which is the more promising and easiest way of handling the problem is to use the colour discrimination data, as obtained by MacAdam (1942 & 1943), since no system is sufficiently uniform and no simple set of transformation equations can distort the C.I.E. space into a uniform space. Various methods proposed by MacAdam, based on his discrimination ellipses have found wide acceptance in industrial tolerance specification.

The work of MacAdam was extended by Brown and MacAdam (1949) and Brown (1957). Many workers, Moon (1943), Davidson and Friede (1952), Brown (1951) and Friele (1961) analysed the MacAdam colour discrimination data and calculations based on these data were found to correlate with the visual results much better than do those based on other methods.

In this present work the MacAdam discrimination data were used to compare nearly identical colours and colour differences of minerals. From the literature the necessary basic information is therefore summarised below.

MacAdam (1942) investigated visual sensitivity to colour differences by studying just equally noticeable differences of colour matches about a colour centre. Twenty-five representative colour centres scattered throughout the colour domain were used in colour matching to determine noticeability of colour differences at constant luminance.

Extensive tests with a colour discrimination apparatus have indicated that the just noticeable differences of colour are directly related to the corresponding standard deviations of colour matching. The standard deviation of colour matching has therefore been adopted as a satisfactory measure of the noticeability of colour differences.

The standard deviations (root mean square of individual deviations from the average setting) of MacAdam's colour matching were plotted on the C.I.E. chromaticity diagram and all were in the form of ellipses of varying size as shown in Figure II 21. These ellipses represent the noticeability of chromaticity variations in all directions from the chromaticities indicated at the centres of the ellipses. That is, these ellipses indicate the noticeabilities of conceivable combinations of purity and dominant wavelength differences.

Silberstein and MacAdam (1945) deduced from discrimination ellipses that if the colour matches were not confined to chromaticity variations (that is the luminance variations are also involved) the surfaces in colour space representing the standard deviation of colour matching would be ellipsoids. Silberstein (1946) proved that the standard deviation figures were in the form of ellipsoids in colour space and gave formulae from which the coefficients of the ellipsoids could be determined.

The ellipses, therefore, are regarded as the constant luminance cross sections of the ellipsoids. MacAdam (1942) describes

as/ that C.I.E. chromaticity diagram appears convenient as possible for the representation of relative chromaticity difference, in the manner that ~~as~~ a plane map represents the relative locations of various places on the earth.

Each ellipse is measured by the lengths of the principal semi-axes 'a' and 'b' and the angle of inclination θ of the major axis from the horizontal as shown in Figure II 22. These values of MacAdam's discrimination ellipses are tabulated in Table II 7.

The sizes, shapes and orientations of the ellipses vary throughout the chromaticity diagram, in a somewhat systematic manner. These trends encouraged the interpolation of ellipses representing colours equally noticeably different from any other fixed colours. MacAdam (1943) has prepared contour diagrams in order to evaluate colour difference specifications for most practical purposes. They are reproduced in Figures II 23, II 24, and II 25, and can be found in the original paper by MacAdam (1943) or in 'Color Science' by Wyszecki and Stiles (1967).

Each of the twenty-five ellipses representing the known standard deviations of colour matching, according to MacAdam, is represented by the equation

$$g_{11}\ dx^2 + g_{12}\ dx.dy + g_{22}\ dy^2 = 1.$$

where dx is the distance of the x coordinates of the centre of the ellipse and any point on the ellipse; dy is the difference of the y coordinates for the the same pair of points; and g_{11}, g_{12} and g_{22} indicated in the diagrams are constants for each ellipse.

These constants can be determined from the length dx_0 of the horizontal radius of the ellipse (for which dy = 0), the length dy_0 of the vertical radius of the ellipse (for which dx = 0), and the lengths dp and dq of the radii which are inclined at ± 45° from the horizontal

$$g_{11} = 1 / dx_0^2$$
$$g_{12} = 1 / dp^2 - 1 / dq^2$$
$$g_{22} = 1 / dy_0^2 .$$

The orientation θ and lengths a and b of the ellipse may be derived from the values of the coefficients g_{11}, g_{12}, g_{22} indicated for that central colour

$$\tan 2\theta = 2g_{12} / (g_{11} - g_{22}).$$

$$\theta < 90° \text{ when } g_{12} < 0 ,$$
$$\theta > 90° \text{ when } g_{12} > 0 .$$

$$1 / a^2 = g_{22} + g_{12} \operatorname{Cot}\theta$$
$$1 / b^2 = g_{11} - g_{12} \operatorname{Cot}\theta$$

From these values an ellipse may be constructed. This ellipse is the equi-luminance cross section of the ellipsoid in colour space.

Every colour on the surface of the ellipsoid represents just equal noticeabilities of total colour difference from the central colour. Any colour which would plot within the ellpsoid would be visually indistinguishable from the colour plotted at the centre of the ellipsoid.

According to MacAdam the necessity of constructing such ellipses will be almost completely eliminated by the method which follows:

The ratio of any chromaticity difference colour matching is denoted by ds. Then

$$ds^2 = g_{11}\ dx^2 + 2\ g_{12}dx.dy + g_{22}\ dy^2.$$

In the calculation each of the numerical values, g_{11} , g_{12}, g_{22} for the region intermediate between the two chromaticities , is multiplied by 10,000.

For example, if two colours A and B are to be compared with each other the differences of their chromaticities and appropriate coefficients found from the contour diagrams are substituted in the above equation and say ds = n . This indicates that the two colours A and B exhibit a difference of chromaticity n times as great as the standard deviations of colour matching.

MacAdam (1943) described other methods of calculating colour differences for particular problems. Brown and MacAdam (1949) studied the visual sensitivities to combined chromaticity and luminance differences and determined the coefficients and axes of ellipsoids derived from standard deviations of colour matches. The cross sections of all ellipsoids correlate well with results previously published by MacAdam (1942).

Thus the precision of colour matching is commonly described by colour-matching ellipses. To obtain colour discrimination specifications, numerous colour-matching experiments have been made later by several workers: Stiles (1946), Brown (1951, 1952 & 1956), MacAdam (1950), Wyszecki and Fielder (1971), Wyszecki (1972). For a given colour centre the ellipses of different observers are not in close agreement, but there is an overall resemblance and a general agreement between ellipses obtained by different investigators.

It has been found that the sizes, shapes and orientations of the ellipsoids depend upon many physical and psychophysical factors such as the luminance level, field size, surroundings, adaptation , portion of the retina, technique of observation, etc.

The effects of colour-matching field size, chromatic surround and luminance level on colour discrimination ellipsoids have been studied by Brown (1951 & 1952). The effect of luminance level is already described in section II 4.

From the work of Brown there are some interesting facts to be noted here. As a rule the colour of the field surrounding the matching field has a quite noticeable effect on colour discrimination when the matching field is small. Best discriminations obtained when the surround has the same chromaticity as the matching field. This agrees with results reported by Schonfelder (1933).

In general, large fields of view (10°) allow better colour discrimination than fields covering only the foveal region (2°). This result is in agreement with observations by Judd (1930, Lobanova and Rautian (1949). The discrimination ellipsoids obtained for large-field and small-field viewing are similar in orientation and shape, but differ in size. The orientation and shape of the ellipsoids (2° matching field) are also affected by the colour of the surround.

However, at the present time the work of MacAdam, and Brown and MacAdam has found wide acceptance for colour discrimination purposes in many industrial and research problems.

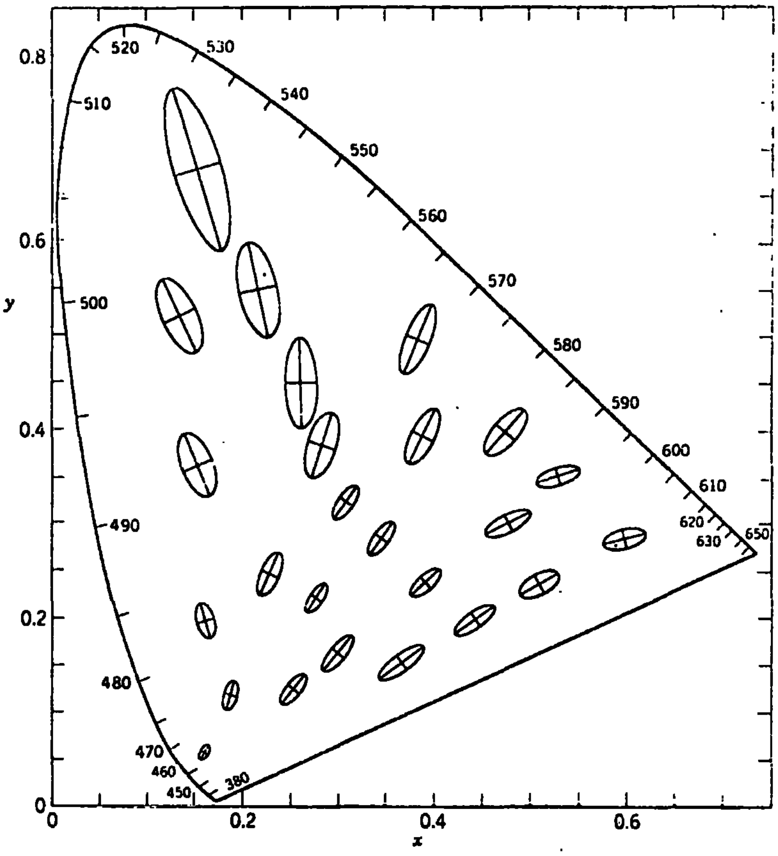


Figure II 21. MacAdam's discrimination ellipses

(ten times enlarged).
(from Wyszecki & Stiles 1967)

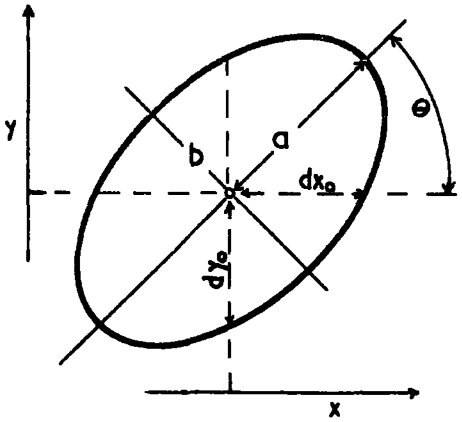


Figure II 22. Measures of a discrimination ellipse.

a = major semiaxis

b = minor semiaxis

dx_0 = horizontal radius (for which $dy = 0$)

dy_0 = vertical radius (for which $dx = 0$)

θ = angle in degrees

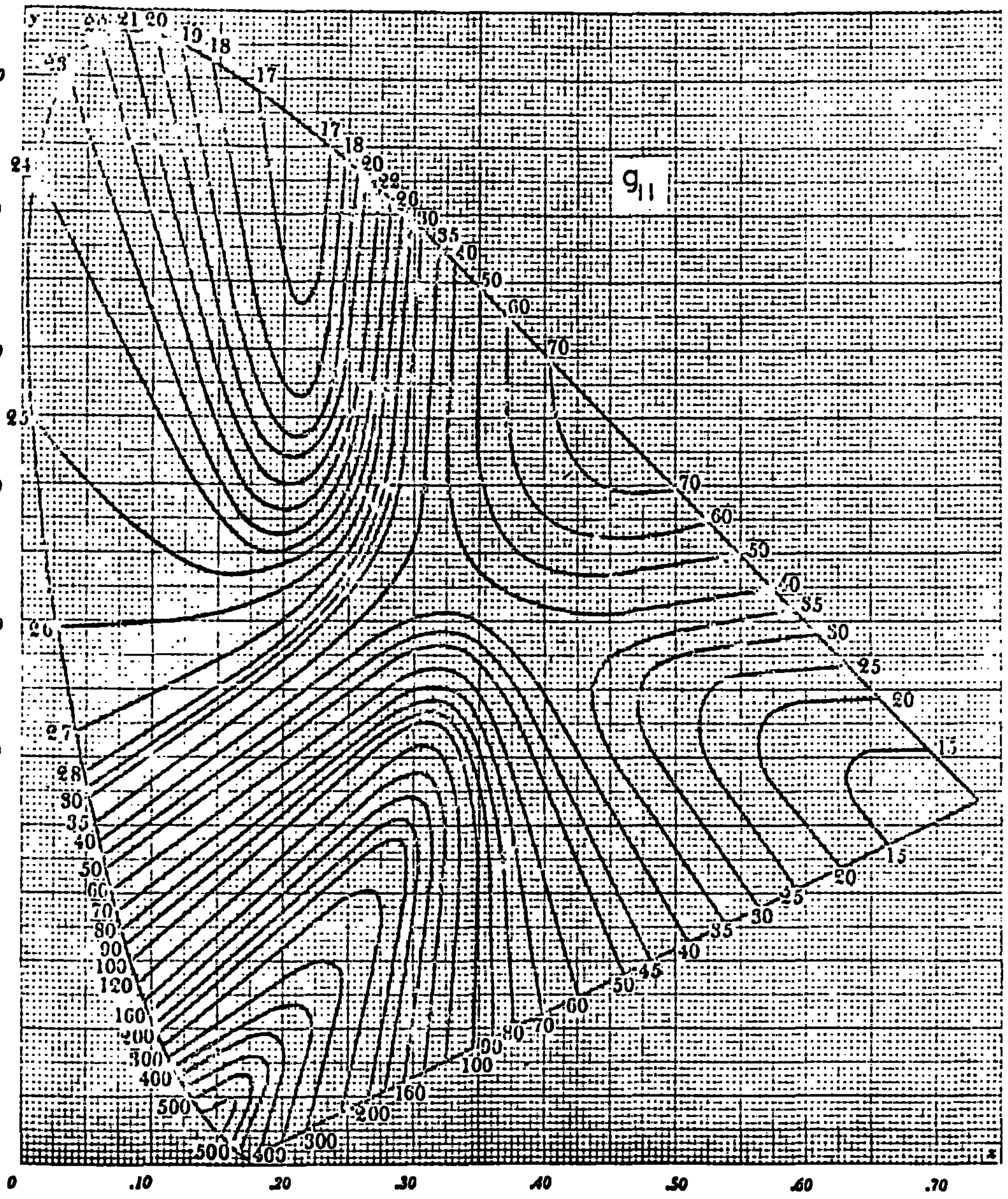


Figure II 23. Contour lines of constant metric coefficient g_{11} for various locations in the C.I.E. chromaticity diagram (from MacAdam 1943).

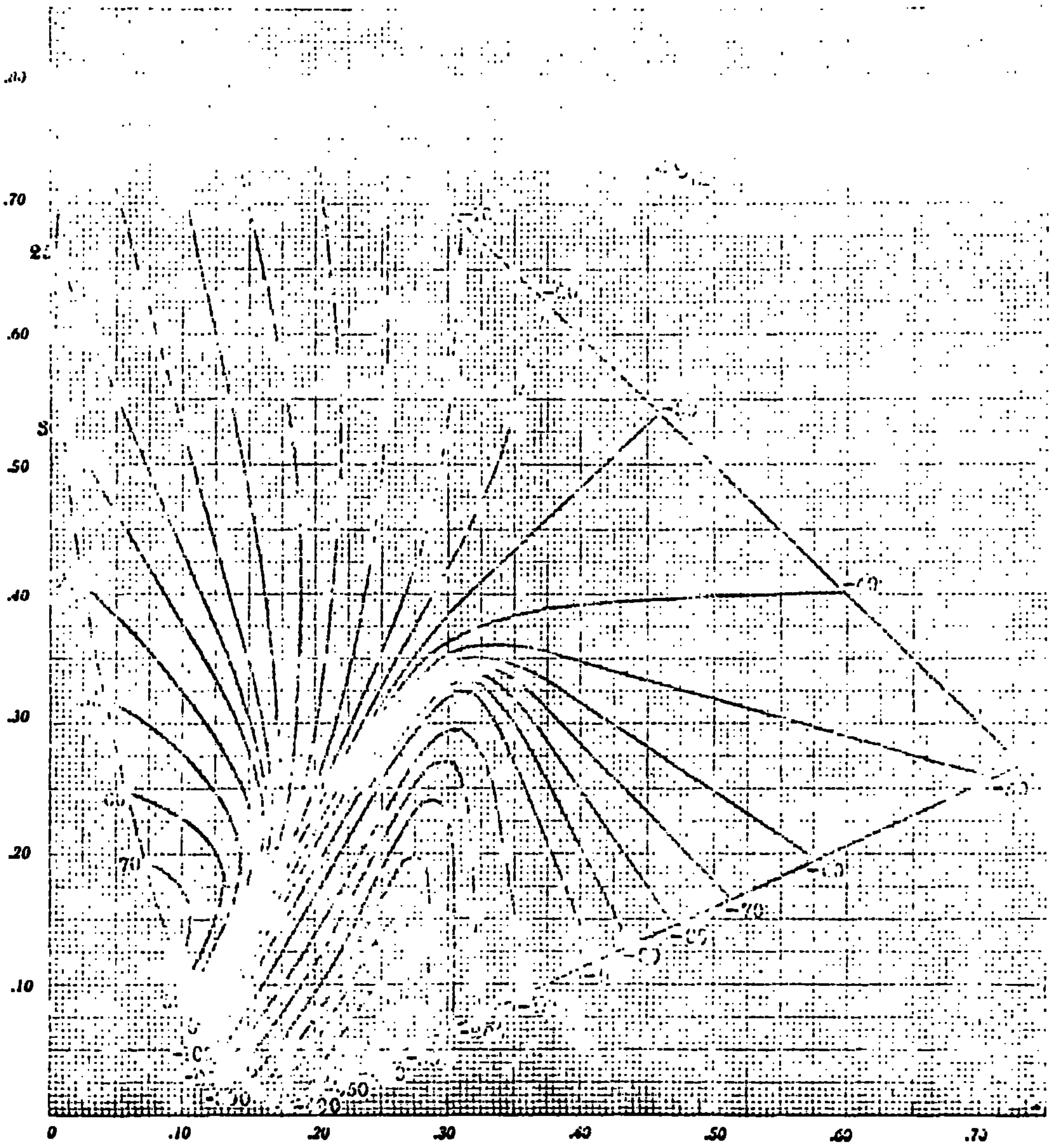


Figure II 24. Contour lines of constant metric coefficient $2g_{12}$ for various locations in the C.I.E. chromaticity diagram (from MacAdam 1943).

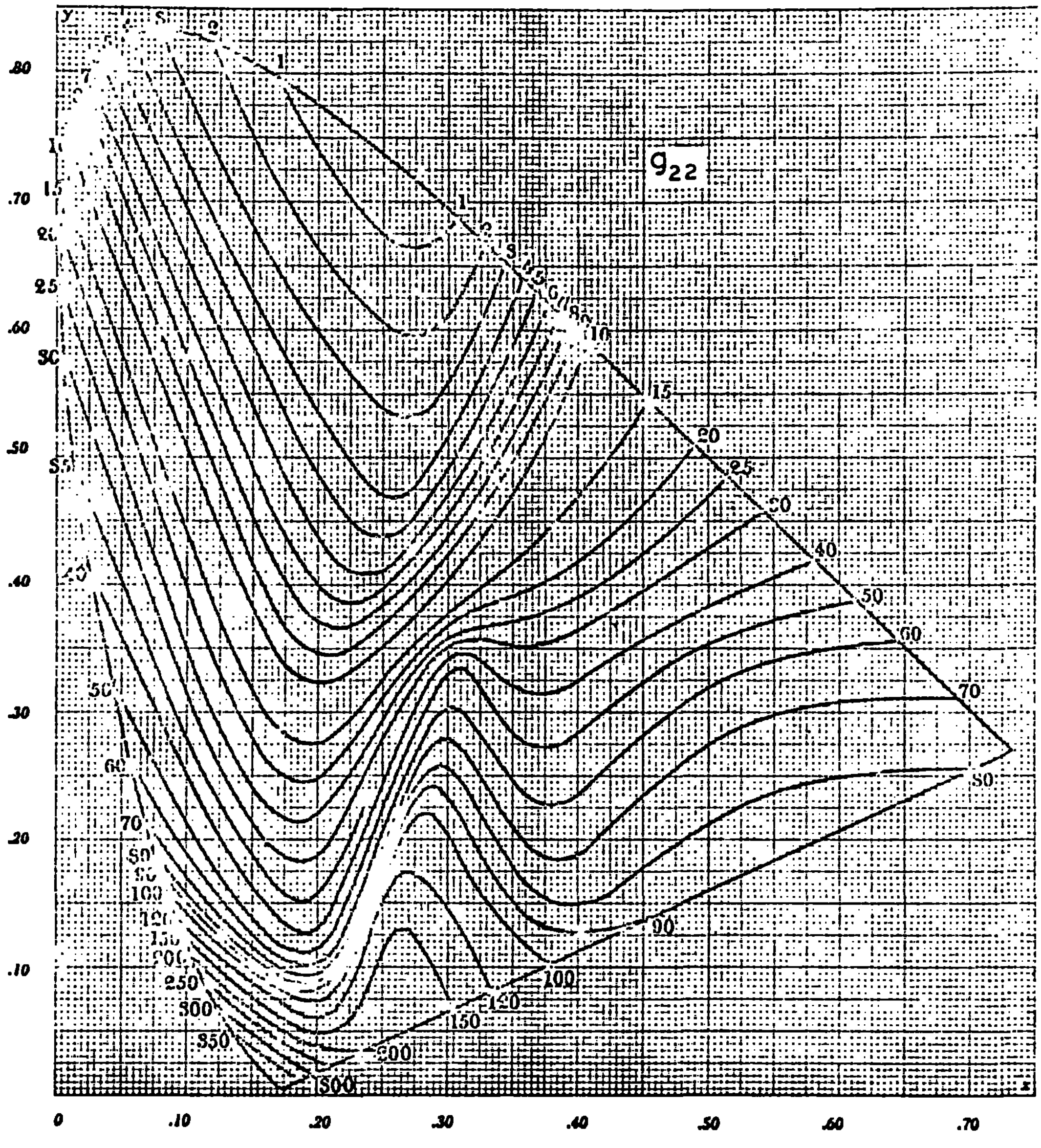


Figure II 25. Contour lines of constant metric coefficient g_{22} for various locations in the C.I.F. chromaticity diagram (from MacAdam 1943).

III. SPECTRAL REFLECTIVITY MEASUREMENTS

III 1. PREVIOUS WORK

The measurement of reflectivity is the only reliable quantitative method in ore microscopy since reflectivity is the most important property of a reflecting material. Significant contributions to the theory and practice of such measurements were made by Folinsbee (1949), Bowie and Taylor (1958), Gray and Millman (1960 & 1962) , Cameron (1961), Bowie (1962), Jones (1962), Nichol (1962), von Gehlen and Piller (1964), and Nichol and Phillips (1964), using photoelectric microphotometers. The photoelectric microphotometer replaces the visual photometer used by previous workers, Hallimond (1957) and Leonard (1960) and others.

The divices and technique of reflectivity measurement for the visible spectrum have been improved in recent years . Unfortunately there are still marked variations in reflectivity values quoted for specific minerals by different workers, as Cameron (1961) points out and as described by Nichol and Phillips (1964). Causes of error in reflectivity and in the calculation for refractive index and absorption coefficient have been discussed by Piller and von Gehlen (1964). Errors due to glare effects from optical parts of the microscope and correction procedures to reduce the errors have been described by Bowie and Henry (1964) and Piller (1965).

According to Piller and von Gehlen (1964) relative error of about ± 0.5% to ± 1% are unavoidable even under most favourable conditions. Cameron (1963) claims an accuracy of ± 0.2% .

An important method of the linearity test of a photomultiplier used for reflectivity measurement has been given by Phillips and Bradshaw (1965).

The interest in reflectivity measurement has been increased to some extent to study other physical properties as well as the chemical composition. By measuring reflectivities of a mineral in air and oil its refractive index (n) and absorption index (K) can be derived, provided that the measured values of reflectivity (R) are accurate (Cameron, 1961; von Gehlen and Piller, 1964; Bradshaw, Phillips and Smith, 1965).

Bowie and Taylor (1958) have proposed a system of ore mineral identification from two quantitative values of reflectivity and micro-hardness. On this basis an unknown mineral can be assigned to one of the five main groups of similar composition and structure (oxides ; cobalt-nickel-iron; sulphides and arsenides; other sulphides; sulphosalts; and metals), and identification thereafter can be made with the aid of other observable properties such as colour, anisotropism, bireflection, etc.

Cameron (1963) has introduced the method of determination of optical symmetry from reflectivity measurements of randomly oriented grains of anisotropic ore minerals in monochromatic light (549 nm). From such measured data the recognition of R_w of uniaxial minerals and R_m , corresponding to $R\beta$, of biaxial minerals can be made. The optical signs are then classified by a suggested convention analogous to that used for transparent minerals. Cameron suggested that with an accuracy of ± 0.2% the value of reflectivity corresponding to the ordinary ray (R_w) for any uniaxial mineral can be used as a prime basis of mineral identification. For minerals sensibly of lower symmetry , a value of R_m, the reflectivity for Y direction, of biaxial minerals can also be determined and used in identification.

Cervelle et al (1968) and Vaasjoki (1969) pointed out an interesting optical phenomenon of reverse bireflectance in a few ore minerals such as mawsonite and loellingite, showing the change of optic signs at some definite wavelength of the visible range. This new phenomenon has not been solved so far.

Vaughan (1969) and Demirsoy (1969) have made attempts to explain variations in reflectivity and composition in zoned bravoites. Engin (1969) showed a correlation between reflectivity and composition of chromite ores from Turkey. $Cr_2 O_3$ has a positive correlation with measured reflectivity values at the 99.9 confidence level. That is reflectivity increases linearly with increasing of Cr_2O_3 weight percent.

Attempts have been made to correlate reflectivity and compositional variations of synthetic sphalerites by Akinci (1970) and of synthetic tetrahedrite-tennantite series by Hall (1972).

Burns and Vaughan (1970) have shown the existance of correlation between reflectivity variations and effective number of electrons in pyrite type compounds and have explained this relation for other solid solution series of ore minerals.

Reflectivity data of most ore minerals can be found in the books by C. Schouten (1962) and by Ramdohr (1969). More important spectral reflectivity values for four wavelengths have been compiled recently in ' International Tables for the Microscopic Determination of Crystalline Substances Absorbing in the Visible Light ' published by the Commission on Ore Microscopy (1970), and ' Tables for Microscopic Identification of Ore Minerals ' by Uytenbogaardt and Burke (1971).

III 2. PRESENT WORK

Specimen Preparation

The polishing procedure of specimens in this laboratory was according to that described in the paper by Nichol and Phillips (1964). For readily tarnishing minerals such as bornite, specimens were kept in a vacuum desiccator immediately after their final polishing.

Transparent, low-absorbing minerals were cut in such a way that the lower surfaces were non-parallel to the upper ones to reduce the back reflection. Facetted gemstones were measured without any preparation other than mounting and levelling in a piece of black plasticine and cleaning the surface thoroughly with very soft tissues.

Apparatus and Technique

The reflectivity apparatus in this laboratory was originally used and described by Nichol (1962), Nichol and Phillips (1964), Phillips and Bradshaw (1966), Burton (1967) who modified the photomultiplier to improve linearity and stability, Engin (1968) who replaced the galvinometer with the better digital voltmeter, and Tugal (1969).

Figure III 1 shows the general arrangement of the present reflectivity apparatus. To increase the accuracy and precision of results instrumental and operational improvements were made as follows:

Two specimen changer-stages which can be fixed one after the other on the rotating stage of the microscope were made. Polished sections of a standard and specimen were levelled with plasticine on flat metal plates. They were fixed on the specimen changer-stages by means of magnets, after choosing areas free from imperfections. By this way whenever measurements were made the same area of standard and specimen was measured. These changer-stages are extremely useful to increase the accuracy and precision and also to save time in the measurement for various wavelengths.

The microscope, photomultiplier tube, illuminator and continuous monochromator, all in optical alignment, were rigidly fixed by clamping to a wooden board to improve the mechanical stability.

All electrical units, which are voltage stabilizer (TSV 70), photomultiplier (EMI type 6094B), stabilized EHT power supply unit (type E2), digital voltmeter (DM 2005), were checked and found the following operational and conditional requirements for accurate measurement.

(1) The calibrated digital voltmeter should be switched on at least 15 minutes before taking a reading.

(2) The voltage stabilizer for the light source must be left switched on for about 2 hours at a required voltage before making any measurement. The result of a check is shown by a curve in Figure II 2.

(3) The stabilized EHT power unit at a suitable voltage (depending on reflectivities of specimen and standards) range must be left switched on continuously for daily task so that a steady sensitivity of the photomultiplier was obtained.

(4) The working room chould be in a reasonably constant temperature (about 21°C) because the sensitivity of the

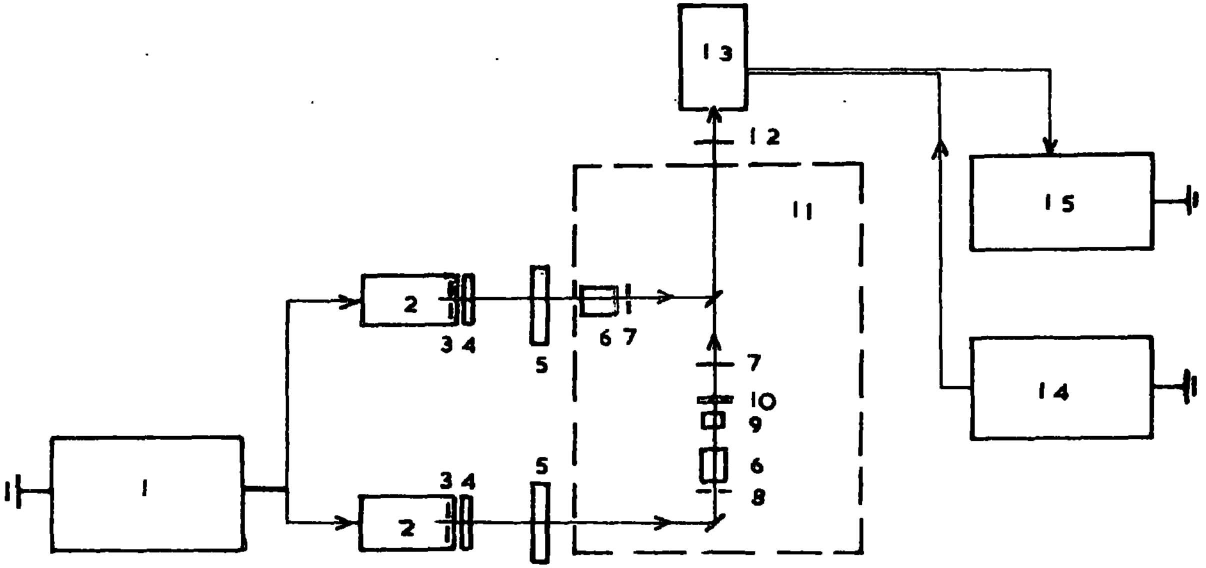


Figure III 1. Schematic diagram of the apparatus for reflectivity and transmiticity measurements.

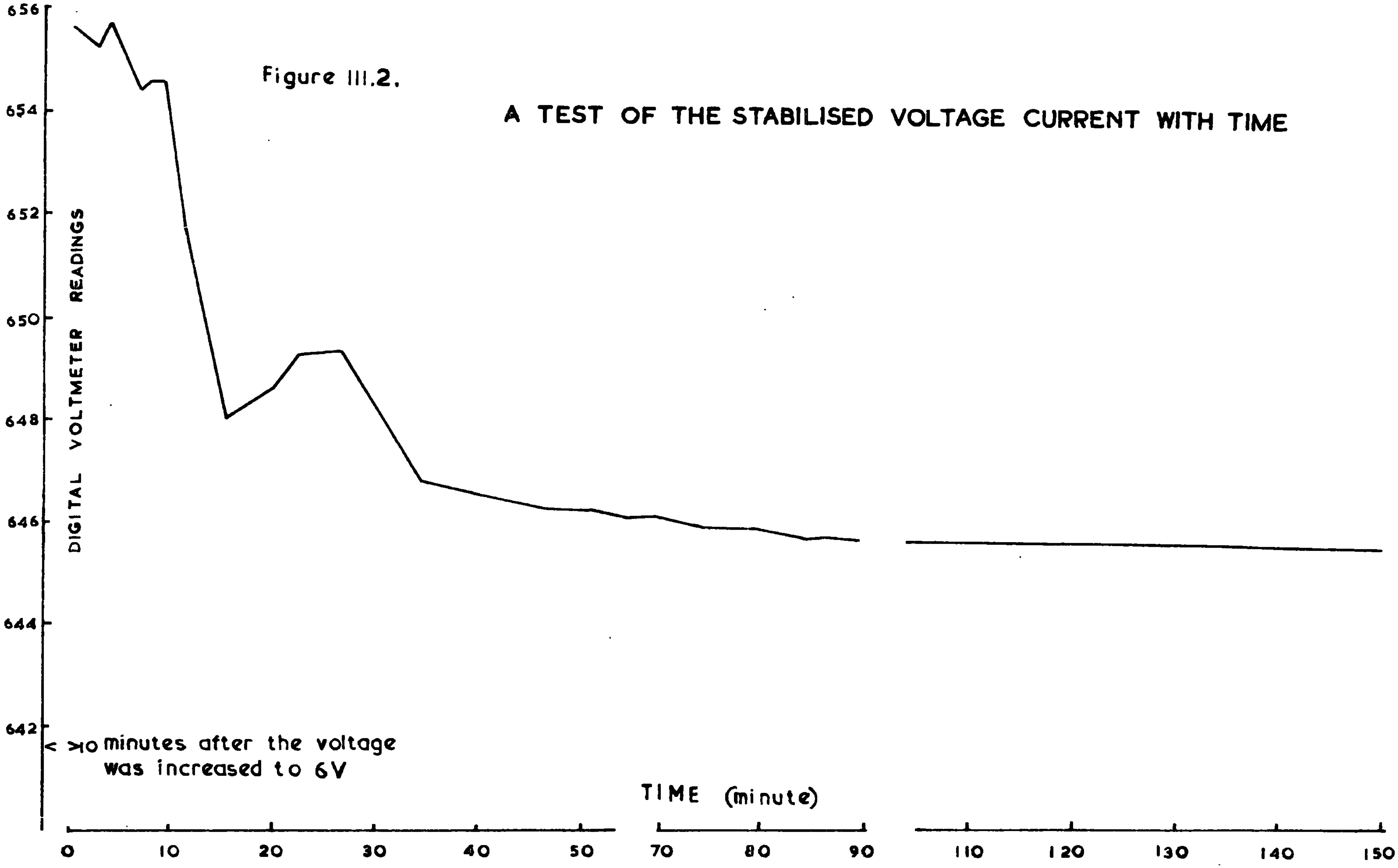
1. Voltage stabiliser TSV 70
2. Illuminator
3. Field diaphragm
4. Heat absorbing glass filter
5. Continuous monochromator
6. Polarizer

7 & 8. Meassuring diaphragm

9. Condenser
10. Specimen
11. Microscope
12. Photometer stop
13. Photomultiplier tube Type EMI 6094B
14. Stabilised EHT power supply unit Type E2
15. Digital voltmeter DM 7999

Figure III.2.

A TEST OF THE STABILISED VOLTAGE CURRENT WITH TIME



< >10 minutes after the voltage
was increased to 6V

photomultiplier became unstable when the room was hot.

(5) No stray light should be around the photomultiplier tube and the miceoscope.

A test of the linearity of the photomultiplier was made according to the method described by Bradshaw and Phillips (1965), and no significant deviation from linearity was found.
Spectral characteristics of the photomultiplier and continuous monochromator are according to the manufacturer's recommandations and are also given in Bradshaw's Ph.D. Thesis (1964).

When the above instrumental conditions were satisfied spectral reflectivity measurements were made using suitable standards. During operation care was taken in every case such as exact levelling polished surfaces, selecting measuring areas, exact focusing onto the surface and accurate setting wavelengths of the sliding monochromator.

At each wavelength three readings of the digital voltmeter were taken for standard, specimen and finally the black box. Measuring the same areas of the standard and of the specimen with the aid of the specimen changer-stages the procedure was repeated for various wavelengths.

Reflectivity value (in percent) corrected for the primary glare effect is computed by the following formula for a given wavelength.

$$R_{\lambda(sp)} = \frac{R_{\lambda}(st)\ \ V_{\lambda}(sp) - V_{\lambda}(b)}{V_{\lambda}(st) - V_{\lambda}(b)}$$

where $R_{\lambda}(sp)$, $R_{\lambda}(st)$ = reflectivity of specimen and standard, respectively, at wavelength λ .

$V_{\lambda}(sp)$, $V_{\lambda}(st)$, $V_{\lambda}(b)$= digital voltmeter readings for specimen, standard and black box, respectively, at wavelength λ .

When a large number of measurements is made it may be preferable to use a PL / 1 computer program, as given in Appendix III 1, to carryout the calculation.

Accuracy and Precision

The reflectivity apparatus of this laboratory and the technique applied provide accurate and high precision results with a small limit of error. Results of silicon standard (NPL) measured against carborundum standard (NPL) are given in Table III 1.

The accuracy and precision of reflectivity values for quantitative colour measurement are discussed in Chapter VI.

Table III 1. Accuracy and Precision of Spectral Reflectivity Measurements

R% of Silicon (NPL) Measured Against Carborundum (NPL)

Si(NPL) Values	Wave-length	Measured Values I	II	III	IV	Mean R%	Mean deviation	Standard Deviation	Coeff. of Variation	% Error	Accuracy
43.1	440	43.19	43.12	43.21	43.15	43.17	±.03	.035	.08	.16	.002
41.3	460	41.54	41.56	41.51	41.68	41.57	±.05	.065	.16	.65	.007
39.9	480	40.02	40.07	40.03	40.17	40.07	±.05	.059	.15	.42	.004
38.9	500	38.93	38.99	38.98	39.10	39.00	±.05	.062	.16	.26	.003
38.0	520	38.07	38.09	38.07	38.20	38.11	±.05	.054	.14	.29	.003
37.2	540	37.26	37.29	37.39	37.41	37.34	±.06	.064	.17	.37	.004
36.6	560	36.62	36.65	36.62	36.75	36.66	±.05	.053	.14	.16	.002
36.0	580	35.96	35.96	35.99	36.10	36.00	±.05	.058	.16	.00	.000
35.5	600	35.50	35.48	35.53	35.62	35.53	±.04	.054	.15	.08	.001
35.1	620	35.20	35.14	35.16	35.29	35.20	±.05	.058	.16	.28	.003
34.8	640	34.68	34.54	34.56	34.67	34.61	±.15	.063	.18	.55	.005
34.4	660	34.83	34.33	34.49	34.50	34.54	±.29	.182	.53	.41	.004

about 21° C room temperature.

III 3. SPECTRAL REFLECTIVITY OF GEMSTONES

Gem varieties of natural minerals, artificial materials and some organic substances of beauty to mankind have been used as gemstones. The qualities of colour and reflection are the most striking and important properties of gemstones.

The colour of a gemstone is used as an aid for identification and also made use of for classifying into different qualities. The colour may be the most important property to assess the relative value of very similar stones, other things being equal.

To measure the colour quantitatively the first problem is to obtain the spectral reflection or transmission values of a gemstone. Once a gem mineral has been facetted, the transmitted light method of determining its spectral transmission is difficult or impossible to apply, because of its odd shape, therefore it was first decided to make an investigation of the use of reflected light method.

The reflectivity of an isotropic gemstone is given by Fresnel's equation

$$R\,\% = \frac{(n - N)^2 + k^2}{(n + N)^2 + k^2} * 100.0$$

where n and k are the index of refraction and absorption coefficient, respectively, of the absorbing mineral. N is the refractive index of the surrounding medium (air $N = 1$), $k = nK$ and $k / \lambda_0 = K / \lambda$ where K is the absorption index, λ_0 is the wavelength in air and λ is the wavelength in mineral. The index of refraction and absorption coefficient of a gemstone vary with wavelength and therefore reflectivity varies accordingly.

For uniaxial gemstones, the reflectivities R_o and R_e of the principal vibration directions are related in the same way to refractive indices n_o and n_e and the absorption coefficients k_o and k_e. Bireflectance of a gemstone is $R_o - R_e$ if it is optically negative or $R_e - R_o$ if it is optically positive.

Similarly, a biaxial gemstone has three principal reflectivities $R\alpha$, $R\beta$ and $R\gamma$ corresponding to $n\alpha\ k\alpha$, $n\beta\ k\beta$ and $n\gamma\ k\gamma$ respectively. The bireflectance is $R\gamma - R\alpha$. If $R\beta$ is nearer to $R\alpha$ than $R\gamma$ the stone is said to be optically positive and if $R\beta$ approaces $R\gamma$ it is optically negative.

As in ore microscopy, the reflection principles for normally incident plane-polarised light are applied to gemstones and the reflectivity measurements are also applicable to polished surfaces of gemstones.

In an ideal brilliant cut stone the total back reflection occurs as shown in Figure III 3. A test showed that black plasticine absorbed all incident light, no detectable light reflected from it and so to reduce the back reflection facetted stones were mounted on pieces of black plasticine.

Inclusions and flaws are not uncommon in natural gemstions. Scattering of light due to such imperfections will cause error and unfortunately, this is unavoidable in the measurement.

However, an area as free as possible from optical imperfections should be chosen and thus the conventional method of reflectivity measruement can be employed to facetted gemstones.

Spectral reflectivity measurements, as described in the previous section II 2, were made on polished surfaces of some ore minerals and facetted gemstones in the visible spectrum ranging from 440 nm to 660 nm at an interval of 20 nm. In all measurements a low-power objective (X 10) and a measuring area of 50 micron were used consistantly. Measured reflectivity values of ore minerals and published data available in the literature were employed in the quantitative measurements of colour.

The spectral reflectivity values of facetted gemstones are presented by the curves in Figure II 4. For non-opaque minerals and gemstones there is no significant variation in reflectivity throughout the visible spectrum. Consequently , their spectral reflectivity values which are not related to the pronounced colours of the specimens are inapplicable for colour measurement.

The probable explaination for this is that reflection of normally incident light actually takes place at the top surface, perhaps a few micron thick layer of a non-opaque specimen. The amount of absorption of such a thin layer of low-absorbing material is negligible (i.e. $k \rightarrow 0$), and therefore it is not effective to reflectivity although measurement is made on thick specimens of pronounced colour.

It follows that reflectivity of a transparent(i.e. light can pass through a petrographic thin section with a thickness of 0.3 mm) mineral is completely dominated by its refractive index n rather than the absorption coefficient k.

For these reasions the accurate measurements of reflectivity suggested that reflectivity values and refractive indices of non-opaque minerals are directly correlated as shown by the linear straight line in Figure III 5.

Therefore reflectivity measurement could provide an additional method for identification in gemmology, especially those stones whose refractive indices are high beyound the range of a normal refracrometer.

Since the application of reflected light method to the measurement of colour in transparent gemstions was unfavourable, an investigation of the use of the transmitted method was made. The proper transmission measurement method requires a thin, parallel sided specimen. The most convenient thickness of a specimen depends on its amount of absorption (Tauc, 1967).
Such measurement is obviously impossible to apply to facetted gemstones. Therefore an alternative method of determining spectral transmission of facetted stones was considered and is described in the next Chapter.

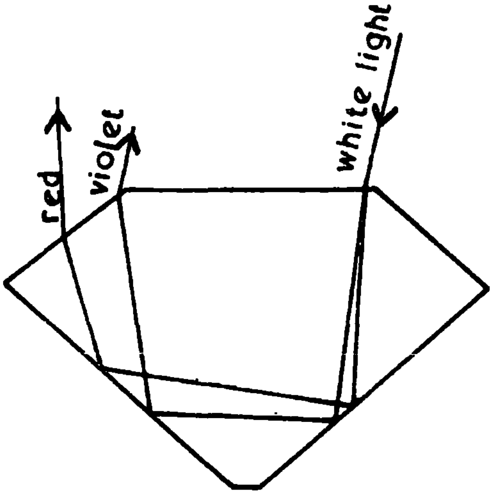
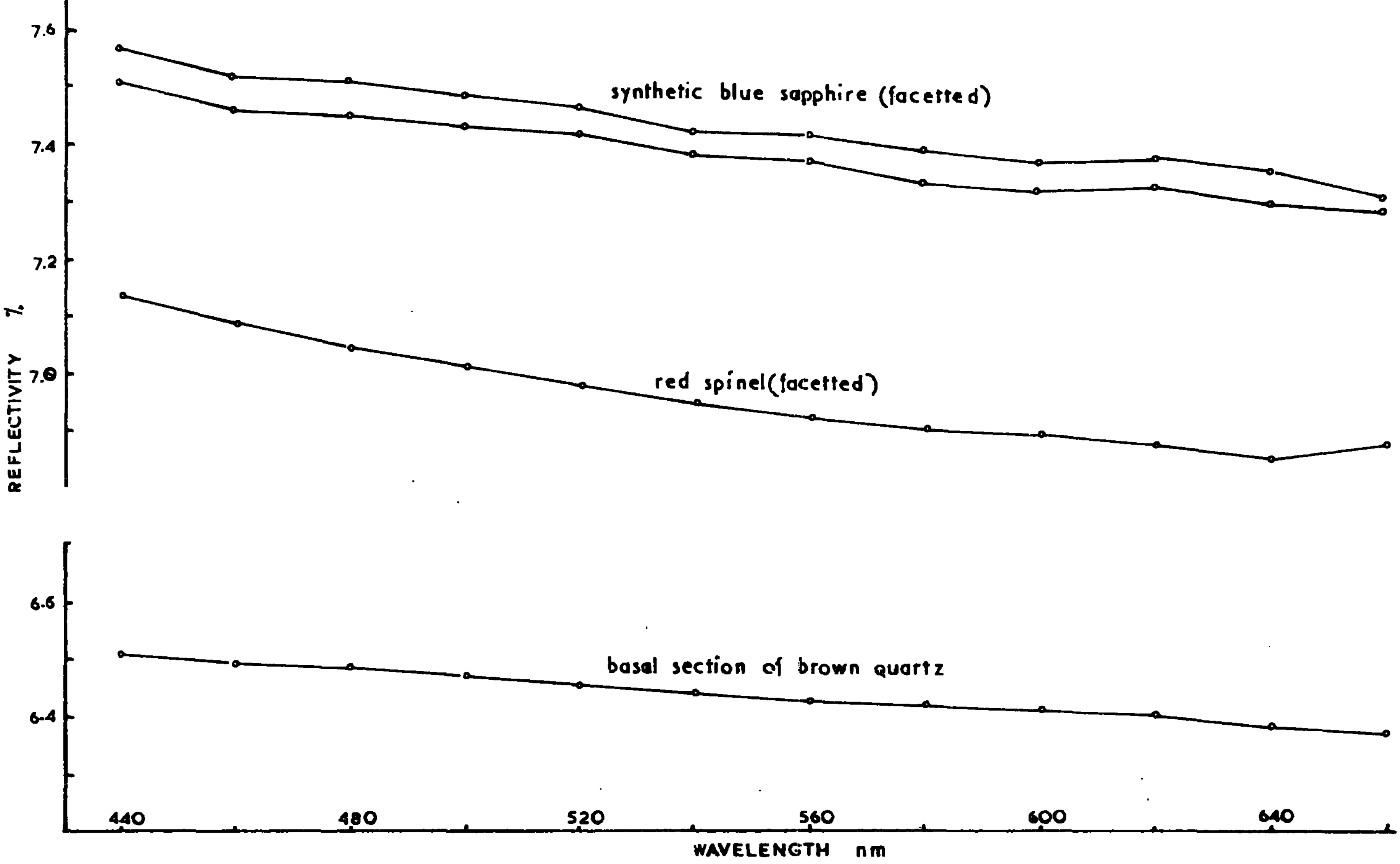


Figure III 3. Total back reflection and dispersion of a ray of light passing through brilliant cut diamond.

Figure III 4. SPECTRAL REFLECTIVITY CURVES OF GEMSTONES



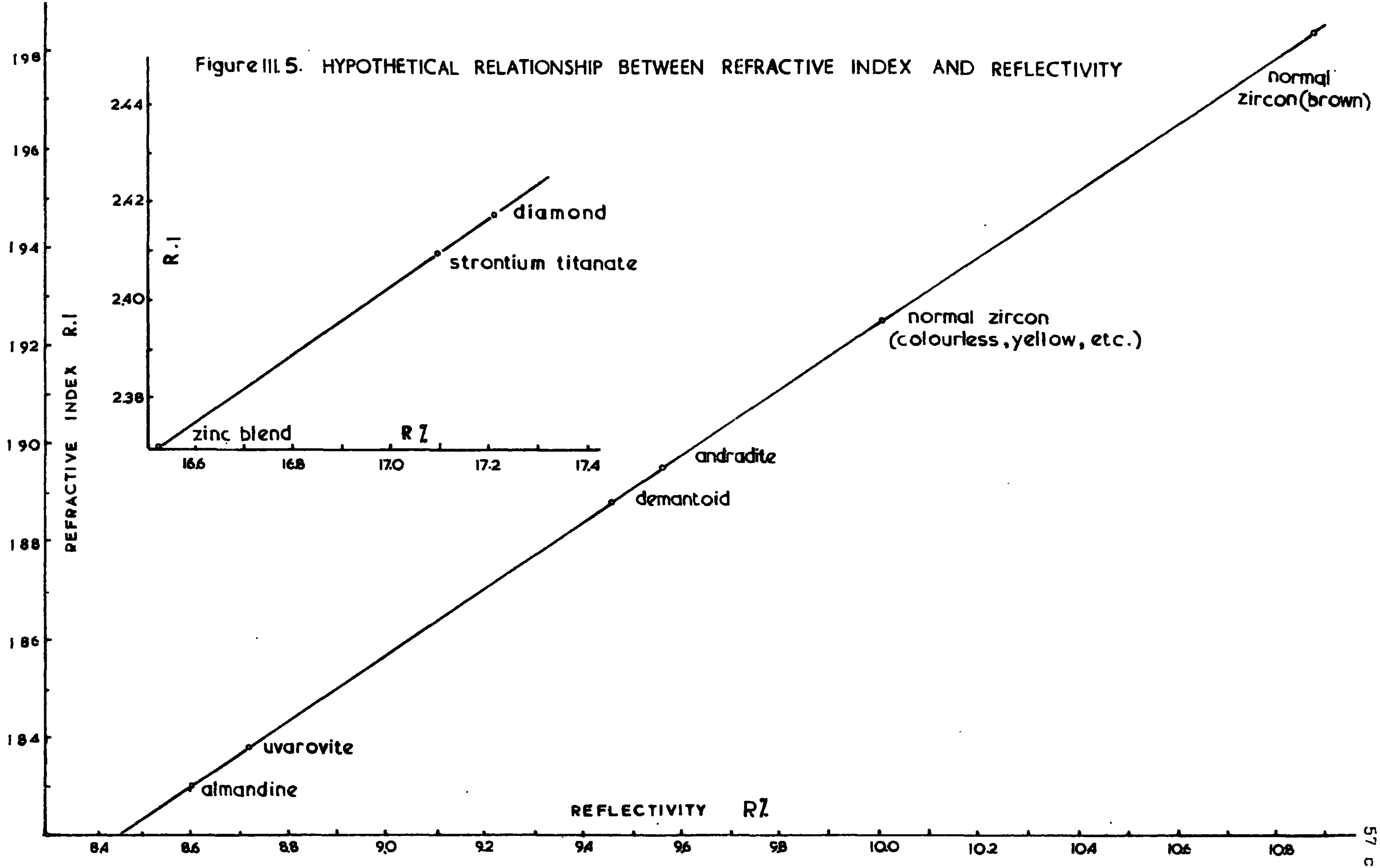


Figure III.5. HYPOTHETICAL RELATIONSHIP BETWEEN REFRACTIVE INDEX AND REFLECTIVITY

IV. POSSIBILITY OF TRANSMISSION MEASUREMENT THROUGH FACETTED GEMSTONES FOR COLOUR MEASUREMENT

THEORECTICAL CONSIDERATIONS

Consider a parallel beam of light incident normally on the surface of a parallel sided plate of thickness t , refractive index n_{λ_0} and absorption index K_{λ_0} . If the intensity is I_0 in the direction shown in Figure IV 1, let J_0 be the intensity of light travelling in the opposite direction due to reflection at the surface AB and transmission of components reflected from the surface CD . With similar meanings for other I_x and J_x we have the following relationships:

Equations for light leaving the surface AB

$$I_1 = R\,J_1 + (1 - R)\,I_0 \;; \qquad J_0 = R\,I_0 + (1 - R)\,J_1 \;;$$

Equations for light leaving the surface CD

$$I_3 = R\,J_3 + (1 - R)\,I_2 \;; \qquad J_2 = R\,I_2 + (1 - R)\,J_3 \;;$$

Equations for absorption in the medium

$$I_2 = I_1 . e^{-mt} \;; \qquad J_1 = J_2 . e^{-mt} \,.$$

where R is the reflection coefficient at normal incidence

$$R = \frac{(n_{\lambda_0} - N)^2 + n^2_{\lambda_0} K^2_{\lambda_0}}{(n_{\lambda_0} - N)^2 + n^2_{\lambda_0} K^2_{\lambda_0}} \qquad (1)$$

K = k/n, N is the refractive index of the surrounding medium.

m_{λ_0} is the absorption modulus $= 4\pi\, n_{\lambda_0} K_{\lambda_0} / \lambda_0 = 4\pi\, k_{\lambda_0} / \lambda_0$ (2)

λ_0 is the wavelength of the light in vacuo.

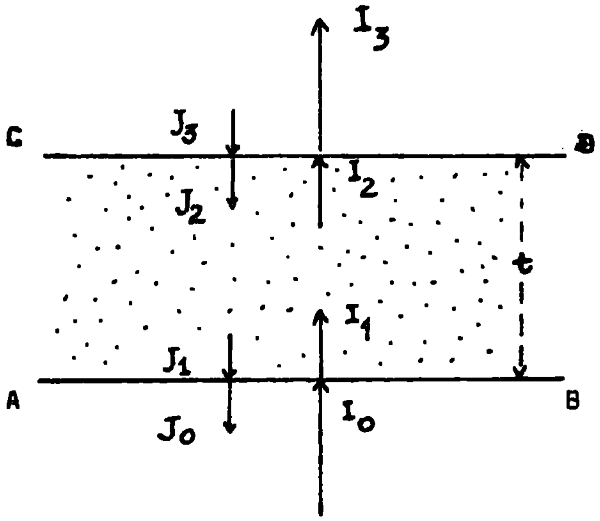


Figure IV. 1 Reflection and absorption of a parallel beam of normally incident light in passing through a parallel sided plate of an absorbing substance.

Assuming no reflection from the measuring instrument $J_3 = 0$.

Hence $I_3 = (1 - R)\, I_2$;

$J_2 = R\, I_2$;

$J_1 = R\, I_2 .\, e^{-mt}$.

substitution gives

$$T_{\lambda_0} = I_3 \,/\, I_0 = \frac{(1 - R_{\lambda_0})^2}{e^{m_{\lambda_0} t} - R^2_{\lambda_0}\, e^{-m_{\lambda_0} t}} \tag{3}$$

For non-absorbing substances it is usually assumed that m = 0, then equation (3) becomes

$$T = \frac{(1 - R)^2}{1 - R^2} \tag{4}$$

Thus for an isotropic absorbing and non-absorbing substance with two parallel surfaces on opposite sides the transmission of normally incident light is given by equations (3) and (4) respectively. From these equations, formulae for transmission of a combination of layers can be d~~i~~rived as follows:

e/

(1) Transmission of a combination of non-absorbing layers separated by air as shown in Figure IV 2 is

$$T = \frac{(1 - R_1)^2 . (1 - R_2)^2}{1 - R_1 . R_2} \tag{5}$$

when both layers have the same refractive index, then

$R_1 = R_2 = R$, and hence

$$T = \frac{(1 - R)^{2 \times 2}}{1 - R^2}$$

(2) Transmission of a combination of non-sbsorbing layers in optical contact, when both layers have the same refractive index as shown

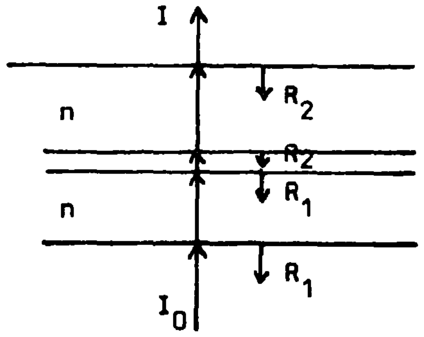


Figure IV.2 A combination of non-absorbing layers separated by Air, both layers have same refractive index'n'

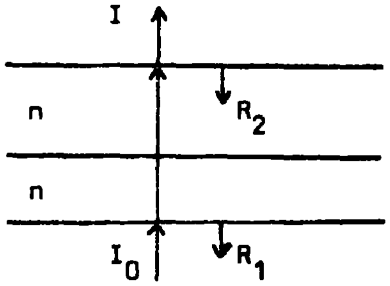


Figure IV.3 A combination of non-absorbing layers in optical contact, both layers have the same refractive index. 'n'

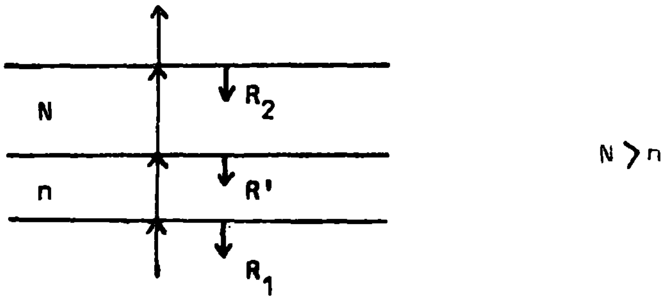


Figure IV. 4 A combination of non-absorbing layers in optical contact, refractive indices of layers are different.

in Figure IV 3, then

$$T = \frac{(1 - R_1)(1 - R_2)}{1 - R_1 . R_2} = \frac{(1 - R)^2}{1 - R^2} = \frac{1 - R}{1 + R} \qquad (6)$$

(3) Transmission of a combination of non-absorbing layers in optical contact when refractive indices of layers are different as shown in Figure IV 4, then

$$T = \frac{(1 - R_1)(1 - R')(1 - R_2)}{1 - R_1 . R' . R_2} \qquad (7)$$

where

$$R_1 = (n - 1)^2 / (n + 1)^2$$

$$R' = (N - n)^2 / (N + n)^2 \; ; \quad N > n.$$

$$R_2 = (N - 1)^2 / (N + 1)^2 \; .$$

(4) Transmission of a combination of an absorbing layer and a non-absorbing layer in optical contact as in Figure IV 5

$$T = \frac{(1 - R_1)(1 - R')\vartheta(1 - R_2)}{1 - R_1 . R' . R_2 \vartheta^2} \qquad (8)$$

where $\vartheta = e^{-mt}$ (Bouguer's law), is called internal transmittance.

There is no parallel transmitted beam of light through a facetted gemstone since total back reflection takes place from inclined faces as shown in Figure IV 6. A parallel transmitted beam of light through such stones can be obtained when immersed in liquid of the same refractive index as shown in Figure IV 6B.

By this way transmission measurement is independent of

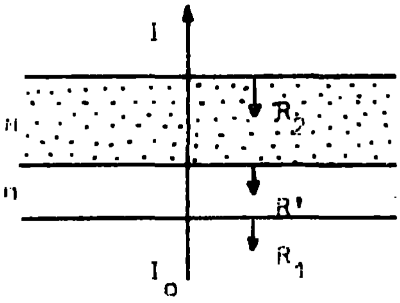


Figure IV 5. Transmission of a combination of an absorbing layer and a non-absorbing layer in optical contact.

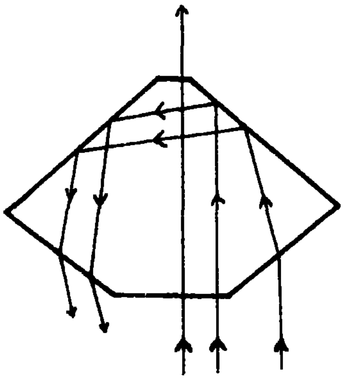


Figure IV 6 a. Back reflection of a ray of light in passing through a facetted stone in air.

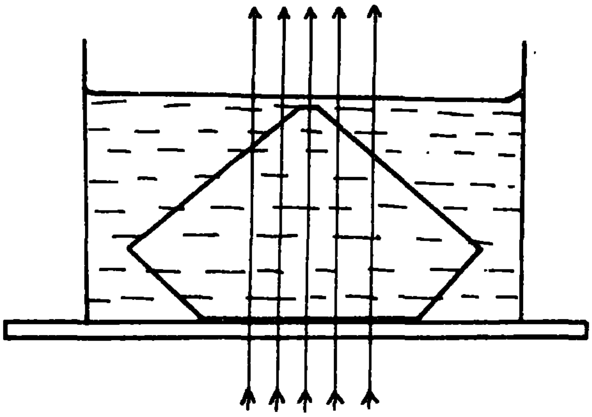


Figure IV 6 b. A parallel transmitted ray of light in passing through a facetted stone in oil of the same R.I.

the shape of a gemstone and the difficulty of preparation for a thin parallel sided section is eliminated. The above equation, therefore, is also applicable for facetted gemstones (without spoling a stone) at a particular wavelength, where the refractive index of a stone and liquid is the same.

When measurement of spectral transmission based on this principle is made errors will be introduced in the experiment.
The probable errors considered are

(1) due to the excess liquid over the stone and

(2) due to higher dispersion of the liquid for other wavelengths, except the matching wavelength.

In the first case the error may be eliminated if the matching liquid is colourless. If the liquid has a negligible amount of absorption at thin layer over the stones the consequent error may also be regarded as negligible. However for accurate measurement colourless immersion liquids are preferable.

In the second case the amount of errors depends upon the dispersion character of a liquid used in the measurement. Unfortunately, the dispersion of immersion liquids are normally higher than that of solids as, for example, shown in Figure IV 7.(after Wahlstrom, 1966). The refractive index of solid and liquid will be matched at a particular wavelength, and so parallel transmitted beam of light through a facetted stone occurs.

For other wavelengths in the visible spectrum the diviation of refractive indecies of liquid from those of a solid will cause the divergence of the transmitted beam from parallelism. From the theorectical point of view, the refractive index of liquid at every wavelength could be matched with that of the solid by adjusting the temperature, since the R.I. of liquid is much more sensitive to temperature than that of a solid. But in practice it will not be very convenient and costly to do it.

However calculation shows that the estimate of the error due to a difference of 0.01 n between liquid and solid is about 0.25% in transmission and due to a difference of 0.1 n is about 2.5% . If the second case is considered as a maximum error the method of transmission measurement in oil is reasonably acceptable.

The relative values of spectral transmission are of interest for colour measurement of a particular gemstone. If the dispersion of liquid is not too much stronger than that of the stone, and as long as the same liquid is used for different cut stones of the same mineral, their relative transmission values are comparable and therefore their colour values are also comparable to one another.

The equation for spectral transmission of an isotropic absorbing gemstone in oil (of the same n as that of the stone) may be written as

$$T\lambda = \frac{(1 - R_1\lambda)(1 - R'\lambda) \quad (1 - R_2\lambda)}{1 - R_1\lambda \cdot R'\lambda \; R_2\lambda\tau^2} \qquad (9).$$

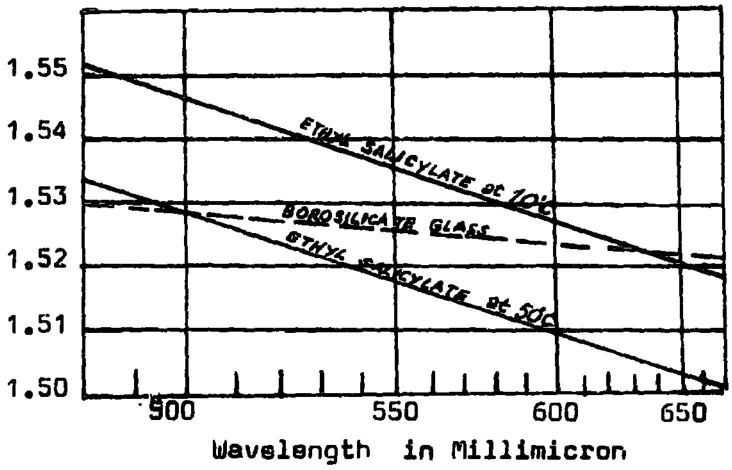


Figure IV.7 Dispersion curves plotted on a Hartman net and showing relationship among the index of refraction wavelength, and temperature (after Wahlstrom, 1966)

EXPERIMENTS AND RESULTS

To establish the validity of the above considerations transmission measurements were made and measured values were compared with those obtained by calculation according to equation (7) for non-absorbing specimens.

For an absorbing mineral two methods of transmission measurement were applied according to the conditions for equation (8) and equation (9). The equation (9) is the same as equation (8) which is from equation (7), but the measuring methods are different. Hence the results obtained by two methods should be the same.

Measurements were made as follows.

The same reflectivity apparatus was used for transmitted light work, with some alterations of the equipment, as shown in the diagram III 2. In the microscope assembly an iris diaphragm below the polarizer, a measuring diaphragm, of about 80 micron in diameter,above the objective, a photomultiplier stop, of about 50 micron in diameter (the same as in reflectivity measurement), below the photomultiplier tube-window, and the condensing lenses just below the microscope stage were used. By using the condensing lenses the image of the light source can be brought up to the specimen surface.

A glass cell was made by joining one end of a glass tube to a surface of a polished petrographic glass slide with 'araldite' . The glass cell was thoroughly cleaned and placed on the microscope stage. The image of the light source was focused as in proper way. Intensities of the light source (I_0) at various wavelengths were read on the digital voltmeter.

One side of a basal section of clear quartz (rock crystal) with polished parallel surfaces was wetted with a drop of Rayner's R.I. liquid of 1.54 n and was placed with gentle pressure on the glass slide in such a way that a thin film of the liquid served to make 'optical contact' with the specimen and the glass slide (i.e. the entire space between the specimen and the glass slide was completely filled without any air bubbles).

An area of the specimen as free from imperfection as possible was selected and the image of the light source was focused. So the distance between the surfaces of photo-cells and the source image was always the same when the specimen was in or without the specimen in the plane polarized light.

Intensities of the emergent light passing through the glass slide and the specimen were read for various wavelengths. Therefore the spectral transmittance of the combination of the glass slide and clear quartz (w) in optical contact is

$$T = I / I_o .$$

In order to compare the measured values with calculated results spectral refractive indices of the same glass slide and the quartz specimen were determined, at working temperature of about 20°C, with an Abbe Refractometer model B and a quartz monochromator. Direct readings on the scale for various wavelengths were corrected by using given calibration tables for the dispersion characteristics of the instrument as a function of the wavelength.

Fresnel reflectances of the quartz specimen, glass slide and quartz-glass interface were computed thereafter and substitutions of these values in the formula (7) gave spectral transmittances of the combination of the two non-absorbing layers at optical contact.

Measured spectral refractive indices and calculated Fresnel reflectances are tabulated in Table IV 1. Measured transmission values and calculated results of the combination of clear quartz and the glass slide at optical contact are given in Table IV 2. The measured values are slightly higher than the calculated values (N.B. according to Ayres, 1949 and Bloss, 1955, the relative errors increase considerably when transmission is lower than about 20% and higher than 60%).

Spectral transmission measurements of a combination of a basal section of brown quartz (cairngorm) and the glass slide were made by two methods.

The first method was as described above for a combination of non-absorbing and absorbing layers (equation 8) in optical contact at interfaces. In the second method the brown quartz basal section was measured in the matching liquid (equation 9). The polished surface of the brown quartz specimen was thoroughly cleaned and wetted with the same Rayner R.I. liquid of 1.544 n. The specimen was placed on the glass in the cell as mentioned above and the cell was filled with the same liquid till it just covered the top of the specimen surface. Measurement, as close as possible to the previous area was made after focusing to the image of the light source.

The measured values by two methods are given in Table

IV 3 and are presented by curves in Figure IV 8. All calculated and measured transmission results were then computed for quantitative colour values. For the clear quartz specimen its chromaticity coordinates must be the same as that of the achromatic point since it is colourless.

For brown quartz its colour coordinate points derived from two transmission measurements must also be more or less the same, or at least fall within the limits of a discrimination threshold. These conditions were satisfied as evidences of the proof are given in Table IV 4.

Thus statistical and experimental results permit the use of matching liquid to determine the spectral transmission characteristics of facetted gemstones.

For an anisotropic gemstone the transmission T is according to the crystallographic orientation under examination. At a wavelength where the R.I. of the stone matches that of the liquid the image of the parallel transmitted beam is at the centre of the field of view and the boundary of the image is sharp. During a gentle rotation of the microscope stage and sliding the monochromator for other wavelengths the image of the emergent light slightly deviates from the centre of the field due to the different dispersion characteristics of liquid and the stone. In this case values of minimum and maximum transmissions were measured in plane polarised light at each of the two extinction positions. It was considered that it may be permissable to take the mean transmission values of an anisotropic stone for general colour measurement.

Table IV 1.

Measured Refractive Indices

Wavelength nm	Clear Quartz n_w	Glass Slide n
460	1.5517	1.524
480	1.5501	1.523
500	1.5488	1.522
520	1.5476	1.520
540	1.5465	1.519
560	1.5455	1.518
580	1.5446	1.517
600	1.5439	1.516
620	1.5431	1.515
640	1.5424	1.514

Calculated Fresnel Reflectances ($r = \frac{(n - N)^2}{(n + N)^2}$)

Wavelength nm	Clear Quartz r_w	Glass Slide r	Quartz-Glass interface r'
460	0.04675	0.04310	0.000081
480	0.04653	0.04297	0.000078
500	0.04636	0.04284	0.000076
520	0.04620	0.04258	0.000081
540	0.04606	0.04245	0.000080
560	0.04592	0.04232	0.000081
580	0.04581	0.04219	0.000081
600	0.04571	0.04206	0.000083
620	0.04561	0.04193	0.000084
640	0.04552	0.04180	0.000086

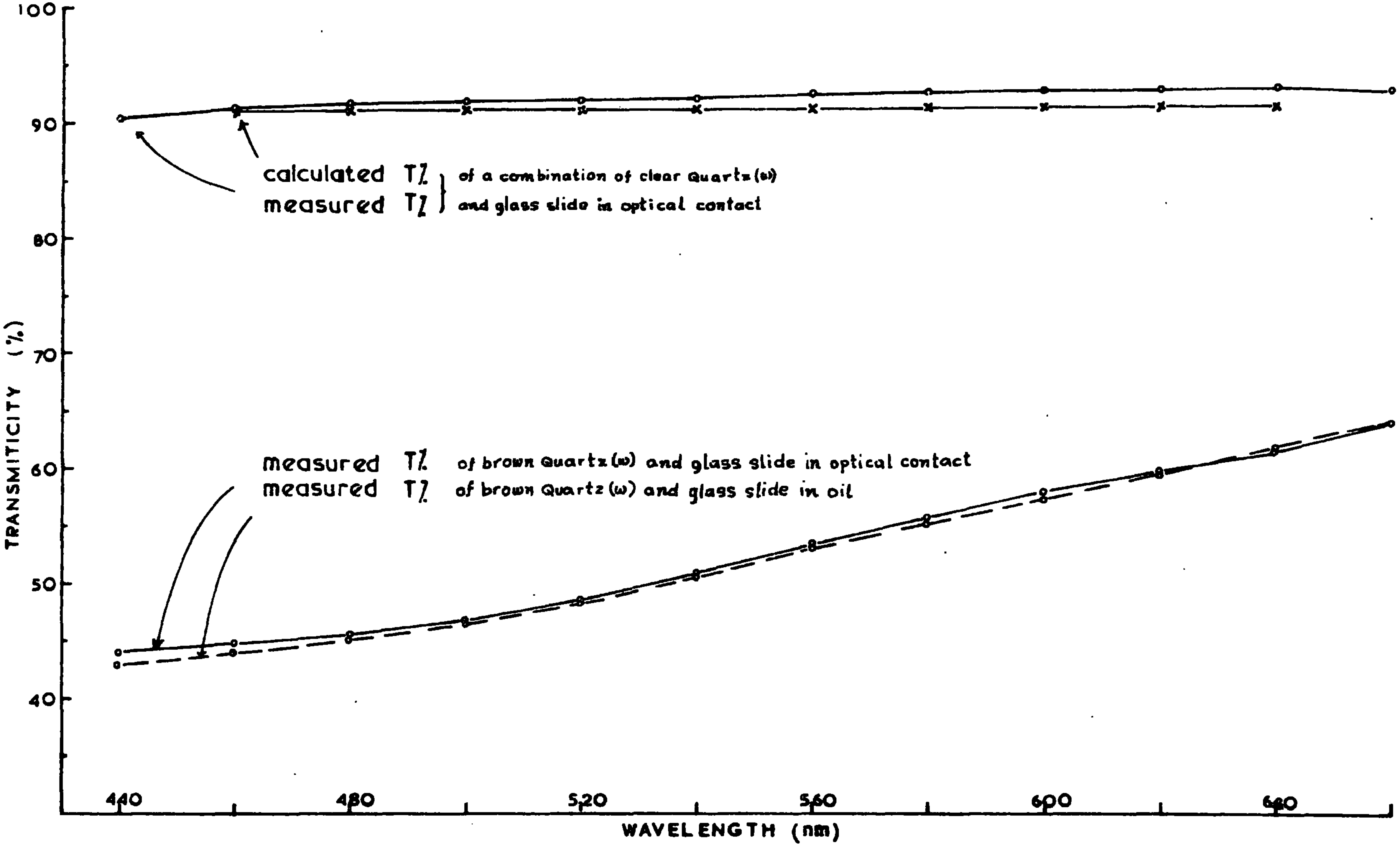
Table IV 2. T % of a Combination of Clear Quartz and a Glass Slide in Optical Contact

Wavelength nm	Calculated T_w %	Measured T %
460	91.21	91.41
480	91.24	91.83
500	91.27	91.90
520	91.31	92.02
540	91.34	92.36
560	91.36	92.66
580	91.39	92.69
600	91.41	92.99
620	91.43	93.12
640	91.53	93.36

Table IV 3. Measured T % of a Combination of Brown Quartz(w) and a Glass Slide

Wavelength nm	in optical contact at interfaces	in matching oil n = 1.544
440	43.97	42.82
460	44.84	43.86
480	45.67	45.01
500	46.95	46.50
520	48.55	48.34
540	50.98	50.52
560	53.36	52.98
580	55.70	55.11
600	58.02	57.30
620	59.80	59.63
640	61.52	61.98
660	64.10	64.10

Figure IV 8.



100
90
80
70
60
50
40
TRANSMITICITY (%)
calculated T%
measured T%
of a combination of clear Quartz (ω) and glass slide in optical contact
measured T% of brown Quartz (ω) and glass slide in optical contact
measured T% of brown Quartz (ω) and glass slide in oil
440
480
520
560
600
640
WAVELENGTH (nm)

Table IV 4. Colour Specifications derived from Calculated and Measured Transmittance Values

Source & Specimens	Chromaticity coordinates x	y	Dominant wavelength d	Excitation purity Pe%
Illuminant A	0.4476	0.4075		
Clear Quartz(w) in air, calculated	0.4477	0.4075		
Clear Quartz-Glass in optical contact, calculated	0.4478	0.4075		
Clear Quartz-Glass in optical contact, measured	0.4491	0.4078		
Brown Quartz-Glass in optical contact, measured	0.4712	0.4090	591.42	17.39
Brown Quartz-Glass in matching oil,measured	0.4722	0.4094	591.10	18.31

V. COMPARISON OF TRANSMISSION MEASUREMENTS MADE WITH A MICROSCOPE PHOTOMETER AND A GRATING SPECTROGRAPH

Spectral transmission measurements have been usually carried out with a recording grating spectrograph(or spectrophotometer). Such apparatus is not suitable to make measurement of very small specimens ($<$ 2 mm in diameter) and specimens with non-parallel sided surfaces. Therefore, for non-opaque minerals and facetted gemstones, spectral transmission measurements were made with a microscope photometer (the same apparatus used for reflectivity measurement ; as described previously).

It was interesting to compare transmission measurements made with two different types of apparatus. For this purpose specimens were prepared as follows.

A red spinel crystal of gem quality, from Burma and a basal section of brown quartz (cairngorm) were embedded in synthetic resin discs. They were ground with medium grade silicon carbide on the first lap and with fine silicon carbide on the second lap. They were then polished with fast cutting alumina, with 6 micron diamond paste, with $\frac{1}{4}$ micron diamond paste and finally with 'finish polishing' alumina. The other sides of the embedded specimens were cut off and these second opposite surfaces of red spinel and brown quartz were ground and polished down to 1.5 mm and 1.0 mm in thickness respectively. Minute solid inclusions in both specimens were observed under the microscope with a low-power objective .

Measurements with the Microscope Photometer

Spectral intensity of the incident beam of light (I_0)

of about 80 micron in diameter was measured before and after measurement of a specimen, as described in the previous section.

The polished specimen was cleaned thoroughly with xylene and soft tissues. It was placed on the microscope stage and an area as clean and free from imperfection as possible was selected. Spectral intensity of the transmitted beam (I) of plane polarised light was recorded from wavelengths of 400 nm to 680 nm. The specimen was turned over to measure the second surface in the same way. The average of two measured I_0 was used to calculate spectral transmittance (in percent) of the specimen as

$$T\,\% = I \,/\, I_0 \times 100.0$$

The measured areas of the first surface and second surface of the specimen may not be the same. However, to estimate the precision of the measurement repeated experiments were made. The spectral transmittance values (%) of red spinel and brown quartz are given in Tables V 1 and V 2. The maximum variation of the average values of two measurements was less than 1 % (absolute) at any wavelength.

Measurements with an Optica Recording Grating Spectrograph

The optica recording grating spectrograph manufactured by Optica United Kingdom Limited has a double beam optical system and a working range of 185 nm to 3200 nm. It has a 600 lines/mm ruled grating with a dispersion of 16 A°/mm for the UV and visible regions (185 nm to 1000 nm).

Holders for a specimen and the reference beam of light of 2 mm in diameter were used. The holders were specially made, as those supplied with the instrument are too large. The deflections of the potentiometers on the chart recorder were set to 0 and 100 over the visible spectrum by means of the 0% and 100% transmission controls, when the light beam was cut off and when the incident beam was passed through the reference holder respectively.

The same specimens were first cleaned thoroughly with xylene and one face of a specimen was stuck on the back of the specimen holder having a 2 mm hole. Measurement of the first surface was made from wavelengths of 400 nm to 700 nm under the following operational conditions.

Source: tungsten lamp(12V, 48W) from 400 to 600 nm
" " " " with a red filter from 600 to 700 nm.
Photomultiplier Type: RCA 1P 28 with a maximum response at about 340 nm.
Slit: automatic slit used to obtain a constant 100% transmission of the incident beam in air.
Time Constant: normal.
Gain: 6 (optimum condition).
Wavelength Scan Speed: 0.5 A°/sec.
Chart Speed: 2°/minute.
Accuracy of the wavelength on the chart was 5 ± 1 A°.

The measurement of the opposite second surface was repeated in the same way. Transmittance values (%) thus obtained are given in Tables V 3 and V 4.

For comparison of the measurements made with two types of different apparatus the spectral transmiticity (i.e. transmittance in %) curves of red spinel and brown quartz are shown in Figures V 1 and V 2.

From tabulated measured values and Figures V 1 and V 2, it was seen that measurements with the spectrograph gave large variation in transmittance values of the first and second surfaces of the specimen. That is probably because of the different polishing qualities of opposite surfaces and imperfect parallelism of the section. Nevertheless, these large variations do not considerably affect quantitative colour measurements as shown in the chromaticity chart of Figure V 3.

With the microscope photometer a specimen can be examined and areas of both surfaces can be selected as free from imperfection as possible. For this reason the variation in transmittance values of the first and second surfaces of the specimen was comparatively smaller. Another advantage of the use of the microscope photometer was that a very small specimen could be measured.

The differences in spectral transmittance values, within the experimental errors, obtained with two different apparatus may be due to the following major reasons.

(1) Spectral sensitivities, over the visible spectrum, of the two types of photomultiplier are different as shown by curves in Figure V 4.
Results of colour matching experiments however, show that for different persons appreciable differences in light sensitivity of retinal photocells result in slightly different sensation of the same colour.

Likewise, two apparatus differing in sensitivity of light for each wavelength produced two different spectral responses resulting slightly different colours of same specimen.

(2) Fields of illumination and measuring sizes were different, although the same type of sources were used.

(3) There is a lower polarizer in the microscope photometer but no polarizer in the spectrograph.

Quantitative colour values were derived from the above measured transmittance values and results are given in Tables V 5 and V 6. Their colour points are plotted in the chromaticity diagrams of Figures V 3.

Table V. 1 .

TRANSMITICITY(Transmittance in %)OF RED SPINEL (111) MEASURED WITH THE MICROSCOPE PHOTOMETER.

(Thickness = 1.5 mm)

	First Measurement			Second Measurement		
(nm)	Face 1	Face 2	Average	Face 1	Face 2	Average
400	9.7	10.1	9.9	10.6	10.6	10.6
410	11.0	11.1	11.05	11.5	11.0	11.25
420	13.3	13.3	13.3	13.9	12.6	13.25
430	17.1	17.1	17.1			
440	22.5	22.1	22.3	23.0	21.25	22.1
450	28.7	28.1	28.4			
460	34.0	33.0	33.5	34.4	32.15	33.3
470	37.4	36.0	36.7	37.8	35.4	36.6
480	37.9	36.4	37.15	38.6	36.1	37.35
490	35.9	34.3	35.1			
500	31.9	30.5	31.2	32.7	30.3	31.5
510	26.8	25.6	26.2			
520	22.2	21.3	21.75	23.0	21.2	22.1
530	18.5	18.0	18.25			
540	16.6	16.1	16.35	17.2	15.7	16.45
550	16.5	16.0	16.25	17.0	15.6	16.3
560	18.3	17.8	18.05	18.85	17.3	18.1
570	22.3	21.5	21.9			
580	28.15	27.0	27.6	28.4	26.2	27.3
590	35.3	33.6	34.45			
600	42.6	40.1	41.35	42.8	39.55	41.2
610	49.3	46.6	47.95			
620	55.1	51.7	53.4	55.0	50.9	52.95
630	59.9	55.9	57.9			
640	62.8	58.9	60.85	63.5	58.5	61.0
650	65.7	60.95	63.3			
660	66.7	63.0	64.85	65.6	62.55	64.1
670	68.5	64.0	66.25	67.9	62.9	65.4
680	67.8	64.9	66.35	68.1	66.0	67.05

Table V.2 .

TRANSMITICITY OF BROWN QUARTZ(W) MEASURED WITH THE MICROSCOPE PHOTOMETER.

(thickness = 1.0 mm)

(nm)	Face 1	Face 2	Average
400	41.3	43.6	42.25
410	42.3	44.8	43.55
420	42.9	44.9	43.9
440	43.1	45.3	44.2
460	43.4	45.8	44.6
480	44.0	46.5	45.25
500	45.1	47.6	46.35
520	46.4	49.1	47.75
540	48.1	50.8	49.45
560	49.9	52.7	51.3
580	51.4	54.4	52.9
600	53.3	56.3	54.8
610	54.4	56.9	55.65
620	55.0	57.6	56.3
630	55.9	58.7	57.3
640	56.9	59.6	58.25
650	57.4	60.4	58.9
660	59.4	60.9	60.15
670	60.0	62.0	61.0
680	59.6	61.7	60.65

Table V 3.

TRANSMITICITY OF RED SPINEL (111) MEASURED WITH THE OPTICA RECORDING GRATING SPECTROGRAPH

(Thickness = 1.5 mm)

First Measurement				Second Measurement		
(nm)	Face 1	Face 2	Average	Face 1	Face 2	Avegare
400	5.6	3.25	4.4	3.3	2.3	2.8
410	8.0	4.7	6.35	4.6	4.0	4.3
420	10.0	5.1	7.55	6.0	5.0	5.5
430	15.7	8.9	12.3	10.0	8.6	9.3
440	21.7	17.4	19.55	17.5	15.5	16.5
450	38.1	24.9	31.5	25.4	22.4	23.9
460	45.5	30.0	37.75	31.0	27.1	29.05
470	49.6	32.9	41.25	33.6	30.0	32.0
480	49.0	32.5	40.75	34.2	30.0	32.1
490	44.3	29.4	36.85	31.0	27.1	29.05
500	36.9	24.3	30.6	26.0	22.8	24.4
510	28.5	19.0	23.75	20.0	18.2	19.1
520	21.4	14.3	17.85	15.0	13.5	14.25
530	17.0	11.4	14.2	12.0	10.7	11.35
540	15.7	10.5	13.1	11.2	9.9	10.55
550	17.0	11.4	14.2	11.5	10.2	10.85
560	21.5	14.6	18.05	14.8	13.2	14.0
570	29.0	20.0	24.5	20.0	18.0	19.0
580	39.6	27.5	33.55	28.0	25.0	26.5
590	50.8	35.3	43.05	36.7	32.0	34.35
600	60.8	42.6	51.7	44.4	39.3	41.85
610	69.0	48.3	58.65	50.4	45.4	47.9
620	74.3	52.0	63.15	55.0	49.3	52.15
630	78.3	54.8	66.55	58.3	52.1	55.2
640	80.4	56.7	68.55	60.2	54.0	57.1
650	82.2	57.6	69.9	61.7	55.5	58.6
660	83.3	59.0	71.15	63.0	57.0	60.0
670	84.3	59.7	72.0	64.2	58.0	61.1
680	84.6	60.4	72.5	64.6	58.4	61.5
690	83.7	60.0	71.85	64.5	58.2	61.35
700	83.9	60.5	72.2	64.5	58.8	61.65

Table V . 4 .

TRANSMITICITY OF BROWN QUARTZ(W) MEASURED WITH OPTICA RECORDING GRATING SPECTROGRAPH.

(Thickness = 1.0 mm)

(nm)	Face 1	Face 2	Average
400	26.4	41.8	34.1
410	26.6	42.0	34.3
420	26.9	42.0	34.45
430	27.0	42.2	34.6
440	27.1	42.2	34.65
450	27.3	42.4	34.85
460	27.5	42.4	34.95
470	27.7	42.5	35.1
480	28.0	42.7	35.35
490	28.3	43.2	35.75
500	28.6	43.7	36.15
510	29.3	44.2	36.75
520	29.9	44.8	37.35
530	30.5	45.6	38.05
540	31.4	46.5	38.95
550	32.0	47.5	39.75
560	32.8	48.7	40.75
570	33.2	49.4	41.3
580	33.8	50.3	42.05
590	34.6	51.0	42.8
600	35.4	52.1	43.75
610	36.1	54.5	45.3
620	36.9	55.4	46.15
630	37.5	56.5	47.0
640	38.2	57.5	47.85
650	38.5	58.7	48.6
660	39.8	59.9	49.85
670	40.8	60.9	50.85
680	41.6	61.8	51.7
690	42.8	62.9	52.85
700	43.9	64.0	53.95

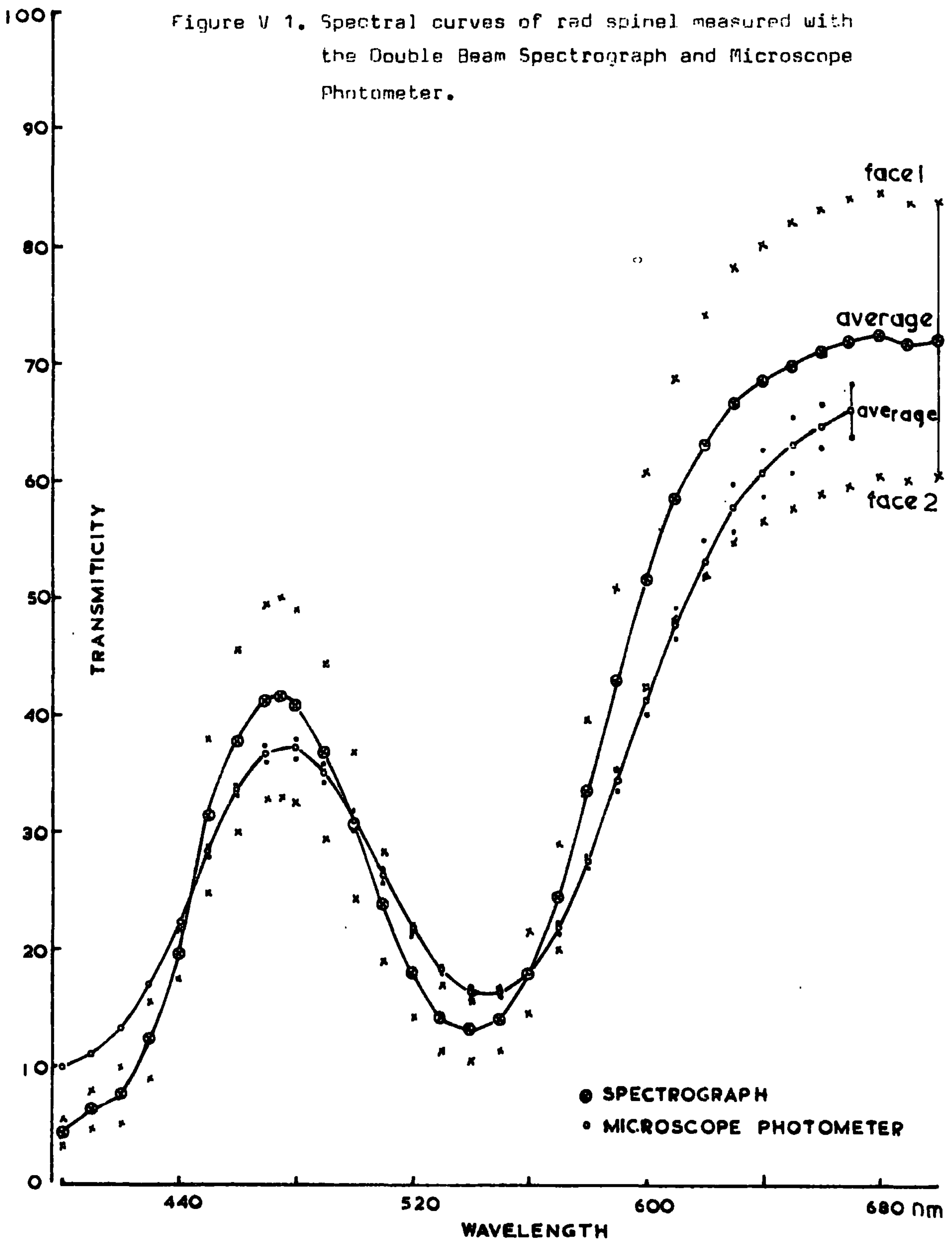


Figure V 1. Spectral curves of red spinel measured with the Double Beam Spectrograph and Microscope Photometer.

Figure V 2. Spectral transmittance curves of brown quartz measured with the Double Beam Spectrograph and Microscope Photometer.

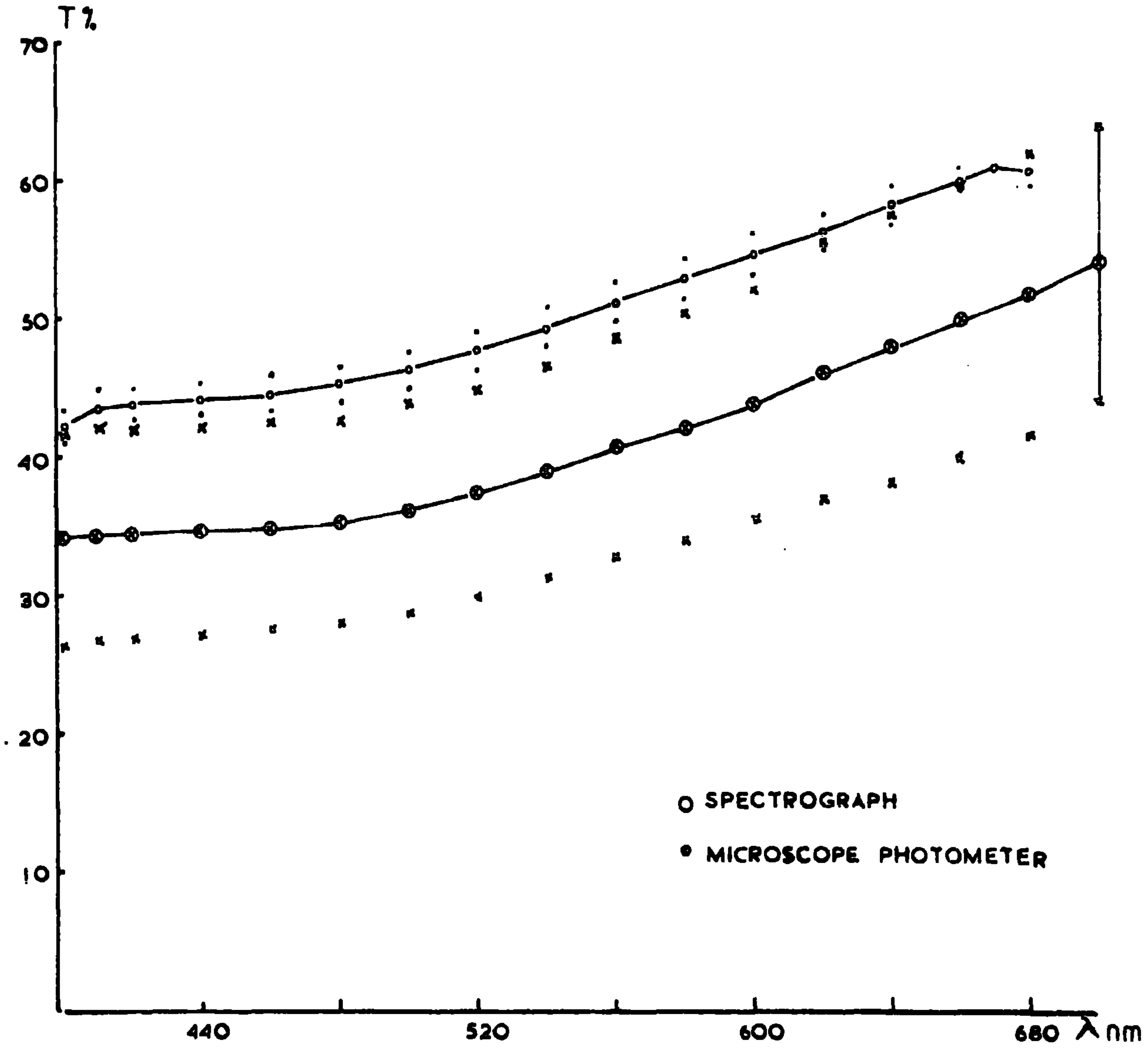


Figure V 4. Chromaticity diagram showing the colours of Red Spinel (1.5 mm) and Brown Quartz (ω, 1.0 mm) under the C.I.E. source C. The differences in chromaticities are mainly due to two different types of apparatus used for transmission measurements.

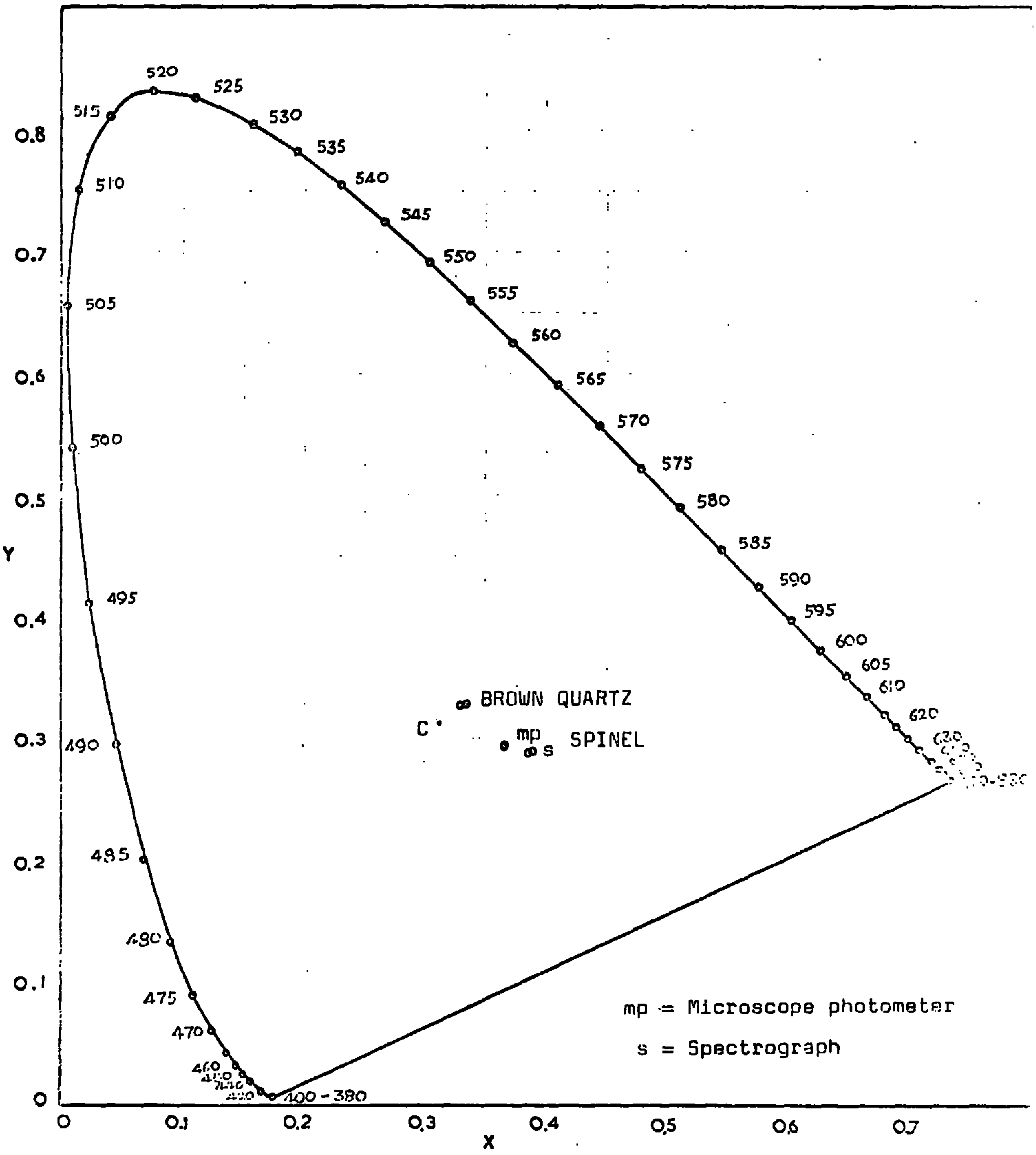


Figure V 4. Spectral sensitivities of the two types of photomultipliers.

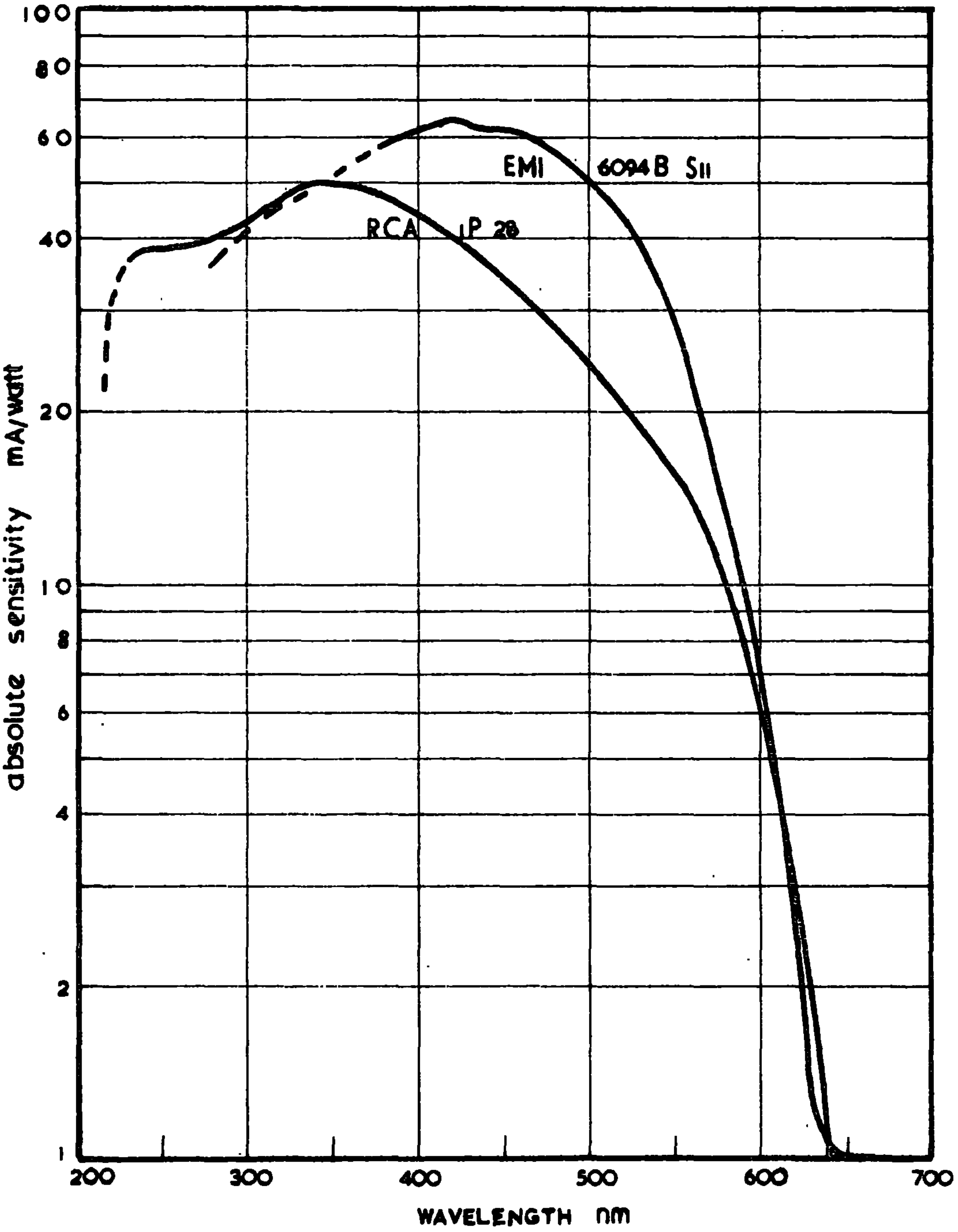


Table V/ 5

QUANTITATIVE COLOUR VALUES OF RED SPINEL (111)
UNDER AVERAGE TUNGSTEN LAMP LIGHT

	CHROMATICITY COORDINATES x	y	COMPLEMENTARY WAVELENGTH(λc)	EXCITATION PURITY(Pe%)
T % Measurement with the Microscope Photometer.				
First measurement				
Face 1	0.5226	0.3602	- 506.51	29.81
Face 2	0.5196	0.3607	- 506.92	29.12
Average	0.5211	0.3604	- 506.73	29.48
Second measurement				
Face 1	0.5197	0.3621	- 506.49	28.63
Face 2	0.5195	0.3615	- 506.70	28.82
Average	0.5196	0.3618	- 506.60	28.72
T % Measurement with the Optica Recording Grating Spectrograph.				
First measurement				
Face 1	0.5349	0.3543	- 506.07	34.02
Face 2	0.5393	0.3541	- 505.51	34.84
Average	0.5367	0.3542	- 505.84	34.36
Second measurement				
Face 1	0.5410	0.3533	- 505.47	35.42
Face 2	0.5422	0.3536	- 505.25	35.51
Average	0.5416	0.3534	- 505.37	35.48

Table IV 5 (continued)

QUANTITATIVE COLOUR VALUES OF RED SPINEL (111)

UNDER AVERAGE DAYLIGHT.

	CHROMATICITY COORDINATES x	y	COMPLEMENTARY WAVELENGTH(λc)	EXCITATION PURITY(Pe%)
T % Measurement with the Microscope Photometer.				
First measurement				
Face 1	0.3671	0.2939	- 495.69	19.69
Face 2	0.3636	0.2926	- 496.30	19.56
Average	0.3654	0.2933	- 495.97	19.62
Second measurement				
Face 1	0.3646	0.2954	- 495.57	18.62
Face 2	0.3640	0.2944	- 495.85	18.91
Average	0.3643	0.2949	- 495.71	18.77
T % Measurement with the Optica Recording Grating Spectrograph.				
First measurement				
Face 1	0.3827	0.2903	- 495.26	24.06
Face 2	0.3887	0.2919	- 494.69	24.54
Average	0.3851	0.2909	- 495.03	24.27
Second measurement				
Face 1	0.3901	0.2920	- 494.60	24.76
Face 2	0.3919	0.2933	- 494.33	24.57
Average	0.3910	0.2926	- 494.47	24.69

Table V/6

QUANTITATIVE COLOUR VALUES OF BROWN QUARTZ (W)
UNDER AVERAGE TUNGSTEN LIGHT.

	CHROMATICITY COORDINATES x	y	DOMINANT WAVELENGTH(λd)	EXCITATION PURITY(Pe %)
T % Measurement with the Microscope Photometer.				
Face 1	0.4672	0.4082	592.06	14.06
Face 2	0.4665	0.4087	591.42	13.93
Average	0.4668	0.4085	591.68	13.99
T % Measurement with the Optica Recording Grating Spectrograph.				
Face 1	0.4714	0.4085	591.91	17.18
Face 2	0.4701	0.4064	594.33	14.70
Average	0.4707	0.4073	593.18	15.36

Table V·6 (continued)

QUANTITATIVE COLOUR VALUES OF BROWN QUARTZ (W) UNDER AVERAGE DAYLIGHT.

	CHROMATICITY COORDINATES		DOMINANT	EXCITATION
	x	y	WAVELENGTH(λd)	PURITY(Pe %)
T % Measurement with the Microscope Photometer.				
Face 1	0.3306	0.3292	584.07	8.96
Face 2	0.3303	0.3296	583.44	8.99
Average	0.3304	0.3294	583.72	8.96
T % Measurement with the Optica Recording Grating Spectrograph.				
Face 1	0.3355	0.3325	583.88	11.16
Face 2	0.3328	0.3281	586.72	9.25
Average	0.3339	0.3299	585.41	10.03

VI. METHODS OF COMPUTING COLOUR SPECIFICATIONS OF MINERALS

Description has already been made of the basic principles of colour measurement. In the past colour specification of objects have been usually carried out graphically in part, from spectral transmittance or spectral reflectance data (Hand Book of Colorimetry by Hardy, 1936; Piller, 1966). Since better accuracy and precision of colour values of minerals are preferable, the absolute mathematical approach is considered and computer programmes developed to evaluate all colour specifications. This has the advantage of eliminating personal errors and reducing the time required for calculation.

VI 1. Computational Procedure for Tristimulus values and Chromaticity Coordinates

Measurements of spectral reflectivity for opaque mineral and spectral transmittance for non-opaque minerals and cut gemstones could be made at various wavelengths only within the sensitivity range of the photomultiplier (i.e. from about 420 nm to 660 nm) since the colour-matching functions are very small below about 400 nm and above 680 nm, the reflectivity curve can be extended justifiably towards the two ends of the spectrum by extrapolation (see Figure II 14).

Therefore the values require for the calculations were then found by interpolation and extrapolation for wavelengths of 360 nm to 780 nm with an equal interval of 5 nm , by the following linear equation:

$$R_x = \frac{\lambda x - \lambda 1}{\lambda 2 - \lambda 1} (R_2 - R_1) + R_1 \qquad (1)$$

where R_x is a required reflectivity at the wavelength λ_x, λ_2 and λ_1 are longer and shorter successive wavelengths respectively, and R_2 and R_1 are the respective measured reflectivities.

The reflectivity values at 5 nm intervals are then multiplied by the corresponding normalized products of the colour-matching functions of the light source obtained from Table II 5. By definition, the tristimulus values XYZ of an object colour can be determined by evaluating the following integrals.

$$X = \int R_\lambda H_\lambda \bar{x}_\lambda \, d\lambda$$

$$Y = \int R_\lambda H_\lambda \bar{y}_\lambda \, d\lambda \qquad (2)$$

$$Z = \int R_\lambda H_\lambda \bar{z}_\lambda \, d\lambda \quad .$$

Since the reflectivity (or transmiticity) values are in percent, the sum of the products for X is divided by 100.0, and similarly for Y and Z. Each integral extends over the visible spectrum at 5 nm intervals , that is an 81 - point multiplication and summation.

The chromaticity coordinates x, y, z are given by

$$x = \frac{X}{X + Y + Z}, \quad y = \frac{Y}{X + Y + Z}, \quad z = \frac{Z}{X + Y + Z} \qquad (3)$$

PL / 1 Computer Programme

A PL/1 (Programming Language / One) programme written by the author and based on the above computational procedures (1), (2) and (3), has the capacity to determine the required values from data for several samples at a time, for one or many different light sources.

The computer output includes measured reflectivity (or transmiticity) data (input), interpolated and extrapolated values and chromaticity coordinates (output). This programme and an example of listings of sample data are given in Appendices VI 1a amd VI 1b respectively .

VI 2. Computational Procedure for Dominant Wavelength, Complementary Wavelength and Excitation Purity

The dominant or complementary wavelength of a sample may be determined graphically from the standard chromaticity diagram (previously described). Judd (1933) gave a computational procedure to calculate the dominant wavelength and colorimetric purity* by linear interpolation from his tabular values given for the C.I.E. standard sources A,B,C and E. Judd's tabular values of slopes of the dominant wavelength lines can also be found in the book ' Color Science' by Wyszecki and Stiles (1967).

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* Colorimetric purity = spectral luminance purity, is the ratio of the luminance of the spectrally pure component of mixture with achromatic component, matching the colour, to the luminance of the colour itself. (CCOSA , 1968)

Such ratios of constant dominant wavlength (also complementary) for any other light source are evaluated by

$$r = (x - X) / (y - Y) \quad \text{if absolute value } (x - X) < (y - Y)$$

$$r = (y - Y) / (x - X) \quad \text{if absolute value } (y - Y) < (x - X). \tag{4}$$

where x,y and X,Y are coordinates of the spectrum and of the light source respectively.

A PL / 1 computer programme to compute tabular ratios was prepared and is given in Appendix VI 2. Tabular ratios for sources A,B and C are listed in Table VI 1.

The computation of the dominant wavelength (λd) or complementary wavelength (λc) by means of the Tables of Appendix VI 3, is as follows:

Knowing the chromaticity coordinates (x,y) of a sample irradiated by a source whose coordinates are (X,Y) the ratio r is computed from (4) above. The ratio r will be found lying between two tabulated ratios r_1 and r_2 which correspond to dominant wavelengths λ_1 and λ_2 respectively. The required dominant wavelength (λd) of the sample was evaluated by linear interpolation within the intervals of 1 nm, therefore

$$\lambda d = \frac{(r - r_1)}{(r_2 - r_1)} (\lambda_2 - \lambda_1) + \lambda_1 \quad . \tag{5}$$

To compute the excitation purity (Pe) it is required to find the coordinates of the dominant wavelength on the spectrum locus. The dominant wavelength of a sample lies between the tabulated wavelengths λ_1 and λ_2 . Their corresponding chromaticity coordinates (x_1, y_1) and (x_2, y_2) were read from Table II 3, and the required coordinates (x_d, y_d) of the calculated dominant wavelength (d) were obtained by linear interpolation.

$$x_d = \frac{(\lambda_d - \lambda_1)}{(\lambda_2 - \lambda_1)} (x_2 - x_1) + x_1$$

$$y_d = \frac{(\lambda_d - \lambda_1)}{(\lambda_2 - \lambda_1)} (y_2 - y_1) + y_1 \qquad (6)$$

The excitation purity (Pe) of the sample colour was then computed from one of the following formulae:

$$Pe = \frac{x - X}{\lambda_d - X} = \frac{y - Y}{\lambda_d - Y} \qquad (7)$$

These two expressions are equivalent, but if the straight line is approaching vertical the first expression is less accurate and vice versa when the straight line is nearly horizontal, and therefore the smaller value with the least rejection error was taken.

To Compute Excitation Purities of Non-Spectral Colours

Excitation purities of spectral colours always have positive signs, but one or both values (Pe) for the stimulus of a non-spectral colour will have a negative sign or signs when the above procedures are carried out. Hence the negative sign or signs of excitation purity would indicate that the required wavelength was not a dominant wavelength (λd) but a complementary wavelength (λc) and that the specimen had a non-spectral colour. Therefore it was necessary to recalculate the excitation purity for the complementary wavelength.

In order to calculate the excitation purity of a non-spectral colour it is first required to find the coordinates of its complementary wavelength on the purple line. This could be done in two ways.

(1) Chromaticity coordinates of complementary wavelengths of maximum purity for the C.I.E. sources A,B and C can be obtained from tabulated values in the book ' Science of Color' by the Committee on Colorimetry, 1968. The calculated complementary wavelength was then read from that table and linear interpolation from tabulated coordinates would give the required coordinates. This method is less accurate because wavelengths are not in linear scale.

(2) The second method used in this present work was as follows:

The equation of the purple line is

$$y = mx + c \text{ , where}$$

$$m = (y_m - y_n) / (x_m - x_n),$$

$$c = (x_m y_n - x_n y_m) / (x_m - x_n)$$

and x_m, y_m and x_n, y_n are coordinates of the two extreme ends of the spectrum locus.

The slope and intercept of the straight line passing through the illuminant point X,Y and sample point x_1, y_1 as shown in Figure VI 1 are

$$m_1 = (Y - y_1) / (X - x_1) \qquad (9)$$
$$c_1 = (Xy_1 - x_1Y) / (X - x_1)$$

The required coordinates x', y' of the complementary wavelength (λc) are involved at the intersection of the above two straight lines . Hence simultaneous equations give

$$x' = (c_1 - c) / (m - m_1)$$
$$y' = m \frac{(c_1 - c)}{(m - m_1)} + c \qquad (10)$$

The excitation purity (Pe) of a non-spectral colour was then calculated by the formulae (4) in which x' and y' replace x_d and y_d respectively.

PL/1 Computer Programme

Acomputer programme written by Dr. Reevs and the writer, based on the above equations (4) to (10) , has the capacity to compute dominant and/ or complementary wavelengths, coördinates and excitation purities of large numbers of specimen data, and to produce input and output data. This programme and an example of listings of necessary data are given in Appendices VI 4 a and VI 4 b respectively.

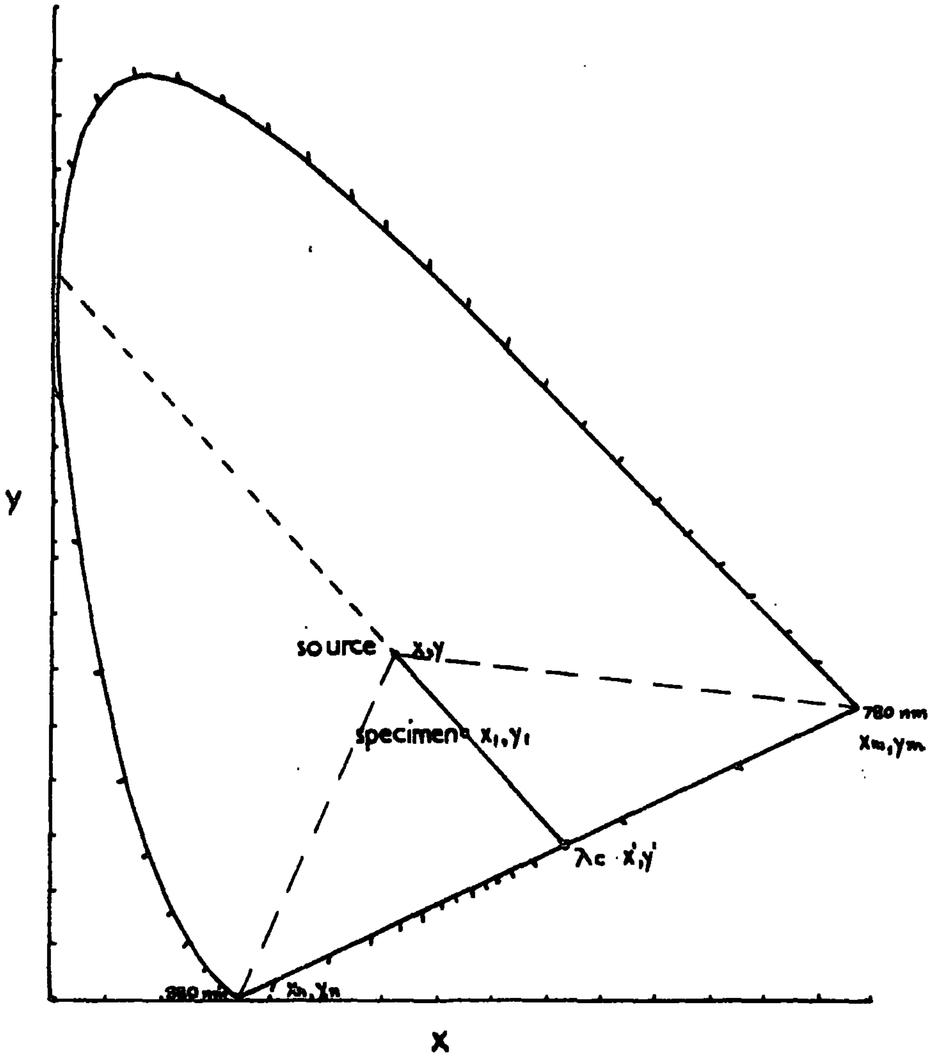


Figure VI 1. Explaination to compute complementary wavelength (λc) and excitation purity (Pe) of a non-spectral colour.

VII. ACCURACY AND PRECISION OF COLOUR SPECIFICATIONS OF MINERALS

Spectral reflectivity data available from different papers were employed to evaluate colour values quantitatively. Different authors gave different accuracy and precision of reflectivity measurements. Piller and von Gehlen (1964) describe accurate measurements of reflectivity with relative errors about ± 0.5% to ± 1%. Cameron (1963) claims an accuracy of ± 0.2% at 549 nm (corresponding to a relative error of ± 1% at a reflectivity of 20%).

Nichol and Phillips (1964) obtained a precision of ± 0.25% at the reflectivity level of 18%. Bowie (1967) gives reflectivity data of some ore minerals with a precision of less than ± 0.5 absolute percent in white light. Levy (1966) obtained precision of about ± 0.2 to 0.6 from twenty measurements of spectral reflectivities.

It is to be pointed out that the precision and accuracy of spectral reflectivity measurements vary over the visible spectrum. This is the case to be considered seriously for reproducibilities of colour values of minerals, because calculations showed that a consistant error of 1% or 2% in every wavelength made no variation in calculated chromaticity coordinates, but small inconsistant error at some wavelengths only gave rise to differences in coordinates.

However, as the C.I.E. colorimetric system has limits of accuracy (threshold values), the accuracy and precision of colour values derived from spectral reflectivities can be estimated in terms of these threshold values.

The Weighted Ordinate method ($d\lambda$ = 5 nm) which is preferable to the Selected Ordinate method (previously described) was adopted as a standard method in this persent work. It follows that the accuracy and precision depends on spectral reflectivity data and the numbers of wavelength intervals used in the measurements. Most of the reflectivity values given in the papers are only for a few wavelengths. Hence several interpolated values required to evaluate the integrals may deviate considerably from actual measureable values. This in turn depends upon the shape of the reflectivity curve.

In order to estimate the precision of quantitative colour values derived from available reflectivity data by the computer programmes it is necessary to estimate the true values. This was done by using reflectivity data with the smallest wavelength intervals. Then the precision of chromaticity values derived from large wavelength intervals can be compared to those obtained from small intervals.

A wide range of specimen data was selected to obtain strong, medium and weak colours with the chromaticity points scattered as regularly as possible around the standard illuminant points A and C.

Calculations for comparisons of results were carried out on the following basis. For a particular mineral measured values of reflectivity with smallest wavelength intervals were first used to derive the chromaticity coordinates. From the same series of measurement a few values of reflectivity were then selected and used to determine the effect of making measurements at wider wavelength intervals. So that deviations from the smallest intervals can be estimated as errors introduced in the colour values.

For example, pyrite has a comparatively medium colour saturation so originally the results of Demirsoy (1968), at 23 wavelengths, were used in the calculations and then values only 16, 12, 8 and 4 were used in turn, as shown in Table VII 1.

Table VII 1 shows the deviations of reflectivity values at omitted wavelengths from the actual measured values of 23 wavelengths, due to linear interpolation. The effective variations in the chromaticity coordinates due to such inconsistant deviations of spectral reflectivities over the spectrum are given in Table VII 2.

In the case of pyrite it was found that the chromaticity coordinates derived from the 23-point, 16-point and 12-point series were identical, although the interpolated reflectivities deviated from the actual measured values of the 23-point series. That is, the deviations ranging from 0.0 to ± 0.15 (see Table VII 2) in the visible spectrum indicate that the chromaticity values are not affected by errors of 0% to 0.3% in spectral reflectivities.

Due to linear interpolation the deviation of the 8-point and 4-point series from the actual measured values of the 23-point series ranged from 0.0 to ± 0.2 and ± 0.01 to ± 2.2 respectively (corresponding to relative errors of ± 0.4% and ± 4% for the upper limits).

Hence the chromaticity values of either the 23-point, 16-point or 12-point series can be taken as standard values for comparison and the deviations of the 8-point and 4-point values can be compared to the standard values, in terms of the MacAdam standard deviation formula ($ds^2 = g_{11}dx^2 + 2g_{12}dx.dy + g_{22}dy^2$; where the unit of ds = 1 ; previously described in Chapter II 12).

The chromaticity values obtained from the 8-point and 4-point series differed from the standard values in the fourth and third decimal places respectively, the results of calculations showed that the chromaticity point derived from the 8-point data was well within the threshold values, but the chromaticities of the 4-point data were only just within the threshold limit. It seems that the MacAdam's standard deviations are slightly large.

In the same way to estimate the accuracy and precision of colour values of minerals the calculated colour specifications and standard deviations for pyrite (Demirsoy, 1968), bornite (the writer), tennantite (Tugal, 1969), hematite (Demirsoy, 1968), covellite (von Gehlen and Piller, 1964) and cattierite (Demirsoy, 1968) are given in Table VII 2.

These considerations and results indicate that:

(1) for most ore minerals 12- to 8-point measurements of reflectivity are sufficient for accuracy and precision,

(2) for a strongly coloured mineral like covellite at least 12 measurements of reflectivity are necessary,

(3) four-point data will only provide reasonably accurate values of colour within the thr~~o~~sholds when the reflectivity curve is fairly linear,

e/

(4) colour specifications derived from measured reflectivity (or transmiticity) values with regular approximate errors of 0 to ± 2% over the visible spectrum are accurate within the small limits of the threshold values.

Table VII 1. Measured Reflectivity Values and Deviations at Omitted Wavelengths Due to Interpolation

Wave-length	23-point Series (measured)	16-Point Series	Deviation	12-Point Series	Deviation	8-Point Series	Deviation	4-Point Series	Deviation
440	40.9	40.9	-	40.9	-	40.9			+ .80
450	42.4	42.4	-		.00		.00		+ .40
460	43.9		.00	43.9		43.9		43.9	
470	45.5	45.5	-		+.05		+.05		- .50
480	47.2	47.2	-	47.2			.00		-1.10
490	48.7		+.15		+.15		+.15		-1.50
500	50.5	50.5	--	50.5	-	50.5	-		-2.20
510	50.9	50.9	-		+.10		+.15		-1.50
520	51.5		+.05	51.5	-		+.10		-1.00
530	52.2	52.2	-		-.10		-.05		-.60
540	52.7	52.7	-	52.7	-	52.7		52.7	-
550	53.2		.00		.00		-.10		- .10
560	53.7	53.7	-	53.7	-		-.20		- .20
570	54.1	54.1	-		-.10		-.20		-. 20
580	54.3		.00	54.3	-	54.3	-	54.3	-
590	54.5	54.5	-		.00		.00		- .06
600	54.7	54.7	-	54.7	-	54.7	-		- .13
610	54.7		.00		.00		-.08		- .01
620	54.7	54.7	-	54.7	-		+.15		+ .15
630	54.9	54.9	-		-.05		+.03		+ .09
640	55.0		+.10	55.0	-	55.0			+ .13
650	55.3	55.3	-		-.10		-.10		- .04
660	55.4	55.4	-	55.4	-	55.4	-	55.4	-

Table VII 2. Variations in Chromaticity Coordinates Due to Interpolation of Reflectivity Values

Specimen	Series	dY	dx	dy	dY/Y
Pyrite	23-Point	Compared to the 23-Point values			
(Demirsoy,	16-Point	0.009	0.000	0.000	0.0002
1968)	12-Point	0.009	0.000	0.000	0.0002
	8-Point	0.025	0.000	0.0001	0.0005
	4-Point	0.362	0.0006	0.0020	0.0068
Bornite					
(the Writer)	12-Point	Compared to the 12-Point values			
	8-Point	0.079	0.0005	0.0002	0.004
	4-Point	0.138	0.0004	0.0048	0.007
Tennantite					
(Tugal, 1969)	12-Point	Compared to the 12-Point values			
	8-Point	0.033	0.0003	0.0001	0.001
	4-Point	0.050	0.0009	0.0017	0.002
Hematite(w)					
(Demirsoy,1968)	23-Point	Compared to the 23-Point values			
	12-Point	0.009	0.0001	0.0001	0.0003
	8-Point	0.018	0.0000	0.0000	0.0006
	4-Point	0.035	0.0002	0.0002	0.001
Vovellite(w)					
(Gehlen & Piller,	14-Point	Compared to the 14-Point values			
1964)	12-Point	0.008	0.0005	0.0001	0.001
	8-Point	0.019	0.0014	0.0004	0.003
	4-Point	0.260	0.0128	0.0030	0.038
Cattierite					
(Demirsoy,1968)	23-Point	Compared to the 23-Point values			
	16-Point	0.000	0.0000	0.0000	0.000
	12-Point	0.009	0.0001	0.0001	0.0003
	8-Point	0.004	0.0002	0.0000	0.001

VIII. MEASUREMENTS OF COLOUR CONSTANCY, BIREFLECTANCE AND REFLECTION PLEOCHROISM

Colour constancy refers to the substantial invariance of object-colour perceptions in the presence of changes in illumination (The Science of Color by Committee on Colorimetry, 1968). Discussion of the phenomenon of colour constancy is as old as the problem of matching surface colours in different illuminants. Two samples, for instance , will match under one illuminant, but they may not match under another. In some cases they will mis-match because the alteration in appearance may be so slight that it would pass undetected if the second sample were not available for comparison.

Each real object has a so-called object colour which is merely its capacity to modify the colour of the light incident upon it. This capacity depends essentially upon the spectral reflectance of the surface and is a more or less unique and constant characteristic of the given object.

Changes in appearance accompanying changes in illuminant may be too weak to be perceived. For instance, coal usually continues to look black, and snow white, in a wide range of illuminants, owing to the effect of colour constancy. They are said to have high degrees of colour constancy.

Changes in colour sensitivity are less frequently noticed although they, too, are continually occurring and may be quite large. The tendency in maintaining the colour constancy of object colours is, on the other hand, due to visual adaptation.

The effect of visual adaptation in colour perception may be illustrated as follows. The colour of daylight and the colour of tungsten light are very different when viewed side by side, but many ordinary objects in a room seem little changed in appearance when they are seen during the day and at night.
Another example of adaptation effect is well known in photographic colour processing. Whites in the original may consist of white surfaces illuminated by daylight , artificial light, or some other illuminant , and hence have varying energy distributions. These are all seen as more or less white, owing to the adaptation of the eye to the illuminant, but of course the sensitivities of the photographic material are unchangable, and therefore will give different reproductions for whites under different illuminants.

Thus process of visual adaptation could largely compensate for changes in sensitivity level of the eye and the colour of the illumination, and hence favours colour constancy. Nevertheless , the compensation is rarely quite complete and a high degree of colour constancy is rare (Wright, 1969; Committee on Colorimetry, 1968). On the other hand, if the illumination changes are too sudden or too great, or if the colour of the object instead of the illuminant is seen , adaptation could not prevent obvious changes in object colour perception due to changes in illuminant.

Changing the illuminant may change the brightness or relative spectral distributions of the light from the objects, and therefore they show changes in appearance. The degree of colour constancy will be of significance to particular light sources.

A classic example of a poor colour constacy can be demonstrated by alexandrite (Cr-bearing chrysoberyl) in the field of mineralogy, particularly in gemmology. Alexandrite is green under daylight and changes very distinctly to a red under tungsten light, because it highly absorbs the light in the yellow and blue regions, gives a main peak in the green and a secondary one in the red. Its spectral diffuse reflectance or transmittance curve may be somewhat like the one as shown in Figure VIII 1. Unfortunately, no quantitative data for alexandrite was obtained vecause of lack of specimens. Its colour values calculated from the above predicted, general curve were plotted on the chromaticity diagram in Figure VIII 2 to show the obvious changes of colour in passing from daylight to tungsten light.

It was, therefore expected that some minerals may have characteristics changes in appearance accompanying the change of illuminant and so some minerals may be easily distinguished from others, which are similar under ordinary observation condition.

According to the literatures of ore microscopy briartite and gallite are difficult to distinguish, galena and sulvanite are similar. They can be distinguished from similar counterparts by observing changes differently in appearance when inserting and taking out a daylight filter infront of the tungsten lamplight. As shown in Table VIII 1 briatite shows very little change in appearance whereas gallite changes in colour noticeably when changing the illuminant from A to C. In the same way the changes in contrast enchancement of galena and sulvanite could be detected. Galena shows noticeably increasing saturation and brightness (additive effect), i.e. its appearance changes towards luminous bluish colour from bright grayish colour; whereas sulvanite performs slight decreasing saturation and brightness (subtractive effect) from gray-yellowish to faint yellowish colour.

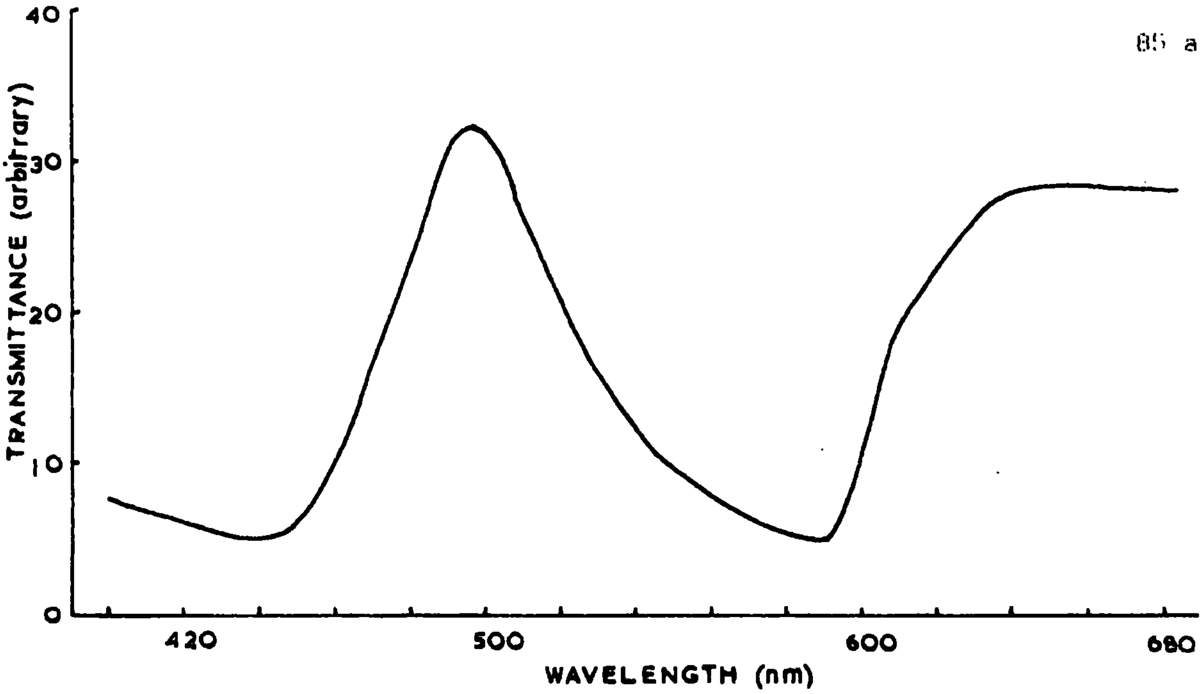


Figure VIII 1. A spectral distribution curve giving a green colour in daylight and changing to a red under tungsten light.

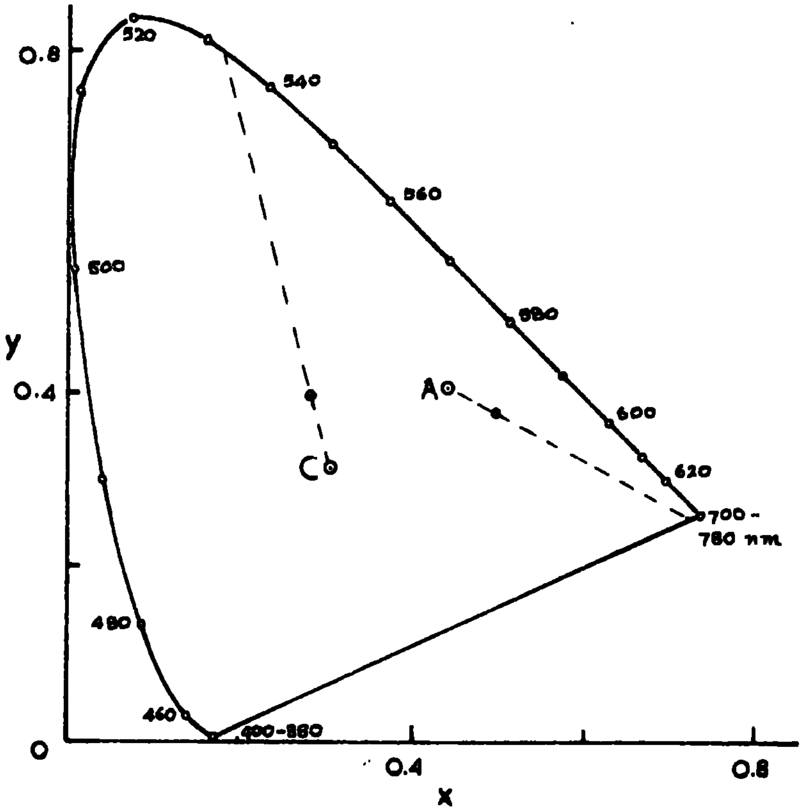


Figure VIII 2. Chromaticity diagram showing a poor colour constancy of a specimen of Figure VIII 1.

The basic quantitative colour values of some ore minerals for the standard light sources A (average tungsten light) and C (artificial average daylight) are tabulated in a later Chapter.

Isometric minerals have a single reflectivity in all directions in white light or in any monochromatic light and consequently they remain unchanged in chromaticness (hue and saturation) and visual brightness as the stage of the microscope is rotated under one light source. Many minerals of other crystal systems show distinct changes in appearance with rotation of the stage under ordinary observation conditions.Such changes are due to the variation of indices of reflection and absorption with different crystallographic orientations. The changes may be in brightness or chromaticness, or both.

The terms bireflectance and reflection pleochroism are here used in separate senses on the basis of quantitative values , although in the literature of ore microscopy these terms have been used with the same or similar meanings but without clear difinitions . (particularly in the books published by Uytenbogaardt and Burke, 1971 page VI; Ramdohr, 1969 page 297).

Bireflectance may be defined as the difference between the maximum and minimum reflectivities of principal crystallographic directions or as the difference of brightness Y vaues (= visual R) , i.e. $dY = Y_{max.} - Y_{min.}$. Effective bireflectance to the visual sensation can be estimated with the threshold value of the brightness which is appeoximately $dY/Y = 1\%$.

Some sections of anisotropic minerals may show changes in brightness alone without changes noticeably in chromaticness, as the stage of the microscope is turned . In other words the change in appearance of a polished section with rotation of the stage is due to the bireflectance, not due to changes in colour.

Reflection pleochroism may be defined as differences in chromaticity values (dx,dy) or as differences in dominant wavelengths (λd) and excitation purities (dPe) between the two principal directions of a section. Effective reflection pleochroism can be estimated with MacAdam's threshold values.

Thus on the basis of quantitative colour values we can say that changes in appearance of anisotropic minerals with rotation of the stage are either due to the effect of bireflectance or due to reflection pleochroism, or due to both effects.

Pleochroism can then be defined quantitatively as differences between respective tristimulus values dX, dY, dZ for the principal directions of a section or expressed differently as the combined effects of bireflectance and reflection pleochroism.

For example, changes in colour of some ore minerals, as the microscope stage is rotated under one illuminant, are shown in Table VIII 2. Such quantitative values of bireflectance and reflection pleochroism may also help to direct the consentration of an observer in a particular case or cases.

Figure VIII 3 shows the changes of dominant wavelengths and excitation purities of some ore minerals in passing from tungsten light (source A) to artificial daylight (source C). In the Figure dots represent positions of the specimens under source A and the shifts are indicated by arrow-heads when the illuminant is changed to source C .

From this Figure the following interesting points are noted.

(1) Most of the ore minerals have hues in two major wavelength regions - i.e. yellow-orange part and purple-blue part.

(2) The shifts of chromaticness, accompanying changes in illuminant, appear in a rather regular fashion. These regular shifts, in general, indicate that the colours of ore minerals having chromaticnesses in yellow-orange region become fainter when a daylight filter is interposed infront of the tungsten light, whereas the colours of other minerals having chromaticnesses in the purple-blue become stronger.

(3) As consequances of the effect three significant characteristics in some cases were observed.

Firstly, in comparison, if two faint coloured minerals occur side by side there may be effective contrast enchancement with changes in illuminant.
For example, galena and briartite will show effective contrasts because the degree of colour constancy of galena is comparatively poorer than that of briartite. Similarly as shown in Table VIII 1, briartite and gallite which are difficult to distinguish from each other can be differentiated and recognised by observing contrasting degrees of colour constancy.

Secondly, some anisotropic minerals will show more effective pleochroism (bireflectance and reflection pleochroism) under one illuminant or under another. For example, the reflection pleochroism of hexagonal pyrrhotite is stronger under illuminant A than under illuminant C. The reflection pleochroism of klockmannite is distinctly stronger under illuminant C than under illuminant A. These examples are illustrated in Figure VIII 4.

Thirdly, the colours of many minerals change correspondingly in passing from illuminant A to C, but their shifts are of the same magnitude, thus the contrast between the colours of many minerals remain the same.

The same effects were observed when attempts were made to obtain significant changes in colour under new light sources. These sources were combinations of source A and a neutral filter with 80 % transmission, and source A and a neutral filter with 20 % transmission characteristics.

The procedures for measurement of a new light source are described below.

First and formost measurements of spectral transmittances of each neutral filter (F_λ) were made in the visible spectrum. The relative energy distributions of the C.I.E. source A ($H_\lambda \, d\lambda$) were multiplied by the 1931 C.I.E. colour-matching functions ($\bar{x}_\lambda$), similarly by ($\bar{y}_\lambda$) and ($\bar{z}_\lambda$) for wavelengths 380 nm to 780 nm with an equal interval of 5 nm.

The sums $\sum \bar{x}_\lambda H_\lambda \, d\lambda$, $\sum \bar{y}_\lambda H_\lambda \, d\lambda$, and $\sum \bar{z}_\lambda H_\lambda \, d\lambda$ were multiplied by a normalizing factor K, where $K = 100.0/\sum \bar{y}_\lambda H_\lambda d\lambda$. Then the spectral transmittances F_λ were multiplied by corresponding products $\bar{x}_\lambda H_\lambda d\lambda$, etc. The normalizing factor K for the new light source was computed by

$$K = 100.0/\sum F_\lambda \bar{y}_\lambda H_\lambda d\lambda \quad .$$

The tristimulus values of the new light source were

$$X_F = K \sum F_\lambda \bar{x}_\lambda H_\lambda d\lambda \quad ,$$

$$Y_F = K \sum F_\lambda \bar{y}_\lambda H_\lambda d\lambda \quad = 100.0 \quad \text{and}$$

$$Z_F = K \sum F_\lambda \bar{z}_\lambda H_\lambda d\lambda \quad .$$

The relative energy distributions or normalized energy distributions of the required light source were obtained thus

$$\text{for X :} \quad \frac{\int (F_\lambda H_\lambda \bar{x}_\lambda d\lambda)\ X_F}{\sum F_\lambda H_\lambda \bar{x}_\lambda}$$

$$\text{for Y :} \quad \frac{\int (F_\lambda H_\lambda \bar{y}_\lambda d\lambda)\ Y_F}{\sum F_\lambda H_\lambda \bar{y}_\lambda}$$

$$\text{for Z :} \quad \frac{\int (F_\lambda H_\lambda \bar{z}_\lambda d\lambda)\ Z_F}{\sum F_\lambda H_\lambda \bar{z}_\lambda}$$

These relative energy distributions were used in the calculation according to the C.I.E. method for the measurement of an object colour with respect to this new light source. The chromaticity coordinates of the source were then calculated by the formulae given previously.

$$x = X_F / (X_F + Y_F + Z_F)$$

$$y = Y_F / (X_F + Y_F + Z_F) .$$

APL/1 computer program written by the author for IBM/360 to compute relative spectral distributions, tristimulus values and chromaticity coordinates of any light source whose spectral characteristics are known is given in Appendix VIII 1.

Colour measurements of a few ore minerals were made for the new light source and results were compared to those obtained previously fot the standard light sources A and C. With changes in illuminant A to the new light sources or C to the new light sources all bases of comparison shifted correspondingly, but nothing looked significantly different compared to the shifts due to changes in illuminant A to C.

Therefore all quantitative colour values of some ore minerals are presented in Tables for the standard light sources A and C.

Table VIII 1.

Example: Degrees of colour constancy in passing from tungsten light (source A) to daylight (source C).

Mineral	$d\lambda$	dPe%	dY	dY/Y %
Briartite	5.8	-0.33	+0.09	0.3
Gallite	10.7	+2.03	+0.18	0.8
Galena	11.15	+2.92	+0.30	0.7
Sulvanite	11.44	-3.75	-0.36	-1.1

Table VIII 2.

Examples of Quantitative Values of Bireflectance and Reflection Pleochroism under average tungsten light (source A).

Anisotropic	Bireflectance	Reflection Pleochroism		Effective Pleochroism	
mineral	dY	dPe%	$d\lambda$	dY/Y	ds
Hematite (w - e)	3.7	0.5	1.1	12.7	1.0
Luzonite(max. - min.)	3.3	5.5	12.4	12.4	1.4
Mawsonite(max. - min.)	0.6	11.1	1.9	2.25	10.9
Chalcopyrite(max. - min.)	0.1	0.9	0.3	- 0.3	-0.9
Chalcophanite(max. - min.)	16.7	3.1	1.3	63.5	7.4
Niccolite(max. - min.)	2.2	2.9	0.1	4.2	7.7
Hodrushite(max. - min.)	1.2	0.0	4.0	3.6	2.1

Note: Pleochroism of hematite from (w) to (e) is mainly due to bireflectance. That is, the brightness difference between (w) and (e) directions is 12.7 times greater than just noticeable difference. Reflection pleochroism is just perceptiable since ds = 1.

The brightness difference (dY) of chalcopyrite between maximum and minimum directions is below noticeable level. The saturation difference (dPe%) is just below noticeable difference. Therefore, its pleochroism (dY/Y & ds) may not be percepti~~a~~ble.

FIGURE VII 3 SHOWING CHANGES IN HUE (λd) AND SATURATION (Pe) OF ORE MINERALS IN PASSING FROM TUNGSTEN LIGHT TO DAYLIGHT

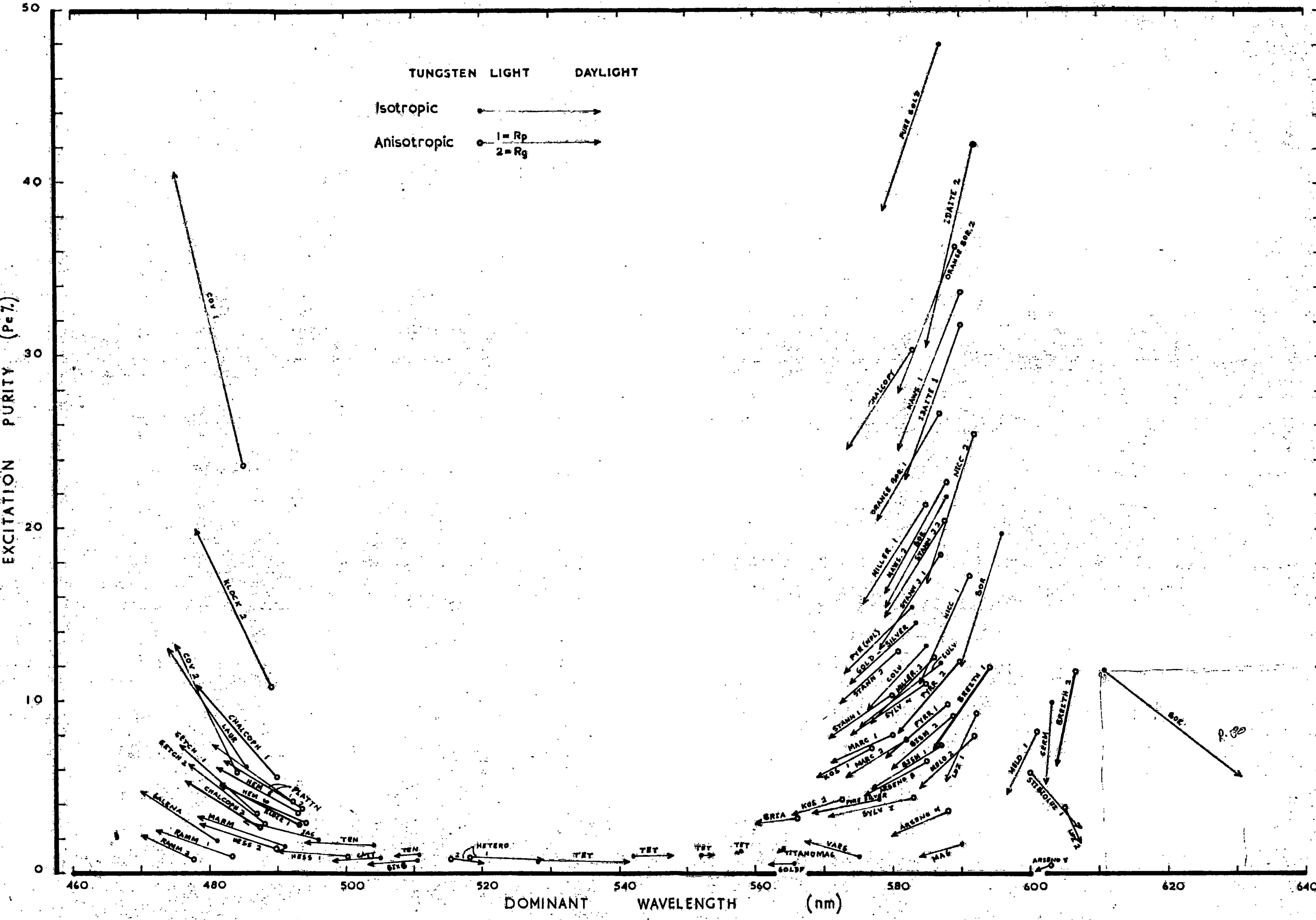
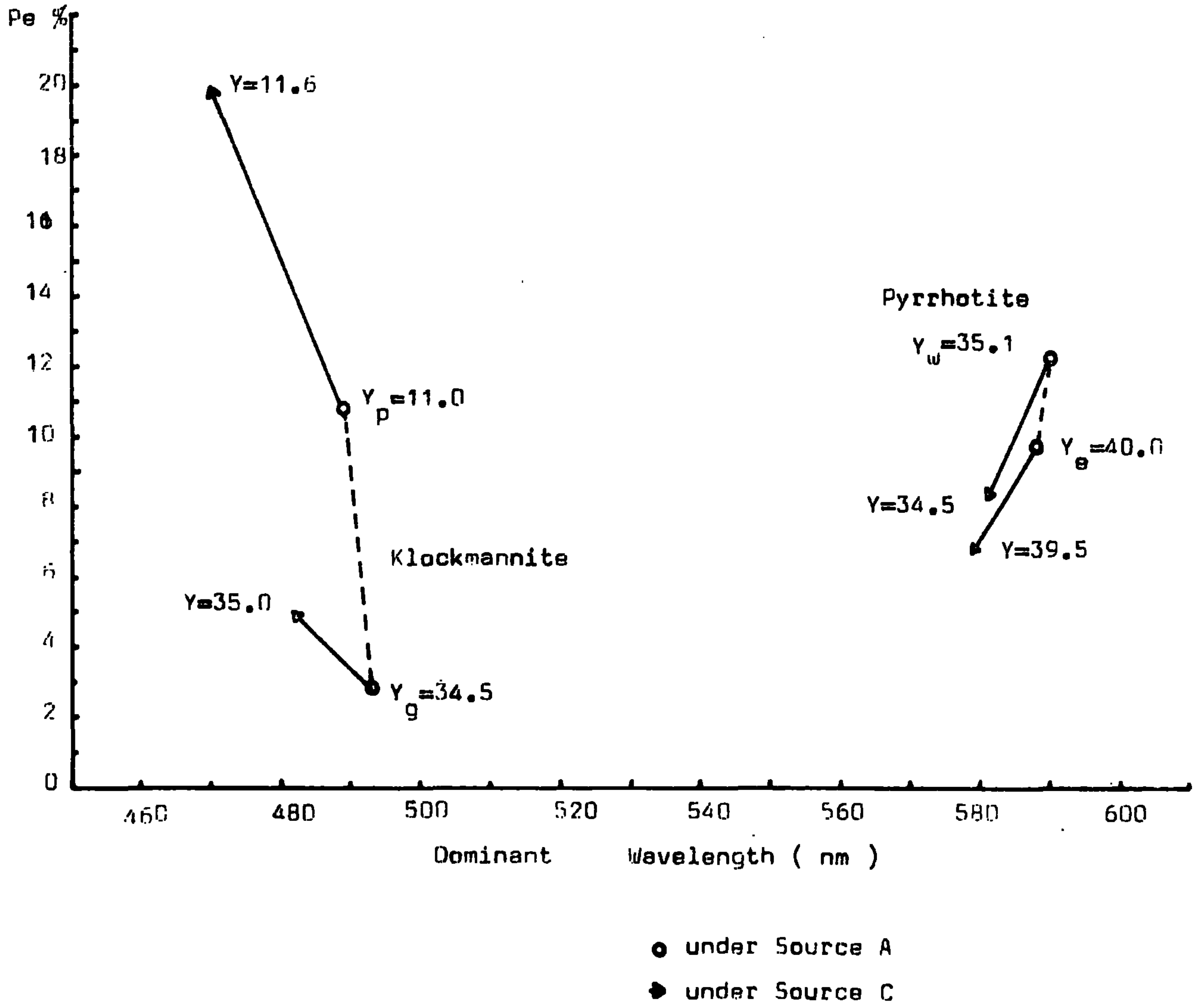


Figure VII/4. Example of different effects of Reflection Pleochroism in passing from Tungsten light (source A) to Daylight(source C)



IX. A STUDY ON SOME COLOUR PROBLEMS IN ORE MINERALS

The major aim of this present work lies in the development of quantitative colour measurement methods for minerals and the establishment of numerical colour values, spectral reflectivity data and graphical representation of the colours of some ore minerals.

On the basis of the quantitative values, attempts were made to understand the nature of the characteristic colour, colour variation, colour discrimination, colour constancy, refelction pleochroism and bireflectance of a mineral. Explainations of these properties have been given in the previous chapters.

Attempts were also made to understand the relationships between variations in colour quality and chemical composition and/ or physical properties. Unfortunately, in the majority of cases, insufficient chemical and other physical data are available for measured specimens, and therefore no promising correlation could be made, but general relations were observed.

The results of the analyses, described in the following pages should be consulted with the appropriate Figures and Tables which are compiled in Chapter X .

PURE GOLD, Au

PURE SILVER, Ag

GOLD - SILVER ALLOY, 50% Au + 50% Ag

The chromaticity coordinates of pure gold, pure silver and synthetic gold-silver alloy were plotted on the x-y chromaticity chart. A gentle curve passing through these points indicates the increase of excitation purity (saturation of hue) with increasing gold content in gold-silver alloys.

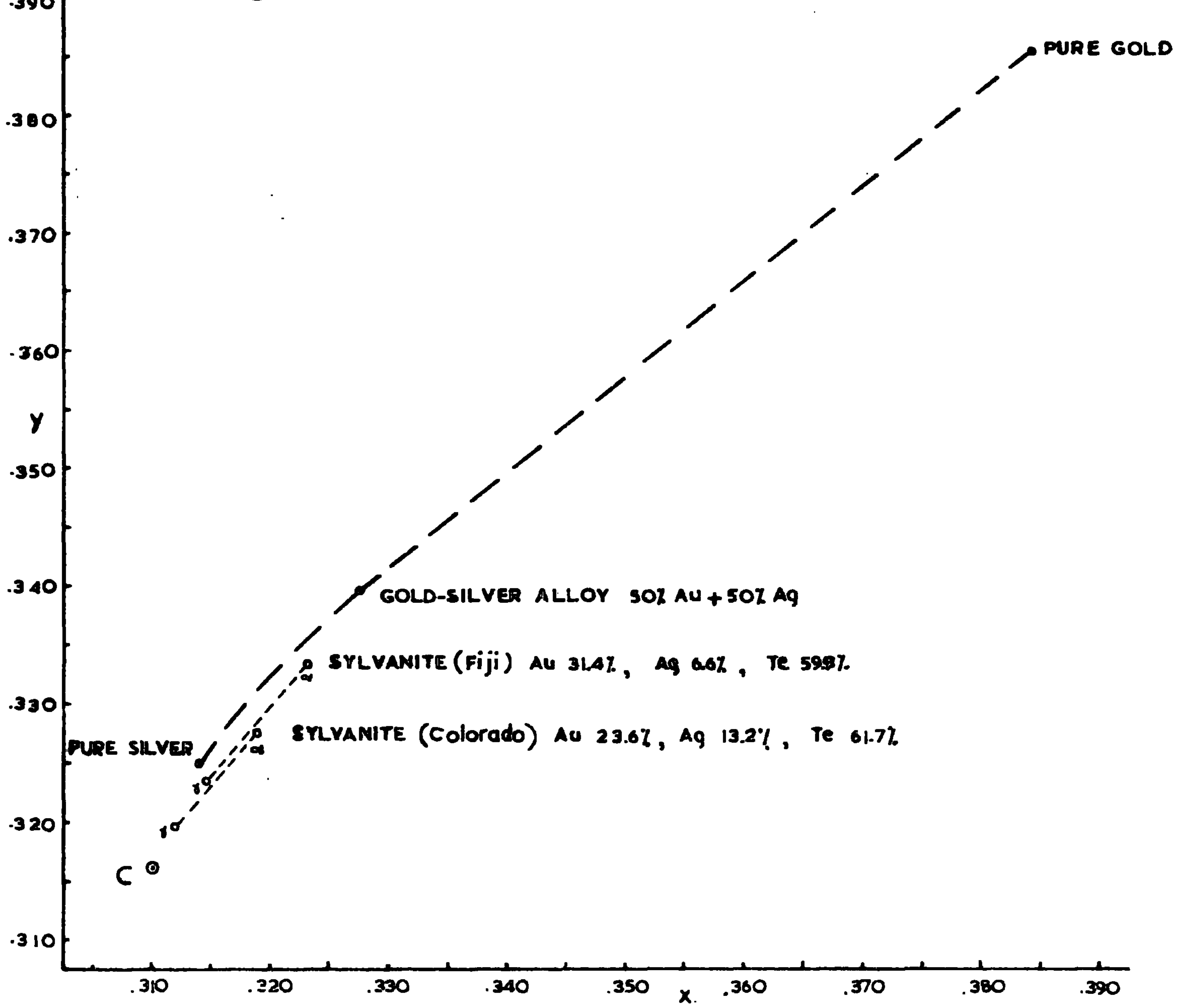
The chromaticity points of two natural sylvanite($AuAgTe_4$) specimens from different localities are also shown in order to compare the positions of relative chromaticities with variable gold-silver content. The change in chromaticness of each sylvanite is due to two principal orientations (α and γ), and is almost parallel to the purity increasing direction of the gold-silver alloy.

It is evident from the chromaticity chart that the higher purity of the sylvanite specimen from Fiji (the maximum purity point) suggest a higher gold content or conversely lower silver content than the specimen from Colorado, as quoted from their electron microprobe (Stumpfl, 1970) analyses on the chart.

These quantitative values of colour agree well with Eales (1961), who noted qualitatively that the colour of gold in polished sections is an index of its fineness. According to Eales nearly pure gold from some Southern Rhodesian mines has a golden colour with a distinct ruddy tint (approximately 950 fine) and with increasing proportion of alloys silver this colour changes through yellow to pale silvery yellow (approximately 600 fine). Eales defined only four shades of colour qualitatively, to which all gold grains encountered could be referred.

It be of interest to determine colour coordinates of several gold-silver alloys having different finenesses because the above data suggest that their colour points will lie on the suggested gentle curve, showing an increase of purities with increasing gold contents and that all gold grains encountered could be compared with known standards.

Figure IX 1.


.390
.380
.370
.360
.350
.340
.330
.320
.310
y
.310
.320
.330
.340
.350
.360
.370
.380
.390
x
PURE GOLD
GOLD-SILVER ALLOY 50% Au + 50% Ag
SYLVANITE (Fiji) Au 31.4%, Ag 6.6%, Te 59.8%
SYLVANITE (Colorado) Au 23.6%, Ag 13.2%, Te 61.7%
PURE SILVER
C

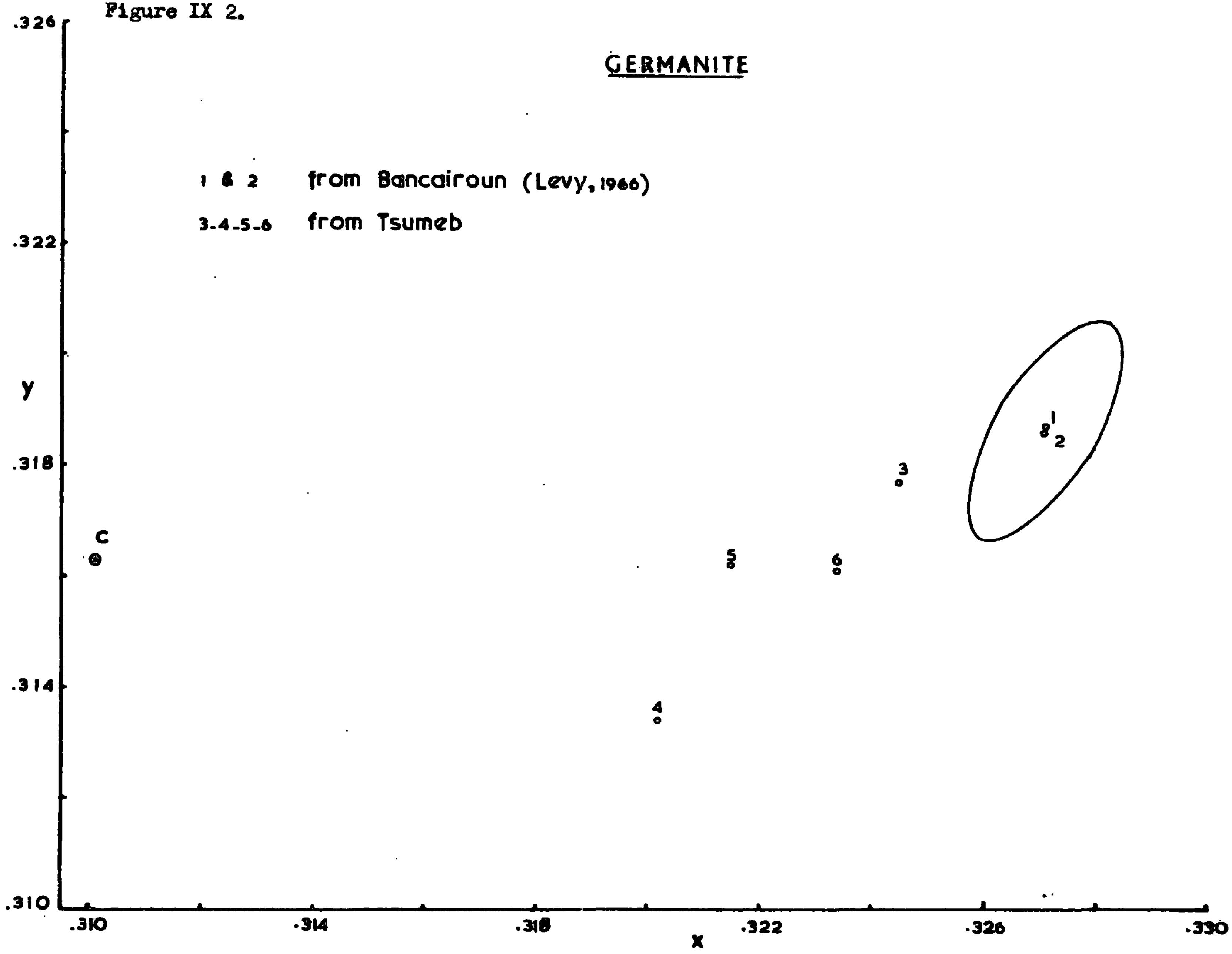
GERMANITE, $Cu_6 Fe Ge S_8$

Quantitative colour values of germanite specimens, as plotted on a chromaticity chart, are in good agreement with Levy (1966) who made measurements of spectral reflectivity on those specimens.

The chromaticity chart shows that the two specimens 1 and 2 from Bancairoun have the same colour as they are chemically homogeneous (Levy, 1966). The chromaticity points 3,4,5 and 6 scattering outside the discrimination ellipse represent the varying shades of colour of four different areas on a heterogeneous specimen from Tsumeb, as the differences are visually noticeable (Levy, 1966).

According to R. Phillips (personal communication), Springer (1969) and Levy (1966) the probable reason for the heterogeneous character of Tsumeb germanite is mainly due to the different contents of tungsten (tungsten-germanite). The colour of homogeneous, probably normal germanite is similar to that of bornite but slightly paler and higher in reflectivity (see in bornite).

Figure IX 2.


GERMANITE
1 & 2 from Bancairoun (Levy, 1966)
3-4-5-6 from Tsumeb
y
.326
.322
.318
.314
.310
x
.310
.314
.318
.322
.326
.330
C
1
2
3
4
5
6

BORNITE, $Cu_5 Fe S_4$

Freshly polished surfaces of some bornite specimens show noticeable colour differences. It was of interest to investigate the colour variation in bornites.

Spectral reflectivity measurements for colour evaluation were made on freshly polished surfaces of six specimens from five different localities, as described previously in Chapter III. In order to know the tarnishing effect with time, repeated reflectivity measurements were made. The values of the second measurement immediately after the first run, within about 40 minutes, showed no sigificant cariation in reflectivity and colour values, but during the third run it was noted that the specimen surface tarnished quickly and consequently gave different values. Therefore the reflectivity values obtained on the first run were believed to be accurate for bornite.

Electron microprobe analyses of these specimens were made by Dr. Peckett (Geology Department, University of Durham) with a 'Cambridge Geoscan' microanalyser. The precision of the measurements was estimated at about ± 2% of the measured value.

All analyses show that the measured specimens are nearly pure as all trace element contents are below the limits of detection. The contents of Ti, Cr, Co, Ni are approximately less than 180 ppm, As is less than 450 ppm and Sb is less than 350 ppm.

Figure IX 3, showing the colour distributions of measured bornite specimens (also other bornite specimens from Turkey; Tugal, 1969), and the Table below indicate that there are slight variations in colour with slight differences in composition, but also shows that there is no linear correlation between colour and composition. The chemical formula of each specimen is given on the basis of 4 sulfur atoms per molecule.

Figure IX 3.

BORNITE

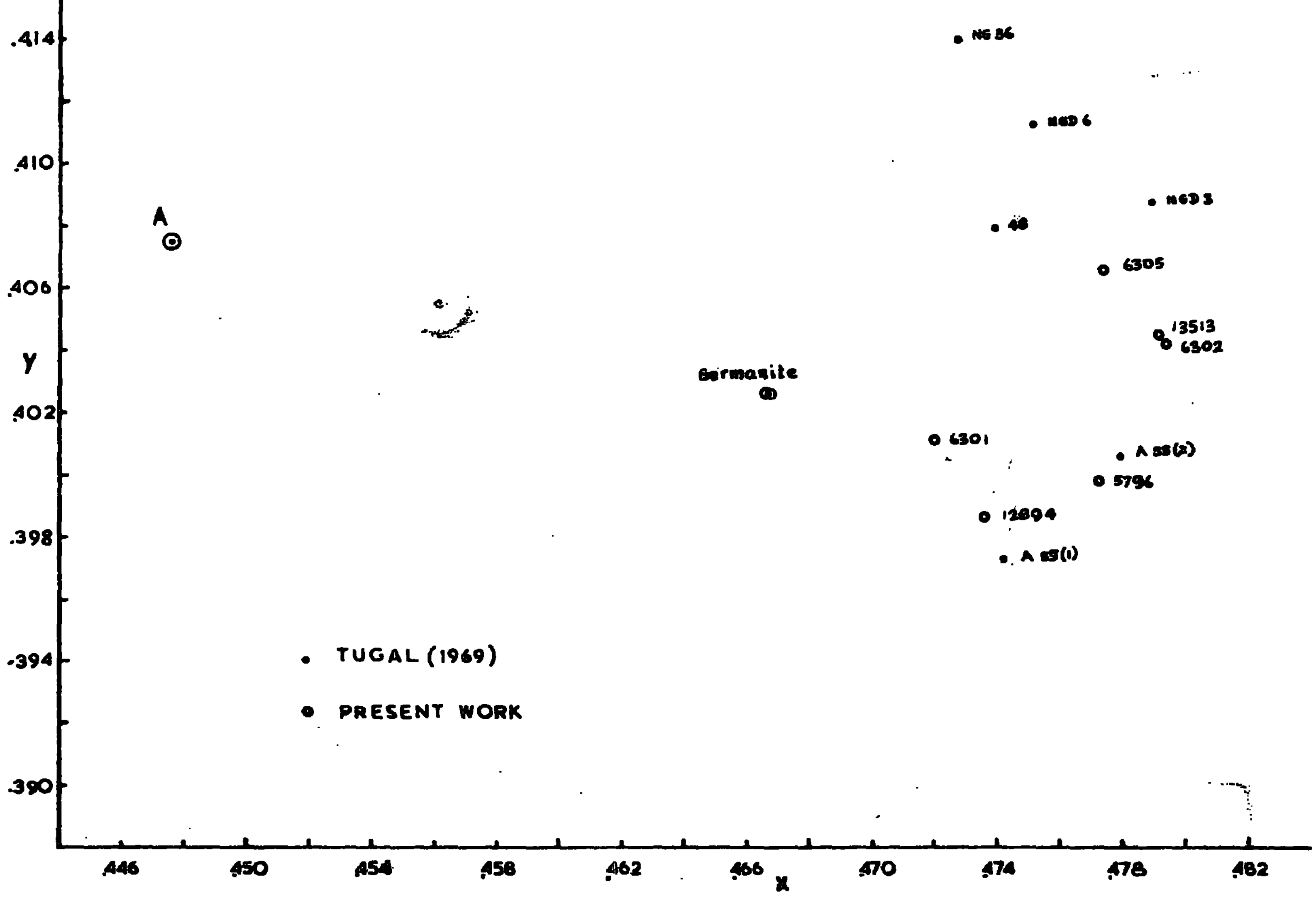


Table IX 1. **Electron Microprobe Analyses and Colour Values of Bornites**

Specimen No.	6305	13513	6320	5796	12894	6301	
Locality	Korea	Australia	Arizona	Rhodesia	Rhodesia	New Jersey	
Cu	63.41	63.47	63.44	63.41	63.39	63.01	Wt. %
Fe	11.41	11.48	11.57	11.50	11.41	11.60	
S	25.49	24.82	24.88	25.70	24.88	25.50	
Sum	100.31	99.77	99.89	100.61	99.68	100.11	
Formula	$Cu_{5.03}Fe_{1.02}S_4$	$Cu_{5.17}Fe_{1.06}S_4$	$Cu_{5.14}Fe_{1.06}S_4$	$Cu_{4.98}Fe_{1.02}S_4$	$Cu_{5.14}Fe_{1.05}S_4$	$Cu_{4.98}Fe_{1.04}S_4$	
Y (brightness)	22.05	21.30	21.83	20.14	19.78	20.32	
d (nm)	593.8	595.8	596.1	603.7	610.6	603.8	
Pe %	19.74	19.74	19.69	15.16	11.82	12.46	

The colour values are with respect to the standard illuminant A.

PYRITE , Fe S_2

The colour distributions of 15 pyrite specimens are shown together with a discrimination ellipse on the chromaticity chart. All colour points are scattered within about 3 nanometers of the dominant wavelength, but the variation in purity (saturation) as a whole is surprisingly large, i.e. their colour qualities may be perceptibly whitest yellow to yellowish white.

Comparing the colour distributions with the threshold ellipse, the colour quality, for instance, of the R.S.M. pyrite is noticeably different from that of the A.E.D. pyrite.

Spectral reflectivities of the (100) face of pyrite (Demirsoy, 1968) are lower, by between 0.3 and 0.6 units, than those of the (111) face, but chromaticity coordinates are identical. Their relative brightness (= visual reflectivity) difference (dY/Y%) is 1% which is just noticeable under an ore microscope.

Singh (1965) demonstrated the variations in spectral reflectivity of a group of pyrite specimens from fifferent localities and the same effect is also described by Gray and Millman (1961) and others. According to Singh the specimens 1877, 1879 and 1883 have no significant variation in composition and contain no trace element greater than 0.1%. In the figure they all will lie within a discrimination ellipse centred on the specimen 1883.

The anisotropic pyrite NG 18 of Tugal (1969) has a slightly larger cell size (about 0.001 to 0.002 A°) than his other pyrite specimens. It seems that this difference is not significant in colour quality as compared with his other pyrites.

Pyrite specimens have been employed as standards in comparative reflectometry but it is doubtful on the above evidence whether pyrite is a reliable standard for spectral reflectivity measurements.

It is not included amongst the standards recommended by the International Mineralogical Association Commission on Ore Microscopy (I.M.A.C.O.M.).

If the spectral reflectivity data given by different authors are assumed to be reliable with small, conventional errors, then appreciable chromaticity variations could be largely a function of chemistry.

Since pyrite may have slight substitutional and non-stoichiometric variation in composition, appreciable changes in optical properties of pyrites from different types of deposits may be due to the presence of a minor element or elements (Co, Ni, Cu, As, Zn), perhaps greater than 0.1 %. Unfortunately, chemical data on measured specimens is not available in most cases.

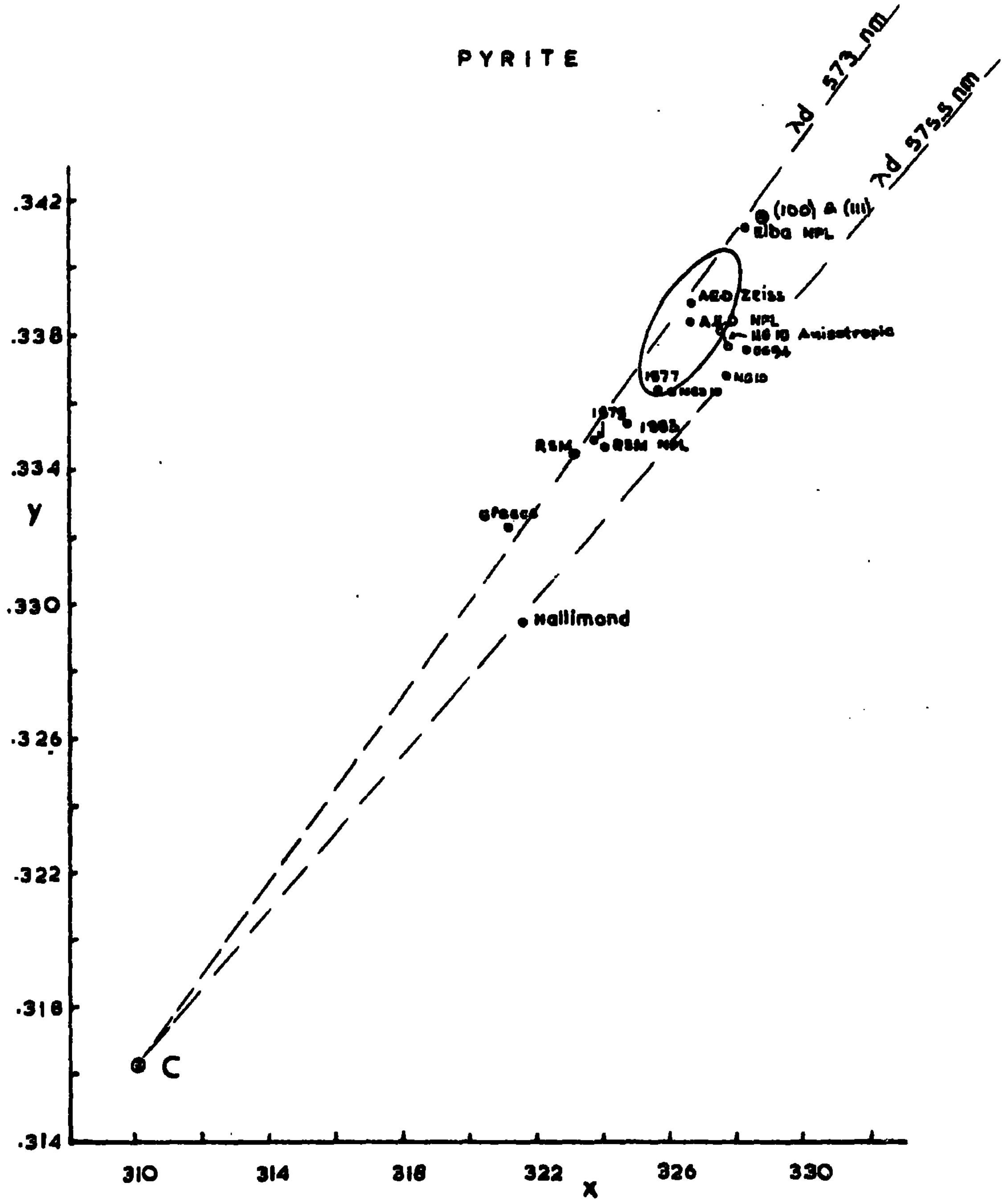

PYRITE
λd 573 nm
λd 575.5 nm
(100) & (111)
EIDG NPL
AEO Zeiss
A.E.O NPL
NG 10 Anisotropic
S6694
NG10
1977
NG3 10
1979
1983
RSM
RSM NPL
Gfeller
Hallimond
C
.342
.338
.334
.330
.326
.322
.318
.314
y
310
314
318
322
326
330
x

Figure IX 4.

CHALCOPYRITE , $CuFeS_2$

The chromaticity distribution of 15 chalcopyrite specimens from three mineral deposits of Turkey (Tugal, 1969) are presented in the x-y colour diagram of figure IX 5. Although the variation in chromaticness is not very large compared to the size of the discrimination ellipse , the brightness (visual reflectivity) differences from one mineral to another could be quite appreciably large, i.e. 47.8 - 43.6; 4.2 units.

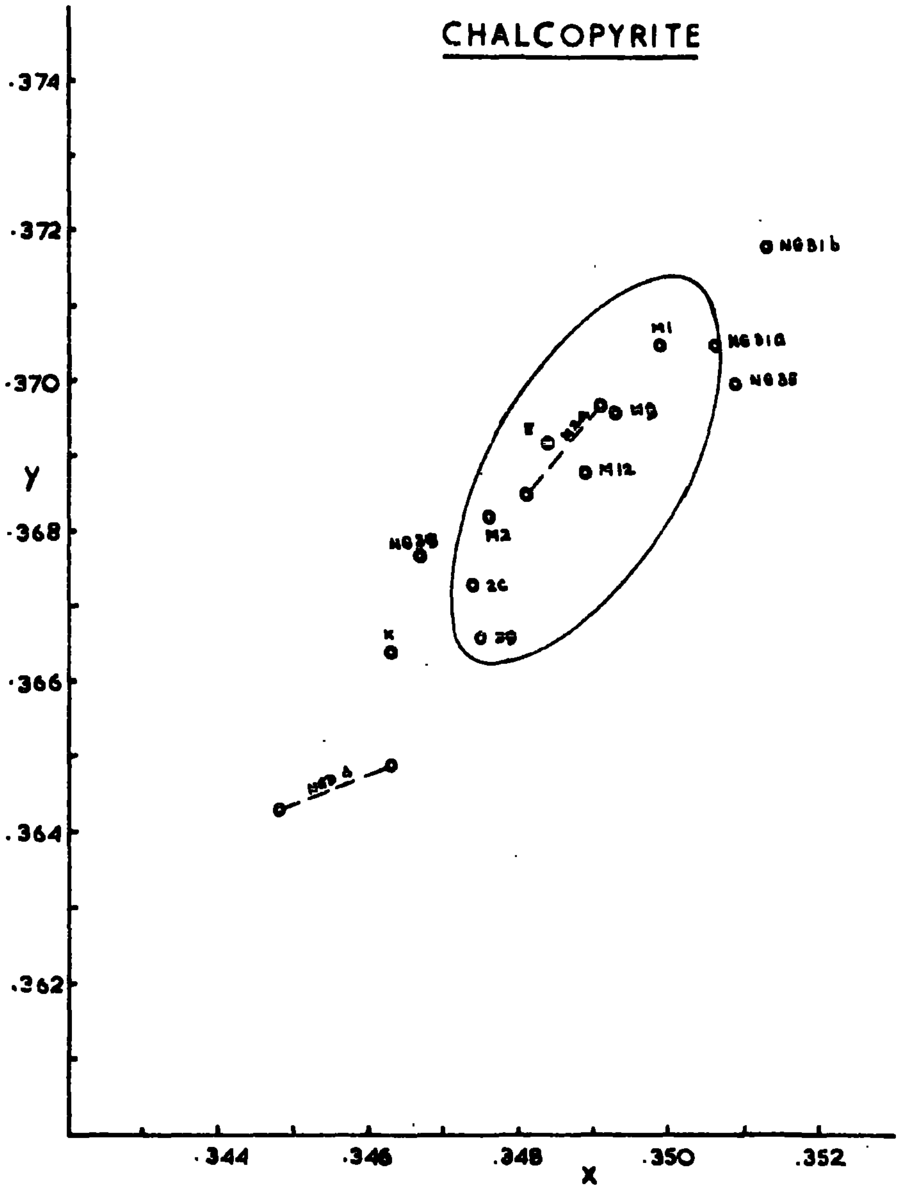

CHALCOPYRITE
Y
·374
·372
·370
·368
·366
·364
·362
X
·344
·346
·348
·350
·352
NG31b
M1
NG31a
NG35
M9
E
M12
M2
NG38
2C
39
K
NG6

Figure IX 5.

TETRAHEDRITE, $Cu_3\,Sb\,S_{3.25}$

TENNANTITE , $Cu_3\,As\,S_{3.25}$

Quantitative colour values show that tetrahedrite specimens have slight colour variation from greenish-yellowish grey to bluish-greenish grey and that tennantite specimens have comparatively larger variation in colour from greenish grey to bluish grey with higher saturation (purity).

Since the range of solid solution in the tetrahedrite-tennantite series is very large, their reflectivities generally vary correspondingly from 32.7 to 29.6 % in tetrahedrite and 31.0 to 26.5 % in tennantite.

The chromaticity coordinates of some members of synthesised tetrahedrite- tennantite series (Hall, 1971) are not directly comparable with those of natural tetrahedrite and tennantite, probably because of large variable substitutions in stoichiometric composition and weak colour values.

Hall (1971) concluded in his doctoral Thesis that with increasing As:Sb ratio there is a general decrease in cubic cell edge, increase in microhardness, decrease in reflectivity and increase in saturation of colour (purity). Unfortunately, it was not possible to support his conclusion for natural tetrahedrite and tennantite, because no chemical and physical data on measured specimens is available in the literature.

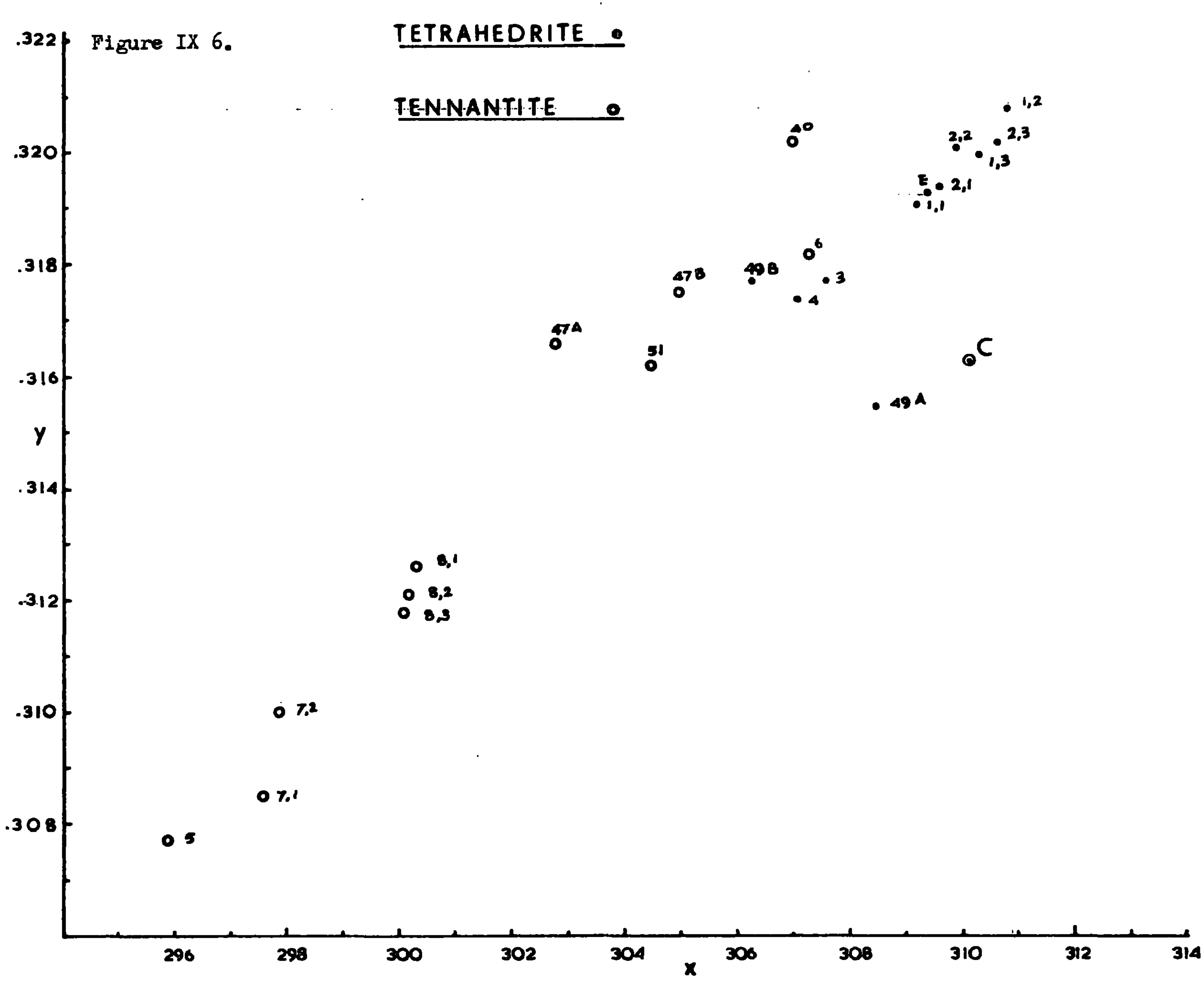

TETRAHEDRITE ●
TENNANTITE ○
.322
.320
.318
.316
.314
.312
.310
.308
y
296
298
300
302
304
306
308
310
312
314
x
1,2
2,2
2,3
1,3
E
2,1
1,1
40
6
49B
3
47B
4
47A
51
C
49A
8,1
8,2
8,3
7,2
7,1
5

Figure IX 6.

SPHALERITE, Zn S

Many investigations on cause of coloration in various sphalerite specimens have been reported. Since pure Zn sphalerites can be colourless, the change in colour of sphalerites, from a translucent yellow through brown to nearly opaque black, is usually considered to be a function of iron content (Dana's System of Mineralogy, 1944; Deer Howie and Zussman, 1969).

Roedder and Dwornik (1968) concluded, in a study on colour banding of some low-iron sphalerites (Pine Point) with the electron microprobe, that there is no correlation between iron content and colour. Graeser (1969) also reported that the coloration of low-iron sphalerites (from Binnatal) in various shades of colour from yellow to black is not due to the increase of iron content, but due to a strong influence of the Mn content: the yellow colour changes to brown and black whenever the Mn content exceeds a value of about 100 ppm. No report to support his view has appeared so far.

The quantitative colour values of 16 sphalerite specimens from Yugoslavia (Grafenauer et al, 1969) do not agree with Graeser's report and have no correlation with chemistry. Although there is a linear relationship between reflectivity and FeS content in synthesised sphalerites (Akinci, 1970), their quantitative colour values again do not correlate with chemistry or cell size.

The reason for lack of correlation with chemistry in this present work might be that the reflection colour of sphalerite is very much less sensitive to its chemistry or other physical properties than the transmission colour.

The same reason will apply for other non-opaque minerals.

Therefore, quantitative colour measurements derived from spectral transmission data of sphalerite may be more suited to investigation in the colour problem.

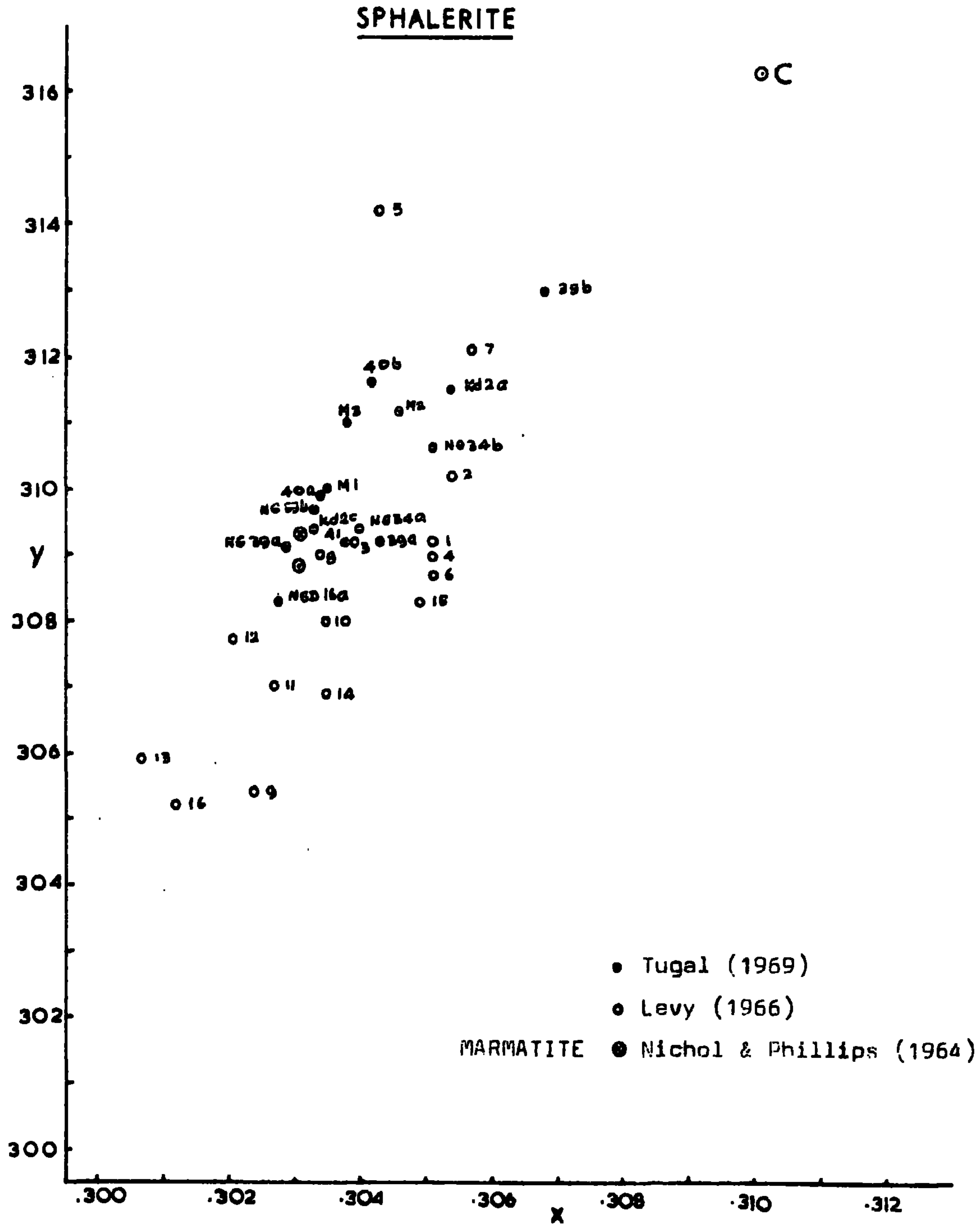

SPHALERITE
C
5
39b
7
40b
Kd2a
M3
M2
N034b
2
40a
M1
NC 33b
Kd2c
N034a
41
NC 39a
3
39a
1
8
4
6
NCD 16a
15
10
12
11
14
13
16
9
316
314
312
310
y
308
306
304
302
300
.300
.302
.304
.306
.308
.310
.312
x
● Tugal (1969)
○ Levy (1966)
MARMATITE
⊛ Nichol & Phillips (1964)

Figure IX 7.

GALENA , Pb S

All quantitative colour values of 7 galena specimens represent greyish white colours with slight differences in purity. The specimen M1 of Tugal (1969), being an average one, is taken as a reference origin of the discrimination ellipse to compare the chromaticity point with those of other specimens.

Figure IX 8 shows that all galena specimens have no difference in colour perception. The specimens of Tugal have the relative brightness difference (dY/Y) not greater than the threshold level, but Demirsoy's galena (100) has 5% greater than the reference.

Under a daylight illumination galena will show a relatively brighter and slightly stronger saturation, as quantitative values are given in Table VIII 1.

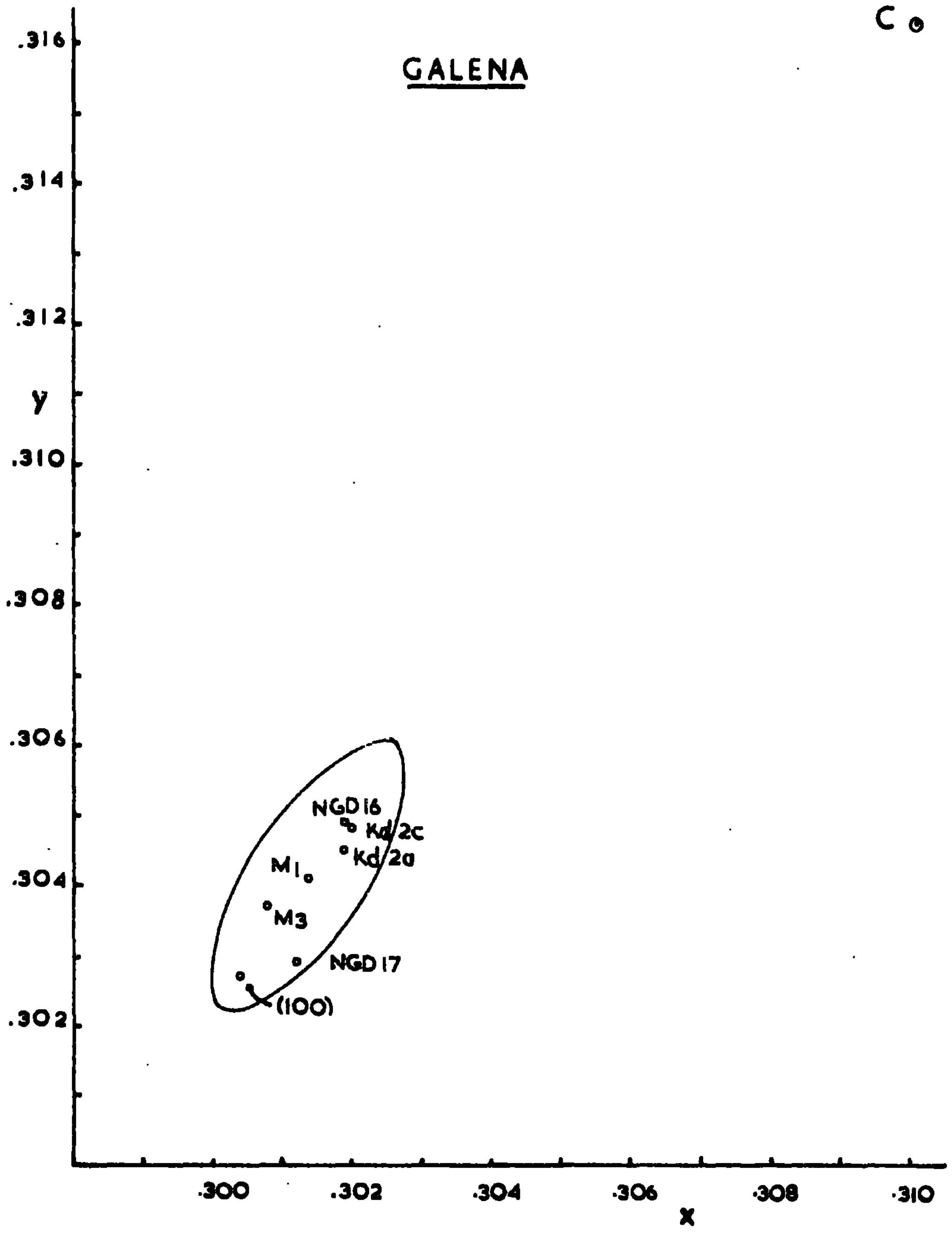

C ⊙
GALENA
.316
.314
.312
y
.310
.308
.306
.304
.302
NGD16
Kd 2c
Kd 2a
M1
M3
NGD17
(100)
.300
.302
.304
.306
.308
.310
x

Figure IX 8.

COLUSITE, $Cu_3 (As,Sn,V,Fe,Sb) S_4$

SULVANITE, $Cu_3 V S_4$

Colusite is very similar to sulvanite (rare) in reflectivity and colour quality as given in Tables and shown on the chromaticity chart of Figure IX 9. Sulvanite has a slightly higher reflectivity whereas colusite commonly shows different shades of zonal structure.

The different shades are not due to difference in chromaticness but due to differences in visual reflectivity (brightness). The chromaticity points of different zones lie within the discrimination ellipse, as shown in the diagram, but the colours of two zoned colusite specimens are different.

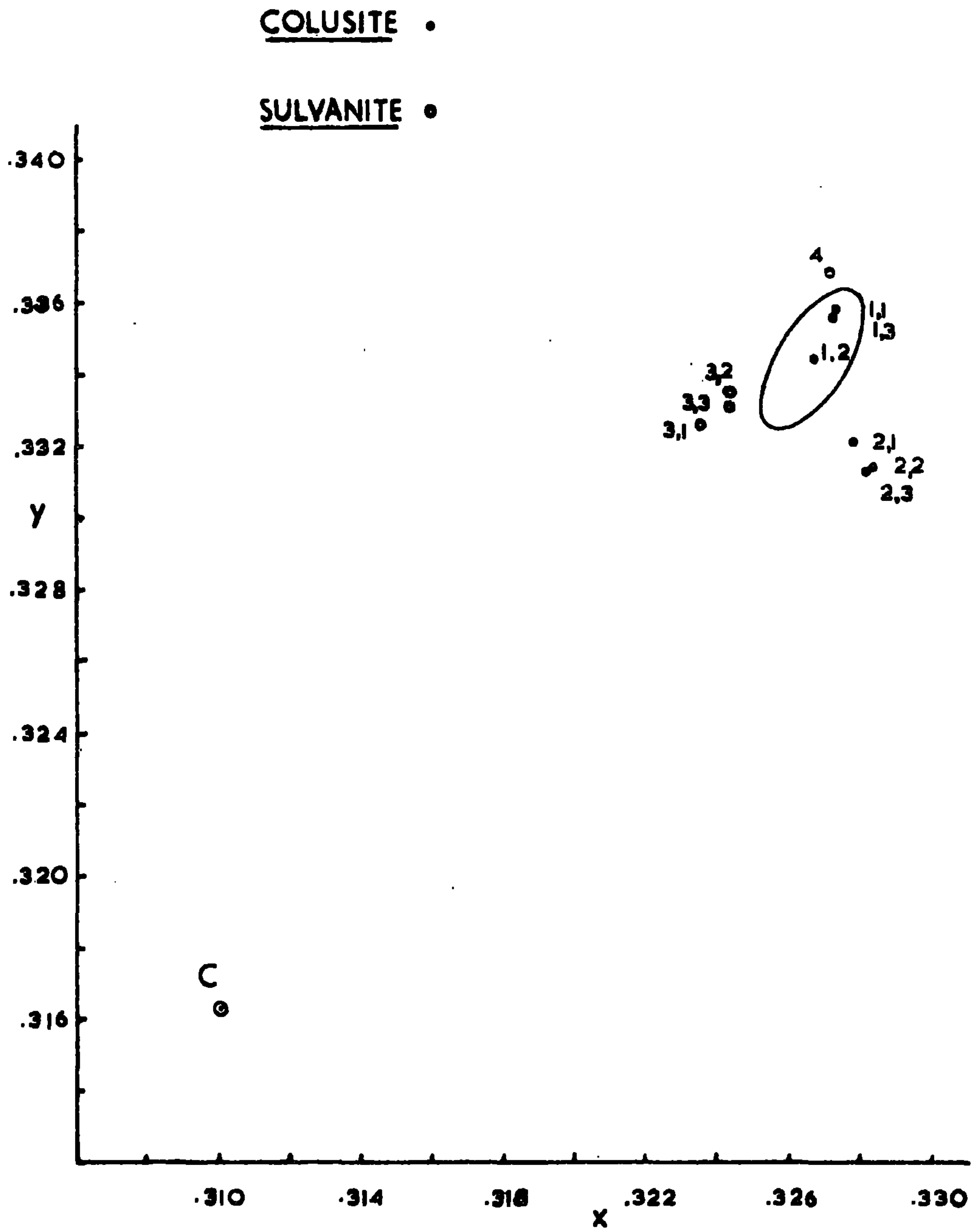

COLUSITE •
SULVANITE ⊙
.340
.336
.332
y
.328
.324
.320
.316
C
4
1,1
1,3
1,2
3,2
3,3
3,1
2,1
2,2
2,3
.310
.314
.318
X
.322
.326
.330

Figure IX 9.

STANNITE, $Cu_2\ Sn\ Fe\ S_4$; Tetragonal

MAWSONITE, $Cu_{2+x}\ Sn_{1-x}\ Fe\ S_4$; Tetragonal

IDAITE , $Cu_3\ Fe\ S_4$; probably Tetragonal

Several unnamed varieties of stannite have been reported (Ramdohr, 1944 & 1960). Ramdohr recognised four different stannites which he called 'Zinnkies I - IV'. Some of them have been named, but still noticeable deviations from ideal compositions of stannite and hexastannite (= stannite jaune of Levy, 1966; renamed as stannoidite by Kato, 1968) from different localities were found by electron microprobe analysis (Springer, 1968).

Mawsonite is considered as an intermediate member between stannite and idaite (Uytenbogaardt and Burke, 1971), but little is known about the relationships between stannite and idaite.

An investigation of the variations in colour and other optical properties of stannite, stannite jaune (hexastannite), mawsonite, orange bornite and idaite were made and observed as follows.

The chromaticity points, as shown in the x-y coordinate chart, show, in general, that excitation purity and combined effects of bireflectance and reflection pleochroism increase from stannite to idaite.

It seems that the colour saturation and reflection pleochroism is largely influenced by the Cu content. That is, as given in Table below, the above properties increase with increasing Cu content from stannite to idaite.

The electron microprobe analyses are average data as quoted below Table IX 2 which shows the general relationship between chemical composition and the optical properties.

For each member of the series the colour variation is also due to slight variation in chemistry and orientation of the measured sections. In Tables (Chapter X) and Figure IX 10 the spectral reflectivity data and respective colour values of 1-3-4 and 5-6-7 belong to the six different areas of the specimens no. 2 and no. 1 respectively (Levy, 1966). According to Levy (1966) the slight difference in reflectivity (as well as in colour) is perhaps due to the fact that the specimen no. 1 contains Zn whilst the specimen no. 2 contains no Zn.

It was seen from the Figure that the colour points of the so-called orange bornite lie inbetween mawsonite and idaite and its colour variation is large perhaps with large variation in composition. Orange bornite (13) from Peru has higher Cu and Fe contents than other orange bornites from Vaulry (Levy, 1966).

Similarly, the reason for large variations in reflectivity and colour of idaites are due to the different orientation and chemistry. Idaite (4-5-6) from Cerro Huemul, Argentina has higher Cu and Fe contents than those (1-2) from France.

Therefore, on above evidences the colour intensity in the series from stannite to idaite is strongly influenced by Cu content, i.e. the brownish yellow saturatión increases with increasing Cu content. A slight variation in colour of a member of the series is probably due to the differences in content of Cu, Fe , perhaps Sn, and minor elements such as Zn, As.

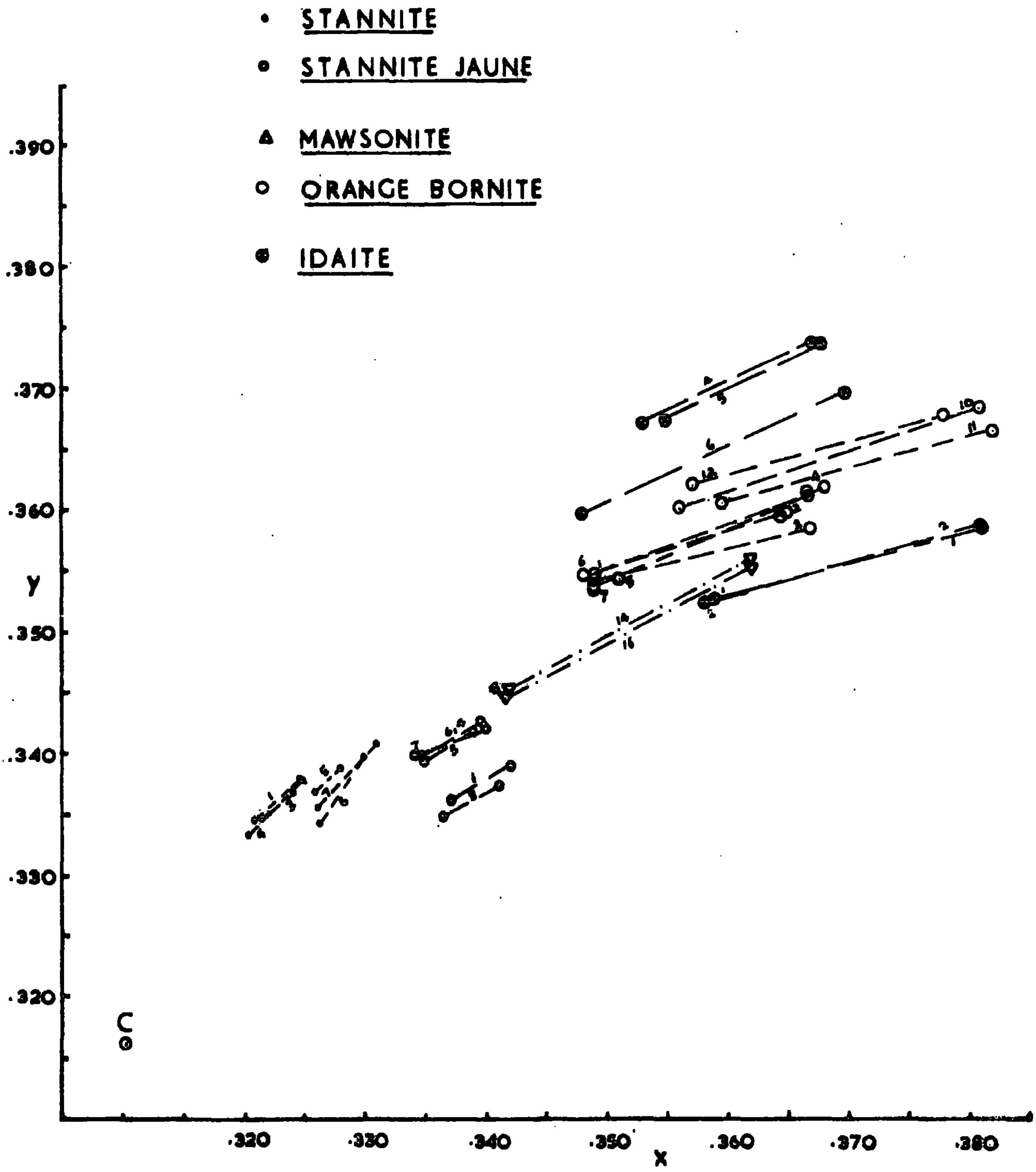

• STANNITE
● STANNITE JAUNE
▲ MAWSONITE
○ ORANGE BORNITE
◉ IDAITE
.390
.380
.370
.360
Y
.350
.340
.330
.320
C
.320
.330
.340
.350
.360
.370
.380
X

Figure IX 10.

Table IX 2. Electron Microprobe Analyses

	Stannite		Stannite Jaune	Hexastannite	Mawsonite		Orange Bornite	Idaite	
Cu	29.7	29.8	37.5	39.8	44.3	43.8	44.2	50.5	
Sn	27.1	26.7	20.1	16.4	12.5	12.6	15.1	-	
Fe	11.5	10.9	11.8	10.8	12.6	12.4	14.7	14.7	
Zn	1.7	3.2	2.7	1.7	-	-	-	-	
S	30.0	30.0	29.8	29.7	31.2	31.4	29.0	34.2	
	S	L	L	S	L	S	L	L	Ref.
	(9)	(5)	(9)	(4)*	(4)	(5)	(7)	(7)	No. of Specimens
Optical Characters									
	13.3-9.6		21.4 - 18.0		33.7-22.7		43.6-27.4	42.1-31.5	Pe % Max.-Min.
	11.4		19.7		28.2		35.5	36.8	Mean Pe%
	1.1		2.3		1.1		0.6	1.6	dY (Ymax.-Ymin.)
	(+)		(+)		(-) from 420 to 540 (+) from 560 to 640		(-) from 420 to 560 (+) from 590 to 640	(-) from 420 to 580 (+) from 600 to 640 nm	Optic Sign

S = Springer (1968)

L = Levy (9166)

* a specimen also contains Sb and As.

ENARGITE, $Cu_3 (As,Sb) S_4$; Orthorhombic

STIBIOLUZONITE-LUZONITE, $Cu_3 (As,Sb) S_4$; Tetragonal

The chromaticity variations of enargite and stibioluzonite are mainly due to the different orientations in the polished sections, whilst the measured luzonite specimens were very small and had many inclusions (Levy, 1966).

A potion of the chromaticity diagram shows the colour distributions of enargite, stibioluzonite and luzonite. In order to visualize the colour quality from part of the chromaticity diagram and their colour values, the qualitative colour discriptions are quoted below.

Enargite:	Pinkish grey to violet grey, bireflectance and reflection pleochroism distinct.
Stibioluzonite:	Pinkish without orange tints, bireflectance and reflection pleochroism distinct to moderate.
Luzonite:	Light pinkish orange, bireflectance and reflection pleochroism distinct to strong.

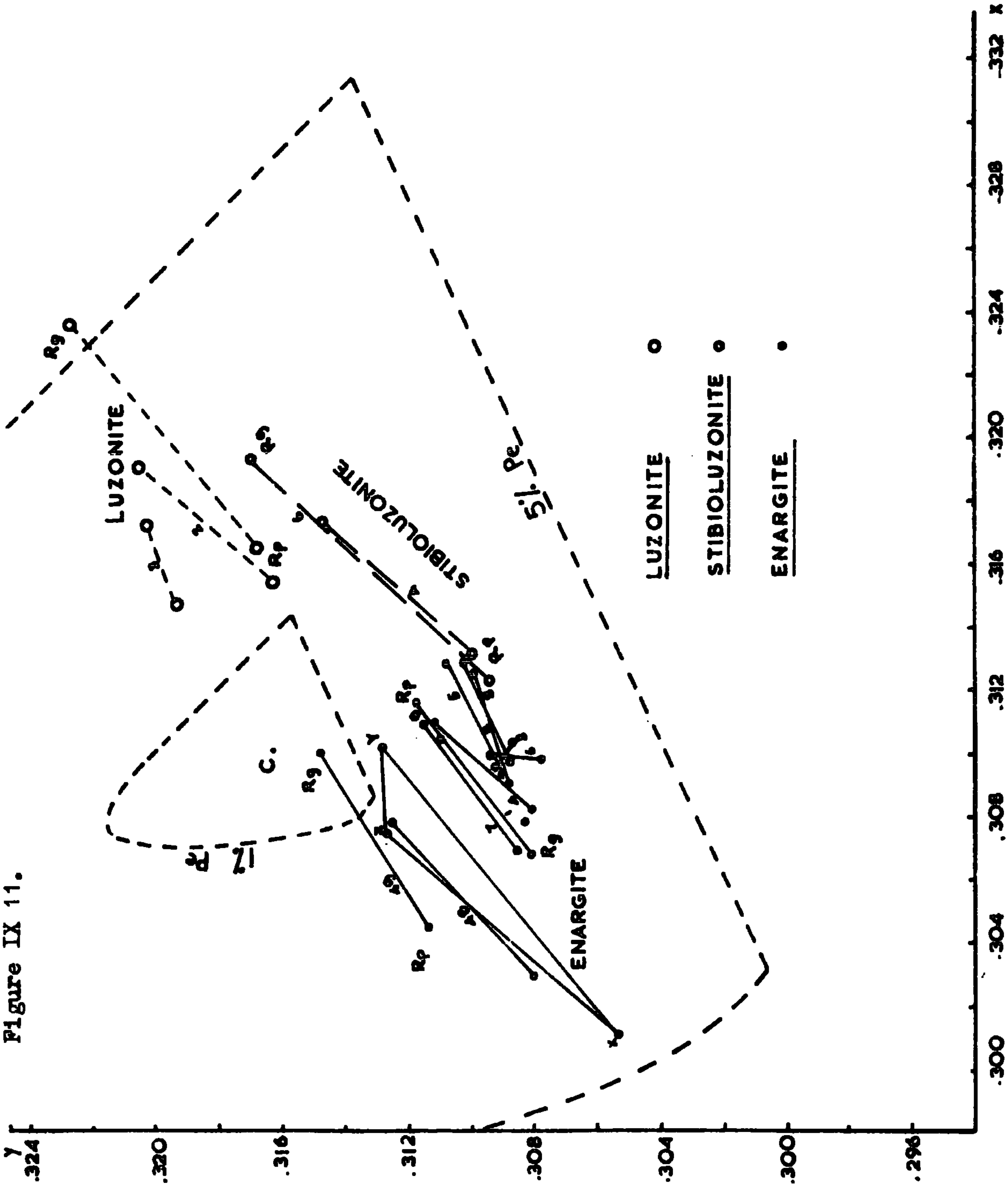


Figure IX 11.

Y
.324
.320
.316
.312
.308
.304
.300
.296
x
.300
.304
.308
.312
.316
.320
.324
.328
.332
LUZONITE
STIBIOLUZONITE
ENARGITE
C.
Rg
Rp
Pe
Y
LUZONITE
STIBIOLUZONITE
ENARGITE

THE EFFECT OF GRAIN SIZE ON CHANGES OF HEMATITE COLOURS

A massive hematite specimen from the Lake District (England) and single hematite crystals from Sweden were ground down separately by means of a Tema disk mill to investigate the change of colour when the grain size is reduced.

Each powdered specimen was passed through successive nylon sieves. All separated samples were then pelletised (dry) with boric acid powder backings by means of hydraulic Ram Press.

Under the reflected light photometer microscope all pellets revealed brown to red earthy grains and fairly, evenly distributed shining tiny specular hematites. Three separate, smooth areas which will represent the overall reflection of each pellet were chosen and spectral reflectivity measurements were made on each area. The average results of each specimen were employed in quantitative colour measurement.

Some pellets having large grain sizes were reground down into sufficient fine powders for x-ray fluorescent analysis, because it was considered that the composition of the samples may change due to separation into different grain sizes.

X-ray fluorescent analysis was carried out on a Philips PW 1212 automatic sequential analyser for the following oxides. $Si O_2$, $Al_2 O_3$ and $Fe_2 O_3$ line intensities of the elements were measured on 10 standards which had previously been analysed by wet chemical methods. Calibration curves for the elements were then obtained and from these the compositions of the unknown samples were determined by interpolation.

The analyses are given in the Table IX 3 and show that the compositions of the different samples of the massive hematite were not significantly different within the experimental error. The composition of the different samples of hematite crystals was therefore assumed to be the same as the original composition. Hence the change in colour of a specimen was mainly due to the change in grain size.

Figure IX 12 shows the effect of grain size on changes of colours of the massive hematite and hematite crystals. When the grain size decreases saturation (purity) of hematite colours distinctly increases together with slight change in hue (dominant wavelength). All sample points are also shown with the discrimination ellipse on an enlarged part of the chromaticity chart of Figure IX 13.

The changes of colour of the massive hematite were large at first and then decreased when the grain size was finer and finer. The dark red colour of the powders of hematite crystals changed little compared to the changes of the massive hematite powders.

For a hematite powdered specimen the variation in colour was due to the change of grain size and also the amount and nature of tiny specular hematites which were present in the powdered specimens.

Therefore the change of colour is probably a function of different light scattering (diffraction and reflection) from tiny spherical grains and crystalline hematites, together with the absorption of light incident upon the powdered specimens.

Table IX 3. X-Ray Fluorescent Analysis of Hematite

Specimen	Mesh of Nylon sieve		SiO_2	Al_2O_3	Fe_2O_3	Total (Wt.%)
Crystals	191		0.73	0.43	98.10	99.26
Massive	25	52	0.80	0.31	95.77	96.88
	52	72	0.72	0.31	96.50	97.53
	72	100	0.72	0.33	95.53	96.57
	100	150	0.78	0.32	96.42	97.52
	150	200	0.79	0.33	96.04	97.16

Figure IX 12. Chromaticity diagram showing the colour sequence of hematite powders under the standard illuminants A and C. Saturation increases with decreasing grain size . Arrow indicates the starting chromaticity points.

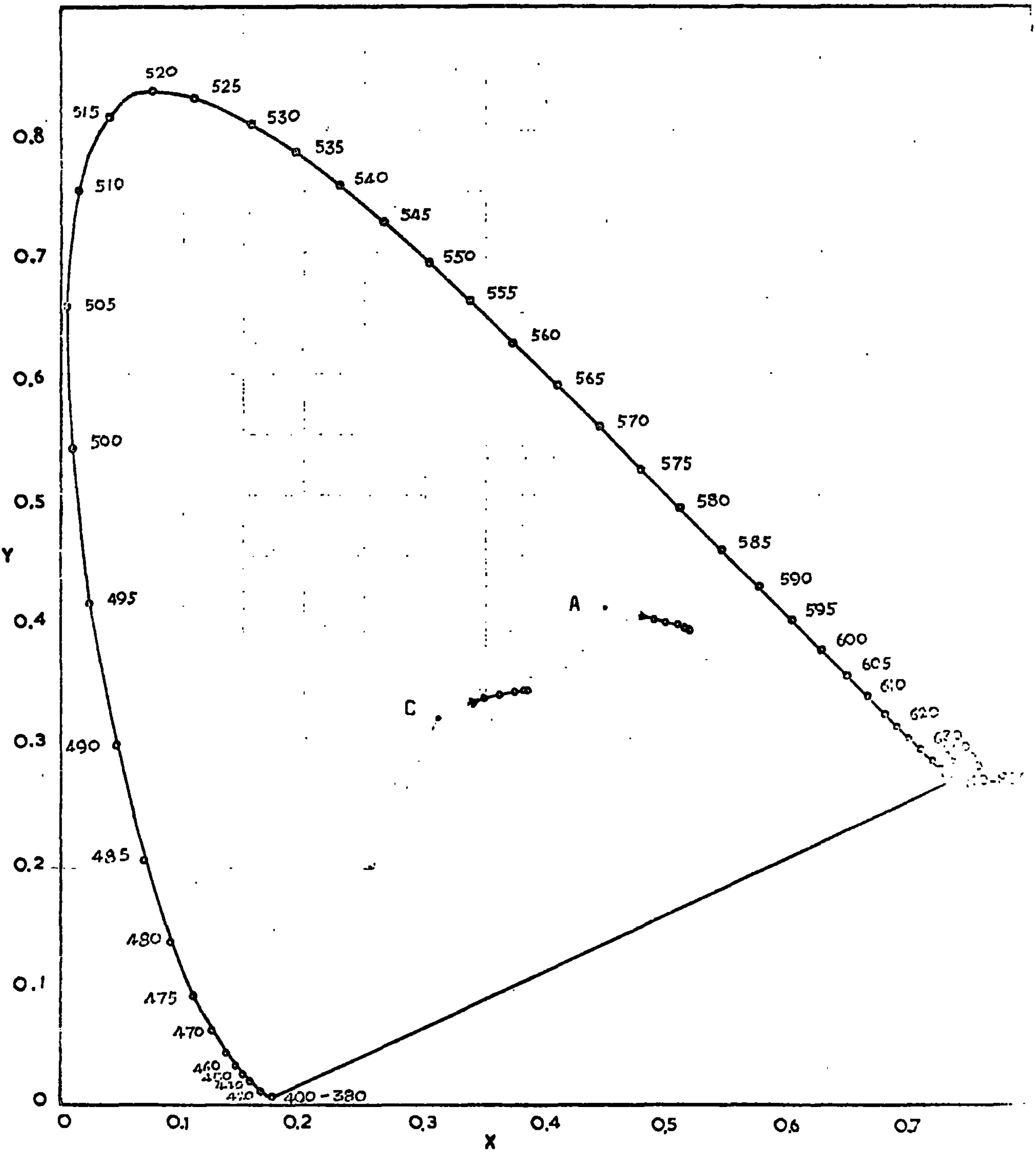
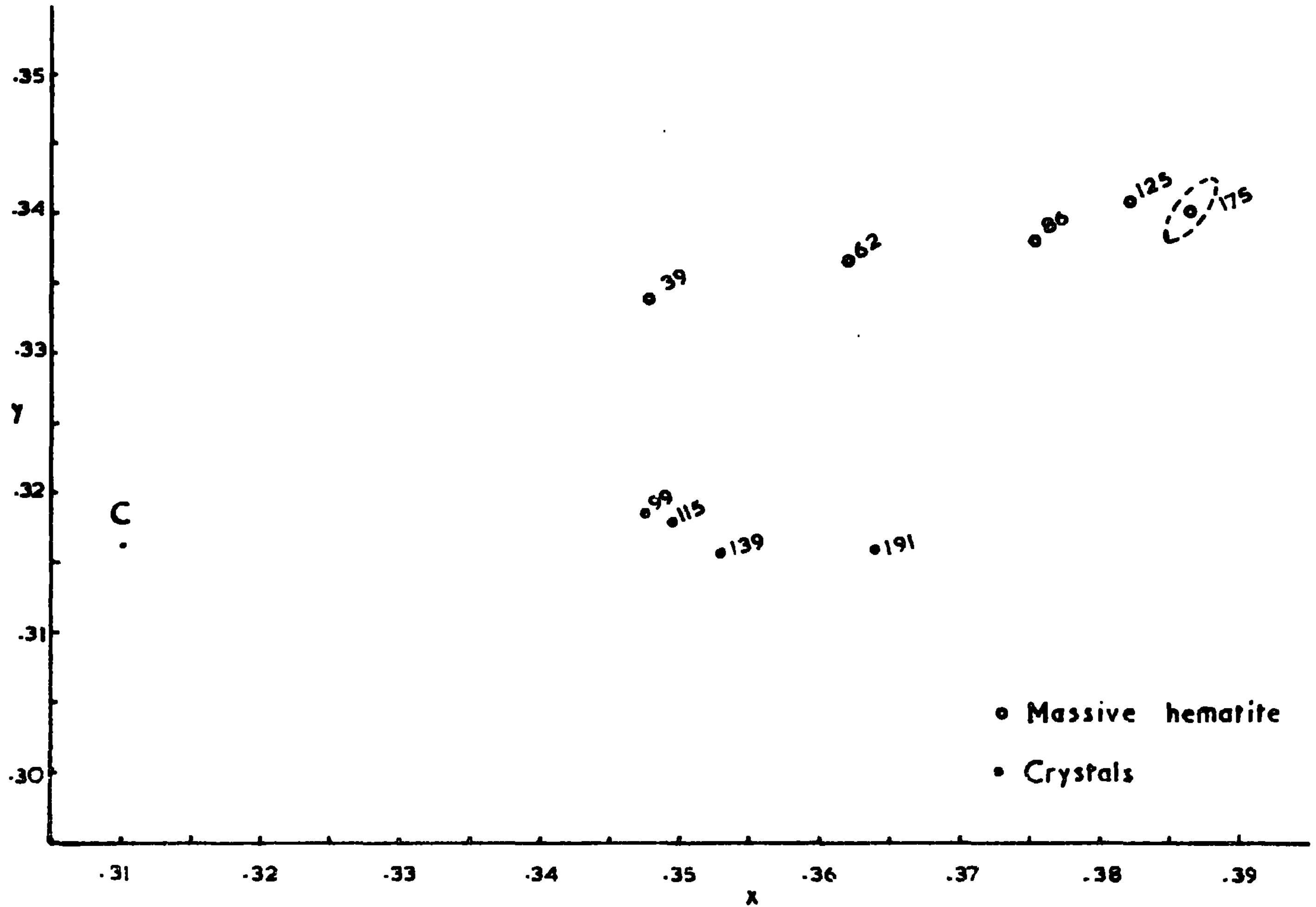


Figure IX 13. Enlarged part of Figure IX.12 to show the noticeably changes of the colours compared with a discrimination ellipse at its actual position.

The figures against the points are the average meshes of nylon sieves.



XII. CONCLUSIONS AND SUGGESTIONS OF POSSIBLE FUTURE WORK

Quantitative colour measurements have been widely applied, in many ways (e.g. the use of the visual quality of a colour for its own sake; the use of the colour of an object as an idicator of other properties which it may possess; etc.), in various laboratories and industries such as colour photography, colour television, signal glasses and road signs, agriculture and food, meteorology and astronomy, chemical tests, analysis of optical and visual phenomena, industries of automobile, dyeing, paint, pulp and paper, etc.

This project was undertaken to investigate the contribution to be made by concepts and methods of quantitative colour measurement to mineralogy and gemmology.

All necessary computer programmes were prepared for IBM/ 360 and used in this work to reduce personal errors and to save time, since numerous calculations are involved in the measurement of colour. (Chapter VI).

An investigation of the use of reflected light methods of determining spectral reflectivity values of facetted gemstones was made for quantitative colour measurement. (Chapter III 3). The same method was applied to the measurement of colour in ore minerals, since it promised to be a useful additional method for the identification of these minerals.

Many ore minerals, especially oxides, sulpho-salts and sulphides have similar reflectivity in white light and some have overlapping values of reflectivity and microhardness. It has been realized that spectral reflectivity measurements, can be made use of in many cases for mineral identification.

Although reflectivity is the most important property of opaque minerals, it is still difficult to compare the measured values with available reflectivity data of a mineral for determination. As shown by curves in Figure XII 1 in the Appendix, spectral reflectivity values of many polished specimens of a mineral vary over the visible spectrum. Such variations may be within the experimental errors and/or due to slight variations in chemical and physical properties. Unfortunately, such slight variation in properties is below detectable limits in many cases.
Therefore, it is difficult to interpret the significances of considerable variation, at a wavelength or at some wavelengths , of spectral reflectivities.

However, from such spectral reflectivity measurements, little work is required to obtain additional quantitative values, colour values, which may be more useful for mineral determination and which may help in explanation of the significant variations of spectral reflectivities of certain minerals (Chapter VIII and IX, Figures 1a and 1b).

The enlarged diagrams of Figures 1a and 1b may be used as an aid for mineral identification on the basis of quantitative colour values.

From the chromaticity diagram of Figure 1a, in general, the measured chromaticity point of a mineral can be compared with those of other minerals. All similar minerals may be eliminated by reading off the tristimulus values Y, which is the relative brightness (or visual reflectivity) at an appropriate dominant (or complementary) wavelength from Figure 1b.

The mineral identification thereafter can be made with the aid of other quantitative properties such as degrees of colour constancy, pleochroism (bireflectance and reflection pleochroism), etc. (Chapter VIII) and of other qualitative properties such as form, texture, mineral associations, etc.

Thus spectral reflectivity data and colour values together may form an additional system of mineral identification. Therefore the compilation of systematic data of spectral reflectivity and colour of ore minerals took the large volume of the present work.

Further more, a chromaticity diagram representing colour qualities of ore minerals will be useful especially in teaching ore mineralogy to students. The colour distributions of ore minerals can be seen in a such a diagram.

It is of interest to look at the chromaticity diagram of Figure 1a, because the colours of most ore minerals distribute across the diagram (i.e. within 40% constant purity curve) from the yellow-orange region through the illuminant point to the blue-purple region. The cause of this somewhat systematic and characteristic colour distribution poses a new problem.

Finally, from this work quantitative colour values may contribute to a useful means of representing colour characteristics of ore minerals in a colour diagram, comparing and distinguishing between similar coloured minerals, and to an understanding of relations between colour quality and other properties such as compositional variations , bonding and structure of minerals.

SUGGESTIONS

More information for other ore minerals is required to complete the chromaticity diagram.

An interference colour of a mineral can also be shown in a colour diagram if its spectral energy distributions are known and such measurement may reward further study.

It was considered that the transmission methods of measurement of facetted gemstones for colour measurement requires further development of accuracy and precision and eventually, standardisation of method. Further investigation could make use of internal transmitted light method, since such a method has already been used to qualitatively determine the absorption spectrum of gemstones (Chapter IV).

Further work will be worthwhile to investigate the measurement of fluorescent colour of particular minerals.The fluorescent colour quality of a mineral is very difficult to discribe and yet is used as an important property for identification of some gemstones and minerals.

Finally, a suggestion is made to investigate the improvement of reflected light methods of observing polished ore minerals by using certain types of illumination under which effective colour constancy and/or different colour contrast of similar minerals may be easily observed.

X. QUANTITATIVE COLOUR VALUES AND SPECTRAL REFLECTIVITY DATA OF SOME ORE MINERALS

The quantitative colour values and spectral reflectivity data of about 340 specimens of 130 different ore minerals are compiled in the table forms.

In compiling these data minerals are divided into two sections, isotropic and anisotropic, according to the crystal system. The visual reflectivity (tristimulus value Y) has been chosen as the chief property in the sub-division, in order of increasing value. The colour values derived form 4-wavelength reflectivity data are given at the bottom of each sub-division in the same order.

All these quantitative data can also be used together with qualitative descriptions given in the literature of ore microscopy for mineral identification.

1. ISOTROPIC MINERALS

```
MINERAL NAME                      CHROMATICITY  DOMINANT            BRIGHTNESS
COMPOSITION                SOURCE COORDINATES   (COMPL.)   PURITY  (VISUAL R) LAMBDA     REFLECTIVITY
CRYSTAL SYSTEM                      X       Y   WAVELENGTH  (P%)       Y        (NM)          R


PURE SILVER                   A   0.4498 0.4115   577.93    4.31     99.25       436         89.70

AG                            C   0.3142 0.3252   567.64    3.49     99.20       450         93.70

CUBIC                                                                            500         99.20

REF. FOR R: (SQUAIC,1965)                                                        550         99.90— X Ko

REMARKS:    LOC.                                                                 590         99.10

                                                                                 590         99.10

                                                                                 650         98.60
```

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (PE)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
GOLD-SILVER	A	0.4603	0.4157	583.50	14.49	89.81	436	68.40
50%AU+50%AG	C	0.3275	0.3397	573.57	10.95	88.77	450	72.50
CUBIC							500	86.00
REF. FOR R: (SQUAID,1965)							550	88.30
REMARKS: LCC.							590	92.10
							650	92.20

```
MINERAL NAME                           CHROMATICITY   DOMINANT           BRIGHTNESS
COMPOSITION                     SOURCE COORDINATES    (COMPL.)   PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                           X       Y   WAVELENGTH  (P%)       Y       (NM)          R


PURE GOLD                          A   0.5004 0.4240    587.05  48.06     60.22      436       25.40

AU                                 C   0.3841 0.3852    578.60  38.33     56.66      450       26.90

CUBIC                                                                               500       37.40

REF. FOR R: (SQUAID,1965)                                                           550       59.00

REMARKS:     LCC.                                                                   590       64.50

                                                                                    650       74.20
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MINERAL NAME                        CHROMATICITY  DOMINANT         BRIGHTNESS
COMPOSITION                  SOURCE COORDINATES    (COMPL.)  PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                        X       Y   WAVELENGTH  (P%)       Y      (NM)          R

PYRITE                         A    0.4595 0.4157   583.14  13.95    54.01      440        42.30

FE S2                          C    0.3267 0.3390   573.35  10.55    53.42      460        45.50   47.1

CUBIC                                                                           480        48.60

REF. FOR R: (SINGH,1964)                                                        500        51.00

REMARKS:    LOC. ELBA. A.E.D. STD.,ZEISS CALIBRATED                             540        53.40

                                                                                580        54.70

                                                                                620        55.10

                                                                                660        55.80
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MINERAL NAME                          CHROMATICITY  DOMINANT          BRIGHTNESS
COMPOSITION                    SOURCE COORDINATES   (COMPL.)   PURITY (VISUAL R) LAMBDA     REFLECTIVITY
CRYSTAL SYSTEM                          X       Y   WAVELENGTH  (P%)      Y       (NM)           R


PYRITE                           A    0.4603 0.4149    584.03  13.94    53.94      430          42.10

FE S2                            C    0.2269 0.3376    574.35  10.22    53.28      470          46.20   47.5

CUBIC                                                                              490          49.50

REF. FOR R: NICHOL & PHILLIPS (1965)                                               520          52.00

REMARKS:    LOC. RIO MARINA,ELBA                                                   550          53.70

                                                                                   580          54.40

                                                                                   610          55.20

                                                                                   650          56.20
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MINERAL NAME                            CHROMATICITY  DOMINANT            BRIGHTNESS
COMPOSITION                      SOURCE COORDINATES    (COMPL.)  PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                            X       Y   WAVELENGTH  (P%)       Y       (NM)         R

PYRITE                             A    0.4571 0.4115    585.69   9.36     53.79      470        49.10

FE S2                              C    0.3217 0.3295    575.82   6.66     53.27      490        50.90

CUBIC                                                                                 520        52.60

REF. FOR R: HALLIMOND (1957)                                                          550        52.70

REMARKS:    LOC. RIO MARINA,ELBA                                                      580        54.30

                                                                                      610        55.10

                                                                                      650        56.40

                                                                                      670        55.00
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MINERAL NAME                     CHROMATICITY  DOMINANT             BRIGHTNESS
COMPOSITION               SOURCE COORDINATES    (COMPL.)  PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                     X        Y  WAVELENGTH  (P%)        Y       (NM)         R


PYRITE                      A   0.4606 0.4167     532.98  15.41     53.86       400       37.10

FE S2                       C   0.3283 0.3412     572.34  11.57     53.22       420       38.80

CUBIC                                                                          440       41.20

REF. FOR R: (COMMUNICATION WITH P.R.SIMPSON)                                   460       44.30

REMARKS:    LOC. ELBA. N.P.L. CALIBRATED(BOWIE)                                480       47.60

                                                                               500       50.30

                                                                               520       52.00

                                                                               540       53.20

                                                                               560       54.00

                                                                               580       54.70

                                                                               600       54.80

                                                                               620       55.00

                                                                               640       55.30

                                                                               660       55.70

                                                                               680       56.00

                                                                               700       56.00
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MINERAL NAME                             CHROMATICITY  DOMINANT             BRIGHTNESS
COMPOSITION                       SOURCE COORDINATES   (COMPL.)   PURITY  (VISUAL R)  LAMBDA      REFLECTIVITY
CRYSTAL SYSTEM                             X       Y   WAVELENGTH  (P%)        Y        (NM)            R

PYRITE                              A    0.4597 0.4154    583.44  13.87      53.54       400           37.80

FE S2                               C    0.3267 0.3384    573.70  10.38      52.94       420           39.60

CUBIC                                                                                    440           42.10

REF. FOR R: (SINGH,1964)                                                                 460           45.10

REMARKS:    LOC. ELBA. A.E.C. STD.,N.P.L. CALIBRATED                                     480           48.20

                                                                                         500           50.40

                                                                                         546           53.20

                                                                                         589           54.40

                                                                                         620           54.70

                                                                                         660           55.60

                                                                                         700           55.80
```

48.6

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
PYRITE,NGD10	A	0.4594	0.4147	583.79	13.18	52.95	440	42.63
FE S2	C	0.3262	0.3363	574.62	9.69	52.32	460	45.34
CUBIC							480	47.68
REF. FOR R: (TUGAL,1969)							500	48.94
REMARKS: LOC. TURKEY							520	50.42
							540	52.03
							560	53.33
							580	54.32
							600	53.47
							620	54.89
							640	53.47
							660	54.13

46.5

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R	
PYRITE 1879	A	0.4576	0.4143	583.21	11.65	52.84	400	38.80	
FE S2	C	0.3238	0.3349	573.44	8.67	52.36	420	40.70	
CUBIC							440	43.20	
REF. FOR R: (SINGH,1964)							460	45.90	47.2
REMARKS: LOC. COLOMBIA,S.AMERICA							480	48.60	
							500	50.20	
							546	52.60	
							589	53.60	
							620	53.70	
							660	54.30	
							700	54.40	

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
PYRITE	A	0.4571	0.4141	583.09	11.17	52.72	400	39.10
FE S2	C	0.3232	0.3345	573.14	8.40	52.28	420	40.90
CUBIC							440	43.40
REF. FOR R: (SINGH,1964)							460	45.80
REMARKS: LOC. UNCERTAIN. R.S.M. STD. MEASURED AGAINST A.E.D. STD.(NPL)							480	48.80 47.3
							500	50.60
							546	52.50
							589	53.20
							620	53.70
							660	54.30
							700	54.30

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R	
PYRITE 1883 (100)	A	0.4586	0.4141	583.88	12.21	52.65	400	38.20	
FE S2	C	0.3248	0.3354	574.03	9.07	52.11	420	40.30	
CUBIC							440	42.60	
REF. FOR R: (SINGH,1964)							460	45.40	46.9
REMARKS: LOC. GRAY RIVER,NEWFOUNDLAND							480	48.30	
							500	49.90	
							546	52.30	
							589	53.20	
							620	53.90	
							660	55.10	
							700	55.20	

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MINERAL NAME                  CHROMATICITY  DOMINANT          BRIGHTNESS
COMPOSITION            SOURCE COORDINATES   (COMPL.)   PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                X         Y   WAVELENGTH  (P%)      Y       (NM)          R

PYRITE                   A    0.4557 0.4133   582.92    9.65    52.48     400         38.20

FE S2                    C    0.3212 0.3323   572.66    7.27    52.12     420         40.20

CUBIC                                                                     440         44.40

REF. FOR R: (SINGH,1964)                                                  460         47.10

REMARKS:    LOC. KASSANDRA MINE,GREECE                                    480         49.40

                                                                          500         50.80

                                                                          546         52.30

                                                                          589         52.80

                                                                          620         53.30

                                                                          660         53.90
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MINERAL NAME                          CHROMATICITY   DOMINANT              BRIGHTNESS
COMPOSITION                   SOURCE  COORDINATES    (COMPL.)    PURITY  (VISUAL R)  LAMBDA     REFLECTIVITY
CRYSTAL SYSTEM                         X        Y    WAVELENGTH   (P%)        Y       (NM)          R


PYRITE,NG10                      A    0.4608 0.4145    584.53    14.01      51.88      440         41.37

FE S2                            C    0.3277 0.3368    575.49    10.22      51.15      460         44.08   · 45.2

CUBIC                                                                                  480         46.33

REF. FOR R: (TUGAL,1969)                                                               500         47.28

REMARKS:     LOC. TURKEY                                                               520         48.79

                                                                                       540         50.51

                                                                                       560         52.45

                                                                                       580         53.35

                                                                                       600         52.80

                                                                                       620         53.54

                                                                                       640         52.78

                                                                                       660         54.13
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MINERAL NAME                          CHROMATICITY   DOMINANT            BRIGHTNESS
COMPOSITION                   SOURCE COORDINATES     (COMPL.)   PURITY  (VISUAL R)  LAMBDA     REFLECTIVITY
CRYSTAL SYSTEM                          X        Y   WAVELENGTH  (P%)        Y       (NM)            R

PYRITE 1877                     A    0.4592 0.4145     583.85   12.90     51.68       400          37.20

FE S2                           C    0.3257 0.3364     574.14    9.58     51.11       420          38.70

CUBIC                                                                                 440          41.40

REF. FOR R: (SINGH,1964)                                                              460          44.50

REMARKS:    LOC. CHARLOTTE MINE,NORWAY                                                480          46.60   455

                                                                                      500          48.70

                                                                                      546          51.20

                                                                                      589          52.60

                                                                                      620          52.90

                                                                                      660          53.50

                                                                                      700          53.90
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MINERAL NAME                          CHROMATICITY  DOMINANT          BRIGHTNESS
COMPOSITION                    SOURCE COORDINATES    (COMPL.)  PURITY (VISUAL R) LAMBDA      REFLECTIVITY
CRYSTAL SYSTEM                          X       Y   WAVELENGTH  (P%)       Y       (NM)           R

PYRITE                           A    0.4581 0.4138    583.88  11.66     51.62      436          41.60

FE S2                            C    0.3241 0.3347    573.87   8.70     51.11      460          45.10     46.2

CUBIC                                                                               480          47.40

REF. FOR R: (SINGH,1964)                                                            500          49.10

REMARKS:    LOC. UNCERTAIN. R.S.M. STD. N.P.L. CALIBRATED                           520          50.30

                                                                                    546          51.20

                                                                                    580          51.80

                                                                                    610          52.80

                                                                                    650          53.40

                                                                                    670          53.60
```

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	 Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
PYRITE,CG94	A	0.4616	0.4144	534.90	14.50	51.39	440	40.46
FE S2	C	0.3283	0.3376	575.43	10.60	50.65	460	43.59
CUBIC							480	45.79
REF. FOR R: (TUGAL,1969)							500	47.09
REMARKS: LOC. TURKEY							520	48.49
							540	50.18
							560	51.60
							580	52.46
							600	52.29
							620	53.54
							640	52.78
							660	54.13

[illegible]

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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	 Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R)	 (R)
PYRITE NO18	A	0.4608	0.4148	584.31	14.22	52.15	440	41.25	41.25
FE S2	A	0.4605	0.4152	583.90	14.29	52.32	460	44.02	44.11
CUBIC	C	0.3278	0.3377	574.99	10.49	51.45	480	46.44	46.68
	C	0.3276	0.3381	574.59	10.54	51.65	500	48.16	48.39
REF. FOR R: TUGAL (1969)							520	49.48	49.74
REMARKS: LOC. TURKEY; ANISOTROPIC PYRITE							540	50.96	51.22
							560	52.37	52.63
							580	53.21	53.50
							600	53.50	53.50
							620	53.53	53.53
							640	53.90	53.90
							660	53.84	53.84

```
MINERAL NAME                      CHROMATICITY  DOMINANT             BRIGHTNESS
COMPOSITION               SOURCE COORDINATES    (COMPL.)   PURITY  (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                    X        Y   WAVELENGTH  (P%)        Y       (NM)          R

COBALTITE(100)              A   0.4556 0.4071   594.37    5.22     50.42       440        48.03

(CO,FE)AS S                 C   0.3178 0.3198   588.54    3.00     49.90       460        47.43

CUBIC                                                                          480        47.44

REF. FOR R: (THE AUTHOR)                                                       500        47.87

REMARKS:    LOC. UNCERTAIN. SINGLE CRYSTAL                                     520        48.45

                                                                               540        49.16

                                                                               560        49.89

                                                                               580        50.67

                                                                               600        51.52

                                                                               620        52.19

                                                                               640        53.13

                                                                               660        53.50
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Electron Probe Analysis:

	Wt. %
Co	33.20
Fe	1.90
Ni	1.87
As	45.23
S	18.80
	101.00

```
MINERAL NAME                      CHROMATICITY  DOMINANT          BRIGHTNESS
COMPOSITION                SOURCE COORDINATES   (COMPL.)  PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                     X       Y   WAVELENGTH  (P%)       Y       (NM)          R


GALENA                       A   0.4403 0.4015    478.70   2.08    43.70      440         49.80

PB S                         C   0.3004 0.3027    469.71   5.24    44.01      460         48.40

CUBIC                                                                        480         47.20

REF. FOR R: DEMIRSOY (1968)                                                  500         45.90

REMARKS:    LOC. UNKNOWN. MEASURED ON CLEAVAGE FACE                          520         44.70

                                                                             540         43.90

                                                                             560         43.50

                                                                             580         43.20

                                                                             600         43.10

                                                                             620         43.30

                                                                             640         43.40

                                                                             660         44.00
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MINERAL NAME                        CHROMATICITY   DOMINANT            BRIGHTNESS
COMPOSITION                  SOURCE COORDINATES    (COMPL.)   PURITY  (VISUAL R)  LAMBDA     REFLECTIVITY
CRYSTAL SYSTEM                       X       Y    WAVELENGTH   (P%)        Y        (NM)          R

GALENA M3                       A   0.4402 0.4024    481.93    2.03     41.96       440         47.49

PB S                            C   0.3008 0.3037    470.78    4.95     42.26       460         46.46

CUBIC                                                                               480         44.70

REF. FOR R: (TUGAL,1969)                                                            500         43.68

REMARKS:    LOC. TURKEY                                                             520         42.71

                                                                                    520         42.71

                                                                                    540         42.22

                                                                                    560         42.08

                                                                                    580         41.62

                                                                                    600         41.33

                                                                                    620         41.62

                                                                                    640         41.41

                                                                                    660         40.77
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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
GALENA,NGD16	A	0.4411	0.4029	481.51	1.79	41.88	440	46.82
PB S	C	0.3019	0.3049	469.99	4.41	42.14	460	45.84
CUBIC							480	44.38
REF. FOR R: (TUGAL,1969)							500	43.24
REMARKS: LOC. TURKEY							520	42.41
							520	42.41
							540	42.02
							560	41.97
							580	41.80
							600	41.41
							620	41.57
							640	41.07
							660	40.77

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	 Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
GALENA,KD2A	A	0.4413	0.4026	479.84	1.77	41.80	440	46.93
PB S	C	0.3019	0.3045	468.86	4.48	42.04	460	45.45
CUBIC							480	44.36
REF. FOR R: (TUGAL,1969)							500	43.22
REMARKS: LOC. TURKEY							520	42.49
							520	42.49
							540	41.91
							560	41.81
							580	41.38
							600	41.47
							620	41.62
							640	41.41
							660	40.77

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MINERAL NAME                          CHROMATICITY  DOMINANT          BRIGHTNESS
COMPOSITION                   SOURCE COORDINATES    (COMPL.)  PURITY (VISUAL R) LAMBDA     REFLECTIVITY
CRYSTAL SYSTEM                         X        Y  WAVELENGTH  (P%)       Y       (NM)          R


GALENA,M1                       A    0.4408 0.4025     480.86   1.89    41.62       440          46.93

PB S                            C    0.3014 0.3041     469.71   4.70    41.88       460          45.61

CUBIC                                                                               480          44.26

REF. FOR R: (TUGAL,1969)                                                            500          43.16

REMARKS:     LOC. TURKEY                                                            520          42.30

                                                                                    520          42.30

                                                                                    540          41.75

                                                                                    560          41.76

                                                                                    580          41.22

                                                                                    600          41.01

                                                                                    620          41.34

                                                                                    640          41.41

                                                                                    660          40.77
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MINERAL NAME                              CHROMATICITY  DOMINANT           BRIGHTNESS
COMPOSITION                        SOURCE COORDINATES    (COMPL.)  PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                             X        Y   WAVELENGTH  (P%)       Y       (NM)         R

GALENA,NGD17                         A    0.4409 0.4018   477.92   1.92     41.57       440        47.37

PB S                                 C    0.3012 0.3029   467.17   4.97     41.81       460        45.62

CUBIC                                                                                 480        44.33

REF. FOR R: (TUGAL,1969)                                                              500        43.11

REMARKS:    LOC. TURKEY                                                               520        41.86

                                                                                      520        41.86

                                                                                      540        41.72

                                                                                      560        41.55

                                                                                      580        41.31

                                                                                      600        41.15

                                                                                      620        41.46

                                                                                      640        41.07

                                                                                      660        40.77
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MINERAL NAME                      CHROMATICITY  DOMINANT          BRIGHTNESS
COMPOSITION               SOURCE COORDINATES   (COMPL.)  PURITY (VISUAL R) LAMBDA     REFLECTIVITY
CRYSTAL SYSTEM                   X        Y   WAVELENGTH  (P%)       Y      (NM)           R

GALENA,K020                 A    0.4413 0.4028   480.61   1.76     41.55     440          46.50

PB S                        C    0.3020 0.3048   469.31   4.40     41.79     460          45.22

CUBIC                                                                        480          44.06

REF. FOR R: (TUGAL,1969)                                                     500          43.01

REMARKS:    LOC. TURKEY                                                      520          42.15

                                                                             520          42.15

                                                                             540          41.66

                                                                             560          41.54

                                                                             580          41.38

                                                                             600          41.05

                                                                             620          41.34

                                                                             640          40.84

                                                                             660          40.77
```

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
KUTINAITE	A	0.4335	0.4059	492.86	3.38	41.50	420	47.20
CU2.07 AG0.84 AS	C	0.2968	0.3055	480.39	6.03	42.15	440	46.90
CUBIC							460	46.50
REF. FOR R: (J.HAK ET AL,1970)							480	45.80
REMARKS: LOC. CZECHOSLOVAKIA							500	44.20
							500	44.20
							520	43.30
							540	42.80
							560	42.20
							580	41.40
							600	41.70
							620	39.30

Chemical Analysis:	Wt. %
Cu	45.3
Ag	21.5
As	25.6
	92.4

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MINERAL NAME                          CHROMATICITY  DOMINANT           BRIGHTNESS
COMPOSITION                    SOURCE COORDINATES    (COMPL.)   PURITY (VISUAL R) LAMBDA     REFLECTIVITY
CRYSTAL SYSTEM                          X       Y   WAVELENGTH  (P%)       Y       (NM)          R

CATTIERITE                        A   0.4502 0.4061   -505.05    0.93    33.81      440         33.80

CO S2                             C   0.3119 0.3154   -498.11    0.72    33.69      460         33.60

CUBIC                                                                               480         33.50

REF. FOR R: (DEMIRSOY,1968)                                                         500         33.40

REMARKS:    LOC. UNKNOWN                                                            520         33.30

                                                                                    520         33.30

                                                                                    540         33.40

                                                                                    560         33.60

                                                                                    580         33.80

                                                                                    600         33.90

                                                                                    620         34.30

                                                                                    640         34.70

                                                                                    660         35.20
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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
GOLDFIELDITE 1,1	A	0.4475	0.4084	567.95	0.56	32.00	420	31.40
CU3(TE,SB)S4	C	0.3105	0.3179	561.58	0.54	32.02	440	31.20
CUBIC							460	32.00
REF. FOR R: (LEVY,1966)							480	31.80
REMARKS: LOC. GOLDFIELD,U.S.A.							500	32.20
							500	32.20
							520	32.00
							540	32.00
							560	32.20
							580	32.00
							600	31.80
							620	32.20
							640	31.80

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
GOLDFIELDITE 1,2	A	0.4477	0.4085	572.37	0.76	31.71	420	31.40
CU3(TE,SB)S4	C	0.3109	0.3180	567.89	0.67	32.29	440	31.60
CUBIC							460	32.20
REF. FOR R: (LEVY,1966)							480	32.00
REMARKS: LOC. GOLDFIELD,U.S.A.							500	32.20
							500	32.20
							520	32.20
							540	32.40
							560	32.40
							580	32.20
							600	32.40
							620	33.00
							640	31.80

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MINERAL NAME                             CHROMATICITY  DOMINANT          BRIGHTNESS
COMPOSITION                       SOURCE COORDINATES    (COMPL.)   PURITY (VISUAL R) LAMBDA     REFLECTIVITY
CRYSTAL SYSTEM                            X        Y   WAVELENGTH  (P%)       Y       (NM)           R

GOLDFIELDITE 1,3                    A    0.4460 0.4087    509.09   0.37     31.71      420          31.40

CU3(TE,SB)S4                        C    0.3093 0.3173    507.00   0.26     31.78      440          31.20

CUBIC                                                                                  460          32.00

REF. FOR R: (LEVY,1966)                                                                480          31.80

REMARKS:    LOC. GOLDFIELD,U.S.A.                                                      500          32.00

                                                                                       500          32.00

                                                                                       520          31.80

                                                                                       540          32.00

                                                                                       560          32.00

                                                                                       580          31.60

                                                                                       600          31.60

                                                                                       620          31.80

                                                                                       640          31.00
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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
SULVANITE 3,2	A	0.4605	0.4122	586.38	12.20	31.59	420	28.60
CU3 V S4	C	0.3244	0.3336	574.95	8.48	31.24	440	26.20
CUBIC							460	25.70
REF. FOR R: LEVY (1966)							480	27.90
REMARKS: LOC. MERCUR,UTAH,U.S.A.							500	31.70
							500	31.70
							520	32.20
							540	31.20
							560	30.20
							580	31.00
							600	31.20
							620	33.30
							640	34.80

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
SULVANITE 3,3	A	0.4607	0.4119	586.74	12.13	31.52	420	28.60
CU3 V S4	C	0.3244	0.3332	575.30	8.37	31.16	440	26.20
CUBIC							460	25.70
REF. FOR R: LEVY (1966)							480	27.90
REMARKS: LOC. MERCUR,UTAH,U.S.A.							500	31.60
							500	31.60
							520	32.20
							540	31.00
							560	30.00
							580	31.00
							600	31.20
							620	33.30
							640	34.80

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
SULVANITE 3,1	A	0.4600	0.4118	586.60	11.57	31.14	420	28.20
CU3 V S4	C	0.3236	0.3327	574.93	8.02	30.82	440	26.20
CUBIC							460	25.40
REF. FOR R: LEVY (1966)							480	27.90
REMARKS: LOC. MERCUR,UTAH,U.S.A.							500	31.50
							500	31.50
							520	32.00
							540	30.60
							560	29.60
							580	30.40
							600	31.20
							620	33.00
							640	34.00

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MINERAL NAME                          CHROMATICITY  DOMINANT            BRIGHTNESS
COMPOSITION                    SOURCE COORDINATES    (COMPL.)  PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                          X       Y   WAVELENGTH  (P%)        Y       (NM)          R

SULVANITE 4                       A   0.4628 0.4129    586.49  14.28     29.85      420         25.30

CU3 V S4                          C   0.3272 0.3369    575.04  10.12     29.50      440         23.80

CUBIC                                                                               460         24.00

REF. FOR R: LEVY (1966)                                                             480         25.80

REMARKS:    LOC. BURRA-BURRA,AUSTRALIA                                              500         30.00

                                                                                    500         30.00

                                                                                    520         30.60

                                                                                    540         29.20

                                                                                    560         28.30

                                                                                    580         29.10

                                                                                    600         30.50

                                                                                    620         31.20

                                                                                    640         33.00
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MINERAL NAME                          CHROMATICITY  DOMINANT          BRIGHTNESS
COMPOSITION                    SOURCE COORDINATES   (COMPL.)  PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                         X        Y  WAVELENGTH  (P%)      Y       (NM)          R


COLUSITE 1,1                     A    0.4603 0.4148    584.10  13.88    30.65     420         23.60

CU3(AS,SN,V,FE,SB)S4             C    0.3274 0.3359    575.88   9.90    30.22     440         25.10

CUBIC                                                                              460         26.00

REF. FOR R: LEVY (1966)                                                            480         26.50

REMARKS:     LOC. BUTTE,MONTANA,CANADA                                             500         27.60

                                                                                   500         27.60

                                                                                   520         28.80

                                                                                   540         29.90

                                                                                   560         31.00

                                                                                   580         31.60

                                                                                   600         31.90

                                                                                   620         31.50

                                                                                   640         30.80
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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	 Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
COLUSITE 1,3	A	0.4603	0.4147	584.18	13.81	30.57	420	23.60
CU3(AS,SN,V,FE,SB)S4	C	0.3273	0.3357	575.94	9.82	30.14	440	25.10
CUBIC							460	26.00
REF. FOR R: LEVY (1966)							480	26.50
REMARKS: LOC. BUTTE,MONTANA							500	27.40
							500	27.40
							520	28.80
							540	29.80
							560	31.00
							580	31.40
							600	31.80
							620	31.50
							640	30.80

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
COLUSITE 1,2	A	0.4602	0.4139	584.75	13.18	30.01	420	23.40
CU3(AS,SN,V,FE,SB)S4	C	0.3268	0.3345	576.40	9.36	29.59	440	24.80
CUBIC							460	25.80
REF. FOR R: LEVY (1966)							480	26.20
REMARKS: LOC. BUTTE,MONTANA,CANADA							500	27.10
							500	27.10
							520	28.30
							540	29.30
							560	30.20
							580	30.80
							600	31.10
							620	31.00
							640	30.50

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MINERAL NAME                    CHROMATICITY  DOMINANT          BRIGHTNESS
COMPOSITION              SOURCE COORDINATES   (COMPL.)   PURITY (VISUAL R) LAMBDA     REFLECTIVITY
CRYSTAL SYSTEM                   X       Y   WAVELENGTH   (P%)       Y      (NM)           R


COLUSITE 2,2               A    0.4634 0.4109    588.51  13.30     29.57     420          24.00

CU3(AS,SN,V,FE,SB)S4       C    0.3284 0.3314    580.28   8.96     29.02     440          24.80

CUBIC                                                                        460          25.40

REF. FOR R: LEVY (1966)                                                      480          25.90

REMARKS:    LOC. CHIZEUIL,FRANCE                                             500          26.60

                                                                             500          26.60

                                                                             520          27.20

                                                                             540          28.20

                                                                             560          29.60

                                                                             580          30.20

                                                                             600          30.60

                                                                             620          31.60

                                                                             640          31.40
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MINERAL NAME                         CHROMATICITY   DOMINANT              BRIGHTNESS
COMPOSITION                   SOURCE COORDINATES    (COMPL.)    PURITY  (VISUAL R)  LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                          X       Y   WAVELENGTH   (P%)        Y       (NM)           R


COLUSITE 2,3                    A   0.4633 0.4108    588.60    13.17      29.53      420          24.00

CU3(AS,SN,V,FE,SB)S4            C   0.3282 0.3312    580.31     8.85      28.98      440          24.80

CUBIC                                                                                460          25.40

REF. FOR R: LEVY (1966)                                                              480          25.90

REMARKS:    LOC. CHIZEUIL,FRANCE                                                     500          26.60

                                                                                     500          26.60

                                                                                     520          27.20

                                                                                     540          28.30

                                                                                     560          29.40

                                                                                     580          30.10

                                                                                     600          30.60

                                                                                     620          31.60

                                                                                     640          31.40
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MINERAL NAME		CHROMATICITY		DOMINANT		BRIGHTNESS		
COMPOSITION	SOURCE	COORDINATES		(COMPL.)	PURITY	(VISUAL R)	LAMBDA	REFLECTIVITY
CRYSTAL SYSTEM		X	Y	WAVELENGTH	(P%)	Y	(NM)	R
COLUSITE 2,1	A	0.4625	0.4117	587.49	13.24	29.50	420	24.00
CU3(AS,SN,V,FE,SB)S4	C	0.3279	0.3321	579.26	9.01	28.99	440	24.80
CUBIC							460	25.00
REF. FOR R: LEVY (1966)							480	26.00
REMARKS: LOC. CHIZEUIL,FRANCE							500	26.80
							520	27.40
							540	28.40
							560	29.20
							580	30.10
							600	31.10
							620	31.30
							640	30.70

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MINERAL NAME                           CHROMATICITY  DOMINANT          BRIGHTNESS
COMPOSITION                     SOURCE COORDINATES    (COMPL.)   PURITY (VISUAL R) LAMBDA     REFLECTIVITY
CRYSTAL SYSTEM                            X       Y  WAVELENGTH  (P%)       Y       (NM)           R

TETRAHEDRITE 1,2                   A   0.4463 0.4109     558.12   1.48     32.67      420          30.80

CU3 SB S3.25                       C   0.3108 0.3208     558.17   1.40     32.73      440          31.80

CUBIC                                                                                 460          32.00

REF. FOR R: (LEVY,1966)                                                               480          32.00

REMARKS:     LOC. HORNHAUSEN                                                          500          32.30

                                                                                      500          32.30

                                                                                      520          32.60

                                                                                      540          33.00

                                                                                      560          33.30

                                                                                      580          33.20

                                                                                      600          32.70

                                                                                      620          31.40

                                                                                      640          31.40
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MINERAL NAME                            CHROMATICITY  DOMINANT              BRIGHTNESS
COMPOSITION                      SOURCE COORDINATES   (COMPL.)    PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                            X        Y  WAVELENGTH  (P%)       Y       (NM)          R

TETRAHEDRITE 2,2                   A    0.4456 0.4108    542.11   0.99     32.61      420         30.90

CU3 SB S3.25                       C    0.3099 0.3201    548.34   0.98     32.70      440         32.00

CUBIC                                                                                 460         32.20

REF. FOR R: (LEVY,1966)                                                               480         32.20

REMARKS:    LOC. BOUDJOUDOUN,ALGERIA                                                  500         32.40

                                                                                      500         32.40

                                                                                      520         32.60

                                                                                      540         33.10

                                                                                      560         33.30

                                                                                      580         33.10

                                                                                      600         32.40

                                                                                      620         31.10

                                                                                      640         31.40
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MINERAL NAME                     CHROMATICITY  DOMINANT          BRIGHTNESS
COMPOSITION               SOURCE COORDINATES    (COMPL.)  PURITY (VISUAL R) LAMBDA   REFLECTIVITY
CRYSTAL SYSTEM                    X        Y   WAVELENGTH  (P%)      Y       (NM)         R

TETRAHEDRITE 2,1            A   0.4454 0.4104    527.97   0.71     32.55     420        31.60

CU3 SB S3.25                C   0.3096 0.3194    541.56   0.72     32.64     440        32.00

CUBIC                                                                        460        32.20

REF. FOR R: (LEVY,1966)                                                      480        32.20

REMARKS:    LOC. BOUDJOUDOUN,ALGERIA                                         500        32.40

                                                                             500        32.40

                                                                             520        32.70

                                                                             540        33.10

                                                                             560        33.10

                                                                             580        32.90

                                                                             600        32.20

                                                                             620        31.60

                                                                             640        31.40
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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
TETRAHEDRITE 1,1	A	0.4451	0.4103	519.19	0.66	32.53	420	31.70
CU3 SB S3.25	C	0.3092	0.3191	529.70	0.57	32.64	440	32.00
CUBIC							460	32.40
REF. FOR R: (LEVY,1966)							480	32.20
REMARKS: LOC. HORNHALSEN							500	32.50
							500	32.50
							520	32.80
							540	33.10
							560	33.10
							580	32.80
							600	32.10
							620	31.60
							640	31.40

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
TETRAHEDRITE 1,3	A	0.4462	0.4104	552.14	1.07	32.46	420	30.80
CU3 SB S3.25	C	0.3103	0.3200	553.84	1.06	32.52	440	31.80
CUBIC							460	32.00
REF. FOR R: (LEVY,1966)							480	32.00
REMARKS: LOC. HORNHAUSEN							500	32.20
							500	32.20
							520	32.50
							540	32.80
							560	33.00
							580	32.90
							600	32.40
							620	31.20
							640	31.40

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MINERAL NAME                        CHROMATICITY  DOMINANT           BRIGHTNESS
COMPOSITION                  SOURCE COORDINATES   (COMPL.)   PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                        X       Y   WAVELENGTH  (P%)      Y       (NM)          R


TETRAHEDRITE 2,3                A  0.4464 0.4106    557.87   1.34    32.46      420         30.90

CU3 SB S3.25                    C  0.3106 0.3202    557.07   1.19    32.52      440         31.70

CUBIC                                                                           460         32.00

REF. FOR R: (LEVY,1966)                                                         480         31.80

REMARKS:    LOC. BOUDJOUDOUN,ALGERIA                                            500         32.00

                                                                                500         32.00

                                                                                520         32.40

                                                                                540         32.90

                                                                                560         33.00

                                                                                580         33.00

                                                                                600         32.40

                                                                                620         31.10

                                                                                640         31.40
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MINERAL NAME                       CHROMATICITY  DOMINANT            BRIGHTNESS
COMPOSITION                 SOURCE COORDINATES    (COMPL.)   PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                       X       Y   WAVELENGTH   (P%)       Y        (NM)         R

TETRAHEDRITE 3                A    0.4437 0.4098    505.66    0.86     31.63      420        30.50

CU3 SB S3.25                  C    0.3076 0.3177    497.76    0.84     31.79      440        31.70

CUBIC                                                                             460        32.20

REF. FOR R: (LEVY,1966)                                                           480        31.80

REMARKS:    LOC. FAMATINA                                                         500        32.00

                                                                                  500        32.00

                                                                                  520        31.90

                                                                                  540        32.20

                                                                                  560        32.20

                                                                                  580        32.00

                                                                                  600        31.20

                                                                                  620        30.40

                                                                                  640        30.30
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MINERAL NAME                          CHROMATICITY  DOMINANT             BRIGHTNESS
COMPOSITION                    SOURCE COORDINATES    (COMPL.)   PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                         X        Y   WAVELENGTH   (P%)       Y       (NM)         R


TETRAHEDRITE 4                   A   0.4428 0.4100    504.27    1.08    30.80      420        29.20

CU3 SB S3.25                     C   0.3071 0.3174    495.37    1.04    30.99      440        31.40

CUBIC                                                                              460        31.40

REF. FOR R: (LEVY,1966)                                                            480        31.10

REMARKS:    LOC. FAMATINA                                                          500        31.00

                                                                                   500        31.00

                                                                                   520        31.40

                                                                                   540        31.40

                                                                                   560        31.30

                                                                                   580        31.10

                                                                                   600        30.40

                                                                                   620        30.40

                                                                                   640        29.00
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MINERAL NAME                     CHROMATICITY  DOMINANT            BRIGHTNESS
COMPOSITION               SOURCE COORDINATES   (COMPL.)   PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                    X        Y   WAVELENGTH  (P%)      Y       (NM)          R


TETRAHEDRITE,E              A   0.4450 0.4107    523.83   0.76    30.56      440         30.19

CU3 SB 53.25                C   0.3094 0.3193    536.39   0.65    30.66      460         29.93

CUBIC                                                                        480         30.09

REF. FOR R: (TUGAL,1969)                                                     500         30.47

REMARKS:    LOC. TURKEY                                                      520         30.80

                                                                             520         30.80

                                                                             540         31.01

                                                                             560         31.12

                                                                             580         30.94

                                                                             600         30.36

                                                                             620         29.91

                                                                             640         29.27

                                                                             660         28.08
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MINERAL NAME                          CHROMATICITY  DOMINANT         BRIGHTNESS
COMPOSITION                    SOURCE COORDINATES   (COMPL.)  PURITY (VISUAL R) LAMBDA     REFLECTIVITY
CRYSTAL SYSTEM                          X       Y  WAVELENGTH  (P%)      Y       (NM)           R


TETRAHEDRITE,49A                 A   0.4458 0.4076   495.74    0.42    29.97      440          30.30

CU3 SB S3.25                     C   0.3085 0.3155   484.72    0.67    30.03      460          30.23

CUBIC                                                                             480          30.25

REF. FOR R: (TUGAL,1969)                                                          500          30.36

REMARKS:    LOC. TURKEY                                                           520          30.28

                                                                                  520          30.28

                                                                                  540          30.03

                                                                                  560          30.07

                                                                                  580          29.88

                                                                                  600          29.87

                                                                                  620          30.17

                                                                                  640          29.55

                                                                                  660          28.67
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MINERAL NAME                      CHROMATICITY  DOMINANT          BRIGHTNESS
COMPOSITION               SOURCE COORDINATES    (COMPL.)  PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                     X        Y  WAVELENGTH  (P%)      Y       (NM)         R

TETRAHEDRITE,49B             A   0.4420 0.4106   504.92   1.26    29.33      440        29.58

CU3 SB 53.25                 C   0.3063 0.3177   495.39   1.32    29.55      460        29.44

CUBIC                                                                        480        29.59

REF. FOR R: (TUGAL,1969)                                                     500        29.78

REMARKS:    LOC. TURKEY                                                      520        30.07

                                                                             520        30.07

                                                                             540        30.13

                                                                             560        30.01

                                                                             580        29.45

                                                                             600        28.78

                                                                             620        28.34

                                                                             640        27.36

                                                                             660        27.11
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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
TENNANTITE 6	A	0.4433	0.4102	506.46	0.97	30.79	420	30.40
CU3 AS S3.25	C	0.3073	0.3182	499.27	0.93	30.97	440	30.80
CUBIC							460	30.70
REF. FOR R: (LEVY,1966)							480	31.20
REMARKS: LOC. TSUMEB							500	31.50
							500	31.50
							520	31.70
							540	31.40
							560	31.00
							580	30.80
							600	30.80
							620	29.60
							640	29.30

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MINERAL NAME                          CHROMATICITY  DOMINANT           BRIGHTNESS
COMPOSITION                    SOURCE COORDINATES    (COMPL.)   PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                          X        Y  WAVELENGTH   (P%)      Y        (NM)          R

TENNANTITE 8,1                   A    0.4358 0.4097    498.01    2.72    29.28      420         31.80

CU3 AS S3.25                     C    0.3003 0.3126    486.30    3.96    29.70      440         30.80

CUBIC                                                                               460         31.40

REF. FOR R: (LEVY,1966)                                                             480         30.70

REMARKS:    LOC. HAURON., SPECIMEN WITH SN                                          500         30.60

                                                                                    500         30.60

                                                                                    520         30.60

                                                                                    540         30.70

                                                                                    560         30.00

                                                                                    580         29.20

                                                                                    600         28.90

                                                                                    620         27.40

                                                                                    640         26.30
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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
TENNANTITE 8,2	A	0.4360	0.4092	497.31	2.68	28.94	420	31.80
CU3 AS S3.25	C	0.3002	0.3121	485.71	4.05	29.35	440	30.40
CUBIC							460	31.20
REF. FOR R: (LEVY,1966)							480	30.30
REMARKS: LOC. HAURON., SPECIMEN WITH SN							500	30.40
							500	30.40
							520	30.30
							540	30.20
							560	29.60
							580	29.00
							600	28.30
							620	27.00
							640	26.30

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MINERAL NAME                    CHROMATICITY  DOMINANT           BRIGHTNESS
COMPOSITION              SOURCE COORDINATES   (COMPL.)  PURITY  (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                   X        Y   WAVELENGTH  (P%)      Y       (NM)          R

TENNANTITE,40               A   0.4420 0.4121   510.73   1.30    28.86      440       28.53

CU3 AS 53.25                C   0.3070 0.3202   507.12   1.02    29.08      460       28.45

CUBIC                                                                       480       28.95

REF. FOR R: (TUGAL,1969)                                                    500       29.25

REMARKS:    LOC. TURKEY                                                     520       29.72

                                                                            520       29.72

                                                                            540       29.78

                                                                            560       29.61

                                                                            580       29.04

                                                                            600       28.16

                                                                            620       27.72

                                                                            640       27.07

                                                                            660       26.14
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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	 Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
TENNANTITE 8,3	A	0.4360	0.4090	497.01	2.69	28.82	420	31.80
CU3 AS S3.25	C	0.3001	0.3118	485.37	4.11	29.23	440	30.40
CUBIC							460	31.00
REF. FOR R: (LEVY,1966)							480	30.30
REMARKS: LOC. HAURON., SPECIMEN WITH SN							500	30.40
							500	30.40
							520	30.10
							540	30.10
							560	29.50
							580	28.80
							600	28.20
							620	26.80
							640	26.30

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	 Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
TENNANTITE,478	A	0.4404	0.4111	503.85	1.62	28.53	440	29.08
CU3 AS S3.25	C	0.3050	0.3175	493.78	1.81	28.80	460	28.72
CUBIC							480	28.65
REF. FOR R: (TUGAL,1969)							500	29.28
REMARKS: LOC. TURKEY							520	29.62
							520	29.62
							540	29.66
							560	29.09
							580	28.63
							600	27.84
							620	27.02
							640	26.50
							660	26.42

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES		DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
		X	Y					
TENNANTITE,47A	A	0.4380	0.4113	501.83	2.17	28.32	440	29.25
CU3 AS S3.25	C	0.3028	0.3166	491.46	2.69	28.68	460	28.82
CUBIC							480	29.05
REF. FOR R: (TUGAL,1969)							500	29.46
REMARKS: LOC. TURKEY							520	29.82
							520	29.82
							540	29.69
							560	28.91
							580	28.36
							600	27.36
							620	27.02
							640	25.84
							660	24.96

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	 Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
TENNANTITE,51	A	0.4403	0.4102	501.34	1.65	28.14	440	28.85
CU3 AS 53.25	C	0.3045	0.3162	490.75	2.09	28.41	460	28.79
CUBIC							480	28.73
REF. FOR R: (TUGAL,1969)							500	29.01
REMARKS: LOC. TURKEY							520	29.16
							520	29.16
							540	29.08
							560	28.77
							580	28.00
							600	27.66
							620	26.97
							640	26.23
							660	25.71

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
TENNANTITE 7,2	A	0.4338	0.4066	496.15	3.22	27.22	420	30.50
CU3 AS S3.25	C	0.2979	0.3100	484.50	5.10	27.67	440	29.70
CUBIC							460	29.50
REF. FOR R: (LEVY,1966)							480	29.20
REMARKS: LOC. NIARI							500	28.90
							500	28.90
							520	28.90
							540	28.60
							560	27.90
							580	27.00
							600	26.20
							620	25.80
							640	24.60

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MINERAL NAME                         CHROMATICITY  DOMINANT          BRIGHTNESS
COMPOSITION                   SOURCE COORDINATES   (COMPL.)   PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                        X       Y    WAVELENGTH  (P%)      Y       (NM)          R

TENNANTITE 7,1                  A    0.4339 0.4078    495.16   3.22    27.20      420        30.90

CU3 AS S3.25                    C    0.2976 0.3085    483.05   5.37    27.64      440        30.40

CUBIC                                                                             460        29.60

REF. FOR R: (LEVY,1966)                                                           480        28.80

REMARKS:    LOC. NIARI                                                            500        29.00

                                                                                  500        29.00

                                                                                  520        28.90

                                                                                  540        28.40

                                                                                  560        27.80

                                                                                  580        27.00

                                                                                  600        26.60

                                                                                  620        25.40

                                                                                  640        24.60
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MINERAL NAME                         CHROMATICITY  DOMINANT              BRIGHTNESS
COMPOSITION                   SOURCE COORDINATES    (COMPL.)    PURITY  (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                          X      Y   WAVELENGTH   (P%)        Y        (NM)          R


TENNANTITE 5                    A    0.4319 0.4078    495.12    3.70      26.05       420        29.40

CU3 AS S3.25                    C    0.2959 0.3077    483.30    6.08      26.53       440        29.30

CUBIC                                                                                 460        28.80

REF. FOR R: (LEVY,1966)                                                               480        28.40

REMARKS:    LOC. SAN VINCENT                                                          500        28.00

                                                                                      500        28.00

                                                                                      520        27.80

                                                                                      540        27.30

                                                                                      560        26.60

                                                                                      580        26.10

                                                                                      600        25.20

                                                                                      620        24.20

                                                                                      640        23.20
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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
VAESITE	A	0.4467	0.4043	-575.05	1.01	30.89	440	32.50
NI S2	C	0.3076	0.3105	-566.90	1.87	30.89	460	31.90
CUBIC							480	31.60
REF. FOR R: (DEMIRSOY,1968)							500	31.10
REMARKS: LOC. UNKNWON							520	31.00
							540	30.70
							560	30.60
							580	30.70
							600	30.80
							620	31.10
							640	31.40
							660	31.90

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
GERMANITE,3	A	0.4645	0.4025	606.26	8.22	22.53	420	21.20
CU6 FE GE S8	C	0.3245	0.3177	605.55	4.23	22.02	440	21.20
CUBIC							460	21.00
REF. FOR R: (LEVY,1966)							480	20.60
REMARKS: LOC. TSUMEB							500	20.30
							500	20.30
							520	20.60
							540	21.00
							560	21.80
							580	22.60
							600	23.40
							620	24.60
							640	25.80

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
GERMANITE,6	A	0.4641	0.4016	612.34	7.33	22.27	420	21.20
CU6 FE GE S8	C	0.3234	0.3161	618.90	3.51	21.77	440	21.20
CUBIC							460	21.00
REF. FOR R: (LEVY,1966)							480	20.70
REMARKS: LOC. TSUMEB							500	20.40
							500	20.40
							520	20.40
							540	20.80
							560	21.30
							580	22.40
							600	23.00
							620	24.00
							640	25.80

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
GERMANITE,5	A	0.4616	0.4025	612.28	6.22	22.04	420	20.90
CU6 FE GE S8	C	0.3215	0.3162	617.83	3.01	21.62	440	21.20
CUBIC							460	21.00
REF. FOR R: (LEVY,1966)							480	20.70
REMARKS: LOC. TSUMEB							500	20.40
							500	20.40
							520	20.40
							540	20.80
							560	21.20
							580	22.20
							600	22.80
							620	23.70
							640	24.80

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MINERAL NAME                          CHROMATICITY  DOMINANT            BRIGHTNESS
COMPOSITION                    SOURCE COORDINATES   (COMPL.)   PURITY  (VISUAL R) LAMBDA     REFLECTIVITY
CRYSTAL SYSTEM                          X       Y   WAVELENGTH  (P%)        Y      (NM)          R


GERMANITE,4                      A   0.4614 0.4008    657.58    4.90      21.60      420         21.20

CU6 FE GE S8                     C   0.3202 0.3134   -494.40    3.05      21.19      440         21.20

CUBIC                                                                                460         21.00

REF. FOR R: (LEVY,1966)                                                              480         20.60

REMARKS:    LOC. TSUMEB                                                              500         20.10

                                                                                     500         20.10

                                                                                     520         20.00

                                                                                     540         20.40

                                                                                     560         20.70

                                                                                     580         21.60

                                                                                     600         22.20

                                                                                     620         23.10

                                                                                     640         24.80
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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	 Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
GERMANITE,2	A	0.4666	0.4026	603.52	9.76	21.58	420	20.00
CU6 FE GE S8	C	0.3271	0.3186	602.68	5.17	21.02	440	20.10
CUBIC							460	19.60
REF. FOR R: (LEVY,1966)							480	19.50
REMARKS: LOC. BANCAIROUN. HOMOGENEOUS SPECIMEN							500	19.20
							500	19.20
							520	19.10
							540	19.90
							560	20.80
							580	21.80
							600	23.10
							620	24.00
							640	24.40

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
GERMANITE,1	A	0.4668	0.4026	603.35	9.90	21.22	420	19.60
CU6 FE GE S8	C	0.3271	0.3187	602.29	5.20	20.67	440	19.80
CUBIC							460	19.30
REF. FOR R: (LEVY,1966)							480	19.00
REMARKS: LOC. BANCAIROUN. HOMOGENEOUS SPECIMEN							500	18.90
							500	18.90
							520	18.90
							540	19.70
							560	20.30
							580	21.40
							600	22.60
							620	23.50
							640	24.20

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
BORNITE,NG36	A	0.4727	0.4140	587.82	21.91	24.91	440	18.21
CU5 FE S4	C	0.3403	0.3437	578.95	15.45	24.21	460	18.71
CUBIC							480	19.83
REF. FOR R: (TUGAL,1969)							500	21.34
REMARKS: LOC. TURKEY							520	22.52
							~~520~~	~~22.52~~
							540	23.53
							560	24.50
							580	25.40
							600	26.18
							620	27.05
							640	27.45
							660	28.67

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
BORNITE,NGD3	A	0.4789	0.4088	591.92	22.58	22.88	440	17.45
CU5 FE S4	C	0.3443	0.3376	584.21	14.89	22.01	460	17.09
CUBIC							480	17.67
REF. FOR R: (TUGAL,1969)							500	18.65
REMARKS: LOC. TURKEY							520	19.81
							~~520~~	~~19.81~~
							540	20.76
							560	22.08
							580	23.16
							600	24.75
							620	25.89
							640	27.47
							660	27.78

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
BORNITE 6305	A	0.4774	0.4066	593.78	19.74	22.05	440	17.55
CU5 FE S4	C	0.3412	0.3327	586.53	12.74	21.22	460	17.42
CUBIC							480	17.53
REF. FOR R: THE AUTHOR							500	18.13
REMARKS: LOC. KOREA							520	18.97
							~~520~~	~~18.97~~
							540	20.00
							560	21.23
							580	22.35
							600	23.63
							620	25.06
							640	26.18
							660	27.43

Electron Probe Analysis:

	Wt. %
Cu	63.41
Fe	11.41
S	25.49
	100.31

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
BORNITE,NG06	A	0.4751	0.4113	589.87	21.69	22.04	440	16.70
CU5 FE S4	C	0.3413	0.3397	581.62	14.65	21.32	460	16.60
CUBIC							480	17.26
REF. FOR R: (TLGAL,1969)							500	18.48
REMARKS: LOC. TURKEY							~~520~~	~~19.41~~
							520	19.41
							540	20.65
							560	21.40
							580	22.49
							600	23.42
							620	24.17
							640	25.03
							660	26.46

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
BORNITE 6302	A	0.4793	0.4042	596.14	19.67	21.83	440	17.88
CU5 FE S4	C	0.3418	0.3293	589.90	11.98	20.94	460	17.37
CUBIC							480	17.20
REF. FOR R: THE AUTHOR							500	17.80
REMARKS: LOC. ARIZONA							520	18.50
							520	18.50
							540	19.57
							560	20.68
							580	22.19
							600	23.60
							620	25.01
							640	26.74
							660	28.13

Electron Probe Analysis:

	Wt. %
Cu	63.44
Fe	11.57
S	24.88
	99.89

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
BORNITE,48	A	0.4739	0.4080	592.47	18.56	21.52	440	17.37
CU5 FE S4	C	0.3380	0.3328	584.93	11.91	20.82	460	17.16
CUBIC							480	17.42
REF. FOR R: (TUGAL,1969)							500	18.18
REMARKS: LOC. TURKEY							520	18.92
							~~520~~	~~18.92~~
							540	19.89
							560	20.84
							580	21.84
							600	22.85
							620	24.16
							640	24.76
							660	25.71

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
BORNITE 13513	A	0.4791	0.4045	595.83	19.74	21.30	440	17.52
CU5 FE S4	C	0.3417	0.3292	585.86	11.96	20.44	460	17.00
CUBIC							480	16.45
REF. FOR R: THE AUTHOR							500	17.38
REMARKS: LOC. AUSTRALIA							520	18.10
							~~520~~	~~18.10~~
							540	19.08
							560	20.24
							580	21.63
							600	23.07
							620	24.37
							640	26.15
							660	27.12

Electron Probe Analysis:	Wt. %
Cu	63.47
Fe	11.48
S	24.82
	99.77

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
BORNITE 6301	A	0.4720	0.4011	603.80	12.46	20.32	440	18.72
CU5 FE S4	C	0.3317	0.3187	604.43	6.43	19.64	460	17.81
CUBIC							480	17.17
REF. FOR R: THE AUTHOR							500	17.28
REMARKS: LOC. NEW JERSEY							520	17.69
							540	18.47
							560	19.35
							580	20.47
							600	21.69
							620	23.03
							640	24.04
							660	25.54

Electron Probe Analysis:

	Wt. %
Cu	63.01
Fe	11.60
S	25.50
	100.11

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
BORNITE 5796	A	0.4772	0.3998	603.66	15.16	20.14	440	18.19
CU5 FE S4	C	0.3366	0.3193	604.27	7.90	19.32	460	17.06
CUBIC							480	16.44
REF. FOR R: THE AUTHOR							500	16.51
REMARKS: LOC. RHODESIA							520	16.98
							~~520~~	~~16.98~~
							540	17.85
							560	18.95
							580	20.43
							600	21.74
							620	23.23
							640	24.86
							660	26.58

Electron Probe Analysis:

	Wt. %
Cu	63.41
Fe	11.50
S	25.70
	100.61

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
BORNITE 12894	A	0.4736	0.3986	610.59	11.82	19.78	440	18.79
CU5 FE S4	C	0.3319	0.3149	631.04	5.46	19.06	460	17.49
CUBIC							480	16.69
REF. FOR R: THE AUTHOR							500	16.58
REMARKS: LOC. RHODESIA							520	16.95
							~~520~~	~~16.95~~
							540	17.66
							560	18.70
							580	19.95
							600	21.31
							620	22.65
							640	24.12
							660	25.44

Electron Probe Analysis:

	Wt. %
Cu	63.39
Fe	11.41
S	24.88
	99.68

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
BORNITE,A55(2)	A	0.4779	0.4006	601.73	16.18	19.67	440	17.55
CU5 FE S4	C	0.3379	0.3210	600.50	8.71	18.86	460	16.37
CUBIC							480	15.72
REF. FOR R: (TUGAL,1969)							500	15.99
REMARKS: LOC. TURKEY							520	16.67
							540	17.48
							560	18.51
							580	19.83
							600	21.41
							620	22.90
							640	24.45
							660	25.27

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MINERAL NAME                              CHROMATICITY  DOMINANT          BRIGHTNESS
COMPOSITION                        SOURCE COORDINATES    (COMPL.)  PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                               X       Y  WAVELENGTH  (P%)       Y       (NM)         R

BORNITE,A55(1)                       A    0.4742 0.3973    615.87  11.34     18.62       440         18.02

CU5 FE S4                            C    0.3318 0.3128    600.98   6.75     17.92       460         16.54

CUBIC                                                                                    480         15.67

REF. FOR R: (TUGAL,1969)                                                                 500         15.65

REMARKS:    LOC. TURKEY                                                                  520         15.94

                                                                                         540         16.51

                                                                                         560         17.48

                                                                                         580         18.61

                                                                                         600         20.17

                                                                                         620         21.69

                                                                                         640         23.20

                                                                                         660         23.87
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MINERAL NAME                    CHROMATICITY  DOMINANT           BRIGHTNESS
COMPOSITION              SOURCE COORDINATES   (COMPL.)   PURITY  (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                   X        Y   WAVELENGTH  (P%)       Y        (NM)         R

BIXBYITE                   A   0.4445 0.4100    510.38    0.72     22.24      430        22.20

(MN,FE)2 O3                C   0.3084 0.3180    503.55    0.55     22.32      470        22.20

CUBIC                                                                         490        22.00

REF. FOR R: (NICHOL & PHILLIPS,1964)                                          520        22.50

REMARKS:    LOC. UNKNWON                                                      550        22.70

                                                                              580        22.40

                                                                              610        21.80

                                                                              650        21.20
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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
MAGNETITE	A	0.4497	0.4078	589.78	1.66	20.92	440	20.50
FE FE2 O4	C	0.3124	0.3178	583.58	1.02	20.64	460	20.50
CUBIC							480	20.60
REF. FOR R: (DEMIRSCY,1968)							500	20.60
REMARKS: LOC. UNKNWON							520	20.60
							540	20.70
							560	21.00
							580	21.00
							600	21.00
							620	21.10
							640	21.10
							660	21.10

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MINERAL NAME                       CHROMATICITY  DOMINANT          BRIGHTNESS
COMPOSITION                 SOURCE COORDINATES   (COMPL.)  PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                      X        Y  WAVELENGTH  (P%)       Y      (NM)          R

JACOBSITE                     A    0.4394 0.4082   496.25   1.91    18.91      430        19.70

(MN,FE,MG)(FE,MN)2 O4         C    0.3029 0.3129   485.09   2.98    19.10      470        20.00

CUBIC                                                                          490        20.00

REF. FOR R: (NICHOL & PHILLIPS,1964)                                           520        19.40

REMARKS:    LOC. UNKNWON                                                       550        19.30

                                                                               580        19.00

                                                                               610        18.40

                                                                               650        17.50
```

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
FRANKLINITE	A	0.4410	0.4075	494.66	1.56	18.15	430	19.20
(ZN,FE,MN)(FE,MN)2 O4	C	0.3039	0.3122	482.54	2.69	18.29	470	18.90
CUBIC							490	18.80
REF. FOR R: (NICHOL & PHILLIPS,1964)							520	18.60
REMARKS: LOC. UNKNWON							550	18.40
							550	18.40
							580	18.20
							610	17.80
							650	17.10

```
MINERAL NAME                            CHROMATICITY  DOMINANT           BRIGHTNESS
COMPOSITION                      SOURCE COORDINATES    (COMPL.)   PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                            X       Y   WAVELENGTH   (P%)       Y       (NM)          R


MAGNESIOFERRITE                    A    0.4354 0.4044    490.45    3.02     17.09      440         19.40

MG FE2 O4                          C    0.2974 0.3047    478.87    5.93     17.33      460         19.10

CUBIC                                                                                  480         18.70

REF. FOR R: (DEMIRSOY,1968)                                                            500         18.40

REMARKS:    LOC. UNKNOWN                                                               520         17.90

                                                                                       520         17.90

                                                                                       540         17.50

                                                                                       560         17.30

                                                                                       580         16.90

                                                                                       600         16.60

                                                                                       620         16.40

                                                                                       640         16.20

                                                                                       660         15.90
```

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
MARMATITE	A	0.4410	0.4055	489.58	1.65	17.63	430	19.00
ZN S	C	0.3031	0.3093	478.00	3.32	17.75	470	18.80
CUBIC							490	18.30
REF. FOR R: (NICHOL & PHILLIPS,1964)							520	18.00
REMARKS: LOC. TREPCA,YUGOSLAVIA							550	17.80
							550	17.80
							580	17.60
							610	17.30
							650	17.00

```
MINERAL NAME                         CHROMATICITY  DOMINANT            BRIGHTNESS
COMPOSITION                   SOURCE COORDINATES    (COMPL.)   PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                         X       Y   WAVELENGTH  (P%)       Y       (NM)          R

SPHALERITE 15                   A   0.4434 0.4044    480.80    1.17     19.19      440        20.72

ZN S                            C   0.3049 0.3083    466.29    2.93     19.25      460        20.50

CUBIC                                                                              480        19.84

REF. FOR R: (GRAFENAUER ET AL,1969)                                                500        19.30

REMARKS:    LOC. NOVO BRDO,YUGOSLAVIA                                              540        19.22

                                                                                   540        19.22

                                                                                   580        19.25

                                                                                   620        19.02

                                                                                   660        18.78
```

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
SPHALERITE 5	A	0.4402	0.4094	499.26	1.69	19.07	440	19.90
ZN S	C	0.3043	0.3142	486.50	2.33	19.23	460	19.71
CUBIC							480	19.51
REF. FOR R: (GRAFENAUER ET AL,1969)							500	19.18
REMARKS: LOC. LECE,YUGOSLAVIA							540	19.60
							540	19.60
							580	19.50
							620	17.90
							660	17.60

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	 Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
SPHALERITE 14	A	0.4422	0.4040	482.84	1.46	18.99	440	20.85
ZN S	C	0.3035	0.3069	469.21	3.59	19.08	460	20.50
CUBIC							480	19.76
REF. FOR R: (GRAFENAUER ET AL,1969)							500	19.22
REMARKS: LOC. STARI TRG,YUGOSLAVIA							540	19.11
							540	19.11
							580	19.02
							620	18.70
							660	18.56

```
MINERAL NAME                         CHROMATICITY  DOMINANT           BRIGHTNESS
COMPOSITION                   SOURCE COORDINATES    (COMPL.)   PURITY (VISUAL R) LAMBDA     REFLECTIVITY
CRYSTAL SYSTEM                         X       Y   WAVELENGTH  (P%)       Y       (NM)           R


SPHALERITE 12                   A    0.4403 0.4050   488.87    1.84     18.97      440          20.81

ZN S                            C    0.3021 0.3077   476.21    3.91     19.12      460          20.40

CUBIC                                                                              480          20.02

REF. FOR R: (GRAFENAUER ET AL,1969)                                                500          19.51

REMARKS:    LOC. AJVALIJA ,YUGOSLAVI                                               540          19.28

                                                                                   540          19.28

                                                                                   580          18.94

                                                                                   620          18.48

                                                                                   660          18.18
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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
SPHALERITE 11	A	0.4415	0.4042	485.10	1.61	18.95	440	20.88
ZN S	C	0.3027	0.3070	472.85	3.82	19.07	460	20.25
CUBIC							480	19.86
REF. FOR R: (GRAFENAUER ET AL,1969)							500	19.58
REMARKS: LOC. KIZNICA,YUGOSLAVIA							540	19.07
							540	19.07
							580	18.90
							620	18.63
							660	18.51

```
MINERAL NAME                         CHROMATICITY  DOMINANT          BRIGHTNESS
COMPOSITION                   SOURCE COORDINATES    (COMPL.)  PURITY (VISUAL R) LAMBDA      REFLECTIVITY
CRYSTAL SYSTEM                         X       Y   WAVELENGTH  (P%)      Y       (NM)           R


SPHALERITE 16                   A    0.4402 0.4035    485.10    1.95    18.94     440          21.28

ZN S                            C    0.3012 0.3052    473.05    4.58    19.08     460          20.55

CUBIC                                                                             480          19.92

REF. FOR R: (GRAFENAUER ET AL, 1969)                                              500          19.76

REMARKS:    LOC. JANJEVO,YUGOSLAVIA                                               540          19.10

                                                                                  540          19.10

                                                                                  580          18.80

                                                                                  620          18.65

                                                                                  660          18.30
```

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
SPHALERITE 13	A	0.4392	0.4042	487.94	2.14	18.62	440	20.80
ZN S	C	0.3007	0.3059	475.66	4.63	18.78	460	20.28
CUBIC							480	19.72
REF. FOR R: (GRAFENAUER ET AL,1969)							500	19.42
REMARKS: LOC. SREBRENICA,YUGOSLAVIA							540	18.92
							540	18.92
							580	18.51
							620	18.12
							660	17.85

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	 Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
SPHALERITE 10	A	0.4421	0.4047	485.73	1.44	18.56	440	20.32
ZN S	C	0.3035	0.3080	472.83	3.41	18.66	460	19.48
CUBIC							480	19.30
REF. FOR R: (GRAFENAUER ET AL,1969)							500	19.08
REMARKS: LOC. SASE,YUGOSLAVIA							540	18.67
							540	18.67
							580	18.56
							620	18.24
							660	18.10

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
SPHALERITE 7	A	0.4431	0.4069	492.52	1.08	18.12	440	19.05
ZN S	C	0.3057	0.3121	478.22	2.08	18.20	460	18.88
CUBIC							480	18.40
REF. FOR R: (GRAFENAUER ET AL,1969)							500	18.21
REMARKS: LOC. OKOSKA GORA,YUGOSLAVIA							540	18.40
							540	18.40
							580	18.20
							620	17.72
							660	17.40

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	 Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
SPHALERITE 8	A	0.4417	0.4053	488.31	1.49	17.93	440	19.41
ZN S	C	0.3034	0.3090	475.97	3.29	18.04	460	18.93
CUBIC							480	18.75
REF. FOR R: (GRAFENAUER ET AL,1969)							500	18.43
REMARKS: LOC. DOBREVO,YUGOSLAVIA							540	18.21
							540	18.21
							580	17.78
							620	17.63
							660	17.42

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
SPHALERITE 4	A	0.4437	0.4045	480.05	1.09	17.92	440	19.18
ZN S	C	0.3051	0.3090	468.33	2.75	17.98	460	19.02
CUBIC							480	18.70
REF. FOR R: (GRAFENAUER ET AL,1969)							500	18.15
REMARKS: LOC. PONOVICE,YUGOSLAVIA							540	17.92
							580	17.92
							620	17.80
							660	17.62

```
MINERAL NAME                           CHROMATICITY  DOMINANT              BRIGHTNESS
COMPOSITION                     SOURCE COORDINATES   (COMPL.)   PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                          X        Y   WAVELENGTH  (P%)       Y      (NM)          R

SPHALERITE 3                       A   0.4420 0.4054    488.27   1.42     17.91     440         19.31

ZN S                               C   0.3039 0.3092    474.99   3.09     18.01     460         19.10

CUBIC                                                                               480         18.51

REF. FOR R: (GRAFENAUER ET AL,1969)                                                 500         18.15

REMARKS:    LOC. REMSNIK,YUGOSLAVIA                                                 540         18.20

                                                                                    580         17.85

                                                                                    620         17.58

                                                                                    660         17.35
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MINERAL NAME                         CHROMATICITY  DOMINANT           BRIGHTNESS
COMPOSITION                   SOURCE COORDINATES    (COMPL.)  PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                          X       Y   WAVELENGTH  (P%)       Y       (NM)          R

SPHALERITE 6                    A    0.4438 0.4046    480.20    1.06     17.83      440        19.28

ZN S                            C    0.3051 0.3087    466.79    2.80     17.89      460        18.68

CUBIC                                                                               480        18.32

REF. FOR R: (GRAFENAUER ET AL,1969)                                                 500        18.07

REMARKS:    LOC. RUDNIK,YUGOSLAVIA                                                  540        17.88

                                                                                    580        17.80

                                                                                    620        17.71

                                                                                    660        17.60
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MINERAL NAME                       CHROMATICITY  DOMINANT         BRIGHTNESS
COMPOSITION                 SOURCE COORDINATES   (COMPL.)  PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                       X        Y  WAVELENGTH  (P%)      Y      (NM)          R

SPHALERITE 1                  A    0.4437 0.4047    481.27   1.08    17.82     440        19.08

ZN S                          C    0.3051 0.3092    469.30   2.71    17.88     460        18.72

CUBIC                                                                          480        18.66

REF. FOR R: (GRAFENAUER ET AL,1969)                                            500        17.95

REMARKS:     LOC. CEMERNICA,YUGOSLAVIA                                         540        17.90

                                                                               580        17.80

                                                                               620        17.70

                                                                               660        17.50
```

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
SPHALERITE M3	A	0.4415	0.4066	492.28	1.47	17.75	440	18.95
ZN S	C	0.3038	0.3110	479.97	2.89	17.88	460	18.50
CUBIC							480	18.37
REF. FOR R: (TUGAL,1969)							500	18.24
REMARKS: LOC. TURKEY							520	18.40
							540	18.02
							560	17.83
							580	17.67
							600	17.47
							620	17.33
							640	17.18
							660	17.12

```
MINERAL NAME                    CHROMATICITY  DOMINANT          BRIGHTNESS
COMPOSITION              SOURCE COORDINATES   (COMPL.)  PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                  X        Y   WAVELENGTH  (P%)      Y       (NM)          R

SPHALERITE KD2A            A    0.4433 0.4061    489.17   1.08    17.38     440        18.32

ZN S                       C    0.3054 0.3115    464.60   2.70    17.46     460        18.04

CUBIC                                                                       480        17.95

REF. FOR R: (TUGAL,1969)                                                    500        17.78

REMARKS:     LOC. TURKEY                                                    520        17.70

                                                                            520        17.70

                                                                            540        17.54

                                                                            560        17.38

                                                                            580        17.35

                                                                            600        17.11

                                                                            620        17.45

                                                                            640        17.25

                                                                            660        16.41
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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
SPHALERITE M2	A	0.4420	0.4066	492.05	1.36	17.34	440	18.39
ZN S	C	0.3046	0.3112	478.65	2.58	17.44	460	18.18
CUBIC							480	17.89
REF. FOR R: (TLGAL,1969)							500	17.65
REMARKS: LOC. TURKEY							520	17.70
							540	17.59
							560	17.39
							580	17.37
							600	17.24
							620	17.30
							640	16.45
							660	16.02

```
MINERAL NAME                          CHROMATICITY  DOMINANT             BRIGHTNESS
COMPOSITION                   SOURCE  COORDINATES   (COMPL.)    PURITY  (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                          X       Y   WAVELENGTH  (P%)        Y       (NM)          R

SPHALERITE 9                     A   0.4415 0.4034    482.31     1.66     17.27      440        19.30

ZN S                             C   0.3024 0.3054    469.40     4.17     17.36      460        18.48

CUBIC                                                                                480        18.20

REF. FOR R: (GRAFENAUER ET AL,1969)                                                  500        17.65

REMARKS:    LOC. SUPLJA STENA,YUGOSLAVIA                                             540        17.40

                                                                                     580        17.18

                                                                                     620        17.08

                                                                                     660        16.85
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MINERAL NAME                          CHROMATICITY  DOMINANT            BRIGHTNESS
COMPOSITION                    SOURCE COORDINATES    (COMPL.)   PURITY (VISUAL R) LAMBDA     REFLECTIVITY
CRYSTAL SYSTEM                           X       Y  WAVELENGTH   (P%)        Y      (NM)           R

SPHALERITE 2                      A   0.4437 0.4052    484.09    1.04     17.19      440         18.25

ZN S                              C   0.3054 0.3102    472.01    2.46     17.26      460         18.06

CUBIC                                                                                480         17.88

REF. FOR R: (GRAFENAUER ET AL,1969)                                                  500         17.45

REMARKS:    LOC. MEZICA,YUGOSLAVIA                                                   540         17.28

                                                                                     580         17.15

                                                                                     620         17.06

                                                                                     660         16.86
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MINERAL NAME                       CHROMATICITY   DOMINANT          BRIGHTNESS
COMPOSITION                 SOURCE COORDINATES    (COMPL.)   PURITY (VISUAL R) LAMBDA     REFLECTIVITY
CRYSTAL SYSTEM                        X     .  Y  WAVELENGTH  (P%)       Y       (NM)          R

SPHALERITE 39B                 A    0.4442 0.4071    492.79   0.82     17.05      440        17.74

ZN S                           C    0.3068 0.3130    477.00   1.36     17.11      460        17.39

CUBIC                                                                             480        17.35

REF. FOR R: (TUGAL 1969)                                                          500        17.24

REMARKS:    LOC. TURKEY                                                           520        17.20

                                                                                  540        17.06

                                                                                  560        17.09

                                                                                  580        17.47

                                                                                  600        16.77

                                                                                  620        16.95

                                                                                  640        16.18

                                                                                  660        16.85
```

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
SPHALERITE 41	A	0.4422	0.4050	486.62	1.40	16.94	440	18.18
ZN S	C	0.3038	0.3092	475.30	3.13	17.04	460	18.06
CUBIC							480	17.76
REF. FOR R: (TUGAL 1969)							500	17.50
REMARKS: LOC. TURKEY							520	17.25
							540	17.08
							560	16.93
							580	16.93
							600	16.66
							620	16.80
							640	16.57
							660	16.54

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
SPHALERITE KO20	A	0.4416	0.4054	468.73	1.51	16.90	440	18.22
ZN S	C	0.3033	0.3094	477.49	3.25	17.02	460	17.86
CUBIC							480	17.73
REF. FOR R: (TUGAL,1969)							500	17.53
REMARKS: LOC. TURKEY							520	17.36
							540	17.09
							560	16.95
							580	16.83
							600	16.56
							620	16.58
							640	16.62
							660	16.41

```
MINERAL NAME                         CHROMATICITY  DOMINANT             BRIGHTNESS
COMPOSITION                   SOURCE COORDINATES    (COMPL.)  PURITY  (VISUAL R)  LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                         X        Y  WAVELENGTH  (P%)       Y        (NM)          R


SPHALERITE M1                   A    0.4414 0.4058    490.10   1.54     16.81       440          17.98

ZN S                            C    0.3035 0.3100    478.22   3.12     16.93       460          17.87

CUBIC                                                                               480          17.63

REF. FOR R: (TUGAL,1969)                                                            500          17.35

REMARKS:    LOC. TURKEY                                                             520          17.21

                                                                                    540          17.06

                                                                                    560          16.85

                                                                                    580          16.70

                                                                                    600          16.73

                                                                                    620          16.63

                                                                                    640          15.95

                                                                                    660          16.02
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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
SPHALERITE NO39B	A	0.4413	0.4057	489.89	1.57	16.73	440	17.97
ZN S	C	0.3033	0.3097	477.92	3.22	16.84	460	17.68
CUBIC							480	17.61
REF. FOR R: (TUGAL,1969)							500	17.25
REMARKS: LOC. TURKEY							520	17.16
							540	16.94
							560	16.78
							580	16.69
							600	16.42
							620	16.54
							640	16.19
							660	16.02

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
SPHALERITE NGD16A	A	0.4411	0.4051	488.36	1.65	16.69	440	18.20
ZN S	C	0.3028	0.3083	475.85	3.59	16.80	460	17.73
CUBIC							480	17.45
REF. FOR R: (TUGAL,1969)							500	17.26
REMARKS: LOC. TURKEY							520	17.03
							540	16.88
							560	16.81
							580	16.64
							600	16.33
							620	16.67
							640	15.87
							660	16.02

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
SPHALERITE NG39A	A	0.4410	0.4055	489.58	1.65	16.62	440	17.98
ZN S	C	0.3029	0.3091	477.00	3.24	16.74	460	17.61
CUBIC							480	17.47
REF. FOR R: (TUGAL,1969)							500	17.20
REMARKS: LOC. TURKEY							520	17.08
							540	16.86
							560	16.64
							580	16.58
							600	16.37
							620	16.32
							640	16.02
							660	16.02

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
SPHALERITE 408	A	0.4418	0.4065	491.85	1.41	16.51	440	17.39
ZN S	C	0.3042	0.3116	480.62	2.66	16.63	460	17.41
CUBIC							480	17.22
REF. FOR R: (TUGAL 1969)							500	17.11
REMARKS: LOC. TURKEY							520	16.90
							540	16.72
							560	16.63
							580	16.43
							600	16.26
							620	16.32
							640	16.01
							660	15.67

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MINERAL NAME                          CHROMATICITY  DOMINANT             BRIGHTNESS
COMPOSITION                    SOURCE COORDINATES   (COMPL.)   PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                          X       Y   WAVELENGTH  (P%)       Y      (NM)          R

SPHALERITE NG348                 A   0.4436 0.4053    484.91    1.06    16.50     440         17.49

ZN S                             C   0.3051 0.3106    475.08    2.49    16.57     460         17.26

CUBIC                                                                             480         17.13

REF. FOR R: (TUGAL,1969)                                                          500         16.94

REMARKS:     LOC. TURKEY                                                          520         16.83

                                                                                  520         16.83

                                                                                  540         16.57

                                                                                  560         16.56

                                                                                  580         16.34

                                                                                  600         16.23

                                                                                  620         16.39

                                                                                  640         16.37

                                                                                  660         16.54
```

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
SPHALERITE 4CA	A	0.4414	0.4057	489.81	1.54	16.47	440	17.62
ZN S	C	0.3034	0.3099	478.21	3.16	16.58	460	17.50
CUBIC							480	17.31
REF. FOR R: (TUGAL 1969)							500	17.13
REMARKS: LOC. TURKEY							520	16.90
							540	16.66
							560	16.48
							580	16.38
							600	16.32
							620	16.24
							640	15.94
							660	15.67

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
SPHALERITE	A	0.4413	0.4052	488.45	1.59	16.35	440	17.70
ZN S	C	0.3031	0.3088	476.27	3.42	16.46	460	17.40
CUBIC							480	17.20
REF. FOR R: (DEMIRSOY,1968)							500	16.90
REMARKS: LOC. UNKNOWN							520	16.70
							540	16.50
							560	16.40
							580	16.30
							600	16.20
							620	16.10
							630	16.00

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
SPHALERITE 39A	A	0.4428	0.4048	484.66	1.27	16.04	440	17.16
ZN S	C	0.3043	0.3092	473.49	2.96	16.11	460	17.06
CUBIC							480	16.87
REF. FOR R: (TUGAL 1969)							500	16.45
REMARKS: LOC. TURKEY							520	16.19
							540	16.11
							560	16.10
							580	15.98
							600	15.88
							620	15.96
							640	15.47
							660	15.85

```
MINERAL NAME                      CHROMATICITY  DOMINANT          BRIGHTNESS
COMPOSITION                SOURCE COORDINATES   (COMPL.)  PURITY (VISUAL R) LAMBDA       REFLECTIVITY
CRYSTAL SYSTEM                    X         Y   WAVELENGTH  (P%)       Y      (NM)             R

MANGANOSITE                  A   0.4410 0.4064    491.95   1.60     14.07     430          15.00

MN O                         C   0.3032 0.3108    480.61   3.12     14.18     470          14.90

CUBIC                                                                         490          14.60

REF. FOR R: (NICHOL & PHILLIPS,1964)                                          520          14.40

REMARKS:     LOC. UNKNOWN                                                     550          14.40

                                                                              550          14.40

                                                                              580          13.90

                                                                              610          13.70

                                                                              650          13.70
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MINERAL NAME                           CHROMATICITY   DOMINANT            BRIGHTNESS
COMPOSITION                     SOURCE COORDINATES    (COMPL.)  PURITY (VISUAL R) LAMBDA   REFLECTIVITY
CRYSTAL SYSTEM                           X       Y   WAVELENGTH  (P%)       Y       (NM)        R

CHROMITE A10                       A   0.4414 0.4069   493.14   1.49    12.55      440        13.28

(FE,MG)(CR,AL,FE)2 O4              C   0.3041 0.3116   480.81   2.70    12.64      460        13.14

CUBIC                                                                              480        13.06

REF. FOR R: (ENGIN,1969)                                                           520        12.85

REMARKS:     LOC. TURKEY                                                           540        12.73

                                                                                   560        12.66

                                                                                   580        12.53

                                                                                   600        12.45

                                                                                   620        12.29

                                                                                   640        12.15

                                                                                   660        11.66
```

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
CHROMITE F119	A	0.4422	0.4060	490.03	1.34	12.47	440	13.33
(FE,MG)(CR,AL,FE)2 O4	C	0.3043	0.3105	477.00	2.75	12.55	460	13.04
CUBIC							480	12.93
REF. FOR P: (ENGIN,1969)							520	12.74
REMARKS: LOC. TURKEY							540	12.62
							560	12.53
							580	12.44
							600	12.32
							620	12.35
							640	12.04
							660	11.98

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MINERAL NAME                          CHROMATICITY  DOMINANT           BRIGHTNESS
COMPOSITION                    SOURCE COORDINATES    (COMPL.)   PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                          X        Y  WAVELENGTH  (P%)       Y      (NM)          R

CHROMITE ZU12                    A    0.4424 0.4063    490.85    1.28     12.46     440        13.21

(FE,MG)(CR,AL,FE)2 O4            C    0.3046 0.3111    478.36    2.59     12.53     460        13.00

CUBIC                                                                               480        12.91

REF. FOR P: (ENGIN,1969)                                                            520        12.69

REMARKS:     LOC. TURKEY                                                            540        12.61

                                                                                    560        12.53

                                                                                    580        12.40

                                                                                    600        12.37

                                                                                    620        12.24

                                                                                    640        12.13

                                                                                    660        11.97
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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
CHROMITE A17	A	0.4429	0.4056	487.73	1.20	12.42	440	13.17
(FE,MG)(CR,AL,FE)2 O4	C	0.3047	0.3106	476.53	2.62	12.49	460	13.12
CUBIC							480	12.88
REF. FOR R: (ENGIN,1969)							520	12.66
REMARKS: LOC. TURKEY							540	12.55
							560	12.45
							580	12.36
							600	12.22
							620	12.29
							640	12.29
							660	12.21

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	 Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
CHROMITE ZU30E	A	0.4421	0.4059	489.80	1.37	12.39	440	13.20
(FE,MG)(CR,AL,FE)2 O4	C	0.3042	0.3105	477.53	2.78	12.46	460	13.04
CUBIC							480	12.86
REF. FOR R: (ENGIN,1969)							520	12.68
REMARKS: LOC. TURKEY							540	12.53
							560	12.43
							580	12.32
							600	12.21
							620	12.20
							640	12.32
							660	11.82

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MINERAL NAME                           CHROMATICITY  DOMINANT            BRIGHTNESS
COMPOSITION                     SOURCE COORDINATES    (COMPL.)   PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                           X       Y   WAVELENGTH   (P%)       Y       (NM)          R

CHROMITE AU32                     A    0.4412 0.4064     491.86    1.55    12.37      440        13.25

(FE,MG)(CR,AL,FE)2 O4             C    0.3036 0.3106     479.43    3.00    12.46      460        12.88

CUBIC                                                                                480        12.91

REF. FOR R: (ENGIN,1969)                                                             520        12.68

REMARKS:     LOC. TURKEY                                                             540        12.54

                                                                                     560        12.47

                                                                                     580        12.35

                                                                                     600        12.25

                                                                                     620        12.00

                                                                                     640        11.99

                                                                                     660        11.78
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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
CHROMITE A78	A	0.4424	0.4059	489.50	1.30	12.34	440	13.15
(FE,MG)(CR,AL,FE)2 O4	C	0.3043	0.3105	477.00	2.85	12.41	460	12.92
CUBIC							480	12.80
REF. FOR R: (ENGIN,1969)							520	12.60
REMARKS: LOC. TURKEY							540	12.50
							560	12.37
							580	12.29
							600	12.12
							620	12.16
							640	12.08
							660	12.08

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
CHROMITE F31	A	0.4414	0.4061	490.94	1.52	12.33	440	13.18
(FE,MG)(CR,AL,FE)2 O4	C	0.3037	0.3103	478.49	3.01	12.42	460	13.01
CUBIC							480	12.86
REF. FOR R: (ENGIN,1969)							520	12.62
REMARKS: LOC. TURKEY							540	12.50
							560	12.40
							580	12.29
							600	12.20
							620	12.06
							640	12.05
							660	11.67

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MINERAL NAME                            CHROMATICITY  DOMINANT          BRIGHTNESS
COMPOSITION                      SOURCE COORDINATES   (COMPL.)  PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                           X        Y   WAVELENGTH (P%)       Y       (NM)          R

CHROMITE ZU9                       A   0.4415 0.4070    493.39   1.46     12.31      440        12.94

(FE,MG)(CR,AL,FE)2 O4              C   0.3042 0.3120    481.59   2.61     12.39      460        12.94

CUBIC                                                                                480        12.82

REF. FOR R: (ENGIN,1969)                                                             520        12.58

REMARKS:    LOC. TURKEY                                                              540        12.49

                                                                                     560        12.42

                                                                                     580        12.28

                                                                                     600        12.16

                                                                                     620        12.15

                                                                                     640        11.72

                                                                                     660        11.47
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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
CHROMITE A1	A	0.4421	0.4062	490.76	1.36	12.27	440	13.06
(FE,MG)(CR,AL,FE)2 O4	C	0.3044	0.3108	478.05	2.70	12.35	460	12.79
CUBIC							480	12.73
REF. FOR R: (ENGIN,1969)							520	12.55
REMARKS: LOC. TURKEY							540	12.43
							560	12.30
							580	12.21
							600	12.17
							620	12.15
							640	11.94
							660	11.58

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
CHROMITE F70	A	0.4420	0.4067	492.36	1.35	12.18	440	12.81
(FE,MG)(CR,AL,FE)2 O4	C	0.3044	0.3118	480.72	2.57	12.26	460	12.77
CUBIC							480	12.69
REF. FOR R: (ENGIN,1969)							520	12.47
REMARKS: LOC. TURKEY							540	12.33
							560	12.24
							580	12.15
							600	12.08
							620	11.84
							640	11.92
							660	11.64

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MINERAL NAME                         CHROMATICITY  DOMINANT            BRIGHTNESS
COMPOSITION                   SOURCE COORDINATES    (COMPL.)   PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                         X       Y   WAVELENGTH   (P%)      Y       (NM)          R


CHROMITE AU12                   A   0.4417 0.4066    492.19    1.43     12.07      440         12.73

(FE,MG)(CR,AL,FE)2 O4           C   0.3042 0.3114    480.13    2.69     12.15      460         12.72

CUBIC                                                                              480         12.60

REF. FOR R: (ENGIN,1969)                                                           520         12.35

REMARKS:    LOC. TURKEY                                                            540         12.21

                                                                                   560         12.10

                                                                                   580         12.12

                                                                                   600         11.91

                                                                                   620         11.94

                                                                                   640         11.57

                                                                                   660         11.33
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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
CHROMITE ZU8	A	0.4427	0.4063	490.61	1.21	12.04	440	12.65
(FE,MG)(CR,AL,FE)2 O4	C	0.3049	0.3117	479.31	2.41	12.11	460	12.63
CUBIC							480	12.51
REF. FOR R: (ENGIN,1969)							520	12.31
REMARKS: LOC. TURKEY							540	12.15
							560	12.08
							580	11.99
							600	11.93
							620	11.81
							640	11.85
							660	11.65

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	 Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
CHROMITE ZU44	A	0.4424	0.4057	488.90	1.31	11.98	440	12.74
(FE,MG)(CR,AL,FE)2 O4	C	0.3043	0.3104	477.40	2.78	12.04	460	12.69
CUBIC							480	12.42
REF. FOR R: (ENGIN,1969)							520	12.23
REMARKS: LOC. TURKEY							540	12.10
							560	12.03
							580	11.90
							600	11.81
							620	11.78
							640	11.70
							660	11.79

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
CHROMITE F19	A	0.4424	0.4064	491.19	1.28	11.57	440	12.19
(FE,MG)(CR,AL,FE)2 O4	C	0.3046	0.3116	479.77	2.52	11.64	460	12.09
CUBIC							480	12.04
REF. FOR R: (ENGIN,1969)							520	11.81
REMARKS: LOC. TURKEY							540	11.75
							560	11.62
							580	11.49
							600	11.41
							620	11.33
							640	11.30
							660	11.33

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
CHROMITE F62	A	0.4417	0.4061	490.74	1.45	11.46	440	12.25
(FE,MG)(CR,AL,FE)2 O4	C	0.3039	0.3104	478.26	2.92	11.54	460	12.04
CUBIC							480	11.92
REF. FOR R: (ENGIN,1969)							520	11.73
REMARKS: LOC. TURKEY							540	11.61
							560	11.51
							580	11.42
							600	11.32
							620	11.34
							640	11.21
							660	10.74

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
CHROMITE F65	A	0.4428	0.4068	492.31	1.16	10.73	440	11.28
(FE,MG)(CR,AL,FE)2 O4	C	0.3052	0.3122	480.03	2.24	10.79	460	11.06
CUBIC							480	11.05
REF. FOR R: (ENGIN,1969)							520	11.00
REMARKS: LOC. TURKEY							540	10.88
							560	10.73
							580	10.69
							600	10.63
							620	10.70
							640	10.37
							660	10.13

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MINERAL NAME                        CHROMATICITY  DOMINANT           BRIGHTNESS
COMPOSITION                  SOURCE COORDINATES   (COMPL.)   PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                        X       Y   WAVELENGTH  (P%)       Y      (NM)          R


CHROMITE F68                   A    0.4430 0.4063    490.33   1.14     10.54     440        11.12

(FE,MG)(CR,AL,FE)2 O4          C    0.3051 0.3115    478.13   2.36     10.59     460        10.93

CUBIC                                                                            480        10.88

REF. FOR R: (ENGIN,1969)                                                         520        10.74

REMARKS:    LOC. TURKEY                                                          540        10.64

                                                                                 560        10.58

                                                                                 580        10.49

                                                                                 600        10.43

                                                                                 620        10.34

                                                                                 640        10.42

                                                                                 660        10.23
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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
ZVYAGINTSEVITE	A	0.4550	0.4102	586.37	7.00	67.18	450	61.40
(PD,PT)3(PD,SN)	C	0.3189	0.3253	577.47	4.74	66.63	550	66.80
CUBIC							580	67.60
							650	69.40

REMARKS: LOC: UNKNOWN

REF. FOR R L.VYALSOV, MOWSCOW

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
COPPER	A	0.5055	0.4005	596.77	35.20	57.58	470	38.40
CU	C	0.3739	0.3412	590.56	23.78	53.18	546	42.60
CUBIC							589	68.20
							650	78.40

REMARKS: GEORGETOWN,USA. CU=99.7%

REF. FOR R CERVELLE & CAYE,1968

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	 Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
SPERRYLITE	A	0.4448	0.4093	506.77	0.63	54.91	460	55.00
PT AS2	C	0.3085	0.3173	498.58	0.54	55.10	540	55.50
CUBIC							580	55.50
							660	52.00
REMARKS: LOC: UNKNOWN								
REF. FOR R L.VYALSOV, MOWSCOW								
CLAUSTHALITE	A	0.4353	0.4016	486.30	3.19	49.08	470	55.40
PB SE	C	0.2960	0.3003	475.17	7.01	49.74	546	49.50
CUBIC							589	48.10
							650	47.10
REMARKS: LOC: EAGLE GROUP,CANADA								
REF. FOR R BURKE, FREE UNIV.,AMSTERDAM								

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	 Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
SKUTTERUDITE	A	0.4462	0.4072	491.14	0.34	53.20	470	53.80
(CO,FE,NI)AS3-X	C	0.3086	0.3150	479.58	0.69	53.29	546	53.40
CUBIC							589	53.00
							650	52.90

REMARKS: LOC:JACHYMOV,CZECHOSLOVAKIA

REF. FOR R BURKE, FREE UNIV.,AMSTERDAM

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	 Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
HOLLINGWORTHITE	A	0.4451	0.4097	512.14	0.59	51.71	460	51.50
(RH,PD)AS S	C	0.3089	0.3182	511.66	0.41	51.89	540	52.50
CUBIC							580	52.00
							640	50.00

REMARKS: LOC: UNKNOWN

REF. FOR R L.VYALSOV,MOSCOW

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
RU-HOLLINGWORTHITE	A	0.4459	0.4075	494.79	0.40	49.04	455	49.60
(RH,RU,PD)AS S	C	0.3085	0.3153	483.04	0.69	49.14	520	49.40
CUBIC							560	49.20
							650	48.40

REMARKS: LOC: UNKNOWN

REF. FOR R L.VYALSOV, MOSCOW

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
GERSDORFFITE	A	0.4490	0.4076	591.24	1.04	48.41	470	47.90
(NI,CO,FE)AS S	C	0.3116	0.3171	586.37	0.62	48.32	546	48.10
CUBIC							589	48.80
							650	48.50

REMARKS: LOC: SUDBURY,ONTARIO CANADA

REF. FOR R BURKE, FREE UNIV.,AMSTERDAM

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	 Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
GERSDORFFITE	A	0.4490	0.4091	580.33	2.08	46.42	470	45.40
(NI,CO,FE)AS S	C	0.3123	0.3198	571.40	1.53	46.37	546	46.70
CUBIC							589	46.30
							650	46.60

REMARKS: LOC: UNKNOWN

REF. FOR R UYTENBOGAARDT & BURKE,1971

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	 Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
GERSDORFFITE	A	0.4488	0.4089	580.22	1.80	53.64	470	52.60
(NI,CO,FE)AS S	C	0.3120	0.3192	571.93	1.29	53.58	546	53.80
CUBIC							589	53.80
							650	53.40

REMARKS: LOC: UNKNOWN

REF. FOR R UYTENBOGAARDT & BURKE,1971

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL P) Y	LAMBDA (NM)	REFLECTIVITY R
POLYDYMITE	A	0.4500	0.4086	590.86	9.34	47.12	470	42.90
NI3 S4	C	0.3230	0.3261	581.44	6.09	46.45	546	46.00
CUBIC							589	47.30
							650	51.70

REMARKS: LOC: DRY NICKEL MINE,S.RHODESIA

REF. FOR R BURKE, FREE UNIV.,AMSTERDAM

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL P) Y	LAMBDA (NM)	REFLECTIVITY R
IRARSITE	A	0.4426	0.4071	493.43	1.19	46.74	455	48.60
(IR,RU,RH,PT)AS S	C	0.3051	0.3127	481.72	2.21	47.02	520	47.80
CUBIC							560	47.00
							650	45.20

REMARKS: LOC: UNKNOWN

REF. FOR R L.VYALSOV, MOSCOW

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
IRARSITE	A	0.4436	0.4084	498.69	0.92	46.55	490	47.60
IR,RU,RH,PT)AS S	C	0.3067	0.3157	486.82	1.31	46.80	520	47.80
CUBIC							589	46.10
							650	45.20

REMARKS: LCC: UNKNOWN

REF. FOR R UYTENBOGAARDT & BURKE,1971

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
TYRRELITE	A	0.4527	0.4087	588.18	4.37	46.01	470	44.00
(NI,CO,CU)3SE4	C	0.3158	0.3212	579.71	2.84	45.73	546	45.50
CUBIC							589	46.50
							650	47.10

REMARKS: EAGLE GROUP,CANADA

REF. FOR R BURKE, FREE UNIV.,AMSTERDAM

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
PENTLANDITE	A	0.4647	0.4101	589.62	13.65	45.84	470	39.80
(NI,FE)9 S8	C	0.3290	0.3314	589.72	9.12	44.93	546	44.10
CUBIC							589	47.00
							650	50.50

REMARKS: LOC: FLAT NICKEL MINE,TELEMARK NORWAY

REF. FOR R BURKE, FREE UNIV.,AMSTERDAM

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
ULLMANITE	A	0.4460	0.4040	577.05	1.00	44.97	470	46.70
NI SB S	C	0.3067	0.3099	453.25	2.17	45.02	546	44.60
CUBIC							589	44.50
							650	46.10

REMARKS: LOC: EISENHARTER,SAXONY

REF. FOR R BURKE, FREE UNIV. ,AMSTERDAM

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MINERAL NAME                                CHROMATICITY  DOMINANT            BRIGHTNESS
COMPOSITION                         SOURCE COORDINATES    (COMPL.)   PURITY  (VISUAL R)   LAMBDA   REFLECTIVITY
CRYSTAL SYSTEM                              X         Y   WAVELENGTH  (P%)       Y         (NM)         R


LAURITE (1) PURE                      A     0.4294 0.4027   490.28     4.51     41.25       470         47.80

RU S2                                 C     0.2914 0.2989   478.60     8.77     42.13       546         42.50

CUBIC                                                                                        589        40.30

                                                                                            650         37.20

REMARKS:     LOC: GOODNEWS BAY,ALASKA.  RU=61.0;IR=1.0;S=38.0 WT.%

REF. FOR R  (LEONARD ET AL,1969)




LAURITE (2) NUGGET                    A     0.4305 0.4030   490.29     4.24     40.94       470         47.00

RU S2                                 C     0.2925 0.2999   478.58     8.26     41.74       546         42.10

CUBIC                                                                                        589        40.00

                                                                                            650         37.20

REMARKS:     LOC: GOODNEWS BAY,ALASKA.  RU=40.5;IR=13.0;S=31.1 WT.%

REF. FOR R  (LEONARD ET AL,1969)
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MINERAL NAME                          CHROMATICITY   DOMINANT           BRIGHTNESS
COMPOSITION                    SOURCE COORDINATES    (COMPL.)   PURITY  (VISUAL R)   LAMBDA   REFLECTIVITY
CRYSTAL SYSTEM                          X       Y   WAVELENGTH   (P%)       Y        (NM)          R


LAURITE (3)                      A    0.4243 0.3954   485.52     6.11     37.98       470          47.70

RU S2                            C    0.2840 0.2860   474.69    13.08     38.95       546          38.50

CUBIC                                                                                  589         36.40

                                                                                      650          35.40

REMARKS:     LOC: GOODNEWS BAY,ALASKA.  RU=59.5;IR=2.0;S=36.0 WT.%

REF. FOR R  (LEONARD ET AL,1969)



LAURITE (4)                      A    0.4274 0.3960   484.52     5.36     39.06       470          48.00

RU S2                            C    0.2870 0.2880   473.47    11.80     39.90       546          39.00

CUBIC                                                                                  589         38.30

                                                                                      650          36.30

REMARKS:     LOC: STILLWATER COMPLEX,MONTANA

REF. FOR R  (LEONARD ET AL,1969)
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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
LAURITE (5)	A	0.4344	0.4037	489.85	3.29	41.00	470	45.80
RU S2	C	0.2962	0.3029	478.07	6.58	41.61	546	41.80
CUBIC							589	40.30
							650	38.20

REMARKS: LOC: BORNEO. RU=30.0;IR=20.0;S=27.0 WT.%

REF. FOR R (LEONARD ET AL,1969)

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
PETZITE	A	0.4427	0.4052	486.50	1.27	40.32	460	42.60
AG3 AU TE2	C	0.3044	0.3096	474.42	2.87	40.52	540	40.50
CUBIC							580	40.20
							640	39.60

REMARKS: LOC: UNKNOWN

REF. FOR R L.VYALSOV, MOSCOW

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MINERAL NAME                        CHROMATICITY   DOMINANT            BRIGHTNESS
COMPOSITION                  SOURCE COORDINATES    (COMPL.)    PURITY  (VISUAL R)   LAMBDA   REFLECTIVITY
CRYSTAL SYSTEM                        X        Y   WAVELENGTH  (P%)        Y        (NM)          R


PETZITE                        A    0.4419 0.4074   494.49      1.35     38.55       460          40.10

AG3 AU TE2                     C    0.3048 0.3127   482.29      2.31     38.81       540          39.10

CUBIC                                                                                 580         38.70

                                                                                     640          37.00

REMARKS:     LOC: UNKNOWN

REF. FOR R  L.VYALSOV, MOSCOW




PETZITE                        A    0.4422 0.4054   488.02      1.37     38.10       460          40.30

AG3 AU TE2                     C    0.3039 0.3098   476.66      3.00     38.33       540          38.50

CUBIC                                                                                 580         37.80

                                                                                     640          37.40

REMARKS:     LOC: UNKNOWN

REF. FOR R  P.BEISTEIN, MOSCOW
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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
PETZITE	A	0.4276	0.3994	487.72	5.10	35.83	460	42.10
AG3 AU TE2	C	0.2884	0.2933	475.46	10.55	36.63	540	37.10
CUBIC							580	34.90
							640	33.30

REMARKS: LOC: UNKNOWN

REF. FOR R UYTENBOGAARDT & BURKE,1971

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
COLORADOITE	A	0.4500	0.4078	590.12	1.87	37.89	460	37.10
HG TE	C	0.3132	0.3175	590.66	1.15	37.73	540	36.80
CUBIC							580	39.20
							640	37.40

REMARKS: LOC: UNKNOWN

REF. FOR R L.VYALSOV, MOSCOW

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
COLORADOITE	A	0.4504	0.4096	582.68	3.40	36.24	460	34.80
HG TE	C	0.3144	0.3207	577.46	2.32	36.10	540	35.50
CUBIC							580	37.50
							640	35.50

REMARKS: LOC: UNKNOWN

REF. FOR R P.BEISTEIN, MOSCOW

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
COLORADOITE	A	0.4433	0.4012	579.25	7.50	34.31	460	36.60
HG TE	C	0.3028	0.3037	577.37	5.34	34.43	540	33.90
CUBIC							580	33.90
							640	34.80

REMARKS: LOC: UNKNOWN

REF. FOR R UYTENBOGAARDT & BURKE,1971

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
MURDOCHITE	A	0.4533	0.4087	588.59	4.78	17.31	470	16.50
CU6 PB O8	C	0.3163	0.3216	579.78	3.09	17.20	546	17.10
CUBIC							589	17.50
							650	17.80

REMARKS: LOC: TCHAH-KHOUNI MINE,IRAN

REF. FOR R BURKE, FREE UNIV.,AMSTERDAM

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
MURDOCHITE	A	0.4534	0.4092	587.33	5.20	17.19	470	16.30
CU6 PB O8	C	0.3168	0.3224	578.90	3.43	17.07	546	17.00
CUBIC							589	17.40
							650	17.60

REMARKS: LOC: UNKNOWN

REF. FOR R UYTENBOGAARDT & BURKE,1971

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
TITANOMAGNETITE	A	0.4469	0.4103	563.76	1.47	16.93	470	16.60
FE1+X,FE2-2X,TIX O4	C	0.3112	0.3200	563.11	1.29	16.94	546	17.00
CUBIC							589	17.30
							650	16.00

REMARKS: LOC: UNKEL,RHENANIE. FE2 O3=84.5%;TI O2=15.3%

REF. FOR R CERVELLE,1967

2. ANISOTROPIC MINERALS

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	 Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	 (R_g)
KOSTOVITE	A	0.4482	0.4130	572.52	4.24	53.22 Y_p	433	49.30	50.10
AL CU TE4	A	0.4508	0.4146	576.98	7.16	57.90 Y_g	469	49.70	53.70
PROBABLY MONO.	C	0.3136	0.3255	565.54	3.41	53.26 Y_p	482	52.10	55.20
	C	0.3172	0.3302	568.84	5.64	57.79 Y_g	518	52.70	56.40
REF. FOR R: (TERZEIV,1966)							559	54.90	60.10
REMARKS: LOC. CHELOPECH,BULGARIA							589	53.00	57.90
							624	52.50	57.00
							668	49.30	55.20
							691	48.40	53.30

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
MARCASITE NGC 9(1)	A	0.4535	0.4127	581.77	7.70	50.84 Y_p	440	44.98	45.92
FE S2	A	0.4534	0.4137	580.69	8.32	53.18 Y_g	460	45.98	48.11
ORTHORHOMBIC	C	0.3189	0.3285	573.17	5.64	50.55 Y_p	480	47.72	50.00
	C	0.3195	0.3306	571.98	6.36	52.91 Y_g	500	48.53	51.15
REF. FOR R: (TUGAL,1969)							520	49.54	51.88
REMARKS: LOC. TURKEY							540	50.56	52.86
							560	51.48	53.56
							580	51.63	54.88
							600	51.40	53.25
							620	50.97	53.41
							640	50.91	52.84
							660	50.17	51.60

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
MARCASITE NGC S(2)	A	0.4496	0.4121	576.81	4.58	49.55 Y_p	440	45.76	45.45
FE S2	A	0.4517	0.4128	579.67	6.52	51.06 Y_g	460	46.41	47.09
ORTHORHOMBIC	C	0.3143	0.3251	568.05	3.49	49.51 Y_p	480	47.82	48.80
	C	0.3170	0.3280	570.59	4.99	50.90 Y_g	500	48.61	49.64
REF. FOR R: (TUGAL,1969)							520	49.30	50.32
REMARKS: LOC. TURKEY							540	49.90	51.17
							560	50.52	51.72
							580	50.22	51.63
							600	48.16	51.24
							620	49.44	50.97
							640	49.62	50.27
							660	48.73	50.17

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
MARCASITE KC 16	A	0.4532	0.4121	582.18	7.08	46.63 Y_p	440	42.01	46.20
FE S2	A	0.4514	0.4140	578.22	7.15	52.84 Y_g	460	42.56	48.13
ORTHORHOMBIC	C	0.3183	0.3269	574.10	5.05	46.37 Y_p	480	43.59	50.61
	C	0.3173	0.3300	569.18	5.61	52.74 Y_g	500	44.38	51.64
REF. FOR R: (TUGAL,1969)							520	45.23	52.35
REMARKS: LOC. TURKEY							540	46.29	53.16
							560	47.48	53.78
							580	47.71	53.78
							600	45.91	51.49
							620	47.70	53.10
							640	47.69	53.49
							660	45.41	50.91

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	 Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)		BRIGHTNESS (VISUAL R) Y		LAMBDA (NM)	REFLECTIVITY (R_p)	 (R_g)
NICCOLITE 1	A	0.4815	0.4134	589.22	27.58		51.29	Y_p	420	35.96	42.96
NI AS	A	0.4703	0.4113	589.34	18.36		54.52	Y_g	440	35.04	42.60
HEXAGONAL	C	0.3507	0.3477	581.18	19.32	O	49.22	Y_p	460	35.36	43.27
	C	0.3360	0.3477	580.99	12.39	E	53.06	Y_g	480	37.33	45.14
									500	39.94	46.79
									520	43.30	48.93
									540	47.01	51.45
									560	50.26	53.67
									580	53.08	55.58
									600	55.60	57.54
									620	57.64	59.10
									640	59.15	60.39

REF. FOR R: (THE AUTHOR)

REMARKS: LOC. ONTARIO, CANADA

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Electron Probe Analysis:

	Wt. %
Ni	44.07
As	55.12
Sb.	00.90
	100.09

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
LOELLINGITE	A	0.4500	0.4110	579.05	4.10	50.20 Y_p	440	46.90	43.80
FE AS2	A	0.4584	0.4145	583.48	12.34	53.22 Y_g	480	48.30	47.40
ORTHORHOMBIC	C	0.3142	0.3236	569.99	3.06	50.12 Y_p	500	49.50	50.10
	C	0.3247	0.3352	574.08	8.99	52.66 Y_g	520	50.00	51.30
REF. FOR R: O.VAASJOKI (1969)							540	50.60	53.00
REMARKS: LOC. UNKNOWN							600	50.20	54.00

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_α)	(R_γ)
SYLVANITE,FIJI	A	0.4580	0.4130	584.55	11.02	50.71 Y_α	440	42.00	56.30
AU AG TE4	A	0.4518	0.4101	583.02	4.37	60.80 Y_γ	460	44.60	57.50
MONOCLINIC	C	0.3233	0.3334	574.07	8.13	50.24 Y_α	480	47.00	59.10
	C	0.3148	0.3237	571.53	3.25	60.65 Y_γ	500	48.40	60.60
REF. FOR R: (STUMPFL,1970)							546	50.80	61.20
REMARKS: LOC. EMPEROR MINE,FIJI							589	50.00	59.50
							600	51.50	61.10
							620	52.30	61.60

Electron Probe Analysis:

	Wt. %
Au	31.4
Ag	6.6
Te	59.9

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_α)	(R_γ)
SYLVANITE,COLORADO	A	0.4552	0.4110	585.25	7.70	44.04 Y_α	440	39.00	57.00
AU AG TE4	A	0.4492	0.4088	582.24	2.01	58.98 Y_γ	460	40.10	57.40
MONOCLINIC	C	0.3190	0.3277	574.22	5.45	43.75 Y_α	480	41.40	58.10
	C	0.3122	0.3197	571.18	1.48	58.92 Y_γ	500	43.10	58.80
REF. FOR R: (STUMPFL,1970)							546	44.20	59.30
REMARKS: LOC. RED CLOUD MINE,COLORADO							589	43.00	58.40
							600	44.10	58.60
							620	45.20	59.20

Electron Probe Analysis:

	Wt. %
Au	23.6
Ag	13.2
Te	61.7
	98.5

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
CHALCOPYRITE,E	A	0.4724	0.4262	582.65	30.16	47.62	440	26.22
CU FE S2	C	0.3484	0.3692	573.22	24.47	46.55	460	31.80
TETRAGONAL							480	37.00
REF. FOR R: (TUGAL,1969)							500	41.23
REMARKS: LOC. TURKEY							520	44.05
							540	46.38
							560	48.41
							580	49.29
							600	49.52
							620	49.67
							640	49.09
							660	48.16

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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
CHALCOPYRITE 4	A	0.4706	0.4243	532.82	27.61	47.61 Y_p	440	27.63	27.63
CU FE S2	A	0.4720	0.4242	533.17	28.51	47.75 Y_g	460	32.66	33.26
TETRAGONAL	C	0.3448	0.3643	573.20	22.19	46.63 Y_p	480	37.75	38.47
	C	0.3463	0.3649	573.95	22.75	46.67 Y_g	500	41.62	42.05
REF. FOR R: TUGAL (1969)							520	44.21	44.18
REMARKS: LOC. TURKEY							540	46.50	46.55
							560	48.11	48.11
							580	49.23	49.14
							600	49.75	49.08
							620	49.53	49.84
							640	49.80	49.17
							660	50.17	48.73

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	 Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
CHALCOPYRITE,NO39	A	0.4711	0.4259	582.45	29.05	47.37	440	26.53
CU FE S2	C	0.3467	0.3677	573.00	23.62	46.38	460	32.33
TETRAGONAL							480	37.47
REF. FOR R: (TUGAL,1969)							500	41.47
REMARKS: LOC. TURKEY							520	44.05
							520	44.05
							540	46.18
							560	47.95
							580	49.19
							600	49.35
							620	49.46
							640	49.09
							660	46.16

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
CHALCOPYRITE,M2	A	0.4721	0.4257	582.73	29.61	47.29	440	26.39
CU FE S2	C	0.3476	0.3682	573.19	23.99	46.25	460	31.74
TETRAGONAL							480	37.06
REF. FOR R: (TUGAL,1969)							500	41.06
REMARKS: LOC. TURKEY							520	44.10
							520	44.10
							540	46.13
							560	47.77
							580	48.91
							600	49.05
							620	49.14
							640	49.62
							660	48.17

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
CHALCOPYRITE,39	A	0.4725	0.4248	583.07	29.28	47.22	440	26.68
CU FE S2	C	0.3475	0.3666	573.56	23.53	46.13	460	32.03
TETRAGONAL							480	37.26
REF. FOR R: (TUGAL,1969)							500	40.89
REMARKS: LOC. TURKEY							520	43.59
							540	45.71
							560	47.72
							580	49.04
							600	49.19
							620	48.88
							640	48.60
							660	49.91

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	 Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
CHALCOPYRITE,M3	A	0.4733	0.4260	582.90	30.67	47.16	440	25.77
CU FE S2	C	0.3493	0.3696	573.42	24.82	46.06	460	31.32
TETRAGONAL							480	36.47
REF. FOR R: (TUGAL,1969)							500	40.72
REMARKS: LOC. TURKEY							520	43.44
							520	43.44
							540	45.90
							560	47.77
							580	48.73
							600	49.20
							620	49.14
							640	49.62
							660	48.17

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MINERAL NAME                         CHROMATICITY  DOMINANT          BRIGHTNESS
COMPOSITION                   SOURCE COORDINATES    (COMPL.)  PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                          X       Y  WAVELENGTH  (P%)       Y       (NM)          R


CHALCOPYRITE,M12                A    0.4731 0.4256    582.97  30.26     47.14      440        25.92

CU FE S2                        C    0.3489 0.3688    573.48  24.50     46.05      460        31.57

TETRAGONAL                                                                          480        36.74

REF. FOR R: (TUGAL1969)                                                             500        40.76

REMARKS:    LOC. TURKEY                                                             520        43.40

                                                                                    520        43.40

                                                                                    540        45.90

                                                                                    560        47.59

                                                                                    580        48.82

                                                                                    600        49.20

                                                                                    620        49.14

                                                                                    640        49.62

                                                                                    660        48.17
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MINERAL NAME                     CHROMATICITY  DOMINANT         BRIGHTNESS
COMPOSITION               SOURCE COORDINATES    (COMPL.)  PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                     X       Y   WAVELENGTH  (P%)       Y      (NM)    (Rg )  (Rp )

CHALCOPYRITE M24            A    0.4722 0.4260   582.67  29.88     46.99Yp   440    25.92  26.08

CU FE S2                    A    0.4730 0.4262   582.78  30.58     47.35Yg   460    31.32  31.49

TETRAGONAL                  C    0.3481 0.3685   573.29  24.21     45.94Yp   480    36.58  36.68

                            C    0.3491 0.3697   573.33  24.80     46.26Yg   500    40.89  40.80

REF. FOR R: TUGAL (1969)                                                     520    43.64  43.36

REMARKS:    LOC. TURKEY                                                      540    46.32  45.71

                                                                             560    47.89  47.65

                                                                             580    48.91  48.73

                                                                             600    49.51  49.20

                                                                             620    49.14  48.83

                                                                             640    49.62  48.98

                                                                             660    48.17  46.78
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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	 Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
CHALCOPYRITE,K	A	0.4713	0.4252	582.71	28.71	46.87	440	26.67
CU FE S2	C	0.3463	0.3664	573.19	23.16	45.87	460	32.05
TETRAGONAL							480	37.21
REF. FOR R: (TUGAL,1969)							500	40.92
REMARKS: LOC. TURKEY							520	43.53
							520	43.53
							540	45.74
							560	47.48
							580	48.52
							600	48.60
							620	48.48
							640	48.47
							660	48.16

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
CHALCOPYRITE,M1	A	0.4736	0.4262	582.90	31.02	46.77	440	25.26
CU FE S2	C	0.3499	0.3705	573.40	25.22	45.66	460	30.61
TETRAGONAL							480	36.23
REF. FOR R: (TUGAL,1969)							500	40.42
REMARKS: LOC. TURKEY							520	43.06
							520	43.06
							540	45.50
							560	47.33
							580	48.32
							600	48.87
							620	48.81
							640	48.72
							660	48.17

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MINERAL NAME                      CHROMATICITY  DOMINANT           BRIGHTNESS
COMPOSITION                SOURCE COORDINATES   (COMPL.)  PURITY (VISUAL R) LAMBDA     REFLECTIVITY
CRYSTAL SYSTEM                     X        Y   WAVELENGTH  (P%)       Y       (NM)          R


CHALCOPYRITE NG31B            A   0.4748 0.4264    583.09  31.99     46.58       440         24.78

CU FE S2                      C   0.3513 0.3718    573.54  25.95     45.42       460         29.94

(TETRAGONAL                                                                      480         35.64

REF. FOR R: (TUGAL,1969)                                                         500         39.88

REMARKS:    LOC. TURKEY                                                          520         42.73

                                                                                 520         42.73

                                                                                 540         45.02

                                                                                 560         47.51

                                                                                 580         48.03

                                                                                 600         48.57

                                                                                 620         48.33

                                                                                 640         48.84

                                                                                 660         49.54
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MINERAL NAME                          CHROMATICITY  DOMINANT          BRIGHTNESS
COMPOSITION                    SOURCE COORDINATES    (COMPL.)  PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                          X       Y   WAVELENGTH  (P%)      Y       (NM)          R

CHALCOPYRITE,NG35                A   0.4749 0.4254   583.41   31.34    46.49     440         25.03

CU FE S2                         C   0.3509 0.3700   573.85   25.36    45.32     460         30.69

TETRAGONAL                                                                       480         35.79

REF. FOR R: (TUGAL,1969)                                                         500         39.89

REMARKS:    LOC. TURKEY                                                          520         42.70

                                                                                 520         42.70

                                                                                 540         44.86

                                                                                 560         46.74

                                                                                 580         48.08

                                                                                 600         48.75

                                                                                 620         49.17

                                                                                 640         49.09

                                                                                 660         48.16
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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
CHALCOPYRITE,20	A	0.4721	0.4253	582.85	29.34	46.48	440	26.08
CU FE S2	C	0.3474	0.3673	573.35	23.69	45.45	460	31.49
TETRAGONAL							480	36.63
REF. FOR R: (TUGAL,1969)							500	40.43
REMARKS: LOC. TURKEY							520	43.03
							520	43.03
							540	45.29
							560	47.17
							580	47.76
							600	48.27
							620	48.83
							640	48.98
							660	46.78

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
CHALCOPYRITE,NO31A	A	0.4745	0.4258	583.21	31.35	46.40	440	24.92
CU FE S2	C	0.3506	0.3705	573.63	25.41	45.25	460	30.51
TETRAGONAL							480	35.69
REF. FOR R: (TUGAL,1969)							500	39.88
REMARKS: LOC. TURKEY							520	42.61
							520	42.61
							540	44.98
							560	46.94
							580	47.86
							600	48.57
							620	48.05
							640	48.48
							660	49.54

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
CHALCOPYRITE 43-46	A	0.4809	0.4288	583.55	37.86	43.60	440	19.97
CU FE S2	C	0.3609	0.3823	574.03	31.35	42.25	460	25.47
TETRAGONAL							480	31.16
REF. FOR R: (TUGAL,1969)							500	35.98
REMARKS: LOC. TURKEY							520	39.24
							520	39.24
							540	41.81
							560	43.77
							580	45.54
							600	46.17
							620	46.04
							640	46.61
							660	46.78

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MINERAL NAME                       CHROMATICITY  DOMINANT           BRIGHTNESS
COMPOSITION                 SOURCE COORDINATES   (COMPL.)   PURITY (VISUAL R) LAMBDA     REFLECTIVITY
CRYSTAL SYSTEM                       X       Y  WAVELENGTH  (P%)       Y       (NM)     (Rp )   (Rg )


GEOCRONITE                     A   0.4445 0.4134    549.02   2.03     37.14 Yp   450     35.50  39.00

27PB S 7(SB,AS)2 S3            A   0.4441 0.4133    542.35   1.74     40.67 Yg   472     36.00  39.50

MONOCLINIC                     C   0.3101 0.3249    551.11   1.59     37.34 Yp   496     37.00  40.80

                               C   0.3096 0.3237    547.48   1.89     40.91 Yg   527     38.30  42.00

REF. FOR R: NADEZDA N.MOZGOVA ET AL,IMM78(1969)                                  550     38.00  41.60

REMARKS:    LOC. UNKNOWN                                                         579     37.70  41.20

                                                                                 608     36.30  39.50

                                                                                 640     35.00  38.30

                                                                                 670     33.80  37.00
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MINERAL NAME                           CHROMATICITY  DOMINANT           BRIGHTNESS
COMPOSITION                     SOURCE COORDINATES    (COMPL.)  PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                           X        Y   WAVELENGTH  (P%)      Y       (NM)          R


GEOCRONITE                        A    0.4448 0.4151    553.80    3.37    40.59      470         39.00

27PB S 7(SB,AS)2 S3               C    0.3111 0.3276    555.39    3.32    40.83      520         42.00

MONOCLINIC                                                                            575         41.50

REF. FOR R: GRAY & MILLMAN (1962)                                                     600         39.00

REMARKS:    LOC. UNKNOWN; UNORIENTED SECTION.                                         700         37.90
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MINERAL NAME                          CHROMATICITY  DOMINANT              BRIGHTNESS
COMPOSITION                    SOURCE COORDINATES    (COMPL.)   PURITY  (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                          X        Y  WAVELENGTH   (P%)        Y       (NM)    (Rp )  (Rg )

BOULANGERITE                      A    0.4434 0.4130    527.56   1.34      36.46 Yp   450     35.30  39.70

5PB S 2SB2 S3                     A    0.4426 0.4122    513.66   1.20      40.36 Yg   472     36.00  39.80

MONOCLINIC                        C    0.3087 0.3228    537.71   1.44      36.70 Yp   496     36.50  40.70

                                  C    0.3076 0.3208    514.63   0.51      40.66 Yg   527     37.90  42.00

REF. FOR R: NADEZDA N.MOZGOVA ET AL,INM78(1969)                                       550     37.50  41.50

REMARKS:    LOC. UNKNOWN; RP=NORMAL TO C, RG=PARALLEL TO C                            579     36.50  40.40

                                                                                      608     35.60  39.30

                                                                                      640     34.30  38.00

                                                                                      670     32.90  36.50
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MINERAL NAME                        CHROMATICITY  DOMINANT          BRIGHTNESS
COMPOSITION                  SOURCE COORDINATES   (COMPL.)  PURITY (VISUAL R) LAMBDA   REFLECTIVITY
CRYSTAL SYSTEM                        X       Y   WAVELENGTH (P%)       Y      (NM)         R

BOULANGERITE                    A   0.4393 0.4130   507.19   1.88    36.49      470        37.00

5PB S 2SB2 S3                   C   0.3046 0.3209   501.33   1.81    36.95      520        38.70

MONOCLINIC                                                                    575        37.00

REF. FOR R: GRAY & MILLMAN (1962)                                             600        34.50

REMARKS:    LOC. UNKNOWN; UNORIENTED SECTION.                                 700        33.60
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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	REFLECTIVITY (R_g)
HETEROMORPHITE	A	0.4441	0.4110	515.31	0.86	36.21 Y_p	450	35.70	39.30
7PB S 4SB2 S3	A	0.4435	0.4120	518.41	1.06	40.17 Y_g	472	35.90	39.80
MONOCLINIC	C	0.3086	0.3198	521.81	0.68	36.39 Y_p	496	36.30	40.30
	C	0.3093	0.3213	526.79	0.99	40.42 Y_g	527	37.00	41.50
REF. FOR R: NADEZDA N.MOZGOVA ET AL,IMM78(1969)							550	37.00	41.00
REMARKS: LOC. UNKNOWN							579	36.50	40.30
							608	35.40	39.10
							640	34.40	38.00
							670	34.20	37.70

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (Rp)	(Rg)
MENEGHINITE	A	0.4428	0.4083	497.66	1.11	35.48 Yp	450	36.30	40.50
CU2 S.26PB S 7SB2 S3	A	0.4424	0.4090	493.83	1.18	39.76 Yg	472	36.40	40.90
ORTHORHOMBIC	C	0.3058	0.3151	497.55	1.70	35.71 Yp	496	36.70	41.00
	C	0.3057	0.3161	497.42	1.65	40.05 Yg	527	36.40	41.00
							550	36.00	40.50
							579	35.20	39.40
							608	34.80	39.00
							640	34.40	38.20
							670	34.20	38.00

REF. FOR R: NADEZDA N.MOZGOVA ET AL,IMM78(1969)

REMARKS: LOC. UNKNOWN; RP=NORMAL TO C,RG=PARALLEL TO C

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MINERAL NAME                      CHROMATICITY  DOMINANT          BRIGHTNESS
COMPOSITION                SOURCE COORDINATES   (COMPL.)  PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                      X       Y   WAVELENGTH  (P%)      Y       (NM)         R

MENEGHINITE                  A    0.4372 0.4075    494.94   2.45    37.58      470       40.20

CU2 S.26PB S 7SB2 S3         C    0.3001 0.3110    484.32   4.20    38.08      520       39.90

ORTHORHOMBIC                                                                   575       37.90

REF. FOR R: GRAY & MILLMAN (1962)                                              600       36.30

REMARKS:    LOC. UNKNOWN; UNORIENTED SECTION.                                  700       35.50
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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	 Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL %) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	 (R_g)
ZINKENITE	A	0.4419	0.4107	514.83	1.31	35.43 Y_p	450	35.60	38.40
PB S SB2S3	A	0.4417	0.4115	507.52	1.34	38.51 Y_g	472	36.00	38.90
HEXAGONAL	C	0.3062	0.3182	496.85	1.23	35.72 Y_p	496	36.30	39.20
	C	0.3064	0.3194	511.35	1.21	38.84 Y_g	527	36.50	40.10
							550	36.50	39.70
							579	35.20	38.20
							608	34.80	37.70
							640	33.80	36.60
							670	31.00	33.70

REF. FOR R: NADEZDA N.MOZGOVA ET AL,IMM78(1969)

REMARKS: LOC. UNKNOWN; RP=NORMAL TO C,RG=PARALLEL TO C

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
ZINKENITE	A	0.4427	0.4155	541.51	2.37	38.48 Y_p	470	37.50	38.50
PB S SB2S3	A	0.4474	0.4167	570.01	5.71	40.95 Y_g	520	41.00	42.70
HEXAGONAL	C	0.3089	0.3277	545.21	2.80	38.85 Y_p	575	38.70	41.30
	C	0.3138	0.3315	561.36	5.09	41.12 Y_g	600	36.50	39.40
REF. FOR R: GRAY & MILLMAN (1962)							700	36.60	40.40

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (Rp)	REFLECTIVITY (Rg)
JAMESONITE	A	0.4373	0.4114	501.50	2.73	34.95 Yp	450	36.00	39.60
4PB S.FE S SB2 S3	A	0.4396	0.4113	502.36	1.89	39.05 Yg	472	36.30	39.70
MONOCLINIC	C	0.3021	0.3168	491.71	2.95	35.44 Yp	496	36.50	40.40
	C	0.3040	0.3181	494.50	2.14	39.49 Yg	527	37.00	41.20
REF. FOR R: NADEZDA N.MOZGOVA ET AL,IMM78(1969)							550	36.50	40.60
REMARKS: LOC. UNKNOWN; RP=NORMAL TO C,RG=PARALLEL TO C							579	34.70	38.70
							608	33.00	36.90
							640	32.50	36.30
							670	31.50	39.20

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (Rp)	(Rg)
JAMESONITE	A	0.4344	0.4095	497.40	3.05	35.13 Yp	470	37.70	39.70
4PB S FE S SB2 S3	A	0.4425	0.4120	512.20	1.20	39.76 Yg	520	38.00	41.00
MONOCLINIC	C	0.2985	0.3127	487.05	4.61	35.75 Yp	575	35.00	40.60
	C	0.3073	0.3207	511.49	0.96	40.06 Yg	600	33.30	38.20
REF. FOR R: GRAY & MILLMAN (1962)							700	31.20	37.20

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
PLAGIONITE	A	0.4425	0.4121	572.69	1.21	33.67 Y_p	450	33.00	37.20
5PB.S 4SB2 S3	A	0.4408	0.4112	575.03	1.53	37.03 Y_g	472	33.80	37.60
MONOCLINIC	C	0.3074	0.3214	505.85	1.72	33.94 Y_p	496	34.60	38.30
	C	0.3056	0.3186	497.35	1.53	37.37 Y_g	527	35.00	38.20
REF. FOR R: NADEZDA N.MOZGOVA ET AL, IMM78(1969)							550	34.50	38.00
REMARKS: LOC. UNKNOWN							579	33.60	37.50
							608	32.80	35.70
							640	31.80	34.50
							670	30.90	33.30

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	 Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (Rω)	 (Rε)
HEXAGONAL PYRRHOTITE	A	0.4632	0.4097	595.82	12.34	35.14 Yω	470	30.90	36.20
FE(1-X) S	A	0.4591	0.4102	598.19	9.84	40.04 Yε	486	31.50	36.90
HEXAGONAL	C	0.3272	0.3299	580.79	8.24	34.50 Yω	546	34.00	39.20
	C	0.3232	0.3281	579.05	6.68	39.52 Yε	589	35.80	40.70
REF. FOR R: VON GEHLEN & PILLER (1964)							650	38.60	42.50
REMARKS: LOC. TREPCA,YUGOSLAVIA;							656	38.90	42.70

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MINERAL NAME                                CHROMATICITY  DOMINANT            BRIGHTNESS
COMPOSITION                          SOURCE COORDINATES    (COMPL.)   PURITY (VISUAL R) LAMBDA     REFLECTIVITY
CRYSTAL SYSTEM                                X        Y  WAVELENGTH  (P%)       Y       (NM)     (Rp )  (Rg )

HODRUSHITE                               A  0.4561 0.4104    586.67   7.90     32.15 Yp   420     26.20  27.00

CU(8.12)BI(11.54)FE(0.29)S22
                                         A  0.4541 0.4124    582.66   7.90     33.35 Yg   440     28.30  29.50

MONOCLINIC                               C  0.3205 0.3273    576.81   5.74     31.86 Yp   460     29.50  30.20

                                         C  0.3197 0.3289    573.89   5.96     33.14 Yg   480     30.70  31.80

REF. FOR R: (KODERA ET AL,1970)                                                            500     31.50  32.40

REMARKS:    LOC.                                                                           520     31.60  32.70

                                                                                           540     31.00  32.90

                                                                                           560     31.40  32.80

                                                                                           580     32.00  33.40

                                                                                           600     34.60  36.00

                                                                                           620     33.40  34.10
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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	REFLECTIVITY (R_g)
PYROLUSITE	A	0.4441	0.4067	490.89	0.86	32.42 Y_p	430	33.30	34.00
BETA-MN O2	A	0.4446	0.4072	493.09	0.72	33.73 Y_g	470	33.80	35.00
TETRAGONAL	C	0.3064	0.3131	479.61	1.70	32.55 Y_p	490	33.20	34.50
	C	0.3072	0.3145	483.10	1.25	33.86 Y_g	520	32.70	34.00
REF. FOR R: (NICHOL & PHILLIPS,1965)							550	32.70	34.00
REMARKS: LOC. UNKNOWN							580	32.40	33.70
							610	31.90	33.30
							650	32.00	33.20

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MINERAL NAME                       CHROMATICITY  DOMINANT            BRIGHTNESS
COMPOSITION                 SOURCE COORDINATES    (COMPL.)   PURITY (VISUAL R) LAMBDA     REFLECTIVITY
CRYSTAL SYSTEM                       X       Y   WAVELENGTH  (P%)       Y       (NM)           R


ALPHA-MN O2-NSUTITE           A    0.4411 0.4086    497.71   1.50     30.79      430         31.70

MN1-X MNX O2-2X(OH)2X,X=.06-.07
                              C    0.3046 0.3144    486.71   2.20     31.04      470         32.00

HEXAGONAL                                                                        490         31.80

REF. FOR R: (NICHOL & PHILLIPS,1964)                                             520         31.50

REMARKS:    LOC. UNKNOWN                                                         550         31.50

                                                                                 550         31.50

                                                                                 580         30.80

                                                                                 610         30.00

                                                                                 650         29.00
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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
							400	15.60	
IDAITE 4	A	0.4888	0.4234	586.10	39.60	31.63 Y_p	420	15.50	16.40
CU3 FE S4	A	0.4775	0.4242	584.26	32.32	32.35 Y_g	440	16.00	18.30
PROBABLY TETRAGONAL	C	0.3673	0.3737	577.92	30.35	30.20 Y_p	460	17.80	20.80
	C	0.3529	0.3674	575.16	25.20	31.38 Y_g	480	19.80	22.90
REF. FOR R: (LEVY,1966)							500	22.90	26.10
REMARKS: LOC. CERRO-HUEMUL-MENDOZA,ARGENTINA							520	25.90	29.00
							540	29.20	31.20
							560	32.20	33.10
							580	33.40	33.40
							600	33.90	33.20
							620	35.10	34.80
							640	35.90	35.10
						660	607.4	36.00	

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	REFLECTIVITY (R_g)
IDAITE 5	A	0.4886	0.4240	585.90	39.88	31.49 Y_p	420	15.30	16.20
CU3 FE S4	A	0.4791	0.4238	584.66	33.14	31.73 Y_g	440	15.80	17.70
PROBABLY TETRAGONAL	C	0.3677	0.3743	577.84	30.65	30.07 Y_p	460	17.60	20.00
	C	0.3549	0.3676	575.73	25.79	30.69 Y_g	480	19.70	22.40
REF. FOR R: (LEVY,1966)							500	22.60	25.20
REMARKS: LOC. CERRO-HUEMUL-MENDOZA,ARGENTINA							520	25.90	28.00
							540	29.10	30.40
							560	31.60	31.90
							580	33.60	33.20
							600	34.50	33.60
							620	35.00	33.90
							640	34.90	34.20

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (Rp)	(Rg)
IDAITE 6	A	0.4920	0.4203	587.39	39.65	28.01 Yp	420	13.80	17.60
CU3 FE S4	A	0.4737	0.4220	584.29	28.16	29.65 Yg	440	14.70	18.10
PROBABLY TETRAGONAL	C	0.3696	0.3697	579.10	30.29	26.59 Yp	460	16.00	20.30
	C	0.3468	0.3598	575.26	21.52	28.86 Yg	480	17.40	22.00
REF. FOR R: (LEVY,1966)							500	19.60	24.80
REMARKS: LOC. CERRO-HUEMUL-MENDOZA,ARGENTINA							520	22.30	26.80
							540	25.10	28.60
							560	28.10	30.20
							580	29.80	30.60
							600	30.60	30.60
							620	32.00	31.70
							640	32.50	31.60

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
IDAITE 2	A	0.5062	0.4097	592.01	42.12	25.85 Y_p	420	14.40	15.40
CU3 FE S4	A	0.4877	0.4129	589.93	31.52	26.55 Y_g	440	14.50	16.70
PROBABLY TETRAGONAL	C	0.3812	0.3587	584.82	30.44	23.96 Y_p	460	14.40	17.90
	C	0.3583	0.3526	581.56	22.67	25.30 Y_g	480	14.90	18.90
REF. FOR R: (LEVY,1966)							500	16.00	20.10
REMARKS: LOC. BANCAIROUN,FRANCE							520	18.20	21.60
							540	21.30	23.80
							560	24.30	25.70
							580	27.50	27.50
							600	29.70	29.10
							620	33.30	30.50
							640	33.70	31.90

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
IDAITE 1	A	0.5065	0.4095	592.10	42.18	25.72 Y_p	420	14.40	15.20
CU3 FE S4	A	0.4883	0.4127	590.06	31.78	26.48 Y_g	440	14.40	16.60
PROBABLY TETRAGONAL	C	0.3816	0.3584	584.99	30.47	23.82 Y_p	460	14.30	17.80
	C	0.3589	0.3527	581.70	22.86	25.20 Y_g	480	14.80	18.80
REF. FOR R: (LEVY,1966)							500	16.00	19.90
REMARKS: LOC. BANCAIROUN,FRANCE							520	18.00	21.40
							540	21.00	23.60
							560	24.20	25.60
							580	27.40	27.60
							600	29.70	29.00
							620	33.20	30.40
							640	33.50	31.90

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
IDAITE 3	A	0.4882	0.4164	588.45	34.30	25.56 Y_p	420	14.90	14.90
CU3 FE S4	A	0.4843	0.4190	587.03	33.43	26.25 Y_g	440	15.20	15.70
PROBABLY TETRAGONAL	C	0.3615	0.3587	580.28	25.16	24.34 Y_p	460	16.10	16.40
	C	0.3583	0.3611	578.62	24.95	25.16 Y_g	480	17.00	17.90
REF. FOR R: (LEVY,1966)							500	18.90	20.00
REMARKS: LOC. SAINT-VERAN							520	20.80	21.90
							540	22.90	24.20
							560	25.00	26.00
							580	27.00	27.80
							600	28.40	28.50
							620	28.90	28.80
							640	29.60	29.60

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_g)	(R_p)
ORANGE BORNITE 6	A	0.4911	0.4153	589.12	35.55	27.10 Y_g	420	14.80	15.70
CU(2+X)SN(1-X)FE S4	A	0.4769	0.4179	586.50	27.52	26.88 Y_p	440	15.70	16.85
TETRAGONAL	C	0.3644	0.3598	580.69	26.24	25.72 Y_p	460	16.80	18.90
	C	0.3483	0.3550	577.69	20.43	26.03 Y_g	480	18.10	20.60
REF. FOR R: (LEVY,1966)							500	20.00	22.60
REMARKS: LOC. VALLRY							520	21.90	23.80
							540	24.10	25.20
							560	26.20	26.50
							580	28.20	27.60
							600	30.30	28.90
							620	31.00	29.80
							640	32.40	29.40

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_g)	(R_p)
ORANGE BORNITE 1	A	0.4916	0.4150	589.28	35.68	27.07 Y_g	420	14.70	15.70
CU(2+X)SN(1-X)FE S4	A	0.4774	0.4177	586.66	27.72	26.93 Y_p	440	15.60	16.85
TETRAGONAL	C	0.3649	0.3598	580.82	26.37	25.68 Y_p	460	16.70	18.90
	C	0.3487	0.3550	577.94	20.46	26.07 Y_g	480	18.20	20.60
REF. FOR R: (LEVY,1966)							500	20.10	22.60
REMARKS: LOC. VALLRY							520	21.80	23.80
							540	24.00	25.20
							560	26.00	26.50
							580	28.20	27.60
							600	30.40	29.00
							620	31.10	30.00
							640	32.50	29.60

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	REFLECTIVITY (R_g)
ORANGE BORNITE 4	A	0.4940	0.4150	589.44	37.34	26.63 Y_p	420	15.50	15.70
CU(2+X)SN(1-X)FE S4	A	0.4774	0.4177	586.66	27.72	26.93 Y_g	440	14.00	16.85
TETRAGONAL	C	0.3680	0.3623	580.81	27.88	25.21 Y_p	460	15.80	18.90
	C	0.3487	0.3550	577.94	20.46	26.07 Y_g	480	17.60	20.60
REF. FOR R: (LEVY,1966)							500	20.20	22.60
REMARKS: LOC. VAULRY							520	21.20	23.80
							540	23.60	25.20
							560	25.20	26.50
							580	27.70	27.60
							600	29.60	29.00
							620	31.80	30.00
							640	32.50	29.60

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	REFLECTIVITY (R_g)
ORANGE BORNITE 3	A	0.4941	0.4136	589.99	36.39	26.51 Y_p	420	15.70	16.60
CU(2+X)SN(1-X)FE S4	A	0.4774	0.4178	586.62	27.87	26.81 Y_g	440	15.10	16.85
TETRAGONAL	C	0.3671	0.3586	581.77	26.64	25.05 Y_p	460	16.00	18.70
	C	0.3486	0.3545	577.27	20.27	25.94 Y_g	480	17.40	20.15
REF. FOR R: (LEVY,1966)							500	19.35	22.20
REMARKS: LOC. VAULRY							520	21.00	23.15
							540	23.20	25.90
							560	25.30	26.20
							580	27.60	27.50
							600	29.70	28.50
							620	31.40	30.00
							640	32.50	29.60

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
ORANGE BORNITE 5	A	0.4946	0.4145	589.67	37.42	26.50 Y_p	420	13.95	15.60
CU(2+X)SN(1-X)FE S4	A	0.4803	0.4160	587.80	28.57	26.67 Y_g	440	14.40	16.50
TETRAGONAL	C	0.3683	0.3622	580.91	27.93	25.06 Y_p	460	15.90	18.40
	C	0.3509	0.3545	578.52	21.19	25.72 Y_g	480	17.70	20.60
REF. FOR R: (LEVY,1966)							500	19.50	21.90
REMARKS: LOC. VALLRY							520	21.30	23.20
							540	23.30	24.80
							560	25.40	26.20
							580	27.30	27.10
							600	29.10	28.30
							620	31.40	30.00
							640	33.00	30.70

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
ORANGE BORNITE 8	A	0.4940	0.4138	589.91	36.52	26.47 Y_p	420	15.70	16.60
CU(2+X)SN(1-X)FE S4	A	0.4776	0.4176	586.73	27.80	26.86 Y_g	440	15.00	16.80
TETRAGONAL	C	0.3672	0.3588	581.72	26.72	25.02 Y_p	460	16.00	18.70
	C	0.3488	0.3545	577.45	20.40	25.98 Y_g	480	17.30	20.30
REF. FOR R: (LEVY,1966)							500	19.30	22.30
REMARKS: LOC. VAULRY							520	21.00	23.70
							540	23.20	25.30
							560	25.20	26.30
							580	27.60	27.60
							600	29.60	28.80
							620	31.80	30.00
							640	32.30	29.60

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
ORANGE BORNITE 7	A	0.4926	0.4156	589.11	36.80	25.80 Y_p	420	13.90	16.60
CU(2+X)SN(1-X)FE S4	A	0.4783	0.4163	587.18	27.73	26.84 Y_g	440	14.20	16.80
TETRAGONAL	C	0.3671	0.3615	580.83	27.42	24.44 Y_p	460	15.70	18.70
	C	0.3491	0.3538	578.15	20.52	25.94 Y_g	480	17.30	20.50
REF. FOR R: (LEVY,1966)							500	18.70	22.40
REMARKS: LOC. VAULRY							520	20.50	23.40
							540	22.60	25.10
							560	24.90	26.40
							580	27.10	27.60
							600	29.10	28.70
							620	30.70	29.50
							640	30.50	30.10

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
ORANGE BORNITE 2	A	0.4923	0.4156	589.09	36.59	25.78 Y_p	420	13.70	16.60
CU(2+X)SN(1-X)FE S4	A	0.4783	0.4168	587.18	27.73	26.84 Y_g	440	14.30	16.85
TETRAGONAL	C	0.3667	0.3615	580.74	27.31	24.44 Y_p	460	15.80	18.70
	C	0.3490	0.3537	578.15	20.47	25.94 Y_g	480	17.15	20.50
REF. FOR R: (LEVY,1966)							500	18.90	22.40
REMARKS: LOC. VAULRY							520	20.60	23.40
							540	22.70	25.10
							560	24.80	26.40
							580	27.00	27.60
							600	29.00	28.70
							620	30.70	29.50
							640	30.50	30.10

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MINERAL NAME                             CHROMATICITY  DOMINANT         BRIGHTNESS
COMPOSITION                       SOURCE COORDINATES   (COMPL.)  PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                             X       Y   WAVELENGTH  (P%)      Y       (NM)    (Rg )  (Rp )

ORANGE BORNITE 10                   A   0.5040 0.4137    590.43  43.38     25.70Yg   420     11.35  13.40

CU(2+X)SN(1-X)FE S4                 A   0.4831 0.4181    587.25  31.96     24.89Yp   440     12.60  14.40

TETRAGONAL                          C   0.3809 0.3685    581.86  33.00     24.00Yg   460     14.10  16.20

                                    C   0.3561 0.3604    578.19  24.17     23.92Yp   480     15.70  18.40

REF. FOR R: (LEVY,1966)                                                              500     17.40  19.80

REMARKS:    LOC. VAULRY                                                              520     19.45  21.40

                                                                                     540     21.80  22.90

                                                                                     560     24.20  24.40

                                                                                     580     26.70  25.80

                                                                                     600     29.30  26.80

                                                                                     620     30.70  27.80

                                                                                     640     33.50  28.40
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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_g)	(R_p)
ORANGE BORNITE 12	A	0.5019	0.4142	590.15	42.27	25.55 Yg	420	11.40	13.40
CU(2+X)SN(1-X)FE S4	A	0.4836	0.4191	586.92	33.01	24.92 Yp	440	13.00	14.20
TETRAGONAL	C	0.3782	0.3680	581.45	32.14	23.94 Yp	460	14.00	16.00
	C	0.3572	0.3624	577.74	24.88	23.95 Yg	480	15.90	17.60
REF. FOR R: (LEVY,1966)							500	17.75	19.90
REMARKS: LOC. VALLRY							520	20.10	21.40
							540	21.80	23.20
							560	23.90	24.40
							580	26.50	25.80
							600	28.80	26.60
							620	30.70	28.20
							640	33.00	28.40

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
ORANGE BORNITE 11	A	0.5055	0.4123	590.98	43.23	24.63 Y_p	420	11.35	13.40
CU(2+X)SN(1-X)FE S4	A	0.4871	0.4164	588.35	33.55	25.34 Y_g	440	12.10	14.40
TETRAGONAL	C	0.3819	0.3667	582.55	32.78	22.94 Y_p	460	13.60	16.20
	C	0.3595	0.3607	579.08	25.17	24.24 Y_g	480	14.85	18.25
REF. FOR R: (LEVY,1966)							500	16.65	19.90
REMARKS: LOC. VAULRY							520	18.40	21.50
							540	20.70	23.10
							560	23.00	24.60
							580	25.40	25.90
							600	28.40	27.40
							620	29.90	28.20
							640	32.50	30.40

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MINERAL NAME                          CHROMATICITY  DOMINANT          BRIGHTNESS
COMPOSITION                    SOURCE COORDINATES   (COMPL.)   PURITY (VISUAL R) LAMBDA     REFLECTIVITY
CRYSTAL SYSTEM                          X        Y  WAVELENGTH  (P%)       Y      (NM)      (Rp )  (Rg )

ORANGE BORNITE 13                 A   0.5098 0.4082    592.67  43.57     23.57Yp   420     12.70  14.90

CU(2+X)SN(1-X)FE S4               A   0.4814 0.4132    589.31  27.37     24.18Yg   440     12.20  15.60

TETRAGONAL                        C   0.3850 0.3604    584.99  31.91     21.76Yp   460     12.90  17.30

                                  C   0.3502 0.3499    580.06  19.77     23.27Yg   480     13.60  18.50

REF. FOR R: (LEVY,1966)                                                            500     15.40  20.20

REMARKS:    LOC. PERU                                                              520     16.85  20.80

                                                                                   540     18.90  22.20

                                                                                   560     21.40  23.40

                                                                                   580     24.60  24.60

                                                                                   600     27.70  25.60

                                                                                   620     30.70  27.60

                                                                                   640     31.80  28.60
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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (Rg) e	(Rp) o
MAWSONITE 14	A	0.4904	0.4133	589.92	33.68	27.18 Yg	420	14.90	17.10
CU2+X SN1-X FE S4,.5<X<1	A	0.4738	0.4141	587.92	22.72	26.10 Yp	440	16.40	18.50
TETRAGONAL	C	0.3621	0.3559	581.40	24.57	25.81 Yg E	460	17.50	19.90
	C	0.3419	0.3452	578.93	16.29	25.34 Yp O	480	19.00	20.80
REF. FOR R: (LEVY,1966)							500	20.50	22.40
REMARKS: LOC. MONT-LYELL							520	21.80	23.20
							540	24.10	24.50
							560	26.20	25.70
							580	28.20	26.60
							600	29.80	27.80
							620	31.90	28.50
							640	33.00	29.00

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	 Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (Rg) e	 (Rp) o
MAWSONITE 16	A	0.4903	0.4132	589.95	33.52	26.64 Yg	420	14.90	17.20
CU2+X SN1-X FE S4,.5<X<1	A	0.4737	0.4138	588.08	22.44	26.00 Yp	440	16.20	18.40
TETRAGONAL	C	0.3620	0.3553	581.59	24.38	25.30 Yg E	460	17.20	20.00
	C	0.3416	0.3448	578.99	16.10	25.24 Yp O	480	18.50	20.70
REF. FOR R: (LEVY,1966)							500	20.20	22.30
REMARKS: MONT-LYELL							520	21.30	23.20
							540	23.60	24.50
							560	25.70	25.50
							580	27.70	26.40
							600	29.30	27.60
							620	31.40	28.50
							640	32.20	29.00

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MINERAL NAME                           CHROMATICITY  DOMINANT           BRIGHTNESS
COMPOSITION                     SOURCE COORDINATES   (COMPL.)   PURITY  (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                          X       Y    WAVELENGTH  (P%)       Y       (NM)     (Rp )  (Rg )
                                                                                              e      o

MAWSONITE 15                      A   0.4739 0.4140    587.99   22.70    26.07Yp     420     17.30  17.10

CU2+X SN1-X FE S4,.5<X<1          A   0.4738 0.4141    587.92   22.72    26.23Yg     440     18.30  18.50

TETRAGONAL                        C   0.3420 0.3450    579.07   16.26    25.29Yp     460     20.00  20.10

                                  C   0.3418 0.3454    578.79   16.31    25.47Yg     480     20.80  20.90

REF. FOR R: (LEVY,1966)                                                              500     22.20  22.50

REMARKS:    LOC. MONT-LYELL                                                          520     23.20  23.50

                                                                                     540     24.40  24.70

                                                                                     560     25.70  25.80

                                                                                     580     26.60  26.60

                                                                                     600     27.70  27.80

                                                                                     620     28.50  28.70

                                                                                     640     29.00  29.30
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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	REFLECTIVITY (R_g)
STANNITE JAUNE,5	A	0.4712	0.4140	587.58	20.86	26.62 Y_p	420	20.50	21.20
CU(I+X)SN(1-X)FE S4	A	0.4684	0.4131	587.67	18.30	28.96 Y_g	440	19.30	22.00
TETRAGONAL	C	0.3389	0.3419	579.24	14.59	25.89 Y_p	460	20.50	23.30
	C	0.3349	0.3394	578.59	12.85	28.29 Y_g	480	21.20	24.40
REF. FOR R: (LEVY,1966)							500	22.60	25.20
REMARKS: LOC. VAULRY							520	23.90	26.70
							540	25.00	27.50
							560	26.60	28.90
							580	27.30	29.40
							600	28.20	30.00
							620	28.60	30.50
							640	29.00	31.90

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
STANNITE JAUNE,6	A	0.4724	0.4133	588.21	21.21	26.54 Y_p	420	20.40	20.50
CU(I+X)SN(1-X)FE S4	A	0.4680	0.4137	587.17	18.44	27.58 Y_g	440	19.40	20.80
TETRAGONAL	C	0.3396	0.3415	579.75	14.67	25.78 Y_p	460	20.30	22.20
	C	0.3348	0.3399	578.24	12.96	26.95 Y_g	480	21.00	22.90
REF. FOR R: (LEVY,1966)							500	22.50	24.00
REMARKS: LOC. VAULRY							520	23.80	25.40
							540	24.80	26.30
							560	26.40	27.60
							580	27.20	28.00
							600	28.00	28.80
							620	28.50	28.90
							640	29.50	30.00

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
STANNITE JAUNE,4	A	0.4720	0.4140	587.71	21.42	26.48 Y_p	420	20.00	20.80
CU(I+X)SN(1-X)FE S4	A	0.4680	0.4136	587.24	18.37	28.17 Y_g	440	19.20	21.30
TETRAGONAL	C	0.3396	0.3425	579.25	14.94	25.74 Y_p	460	20.20	22.70
	C	0.3348	0.3399	578.24	12.96	27.53 Y_g	480	21.05	23.40
REF. FOR R: (LEVY,1966)							500	22.40	24.60
REMARKS: LOC. VAULRY							520	23.80	26.00
							540	24.80	26.80
							560	26.40	28.20
							580	27.10	28.60
							600	28.20	29.30
							620	28.40	29.60
							640	29.00	30.70

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
STANNITE JAUNE,7	A	0.4724	0.4136	588.01	21.38	26.29 Y_p	420	20.00	20.70
CU(I+X)SN(1-X)FE S4	A	0.4673	0.4138	586.95	18.03	28.12 Y_g	440	19.00	21.20
TETRAGONAL	C	0.3401	0.3422	579.65	15.00	25.53 Y_p	460	20.00	22.90
	C	0.3344	0.3396	578.19	12.77	27.49 Y_g	480	21.00	23.50
REF. FOR R: (LEVY,1966)							500	22.20	24.50
REMARKS: LOC. VAULRY							520	23.50	25.90
							540	24.50	26.50
							560	26.00	28.40
							580	27.20	28.70
							600	28.10	29.40
							620	28.20	29.50
							640	28.80	30.20

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	 Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	 (R_g)
STANNITE JAUNE,1	A	0.4762	0.4105	590.53	21.90	25.59 Y_p	420	20.20	21.00
CU(1+X)SN(1-X)FE S4	A	0.4725	0.4100	590.62	18.99	27.18 Y_g	440	18.80	20.90
TETRAGONAL	C	0.3421	0.3391	582.34	14.70	24.72 Y_p	460	19.55	21.90
	C	0.3373	0.3363	581.89	12.66	26.38 Y_g	480	20.00	22.20
REF. FOR R: (LEVY,1966)							500	21.40	23.40
REMARKS: LOC. VAULRY							520	22.60	24.50
							540	23.30	25.20
							560	25.00	26.80
							580	26.20	27.40
							600	27.40	28.50
							620	27.90	29.00
							640	29.60	31.40

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	REFLECTIVITY (R_g)
STANNITE JAUNE,3	A	0.4759	0.4095	591.25	21.00	25.38 Y_p	420	19.45	21.00
CU(I+X)SN(1-X)FE S4	A	0.4721	0.4092	591.28	18.15	27.55 Y_g	440	19.50	21.60
TETRAGONAL	C	0.3410	0.3374	582.93	13.95	24.52 Y_p	460	19.50	22.60
	C	0.3366	0.3348	582.63	12.07	26.75 Y_g	480	20.20	22.80
REF. FOR R: (LEVY,1966)							500	21.20	23.80
REMARKS: LOC. VAULRY							520	22.60	24.50
							540	23.00	25.60
							560	24.90	27.20
							580	25.60	27.80
							600	27.20	28.80
							620	27.70	29.50
							640	29.60	31.90

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	REFLECTIVITY (R_g)
STANNITE,3	A	0.4568	0.4164	581.21	12.51	28.21 Yp	420	22.20	22.20
CU2 SN FE S4	A	0.4543	0.4158	579.91	10.41	28.63 Yg	440	22.80	24.00
TETRAGONAL	C	0.3243	0.3371	572.45	9.39	27.96 Yp	460	24.00	25.20
	C	0.3215	0.3347	571.22	8.00	28.46 Yg	480	25.20	26.20
REF. FOR R: (LEVY,1966)							500	26.20	27.20
REMARKS: LOC. SAINT-AGNES,CORNOUAILLES							520	27.20	27.80
							540	28.20	28.70
							560	28.70	29.00
							580	28.80	29.50
							600	28.70	29.00
							620	28.20	28.20
							640	28.00	28.00

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
STANNITE,1	A	0.4571	0.4167	581.21	12.92	28.17 Y_p	420	22.20	22.20
CU2 SN FE S4	A	0.4541	0.4158	579.74	10.27	28.64 Y_g	440	22.50	24.00
TETRAGONAL	C	0.3247	0.3377	572.44	9.66	27.93 Y_p	460	24.00	25.40
	C	0.3212	0.3345	571.03	7.86	28.48 Y_g	480	24.80	26.20
REF. FOR R: (LEVY,1966)							500	26.30	27.20
REMARKS: LOC. SAINT-AGNES,CORNOUAILLES							520	27.20	27.80
							540	28.20	28.80
							560	28.60	29.10
							580	28.80	29.40
							600	28.60	29.00
							620	28.20	28.20
							640	28.00	28.00

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMFL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
STANNITE,4	A	0.4575	0.4168	581.39	13.29	28.14 Y_p	420	22.20	23.50
CU2 SN FE S4	A	0.4537	0.4152	579.80	9.58	29.13 Y_g	440	22.50	24.70
TETRAGONAL	C	0.3252	0.3381	572.64	9.90	27.88 Y_p	460	23.60	25.80
	C	0.3203	0.3334	570.74	7.33	28.99 Y_g	480	24.80	26.70
REF. FOR R: (LEVY,1966)							500	26.20	28.20
REMARKS: LOC. SAINT-AGNES,CORNOUAILLES							520	27.20	28.60
							540	28.00	29.30
							560	28.60	29.40
							580	28.80	29.50
							600	28.60	29.60
							620	28.20	29.00
							640	28.00	28.60

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
STANNITE,6	A	0.4629	0.4153	584.73	16.02	28.01 Y_p	420	20.60	22.70
CU2 SN FE S4	A	0.4606	0.4130	585.67	12.83	28.84 Y_g	440	21.90	23.70
TETRAGONAL	C	0.3299	0.3398	575.24	11.62	27.59 Y_p	460	22.70	24.30
	C	0.3264	0.3344	576.15	9.23	28.45 Y_g	480	24.40	26.10
REF. FOR R: (LEVY,1966)							500	25.60	27.20
REMARKS: LOC. SAINT-AGNES,CORNOUAILLES							520	26.80	27.90
							540	27.50	27.40
							560	27.90	28.80
							580	28.20	29.20
							600	28.90	30.20
							620	28.90	29.70
							640	29.40	29.80

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES		DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY	
		X	Y					(R_p)	(R_g)
STANNITE,7	A	0.4637	0.4154	584.92	16.65	27.94 Yp	420	20.70	22.80
CU2 SN FE S4	A	0.4599	0.4141	584.47	13.10	29.05 Yg	440	21.40	23.80
TETRAGONAL	C	0.3308	0.3408	575.28	12.13	27.50 Yp	460	22.30	24.30
	C	0.3262	0.3356	575.11	9.50	28.69 Yg	480	24.40	26.10
REF. FOR R: (LEVY,1966)							500	25.50	27.20
REMARKS: LOC. SAINT-AGNES,CORNOUAILLES							520	26.50	27.90
							540	27.50	28.50
							560	27.90	28.90
							580	27.90	29.30
							600	28.90	30.30
							620	29.00	29.70
							640	29.50	29.80

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	 Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	 (R_g)
STANNITE,5	A	0.4606	0.4159	583.49	14.84	27.71 Y_p	420	21.60	21.10
CU2 SN FE S4	A	0.4591	0.4152	583.30	13.31	28.53 Y_g	440	21.60	23.20
TETRAGONAL	C	0.3283	0.3390	574.57	10.97	27.35 Y_p	460	22.60	24.00
	C	0.3261	0.3372	573.96	9.90	28.21 Y_g	480	24.50	25.70
REF. FOR R: (LEVY,1966)							500	25.60	26.70
REMARKS: LOC. SAINT-AGNES,CORNOUAILLES							520	26.20	27.20
							540	27.40	28.20
							560	27.80	28.70
							580	28.00	29.00
							600	28.80	29.20
							620	29.20	29.20
							640	27.90	29.00

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MINERAL NAME                           CHROMATICITY  DOMINANT           BRIGHTNESS
COMPOSITION                     SOURCE COORDINATES   (COMPL.)   PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                           X       Y   WAVELENGTH  (P%)      Y       (NM)     (Rg )  (Rp )

RENIERITE,1(RE>RO)                A   0.4846 0.4184    587.30   33.20     28.64Yg   420     17.30  17.60

CU(3-X)GE(X)FE S4,X=<0.5)         A   0.4841 0.4150    588.68   30.49     27.77Yp   440     16.90  17.20

TETRAGONAL                        C   0.3582 0.3599    578.96   24.60     27.42Yg   460     18.00  18.00

                                  C   0.3561 0.3550    580.00   22.73     26.38Yp   480     19.70  19.20

REF. FOR R: (LEVY,1966)                                                             500     21.50  20.80

REMARKS:    LOC. KIPUSHI                                                            520     23.80  22.90

                                                                                    540     26.40  25.10

                                                                                    560     28.40  27.20

                                                                                    580     30.20  29.00

                                                                                    600     31.00  30.20

                                                                                    620     31.80  30.60

                                                                                    640     32.50  31.40
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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_g)	(R_p)
RENIERITE,6(RE>RO)	A	0.4856	0.4179	587.61	33.55	28.44 Y_g	420	17.40	18.80
CU(3-X)GE(X)FE S4,X=<0.5)	A	0.4843	0.4149	588.74	30.56	27.77 Y_p	440	17.30	18.50
TETRAGONAL	C	0.3592	0.3560	580.57	23.82	26.53 Y_g	460	17.80	18.30
	C	0.3550	0.3475	582.69	20.41	25.76 Y_p	480	18.50	18.50
REF. FOR R: (LEVY,1966)							500	20.40	20.10
REMARKS: LOC. TSUMEB							520	22.60	22.00
							540	25.20	24.20
							560	27.30	26.30
							580	29.40	28.40
							600	31.00	29.90
							620	31.70	31.10
							640	31.60	31.40

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_g)	REFLECTIVITY (R_p)
RENIERITE,8(RE>RO)	A	0.4869	0.4159	583.54	33.05	28.15 Y_g	420	17.60	17.60
CU(3-X)GE(X)FE S4,X=<0.5)	A	0.4822	0.4138	585.07	28.34	26.03 Y_p	440	17.40	17.70
TETRAGONAL	C	0.3568	0.3546	580.37	22.80	26.76 Y_g	460	18.70	18.30
	C	0.3521	0.3482	581.44	19.82	24.94 Y_p	480	19.00	18.20
REF. FOR R: (LEVY,1966)							500	21.00	19.70
REMARKS: LOC. M PASSA,CONGO							520	23.10	21.70
							540	25.40	23.70
							560	27.60	25.60
							580	29.40	27.20
							600	30.90	28.60
							620	31.40	29.40
							640	31.90	29.60

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	 Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_g)	 (R_p)
RENIERITE,4(RE>RO)	A	0.4855	0.4174	587.74	33.14	27.93 Y_g	420	17.30	17.60
CU(3-X)GE(X)FE S4,X=<0.5)	A	0.4853	0.4125	589.97	29.56	27.02 Y_p	440	16.60	17.10
TETRAGONAL	C	0.3593	0.3596	579.38	24.81	27.19 Y_g	460	17.80	17.60
	C	0.3561	0.3541	580.34	22.48	25.90 Y_p	480	19.60	18.90
REF. FOR R: (LEVY,1966)							500	21.20	20.50
REMARKS: LOC. KIPUSHI							520	23.60	22.20
							540	26.00	24.60
							560	28.00	26.60
							580	29.80	28.60
							600	31.40	30.10
							620	32.10	30.60
							640	32.20	30.30

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	REFLECTIVITY (R_g)
RENIERITE,3(RE>RO)	A	0.4841	0.4163	588.03	31.38	27.56 Y_p	420	17.30	16.90
CU(3-X)GE(X)FE S4,X=<0.5)	A	0.4864	0.4162	588.37	32.92	27.82 Y_g	440	16.60	16.30
TETRAGONAL	C	0.3587	0.3585	579.57	24.36	26.70 Y_p	460	17.50	17.00
	C	0.3555	0.3528	580.64	21.97	24.66 Y_g	480	19.40	18.30
REF. FOR R: (LEVY,1966)							500	20.80	19.80
REMARKS: LOC. KIPUSHI							520	23.10	21.20
							540	25.40	23.40
							560	27.60	25.20
							580	29.40	27.00
							600	30.70	28.50
							620	31.20	28.80
							640	31.80	29.60

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
RENIERITE,7(RE>RO)	A	0.4839	0.4161	588.16	31.12	27.07 Y_p	420	17.40	18.40
CU(3-X)GE(X)FE S4,X=<0.5)	A	0.4847	0.4159	588.33	31.54	27.99 Y_g	440	17.30	18.30
TETRAGONAL	C	0.3597	0.3560	580.71	23.96	26.82 Y_p	460	18.10	18.50
	C	0.3557	0.3515	581.21	21.68	26.54 Y_g	480	18.80	18.90
REF. FOR R: (LEVY,1966)							500	20.70	20.60
REMARKS: LOC. TSUMEB							520	22.90	22.70
							540	25.40	25.20
							560	27.50	27.20
							580	29.70	29.40
							600	31.20	30.90
							620	32.00	31.40
							640	32.50	31.40

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
RENIERITE,5(RE>RO)	A	0.4844	0.4149	588.75	30.63	25.78 Yp	420	17.40	18.40
CU(3-X)GE(X)FE S4,X=<0.5)	A	0.4872	0.4157	588.65	33.12	28.15 Yg	440	17.30	18.30
TETRAGONAL	C	0.3596	0.3563	580.57	24.01	26.88 Yp	460	18.10	18.50
	C	0.3554	0.3516	581.08	21.62	26.55 Yg	480	18.80	18.90
REF. FOR R: (LEVY,1966)							500	20.80	20.70
REMARKS: LOC. TSUMEB							520	23.00	22.80
							540	25.50	25.20
							560	27.60	27.30
							580	29.70	29.30
							600	31.20	30.80
							620	32.00	31.40
							640	32.50	31.40

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_g)	(R_p)
LUZONITE 1	A	0.4607	0.4078	592.38	9.28	28.90 Y_g	420	27.60	25.00
CU3(AS,SB)S4	A	0.4552	0.4054	604.76	3.81	25.62 Y_p	440	26.80	25.30
TETRAGONAL	C	0.3236	0.3228	587.76	5.36	28.39 Y_g	460	25.80	24.60
	C	0.3165	0.3168	607.19	1.85	25.36 Y_p	480	25.20	24.30
REF. FOR R: (LEVY,1966)							500	26.00	24.70
REMARKS: LOC. MANKAYAN,PHILIPPINES							520	26.70	24.50
							540	27.90	24.80
							560	28.50	25.20
							580	29.40	26.00
							600	30.60	25.80
							620	30.00	26.80
							640	30.50	27.20

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (Rg)	(Rp)
LUZONITE 2	A	0.4560	0.4081	591.24	6.24	28.42 Yg	420	27.60	26.00
CU3(AS,SB)S4	A	0.4543	0.4054	607.72	3.18	25.68 Yp	440	27.20	25.30
TETRAGONAL	C	0.3191	0.3206	587.86	3.57	28.08 Yg	460	26.40	24.80
	C	0.3155	0.3163	616.39	1.01	25.45 Yp	480	25.60	24.30
REF. FOR R: (LEVY,1966)							500	26.30	25.10
REMARKS: LOC. MANKAYAN,PHILIPPINES							520	26.90	24.70
							540	27.80	25.00
							560	28.20	25.30
							580	28.90	25.90
							600	29.60	25.80
							620	29.60	26.80
							640	29.00	27.20

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_g)	(R_p)
LUZONITE 3	A	0.4545	0.4079	591.54	5.06	26.54 Yg	420	25.00	25.50
CU3(AS,SB)S4	A	0.4523	0.4079	590.93	3.52	25.84 Yp	440	25.30	24.80
TETRAGONAL	C	0.3173	0.3204	585.46	3.03	26.30 Yg	460	25.10	24.60
	C	0.3148	0.3194	583.42	2.09	25.69 Yp	480	25.00	24.90
REF. FOR R: (LEVY,1966)							500	25.20	25.10
REMARKS: LOC. MANKAYAN,PHILIPPINES							520	25.40	25.20
							540	26.10	25.60
							560	26.30	25.80
							580	26.80	26.00
							600	27.40	25.80
							620	27.20	26.20
							640	27.20	26.70

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y		LAMBDA (NM)	REFLECTIVITY (R_g)	(R_p)
STIBIOLUZONITE 5	A	0.4581	0.4054	600.25	5.81	27.07	Y_g	420	28.40	26.80
CU3(AS,SB)S4	A	0.4532	0.4017	-516.38	3.05	24.30	Y_p	440	26.30	25.40
TETRAGONAL	C	0.3194	0.3170	607.45	2.68	26.65	Y_g	460	25.20	24.40
	C	0.3124	0.3095	-528.43	3.17	24.09	Y_p	480	24.50	23.80
REF. FOR R: (LEVY,1966)								500	24.70	23.70
REMARKS: LOC. FAMATINA,ARGENTINA								520	25.00	23.40
								540	26.20	23.70
								560	27.00	23.80
								580	27.40	24.00
								600	27.90	24.50
								620	27.90	25.30
								640	29.00	26.40

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES		DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R)	LAMBDA (NM)	REFLECTIVITY	
		X	Y			Y		(R_g)	(R_p)
STIBIOLUZONITE 4	A	0.4565	0.4045	610.03	4.08	26.30 Y_g	420	27.90	26.30
CU3(AS,SB)S4	A	0.4540	0.4018	-512.41	3.15	24.59 Y_p	440	26.30	25.80
TETRAGONAL	C	0.3174	0.3148	-493.42	1.97	25.95 Y_g	460	25.00	24.60
	C	0.3132	0.3100	-517.83	3.12	24.34 Y_p	480	24.20	23.80
REF. FOR R: (LEVY,1966)							500	24.40	23.80
REMARKS: LOC. FAMATINA,ARGENTINA							520	24.50	23.50
							540	25.40	23.90
							560	26.40	24.20
							580	26.40	24.20
							600	26.70	25.00
							620	27.90	25.40
							640	28.10	26.80

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	 Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
BRIARTITE 11	A	0.4466	0.4131	566.09	3.21	26.99	420	24.20
CU2(FE,ZN)GE S4	C	0.3120	0.3252	560.32	2.91	27.07	440	25.20
TETRAGONAL							460	25.80
REF. FOR R: (LEVY,1966)							480	26.20
REMARKS: LOC. KIPUSHI							500	27.00
							500	27.00
							520	27.30
							540	27.60
							560	27.40
							580	27.40
							600	26.50
							620	26.00
							640	26.00

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (R%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
BRIARTITE 9	A	0.4463	0.4134	564.77	3.21	26.89	420	24.30
CU2(FE,ZN)GE S4	C	0.3117	0.3254	558.94	2.88	26.98	440	25.30
TETRAGONAL							460	25.40
REF. FOR R: (LEVY,1966)							480	26.10
REMARKS: LOC. KIPUSHI							500	26.90
							500	26.90
							520	27.60
							540	27.60
							560	27.20
							580	27.00
							600	26.50
							620	26.20
							640	25.80

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
BRIARTITE 10	A	0.4471	0.4140	568.79	4.14	26.87	420	23.30
CU2(FE,ZN)GE S4	C	0.3129	0.3273	561.73	3.71	26.95	440	24.40
TETRAGONAL							460	25.50
REF. FOR R: (LEVY,1966)							480	26.10
REMARKS: LOC. KIPUSHI							500	26.80
							520	27.50
							540	27.50
							560	27.20
							580	27.00
							600	26.60
							620	26.20
							640	25.80

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
CORONADITE	A	0.4379	0.4067	493.39	2.32	26.09 Y_p	430	28.20	34.40
PB<=2 MN8 O16	A	0.4354	0.4077	495.07	2.87	31.48 Y_g	470	28.30	34.20
TETRAGONAL	C	0.3007	0.3096	481.82	4.14	26.39 Y_p	490	27.20	33.30
	C	0.2989	0.3096	483.40	4.79	31.94 Y_g	520	27.20	33.30
REF. FOR R: (NICHOL & PHILLIPS,1965)							550	26.70	32.30
REMARKS: LOC. UNKNOWN							580	26.00	31.50
							610	25.00	30.00
							650	24.70	28.70

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MINERAL NAME                         CHROMATICITY  DOMINANT          BRIGHTNESS
COMPOSITION                   SOURCE COORDINATES   (COMPL.)  PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                         X       Y  WAVELENGTH  (P%)       Y       (NM)         R


CRYPTOMELANE                    A   0.4371 0.4077   495.12    2.47     25.99      430       27.80

A<=2 B8 O16                     C   0.3006 0.3109   483.81    4.03     26.32      470       28.00

TETR. & MONO.                                                                     490       27.60

REF. FOR R: (NICHOL & PHILLIPS,1964)                                              520       27.00

REMARKS:    LOC. UNKNWON                                                          550       26.70

                                                                                  550       26.70

                                                                                  580       26.00

                                                                                  610       25.00

                                                                                  650       23.90
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MINERAL NAME                         CHROMATICITY  DOMINANT          BRIGHTNESS
COMPOSITION                   SOURCE COORDINATES   (COMPL.)  PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                         X       Y   WAVELENGTH  (P%)      Y       (NM)    (Rp )  (Rg )

HOLLANDITE                       A   0.4397 0.4064    492.42   1.91     25.29Yp   430    27.00  33.90

BA<=2 R8 O16                     A   0.4386 0.4087    497.08   2.09     31.78Yg   470    27.10  33.00

TETR.& MONO.                     C   0.3021 0.3103    481.29   3.56     25.53Yp   490    26.60  33.40

                                 C   0.3024 0.3126    484.98   3.19     32.12Yg   520    26.20  32.80

REF. FOR R: (NICHOL & PHILLIPS,1965)                                              550    25.60  32.30

REMARKS:    LOC. UNKNOWN                                                          580    25.20  32.50

                                                                                  610    24.50  30.20

                                                                                  650    24.30  29.40
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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R_x	R_y	R_z
ENARGITE	A	0.4408	0.4026	481.21	1.88	25.02 Y_x	440	27.7	26.7	29.8
CU3(AS,SB)S4	A	0.4497	0.4043	-537.34	1.52	26.30 Y_y	460	27.6	26.9	29.4
ORTHORHOMBIC	A	0.4454	0.4063	485.01	0.58	28.68 Y_z	480	27.2	26.8	29.1
	C	0.3011	0.3054	473.75	4.58	25.21 Y_x	500	26.5	26.5	28.9
	C	0.3103	0.3129	-547.90	1.41	26.23 Y_y	520	25.9	26.2	28.8
	C	0.3075	0.3127	470.11	1.40	28.73 Y_z	540	25.3	25.9	28.7
							560	24.8	25.9	28.7
							580	24.5	25.9	28.7
							600	24.4	26.3	28.6
							620	24.6	25.8	28.5
							640	25.3	27.7	28.4
							660	25.9	28.3	28.3

REF. FOR R: LOPEZ-SOLER ET AL (1970)

REMARKS: LOC. UTAH,U.S.A.: ORIENTED SECTION PARALLEL TO X- Y- Z-AXIS

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
ENARGITE 7	A	0.4510	0.4032	-525.43	2.13	25.75 Y_p	420	26.70	29.10
CU3(AS,SB)S4	A	0.4469	0.4029	-573.22	1.55	26.96 Y_g	440	26.30	28.80
ORTHORHOMBIC	C	0.3110	0.3116	-539.45	2.06	25.62 Y_p	460	26.30	28.50
	C	0.3070	0.3086	-566.15	2.52	26.96 Y_g	480	26.00	27.40
REF. FOR R: (LEVY,1966)							500	25.60	27.50
REMARKS: LOC. PARAD							520	25.30	26.90
							540	25.20	26.90
							560	25.40	26.40
							580	25.40	26.90
							600	25.90	26.60
							620	26.20	27.30
							640	27.40	28.00

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
ENARGITE 9	A	0.4520	0.4031	-580.00	2.34	25.62 Y_p	420	26.50	29.20
CU3(AS,SB)S4	A	0.4469	0.4026	-573.08	1.66	26.83 Y_g	440	26.20	28.60
ORTHORHOMBIC	C	0.3117	0.3118	-527.12	2.11	25.46 Y_p	460	26.20	28.50
	C	0.3068	0.3081	-566.15	2.69	26.82 Y_g	480	25.10	27.40
REF. FOR R: (LEVY,1966)							500	25.50	27.50
REMARKS: LOC. PARAC							520	25.20	26.80
							540	25.10	26.70
							560	25.30	26.20
							580	25.00	26.80
							600	25.70	26.40
							620	26.10	27.10
							640	27.70	28.00

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MINERAL NAME                      CHROMATICITY   DOMINANT          BRIGHTNESS
COMPOSITION                SOURCE COORDINATES    (COMPL.)   PURITY (VISUAL R) LAMBDA      REFLECTIVITY
CRYSTAL SYSTEM                   X         Y    WAVELENGTH   (P%)      Y       (NM)      (Rp )   (Rg )

ENARGITE 1                    A  0.4503 0.4032   -540.06    2.02    25.59Yp    420      26.70   29.30

CU3(AS,SB)S4                  A  0.4481 0.4024   -568.27    1.94    26.91Yg    440      26.40   28.60

ORTHORHOMBIC                  C  0.3105 0.3110   -547.02    2.21    25.48Yp    460      26.30   28.20

                              C  0.3079 0.3083   -562.40    2.81    26.86Yg    480      25.80   27.50

REF. FOR R: (LEVY,1966)                                                        500      25.40   27.20

REMARKS:     LOC. HAURON,PERU                                                  520      25.20   26.70

                                                                               540      25.00   26.50

                                                                               560      25.20   26.50

                                                                               580      25.50   26.70

                                                                               600      25.70   26.70

                                                                               620      26.00   27.50

                                                                               640      27.00   28.20
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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
ENARGITE 4	A	0.4508	0.4031	-530.71	2.14	25.18 Yp	420	26.20	29.40
CU3(AS,SB)S4	A	0.4485	0.4023	-566.25	2.04	26.85 Yg	440	25.90	28.70
ORTHORHOMBIC	C	0.3110	0.3112	-540.51	2.22	25.05 Yp	460	25.70	28.00
	C	0.3083	0.3081	-560.53	2.97	26.77 Yg	480	25.40	27.30
REF. FOR R: (LEVY,1966)							500	25.00	26.80
REMARKS: LOC. BOR,YOUGOSLAVIA							520	24.80	26.60
							540	24.60	26.40
							560	24.60	26.40
							580	25.00	26.60
							600	25.50	27.10
							620	26.00	27.30
							640	26.50	28.00

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
ENARGITE 6	A	0.4509	0.4011	-544.98	2.48	25.13 Y_p	420	27.20	28.90
CU3(AS,SB)S4	A	0.4507	0.4021	-549.77	2.88	27.14 Y_g	440	26.70	28.60
ORTHORHOMBIC	C	0.3099	0.3078	-551.92	2.76	24.98 Y_p	460	26.10	27.90
	C	0.3100	0.3094	-552.37	3.39	27.01 Y_g	480	25.50	27.30
REF. FOR R: (LEVY,1966)							500	24.90	27.20
REMARKS: LOC. BOR,YOUGOSLAVIA							520	24.70	26.70
							540	24.50	26.70
							560	24.40	26.50
							580	24.90	26.80
							600	25.10	27.00
							620	26.40	27.90
							640	27.00	29.20

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
ENARGITE 3	A	0.4510	0.4017	-543.90	2.68	24.82 Y_p	420	26.70	28.40
$CU_3(AS,SB)S_4$	A	0.4500	0.4024	-552.96	2.26	26.59 Y_g	440	26.20	28.10
ORTHORHOMBIC	C	0.3104	0.3087	-549.08	3.12	24.68 Y_p	460	25.60	27.40
	C	0.3096	0.3093	-554.64	2.73	26.48 Y_g	480	25.00	26.80
REF. FOR R: (LEVY,1966)							500	24.60	26.70
REMARKS: LOC. HAURON,PERU							520	24.20	26.20
							540	24.30	26.20
							560	24.20	26.00
							580	24.60	26.30
							600	25.00	26.50
							620	25.80	27.40
							640	26.50	28.30

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MINERAL NAME                    CHROMATICITY  DOMINANT          BRIGHTNESS
COMPOSITION               SOURCE COORDINATES   (COMPL.)  PURITY (VISUAL R) LAMBDA     REFLECTIVITY
CRYSTAL SYSTEM                   X       Y    WAVELENGTH  (P%)       Y      (NM)     (Rp )  (Rg )

ENARGITE 5                  A  0.4537 0.4021   -512.28    2.99     24.76 Yp   420     26.20  29.00

CU3(AS,SB)S4                A  0.4499 0.4021   -555.75    2.35     27.03 Yg   440     25.70  28.40

ORTHORHOMBIC                C  0.3129 0.3108   -516.90    2.74     24.54 Yp   460     24.70  28.10

                            C  0.3094 0.3090   -555.71    2.81     26.93 Yg   480     24.40  27.40

REF. FOR R: (LEVY,1966)                                                       500     24.10  27.10

REMARKS:    LOC. BOR,YOUGOSLAVIA                                              520     24.20  26.70

                                                                              540     24.00  26.70

                                                                              560     24.20  26.40

                                                                              580     24.50  26.50

                                                                              600     24.70  27.10

                                                                              620     25.70  27.90

                                                                              640     27.20  28.80
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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
ENARGITE 8	A	0.4537	0.4015	-514.83	3.21	24.70 Yp	420	26.40	29.20
CU3(AS,SB)S4	A	0.4495	0.4022	-559.28	2.24	26.99 Yg	440	25.90	28.30
ORTHORHOMBIC	C	0.3126	0.3099	-524.53	3.05	24.47 Yp	460	24.70	28.10
	C	0.3091	0.3089	-557.35	2.79	26.89 Yg	480	24.40	27.40
REF. FOR R: (LEVY,1966)							500	24.10	27.20
REMARKS: LOC. PARAD							520	24.20	26.70
							540	23.80	26.50
							560	24.10	26.40
							580	24.40	26.50
							600	24.70	27.30
							620	25.70	27.70
							640	27.20	28.50

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
ENARGITE 48	A	0.4424	0.4036	480.51	1.45	24.70 Y_p	440	26.65	29.24
CU3(AS,SB)S4	A	0.4463	0.4059	461.18	0.43	28.17 Y_g	460	26.69	28.73
ORTHORHOMBIC	C	0.3030	0.3080	474.54	3.57	24.86 Y_p	480	26.42	28.37
	C	0.3079	0.3126	461.69	1.30	28.19 Y_g	500	26.01	28.42
REF. FOR R: (TUGAL,1969)							520	25.45	28.33
REMARKS: LOC. TURKEY							540	24.91	28.29
							560	24.51	27.94
							580	24.18	28.12
							600	24.16	28.11
							620	24.48	28.03
							640	24.76	28.11
							660	25.71	28.74

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
ENARGITE 49	A	0.4429	0.4056	487.73	1.20	24.46 Y_p	440	25.68	26.01
CU3(AS,SB)S4	A	0.4486	0.4059	-540.33	0.75	25.87 Y_g	460	25.73	26.09
ORTHORHOMBIC	C	0.3045	0.3114	479.46	2.59	24.61 Y_p	480	25.72	26.07
	C	0.3101	0.3149	-551.55	0.56	25.84 Y_g	500	25.55	26.12
REF. FOR R: (TUGAL,1969)							520	25.12	25.98
REMARKS: LOC. TURKEY							540	25.05	25.77
							560	24.17	25.63
							580	23.96	25.49
							600	24.04	25.78
							620	24.29	26.16
							640	24.74	26.70
							660	24.26	27.11

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	REFLECTIVITY (R_g)
ENARGITE 2	A	0.4540	0.4016	-513.20	3.22	23.68 Y_p	420	25.20	28.00
CU3(AS,SB)S4	A	0.4505	0.4018	-550.28	2.56	26.11 Y_g	440	24.60	27.50
ORTHORHOMBIC	C	0.3130	0.3102	-518.79	3.00	23.46 Y_p	460	23.80	27.00
	C	0.3098	0.3088	-553.17	2.96	25.98 Y_g	480	23.30	26.50
REF. FOR R: (LEVY,1966)							500	23.00	26.00
REMARKS: LOC. HAURON,PERU							520	23.00	25.80
							540	23.00	25.60
							560	23.00	25.50
							580	23.40	25.60
							600	23.80	26.20
							620	24.80	27.00
							640	26.00	28.00

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
KOSTERITE 2,2	A	0.4502	0.4118	578.39	4.79	25.56	420	22.60
CU2 SN ZN S4	C	0.3149	0.3258	568.71	3.84	25.52	440	22.70
TETRAGONAL							460	24.60
REF. FOR R: (LEVY,1966)							480	24.70
REMARKS: LOC. VAULRY							500	25.20
							500	25.20
							520	25.70
							540	25.80
							560	25.50
							580	25.70
							600	25.50
							620	25.50
							640	25.40

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MINERAL NAME                          CHROMATICITY  DOMINANT          BRIGHTNESS
COMPOSITION                    SOURCE COORDINATES   (COMPL.)   PURITY (VISUAL R) LAMBDA   REFLECTIVITY
CRYSTAL SYSTEM                          X       Y   WAVELENGTH  (P%)      Y       (NM)         R

KOSTERITE 1,1                    A    0.4505 0.4122   578.49    5.27    25.55      420        22.10

CU2 SN ZN S4                     C    0.3154 0.3268   568.70    4.24    25.52      440        22.50

TETRAGONAL                                                                         460        24.40

REF. FOR R: (LEVY,1966)                                                            480        24.80

REMARKS:    LOC. VAULRY                                                            500        25.20

                                                                                   500        25.20

                                                                                   520        25.60

                                                                                   540        25.80

                                                                                   560        25.50

                                                                                   580        25.80

                                                                                   600        25.40

                                                                                   620        25.50

                                                                                   640        25.40
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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
KOSTERITE 3,1	A	0.4502	0.4122	577.96	5.07	25.54	420	22.20
CU2 SN ZN S4	C	0.3151	0.3267	568.13	4.14	25.51	440	22.50
TETRAGONAL							460	24.40
REF. FOR R: (LEVY,1966)							480	24.90
REMARKS: LOC. VAULRY							500	25.20
							500	25.20
							520	25.60
							540	25.80
							560	25.60
							580	25.70
							600	25.30
							620	25.50
							640	25.40

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
KOSTERITE 3,2	A	0.4494	0.4119	576.54	4.30	25.53	420	22.60
CU2 SN ZN S4	C	0.3142	0.3255	567.26	3.57	25.52	440	22.90
TETRAGONAL							460	24.60
REF. FOR R: (LEVY,1966)							480	24.80
REMARKS: LOC. VAULRY							500	25.40
							500	25.40
							520	25.60
							540	25.80
							560	25.60
							580	25.70
							600	25.40
							620	25.40
							640	25.20

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MINERAL NAME                          CHRCMATICITY  CCMINANT           BRIGHTNESS
CCMPCSITICN                    SOURCE CCCRCINATES   (CCMPL.)   PURITY (VISUAL R) LAMBCA    REFLECTIVITY
CRYSTAL SYSTEM                          X       Y   WAVELENGTH  (P%)       Y       (NM)         R


KCSTERITE 2,1                    A    0.4506 C.4121    578.78   5.28     25.52      420       22.20

CU2 SN ZN S4                     C    0.3154 C.3266    568.93   4.19     25.48      44C       22.5C

TETRAGCNAL                                                                          460       24.40

REF. FCR R: (LEVY,1966)                                                             480       24.7C

REMARKS:    LOC. VALLRY                                                             500       25.2C

                                                                                    5C0       25.20

                                                                                    520       25.60

                                                                                    540       25.7C

                                                                                    56C       25.5C

                                                                                    580       25.70

                                                                                    6C0       25.4C

                                                                                    620       25.50

                                                                                    64C       25.4C
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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
KOSTERITE 1,2	A	0.4490	0.4119	575.50	4.03	25.41	420	22.60
CU2 SN ZN S4	C	0.3138	0.3250	566.74	3.33	25.41	440	22.90
TETRAGONAL							460	24.60
REF. FOR R: (LEVY,1966)							480	24.80
REMARKS: LOC. VALLRY							500	25.20
							500	25.20
							520	25.50
							540	25.70
							560	25.40
							580	25.70
							600	25.40
							620	25.10
							640	24.90

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_ε)	(R_ω)
HEMATITE	A	0.4335	0.4061	493.10	3.37	25.40 Y_ε	470	28.00	31.50
FE2 O3	A	0.4355	0.4071	494.23	2.87	29.12 Y_ω	486	27.60	31.20
TRIGONAL	C	0.2965	0.3059	481.08	6.08	25.82 Y_ε	546	26.20	30.00
	C	0.2988	0.3086	482.26	4.94	29.53 Y_ω	589	25.10	28.80
REF. FOR R: (VON GEHLEN & PILLER,1965)							650	22.80	26.50
REMARKS: LOC. ELBA,ITALY							656	22.60	26.20

Chemical Analysis:	Wt.%
Fe_2O_3	99.55
$FeTiO_3$	- -
$MnTiO_3$	0.04
$MgTiO_3$	---
	99.59

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_ε)	(R_ω)
TI-HEMATITE	A	0.4357	0.4058	492.36	2.87	23.98 Y_ε	470	26.10	29.80
FE(FE,TI)O3	A	0.4362	0.4066	493.45	2.72	27.57 Y_ω	486	25.70	29.50
TRIGONAL	C	0.2983	0.3066	480.25	5.37	24.30 Y_ε	546	24.60	28.30
	C	0.2992	0.3084	481.65	4.82	27.94 Y_ω	589	23.70	27.30
REF. FOR R: (VON GEHLEN & PILLER,1965)							650	22.00	25.20
REMARKS: LOC. SNARUM,NORWAY							656	21.90	25.10

Chemical Analysis:	Wt.%
Fe_2O_3	90.7
$FeTiO_3$	7.8
$MnTiO_3$	0.06
$MgTiO_3$	0.6
	99.16

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	 Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_ε)	 (R_ω)
ILM~~A~~ENITE	A	0.4504	0.4047	-515.00	1.49	17.32 Y_ε	470	17.30	20.60
FE TI O3	A	0.4467	0.4054	-575.75	0.61	20.22 Y_ω	486	17.10	20.40
TRIGONAL	C	0.3114	0.3130	-524.29	1.57	17.24 Y_ε	546	17.00	20.10
	C	0.3082	0.3122	-567.71	1.30	20.22 Y_ω	589	17.40	20.20
REF. FOR R: (VON GEHLEN & PILLER,1965)							650	18.00	20.40
REMARKS: LOC. ILMEN MTS.,USSR							656	18.10	20.40

Chemical Analysis:

	Wt.%
Fe_2O_3	6.6
$FeTiO_3$	80.5
$MnTiO_3$	9.4
$MgTiO_3$	3.0
	99.5

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
CREDNERITE	A	0.4373	0.4078	495.29	2.42	23.12 Y_p	430	24.70	35.80
CU MN O2	A	0.4348	0.4095	497.48	2.96	33.91 Y_g	470	24.90	36.80
MONOCLINIC	C	0.3007	0.3110	483.87	3.98	23.41 Y_p	490	24.30	36.10
	C	0.2592	0.3125	486.67	4.37	34.46 Y_g	520	24.30	36.00
REF. FOR R: (NICHOL & PHILLIPS,1965)							550	23.60	35.00
REMARKS: LOC. UNKNOWN							580	23.10	34.00
							610	22.30	32.20
							650	21.30	30.20

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
CHALCOPHANITE	A	0.4379	0.4034	487.39	2.49	9.57 Y_p	430	10.80	33.50
(ZN,MN,FE)MN3 O7.3H2 O	A	0.4252	0.4008	489.65	5.59	26.29 Y_g	470	10.60	32.20
TRICLINIC	C	0.2992	0.3047	476.39	5.31	9.68 Y_p	490	10.30	30.00
	C	0.2871	0.2942	473.12	10.88	26.96 Y_g	520	10.00	28.50
REF. FOR R: (NICHOL & PHILLIPS,1965)							550	9.60	27.30
REMARKS: LOC. UNKNOWN							580	9.40	25.70
							610	9.50	24.60
							650	9.10	23.50

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MINERAL NAME                          CHROMATICITY  DOMINANT           BRIGHTNESS
COMPOSITION                    SOURCE COORDINATES   (COMPL.)   PURITY (VISUAL R) LAMBDA   REFLECTIVITY
CRYSTAL SYSTEM                           X        Y WAVELENGTH  (P%)       Y       (NM)        R

PSILOMELANE                       A    0.4375 0.4070    493.95   2.40     22.96      430       24.70

A3 X6 MN8 O16                     C    0.3005 0.3097    482.18   4.20     23.23      470       25.00

ORTHORHOMBIC                                                                         490       24.10

REF. FOR R: (NICHOL & PHILLIPS,1964)                                                 520       23.80

REMARKS:    LOC. UNKNWON                                                             550       23.50

                                                                                     580       23.00

                                                                                     610       22.10

                                                                                     650       21.30
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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
GALLITE 1	A	0.4421	0.4051	487.13	1.41	21.65	420	23.60
CU GA S2	C	0.3036	0.3094	476.43	3.16	21.78	440	23.20
TETRAGONAL							460	23.00
REF. FOR R: (LEVY,1966)							480	22.70
REMARKS: LOC. TSUMEB							500	22.40
							500	22.40
							520	22.10
							540	22.00
							560	21.70
							580	21.40
							600	21.20
							620	21.20
							640	21.50

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
GALLITE 3	A	0.4406	0.4050	488.60	1.77	21.55	420	23.90
CU GA S2	C	0.3022	0.3085	477.40	3.72	21.72	440	23.20
TETRAGONAL							460	23.20
REF. FOR R: (LEVY,1966)							480	22.80
REMARKS: LOC. TSUMEB							500	22.70
							500	22.70
							520	22.20
							540	21.90
							560	21.50
							580	21.40
							600	21.10
							620	21.10
							640	21.10

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R
GALLITE 2	A	0.4405	0.4049	483.43	1.80	21.54	420	23.90
CU GA S2	C	0.3020	0.3084	477.78	3.83	21.72	440	23.20
TETRAGONAL							460	23.20
REF. FOR R: (LEVY,1966)							480	22.90
REMARKS: LOC. TSUMEB							500	22.70
							500	22.70
							520	22.40
							540	21.80
							560	21.40
							580	21.40
							600	21.10
							620	21.10
							640	21.10

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (Rp)	(Rg)
BRAUNITE	A	0.4391	0.4062	492.18	2.06	19.97 Yp	430	21.70	22.80
MN MN6(O8/SI O4)	A	0.4382	0.4064	492.80	2.26	20.88 Yg	470	21.50	22.50
TETRAGONAL	C	0.3015	0.3092	480.20	3.92	20.16 Yp	490	20.60	21.70
	C	0.3008	0.3091	480.95	4.17	21.10 Yg	520	20.70	21.70
REF. FOR R: (NICHOL & PHILLIPS,1965)							550	20.40	21.40
REMARKS: LOC. UNKNOWN							580	19.80	20.70
							610	19.40	20.20
							650	19.00	19.70

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	 Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	 (R_g)
HAUSMANNITE	A	0.4382	0.4073	494.43	2.23	16.85 Y_p	430	18.00	21.70
(MN,FE)MN2 O4	A	0.4368	0.4073	494.47	2.56	19.93 Y_g	470	18.10	21.40
TETRAGONAL	C	0.3013	0.3107	482.88	3.80	17.04 Y_p	490	17.80	21.20
	C	0.3000	0.3099	482.92	4.35	20.19 Y_g	520	17.50	20.80
REF. FOR R: (NICHOL & PHILLIPS,1965)							550	17.20	20.50
REMARKS: LOC. UNKNOWN							580	16.80	19.80
							610	16.40	19.20
							650	15.60	18.40

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MINERAL NAME                         CHROMATICITY   DOMINANT            BRIGHTNESS
COMPOSITION                  SOURCE COORDINATES     (COMPL.)    PURITY  (VISUAL R)  LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                          X       Y   WAVELENGTH   (P%)        Y       (NM)     (Rp )   (Rg )

PYROCHROITE                     A    0.4388 0.4052     490.32    2.18     14.99Yp     430     16.40   19.10

MN(OH)2                         A    0.4388 0.4067     493.24    2.10     17.59Yg     470     16.30   18.60

HEXAGONAL                       C    0.3009 0.3077     478.53    4.32     15.13Yp     490     16.00   18.80

                                C    0.3016 0.3100     481.42    3.78     17.78Yg     520     15.30   18.10

REF. FOR R: (NICHOL & PHILLIPS,1965)                                                  550     15.20   17.90

REMARKS:    LOC. UNKNOWN                                                              580     15.00   17.60

                                                                                      610     14.60   17.10

                                                                                      650     14.20   16.50
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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
HETAEROLITE	A	0.4379	0.4065	493.03	2.32	13.17 Y_p	430	14.30	19.00
ZN MN2 O4	A	0.4373	0.4062	492.64	2.48	17.22 Y_g	470	14.20	18.60
TETRAGONAL	C	0.3008	0.3092	481.10	4.16	13.32 Y_p	490	14.00	18.20
	C	0.3000	0.3084	480.83	4.54	17.43 Y_g	520	13.60	18.00
REF. FOR R: (NICHOL & PHILLIPS,1965)							550	13.40	17.50
REMARKS: LOC. UNKNOWN							580	13.20	17.20
							610	12.80	16.70
							650	12.20	16.00

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
GROUTITE	A	0.4415	0.4080	496.19	1.42	12.23 Y_p	430	12.80	21.40
ALPHA-MN OOH	A	0.4416	0.4059	490.23	1.49	19.82 Y_g	470	12.60	20.80
ORTHORHOMBIC	C	0.3045	0.3135	484.72	2.33	12.32 Y_p	490	12.70	20.50
	C	0.3039	0.3099	476.94	2.99	19.94 Y_g	520	12.60	20.00
REF. FOR R: (NICHOL & PHILLIPS,1965)							550	12.40	20.00
REMARKS: LOC. UNKNOWN							580	12.20	20.00
							610	12.00	19.50
							650	11.60	18.90

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
ANTIMONY	A	0.4426	0.4081	496.85	1.16	73.54 Y_p	470	75.50	77.30
SB	A	0.4434	0.4079	496.42	0.98	75.53 Y_g	546	74.70	76.60
TRIGONAL	C	0.3058	0.3143	485.18	1.78	73.98 Y_p	589	73.30	75.20
	C	0.3063	0.3145	485.07	1.57	75.92 Y_g	650	70.20	72.80

REF. FOR R: CERVELLE & CAYE (1968)

REMARKS: LOC: MEYMAC,FRANCE. SB=99%;AG=TRACES

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
DYSCRASITE	A	0.4505	0.4088	585.39	2.92	61.73 Y_p	470	59.90	62.60
AG3 SB	A	0.4536	0.4072	594.37	3.91	65.00 Y_g	546	61.50	64.00
ORTHORHOMBIC	C	0.3136	0.3200	576.82	1.93	61.53 Y_p	589	62.20	65.10
	C	0.3157	0.3195	585.42	2.36	64.54 Y_g	650	62.10	68.50

REF. FOR R: ARAYA (1968)

REMARKS: LOC: UNKNOWN

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R_p	R_m	R_g
PARADOCRASITE	A	0.4451	0.4074	494.11	0.59	67.50 Y_p	470	68.6	71.2	75.0
SB2 (SB,AS)2	A	0.4449	0.4078	496.70	0.63	70.22 Y_m	546	67.8	70.5	73.8
MONOCLINIC	A	0.4437	0.4076	495.23	0.92	73.27 Y_g	589	67.6	70.7	73.6
	C	0.3077	0.3145	481.29	1.07	67.69 Y_p	650	65.9	67.8	70.2
	C	0.3079	0.3150	483.50	0.94	70.42 Y_m				
	C	0.3066	0.3140	482.59	1.52	73.59 Y_g				

REF. FOR R: B.F. LEONARD & MEAD(1971)

REMARKS: LOC. BROKEN HILL,NEW SOUTH WALES. A NEW MINERAL

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
MELONITE	A	0.4586	0.4080	591.84	8.04	59.01 Yp	470	54.50	56.30
NI TE2	A	0.4626	0.4043	600.93	8.17	60.88 Yg	546	57.00	56.30
HEXAGONAL	C	0.3215	0.3236	583.83	5.02	58.22 Yp	589	60.40	64.00
	C	0.3239	0.3196	595.64	4.58	59.66 Yg	650	62.90	66.90

REF. FOR R: BURKE,FREE UNIV.,AMSTERDAM

REMARKS: LOC: ROBB MONTBRAY MINE,QUEBEC,CANADA

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
BISMUTH	A	0.4585	0.4097	583.74	9.08	58.55 Yp	470	53.30	58.50
BI	A	0.4555	0.4102	586.67	7.35	63.07 Yg	546	57.10	62.90
TRIGONAL	C	0.3224	0.3266	580.07	6.06	57.81 Yp	589	59.60	62.90
	C	0.3192	0.3259	577.24	4.98	62.55 Yg	650	61.60	66.40

REF. FOR R: CERVELLE & CAYE (1968)

REMARKS: LOC: ALLEMONT,FRANCE. BI=96.8%; SB=2.3%; AS=0.2%

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
KITKAITE	A	0.4581	0.4099	588.29	8.94	57.01 Yp	470	52.00	54.70
NI TE SE	A	0.4576	0.4097	588.44	8.45	59.65 Yg	546	55.80	58.30
HEXAGONAL	C	0.3220	0.3267	579.48	5.98	56.32 Yp	589	58.10	61.00
	C	0.3214	0.3259	579.87	5.61	58.96 Yg	650	60.00	62.30

REF. FOR R: BURKE,FREE UNIV.,AMSTERDAM

REMARKS: LOC: KUUSAMO,FINLAND

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
RAMMESLBERGITE	A	0.4448	0.4051	477.74	0.81	56.90 Yp	470	59.00	62.50
NI AS	A	0.4439	0.4051	482.83	1.00	59.92 Yg	546	56.80	59.90
ORTHORHOMBIC	C	0.3062	0.3109	470.11	2.09	57.06 Yp	589	56.50	59.60
	C	0.3054	0.3103	472.44	2.44	60.15 Yg	650	57.00	59.40

REF. FOR R: W.PETRUK, OTTAWA

REMARKS: LOC: EISLEBEN,GERMANY

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MINERAL NAME                        CHROMATICITY  DOMINANT          BRIGHTNESS
COMPOSITION                  SOURCE COORDINATES   (COMPL.)  PURITY (VISUAL R) LAMBDA     REFLECTIVITY
CRYSTAL SYSTEM                        X       Y   WAVELENGTH  (P%)       Y      (NM)     (Rp )  (Rg )


RAMMELSBERGITE                 A    0.4449 0.4058   483.24    0.73    56.47Yp    470     58.20  61.80

NI AS                          A    0.4437 0.4057   486.65    1.01    59.43Yg    546     56.60  59.70

ORTHORHOMBIC                   C    0.3066 0.3121   473.97    1.77    56.64Yp    589     56.00  58.90

                               C    0.3054 0.3111   475.66    2.32    59.69Yg    650     56.40  58.80

REF. FOR R: W.PETRUK, OTTAWA

REMARKS:     LOC: EISLEBEN,GERMANY



                                                                                          Re     Rw
MILLERITE                      A    0.4683 0.4175   584.99   21.29    55.24YE    470     43.60  43.90

NI S                           A    0.4605 0.4127   585.89   12.56    50.17 Yw   546     54.30  49.40

HEXAGONAL                      C    0.3377 0.3472   576.04   15.70    54.02 YE   589     57.40  51.40

                               C    0.3261 0.3331   576.92    8.80    49.46 Yw   650     58.40  52.40

REF. FOR R: BURKE,FREE UNIV.,AMSTERDAM

REMARKS:     LOC: LIBUSIN,KLADNO BOHEMIA
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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	 Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R_α	 R_β	 R_γ
ARSENOPYRITE	A	0.4518	0.4085	588.14	3.60	52.68 Y_α	470	50.8	48.7	51.8
FE AS S	A	0.4539	0.4106	584.91	6.52	52.12 Y_β	546	52.2	51.8	51.9
MONOCLINIC	A	0.4468	0.4077	603.02	0.42	51.73 Y_γ	589	53.2	52.8	51.7
	C	0.3148	0.3203	579.85	2.33	52.43 Y_α	650	53.6	52.9	51.3
	C	0.3180	0.3251	576.11	4.48	51.77 Y_β				
	C	0.3095	0.3162	600.65	0.19	51.77 Y_γ				

REF. FOR R: P.R. SIMPSON(LONDON)

REMARKS: LOC. UNKNOWN

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
STANNOPALLADINITE	A	0.4601	0.4130	585.48	12.48	53.68 Yp	460	46.20	48.50
PD3 SN2	A	0.4606	0.4109	587.78	11.37	55.30 Yg	540	53.00	54.00
HEXAGONAL	C	0.3257	0.3336	576.17	8.83	52.98 Yp	580	54.00	55.50
	C	0.3249	0.3302	578.48	7.70	54.51 Yg	660	57.00	60.00

REF. FOR R: L.VYALSOV, MOSCOW

REMARKS: LOC: UNKNOWN

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
ARSENIC	A	0.4433	0.4061	489.17	1.08	44.28 Yp	470	46.00	46.70
AS	A	0.4428	0.4054	487.11	1.23	44.57 Yg	546	44.60	44.80
TRIGONAL(PSEUDOCUBIC)	C	0.3053	0.3116	477.65	2.27	44.49 Yp	589	43.90	44.20
	C	0.3045	0.3102	475.97	2.75	44.81 Yg	650	43.50	43.80

REF. FOR R: CERVELLE & CAYE (1968)

REMARKS: LOC: STE.MARIE AUX MINE,FRANCE. AS=98%; SB=2%

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY ($R_ε$)	($R_ω$)
BREITHAUPITE	A	0.4719	0.4002	606.62	11.75	41.72 $Y_ε$	470	37.40	45.50
NI SB	A	0.4658	0.4067	594.18	11.95	51.33 $Y_ω$	546	36.90	48.20
HEXAGONAL	C	0.3312	0.3187	604.23	6.29	40.37 $Y_ε$	589	43.70	53.00
	C	0.3283	0.3261	586.24	7.51	50.18 $Y_ω$	650	51.00	58.00

REF. FOR R: BURKE, FREE UNIV.,AMSTERDAM

REMARKS: LOC: COBALT,ONTARIO CANADA

								R_p	R_g
SCHAPBACHITE(MATILDITE)	A	0.4450	0.4075	494.79	0.61	43.49 Y_p	470	44.20	45.30
AG BI S2	A	0.4453	0.4073	493.31	0.55	44.60 Y_g	546	43.80	44.90
HEXAGONAL	C	0.3077	0.3147	482.46	1.04	43.63 Y_p	589	43.40	44.40
	C	0.3079	0.3147	481.61	0.97	44.72 Y_g	650	42.60	44.00

REF. FOR R: HARRIS & THORPE (1969)

REMARKS: LOC: CANSELL RIVER,CANADA

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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R_α	R_β	R_γ
STIBNITE	A	0.4397	0.4049	439.11	1.98	41.40 Y_α	470	44.4	30.8	52.6
SB2 S3	A	0.4425	0.4090	499.93	1.16	30.13 Y_β	546	42.1	31.1	48.1
ORTHORHOMBIC	A	0.4276	0.4039	491.72	4.87	45.27 Y_γ	589	40.4	29.3	42.1
	C	0.3013	0.3079	478.22	4.15	41.78 Y_α	650	40.4	29.3	42.1
	C	0.3057	0.3160	490.15	1.66	30.35 Y_β				
	C	0.2899	0.3005	480.83	9.08	46.39 Y_γ				

REF. FOR R: P.R. SIMPSON(LONDON)

REMARKS: LOC. UNKNOWN

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
HESSITE	A	0.4420	0.4057	489.25	1.40	38.17 Y_p	460	40.30	40.70
AG2 TE	A	0.4518	0.4062	500.22	0.95	41.43 Y_g	540	38.70	40.80
MONOCLINIC	C	0.3039	0.3103	478.01	2.94	38.41 Y_p	580	37.80	41.30
	C	0.3135	0.3167	489.54	1.29	41.20 Y_g	640	37.40	43.00

REF. FOR R: L.LOGINOVA, MOSCOW

REMARKS: LOC UNKNOWN

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
GEOCRONITE	A	0.4432	0.4076	495.18	1.03	37.92 Y_p	460	39.00	43.20
27PB S 7(SE,AS)2 S3	A	0.4408	0.4060	491.03	1.67	40.70 Y_g	540	38.40	41.30
MONOCLINIC	C	0.3061	0.3139	483.38	1.71	38.11 Y_p	580	38.00	40.60
	C	0.3030	0.3100	479.27	3.29	41.01 Y_g	650	36.50	39.00

REF. FOR R: L.VYALSOV, MOSCOW

REMARKS: LOC: UNKNOWN

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
BISMUTHINITE	A	0.4425	0.4054	487.59	1.30	37.63 Y_p	470	39.50	50.60
BI2 S3	A	0.4428	0.4082	497.30	1.11	49.39 Y_g	546	37.80	50.20
ORTHORHOMBIC	C	0.3043	0.3100	476.03	2.84	37.84 Y_p	589	37.40	49.20
	C	0.3060	0.3146	485.83	1.67	49.68 Y_g	650	36.80	47.20

REF. FOR R: BURKE, FREE UNIV.,AMSTERDAM

REMARKS: LOC: AVENTURA MINE,BOLIVIA

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
LAUNAYITE	A	0.4414	0.4055	489.23	1.55	36.56 Y_p	470	38.60	46.20
22PB S 13(SB,AS)2 S3	A	0.4389	0.4056	491.07	2.14	43.13 Y_g	546	36.90	43.80
MONOCLINIC	C	0.3033	0.3096	477.72	3.24	36.81 Y_p	589	36.20	42.70
	C	0.3011	0.3083	479.24	4.17	43.56 Y_g	650	35.50	40.90

REF. FOR R: JAMBOR (1967)

REMARKS: LOC: MADOC,ONTARIO CANADA

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	REFLECTIVITY (R_g)
VEENITE	A	0.4375	0.4063	492.77	2.43	36.75 Y_p	470	39.50	45.50
2PB S.(SB,AS)2 S3	A	0.4383	0.4059	491.86	2.26	42.42 Y_g	546	37.60	43.20
ORTHORHOMBIC	C	0.3001	0.3086	481.01	4.48	37.18 Y_p	589	36.30	42.00
	C	0.3007	0.3084	479.98	4.30	42.87 Y_g	650	34.30	39.90

REF. FOR R: JAMBOR (1967)

REMARKS: LOC: MADOC,ONTARIO CANADA

SORBYITE	A	0.4380	0.4060	492.13	2.32	36.32 Y_p	470	39.00	45.00
17PB S.11(SB,AS)2 S3	A	0.4382	0.4060	492.07	2.28	41.94 Y_g	546	37.00	43.00
MONOCLINIC	C	0.3005	0.3084	480.24	4.37	36.72 Y_p	589	36.00	41.00
	C	0.3005	0.3087	480.69	4.33	42.41 Y_g	650	34.00	40.00

REF. FOR R: JAMBOR (1967)

REMARKS: LOC: MADOC,ONTARIO CANADA

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
TWINNITE	A	0.4394	0.4059	491.47	2.00	36.31 Y_p	470	38.70	45.60
PB S(SE,AS)2 S3	A	0.4374	0.4055	491.45	2.49	42.15 Y_g	546	36.90	43.00
MONOCLINIC(PSEUDO-ORTHO.)	C	0.3017	0.3090	479.55	3.87	36.65 Y_p	589	35.90	41.60
	C	0.2997	0.3074	479.75	4.77	42.65 Y_g	650	34.60	39.60

REF. FOR R: JAMBOR (1967)

REMARKS: LOC: MADOC,ONTARIO CANADA

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
HETEROMORPHITE	A	0.4442	0.4109	515.31	0.83	36.17 Y_p	450	35.70	39.30
7PB S 4SB2 S3	A	0.4442	0.4112	518.08	0.88	39.98 Y_g	550	37.00	41.00
MONOCLINIC	C	0.3086	0.3196	520.07	0.64	36.34 Y_p	579	36.50	40.30
	C	0.3088	0.3202	528.79	0.79	40.17 Y_g	640	34.40	38.00

REF. FOR R: A.RAKTSHEEV, MOSCOW

REMARKS: LOC: UNKNOWN

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
TINTINAITE	A	0.4419	0.4062	490.90	1.40	35.71 Y_p	470	37.40	43.90
5PB S 4(BI><SB)2 S3	A	0.4434	0.4071	493.17	1.00	42.61 Y_g	546	36.30	43.30
ORTHORHOMBIC	C	0.3040	0.3111	479.80	2.80	35.95 Y_p	589	35.00	41.90
	C	0.3058	0.3134	482.36	1.88	42.84 Y_g	650	35.10	42.00

REF. FOR R: BURKE, FREE UNIV.,AMSTERDAM

REMARKS: LOC: TINTINA,CANADA

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
PLAYFAIRITE	A	0.4390	0.4058	491.42	2.10	35.80 Y_p	470	38.30	42.30
16PB S.9(SB,AS)2 S3	A	0.4393	0.4059	491.51	2.03	39.64 Y_g	546	36.40	40.30
MONOCLINIC	C	0.3012	0.3086	479.60	4.10	36.16 Y_p	589	35.40	39.20
	C	0.3015	0.3089	479.68	3.95	40.02 Y_g	650	34.00	37.70

REF. FOR R: JAMBOR (1967)

REMARKS: LOC: MADOC,ONTARIO CANADA

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	CHROMATICITY COORDINATES Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	REFLECTIVITY (R_g)
STERRYITE	A	0.4401	0.4061	491.61	1.83	35.46 Yp	470	37.60	40.40
12PB S 5(SB,AS)2 S3	A	0.4399	0.4062	491.91	1.87	38.09 Yg	546	36.00	38.70
ORTHORHOMBIC	C	0.3023	0.3096	479.70	3.58	35.77 Yp	589	35.10	37.70
	C	0.3022	0.3097	480.05	3.61	38.43 Yg	650	33.90	36.30

REF. FOR R: JAMBOR (1967)

REMARKS: LOC: MADOC,ONTARIO CANADA

GUETTARDITE	A	0.4394	0.4065	492.71	1.97	34.22 Yp	470	36.30	44.20
9PB S.8(SB,AS)2 S3	A	0.4386	0.4059	491.76	2.19	41.26 Yg	546	34.80	42.00
MONOCLINIC	C	0.3020	0.3099	480.71	3.65	34.54 Yp	589	34.00	40.80
	C	0.3009	0.3085	479.87	4.21	41.69 Yg	650	32.20	39.00

REF. FOR R: JAMBOR (1967)

REMARKS: LOC: MADOC,ONTARIO CANADA

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R_α	R_β	R_γ
BOURNONITE	A	0.4405	0.4080	495.99	1.66	34.87 Y_α	470	36.3	35.5	37.6
2PB S CU2 S SB2 S3	A	0.4392	0.4062	492.15	2.03	33.34 Y_β	546	35.6	33.9	35.5
ORTHORHOMBIC	A	0.4383	0.4057	491.49	2.27	35.04 Y_γ	589	34.7	32.9	34.9
	C	0.3038	0.3129	484.19	2.65	35.16 Y_α	650	32.7	31.6	32.7
	C	0.3016	0.3094	480.40	3.86	33.66 Y_β				
	C	0.3007	0.3079	479.17	4.36	35.40 Y_γ				

REF. FOR R: P.R. SIMPSON(LONDON)

REMARKS: LOC. PRIBRAM,CSSR

[illegible]

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY R_α	R_β	R_γ
CHALCOCITE	A	0.4319	0.4039	490.88	3.86	32.43 Y_α	470	36.7	36.7	36.7
CU2 S	A	0.4323	0.4038	490.66	3.78	32.48 Y_β	546	33.3	33.3	33.1
ORTHORHOMBIC	A	0.4326	0.4029	489.51	3.75	32.33 Y_γ	589	31.7	31.8	31.5
	C	0.2941	0.3019	479.08	7.44	33.01 Y_α	650	29.6	29.7	30.2
	C	0.2944	0.3020	478.91	7.32	33.05 Y_β				
	C	0.2942	0.3009	477.99	7.53	32.88 Y_γ				

REF. FOR R: P.R. SIMPSON(LONDON)

REMARKS: LOC. UNKNOWN

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_ε)	(R_ω)
ESKEBORNITE	A	0.4726	0.4130	588.44	21.14	25.66 Y_ε	470	20.40	30.60
CU FE SE2	A	0.4628	0.4122	587.09	13.80	35.39 Y_ω	546	24.40	34.60
HEXAGONAL	C	0.3398	0.3421	579.56	14.89	24.93 Y_ε	589	26.70	36.20
	C	0.3282	0.3338	574.61	10.89	34.79 Y_ω	650	29.00	37.90

REF. FOR R: BURKE, FREE UNIV.,AMSTERDAM

REMARKS: LOC: EAGLE GROUP,CANADA

								R_p	R_g
GETCHELLITE	A	0.4360	0.4031	488.19	2.94	25.55 Y_p	470	28.40	30.70
AS SB S3	A	0.4341	0.4016	487.12	3.47	27.01 Y_g	546	25.90	27.30
MONOCLINIC	C	0.2973	0.3029	476.68	6.20	25.88 Y_p	589	25.10	26.50
	C	0.2950	0.2996	475.67	7.44	27.41 Y_g	650	24.30	25.60

REF. FOR R: BURKE, FREE UNIV.,AMSTERDAM

REMARKS: LOC: GETCHELL MINE,NEVADA,USA

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MINERAL NAME                       CHROMATICITY  DOMINANT           BRIGHTNESS
COMPOSITION               SOURCE COORDINATES   (COMPL.)  PURITY (VISUAL R) LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                    X        Y   WAVELENGTH  (P%)       Y       (NM)     (Rp )  (Rg )

STANNOIDITE                 A    0.4678 0.4137   587.13   18.30    25.08 Yp   470     20.60  22.60

CU5 SN(FE,ZN)2 S8           A    0.4664 0.4132   587.18   16.99    27.12 Yg   546     24.40  26.40

ORTHORHOMBIC                C    0.3345 0.3401   577.86   12.90    24.52 Yp   589     25.70  27.80

                            C    0.3328 0.3382   578.10   11.97    26.55 Yg   650     27.60  29.60

REF. FOR R: BURKE, FREE UNIV.,AMSTERDAM

REMARKS:    LOC: KONJO MINE,JAPAN



CINNABAR                    A    0.4381 0.4031   486.62    2.46    24.71 Yp   460     27.40  29.90

HG S                        A    0.4386 0.4082   496.12    2.10    28.33 Yg   540     25.00  29.30

TRIGONAL                    C    0.2993 0.3040   475.10    5.38    24.96 Yp   580     24.50  28.20

                            C    0.3019 0.3123   484.88    3.40    28.64 Yg   640     23.90  26.60

REF. FOR R: L.VYALSOV, MOSCOW

REMARKS:    LOC: UNKNOWN
```

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
CINNIBAR	A	0.4390	0.4038	487.24	2.21	23.88 Y_p	470	25.90	30.40
HG S	A	0.4403	0.4066	492.69	1.76	28.87 Y_g	546	23.90	29.10
TRIGONAL	C	0.3005	0.3054	475.16	4.78	24.09 Y_p	589	23.90	29.10
	C	0.3031	0.3103	497.73	3.22	29.10 Y_g	650	22.70	26.90

REF. FOR R: HABER, FREE UNIV.,AMSTERDAM

REMARKS: LOC: ZIPS-GOMORER,USSR

								R_w	R_ε
CINNABAR	A	0.4382	0.4043	488.91	2.36	24.42 Y_w	470	26.53	30.73
HG S	A	0.4364	0.4071	494.18	2.65	28.57 Y_ε	546	24.68	29.51
TRIGONAL	C	0.2999	0.3059	477.32	4.89	24.67 Y_w	589	24.17	28.03
	C	0.2995	0.3093	482.55	4.61	28.95 Y_ε	650	23.26	26.44

REF. FOR R: LOPEZ-SOLER ET AL (1970)

REMARKS: LOC: RIANO,LEON,SPAIN

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_ε)	(R_ω)
MAGNETOPLUMBITE	A	0.4396	0.4064	492.45	1.93	21.48 Y_ε	470	22.80	24.90
PB 0.6FE2 03	A	0.4393	0.4065	492.74	2.00	23.44 Y_ω	546	22.00	24.00
HEXAGONAL	C	0.3019	0.3101	481.20	3.66	21.69 Y_ε	589	21.00	23.00
	C	0.3017	0.3101	481.46	3.73	23.68 Y_ω	650	20.70	22.40

REF. FOR R: BURKE, FREE UNIV.,AMSTERDAM

REMARKS: LOC: LONG BAN,SWEDEN

								R_p	R_g
RUTILE	A	0.4395	0.4042	487.67	2.07	19.74 Y_p	470	21.30	24.70
TI 02	A	0.4400	0.4046	488.15	1.93	23.02 Y_g	546	19.90	23.20
TETRAGONAL	C	0.3010	0.3065	476.18	4.45	19.91 Y_p	589	19.50	22.80
	C	0.3016	0.3073	476.48	4.13	23.22 Y_g	650	19.10	22.25

REF. FOR R: HABER, FREE UNIV.,AMSTERDAM

REMARKS: LOC: ZIPS-GOMCRER,USSR

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	 Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R)	 (R)
NB-RUTILE(ILMENORUTILE)	A	0.4415	0.4051	487.93	1.55	19.18	470	20.30	21.40
(FE>MN)X+Y(NB>TA)2X TI2-(3X+Y)O4-Y	A	0.4411	0.4046	486.95	1.67	20.09	546	19.30	20.20
TETRAGONAL	C	0.3032	0.3089	476.25	3.37	19.30	589	19.00	19.90
	C	0.3026	0.3080	475.66	3.70	20.23	650	18.70	19.60

REF. FOR R: BURKE, FREE UNIV.,AMSTERDAM

REMARKS: LOC: LEIRA,N.E.BRAZIL

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	 Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R)	 (R)
TAPIOLITE	A	0.4444	0.4071	492.66	0.77	16.61	470	17.00	16.00
(FE,MN)TA2 O6	A	0.4420	0.4063	491.14	1.37	15.30	546	16.70	15.50
TETRAGONAL	C	0.3069	0.3136	479.93	1.46	16.67	589	16.60	15.10
	C	0.3041	0.3112	479.83	2.75	15.40	650	16.20	14.90

REF. FOR R: BURKE, FREE UNIV.,AMSTERDAM

REMARKS: LOC: N.E. BRAZIL

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_ε)	(R_ω)
TAPIOLITE	A	0.4476	0.4088	489.04	0.98	17.69 Y_ε	470	17.50	16.40
(FE,MN)TA2 06	A	0.4437	0.4062	489.04	0.98	15.84 Y_ω	546	17.80	15.90
TETRAGONAL	C	0.3108	0.3183	564.67	0.73	17.70 Y_ε	589	17.70	15.80
	C	0.3058	0.3118	476.69	2.08	15.91 Y_ω	650	17.50	15.50

REF. FOR R: BURKE, FREE UNIV.,AMSTERDAM

REMARKS: LOC: N.E. BRAZIL

								R_p	R_g
PLATTNERITE	A	0.4320	0.4065	493.70	3.71	16.50 Y_p	470	18.30	19.50
PB 02	A	0.4307	0.4049	492.17	4.09	17.24 Y_g	546	17.20	17.90
TETRAGONAL	C	0.2953	0.3060	482.06	6.49	16.81 Y_p	589	16.10	16.80
	C	0.2935	0.3029	480.46	7.52	17.58 Y_g	650	14.80	15.50

REF. FOR R: BURKE, FREE UNIV.,AMSTERDAM

REMARKS: LOC: TCHAH-KHOUNI MINE,ANARAK,IRAN

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
WOLFRAMITE	A	0.4455	0.4069	507.27	0.48	15.78 Y_p	470	15.80	18.50
(FE,MN)WO4	A	0.4456	0.4068	506.92	0.45	18.46 Y_g	546	16.00	18.70
MONOCLINIC	C	0.3088	0.3174	501.46	0.43	15.82 Y_p	589	15.70	18.40
	C	0.3088	0.3172	499.44	0.43	18.51 Y_g	650	15.40	18.00

REF. FOR R: BURKE, FREE UNIV.,AMSTERDAM

REMARKS: LOC: UNKNOWN

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_p)	(R_g)
WODGINITE	A	0.4438	0.4046	489.82	0.95	14.23 Y_p	470	14.70	15.80
(TA,NB,FE,MN,SN,ZR)16 O32	A	0.4457	0.4060	479.54	0.54	15.43 Y_g	546	14.30	15.40
MONOCLINIC	C	0.3060	0.3123	477.88	1.95	14.29 Y_p	589	14.20	15.40
	C	0.3076	0.3127	477.72	3.24	15.46 Y_g	650	13.90	15.40

REF. FOR R: BURKE, FREE UNIV.,AMSTERDAM

REMARKS: LOC: SERIDOZINHO,BRAZIL

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_ε)	(R_ω)
UMANGITE	A	0.4309	0.4004	487.34	4.28	16.27 Y_ε	470	19.00	17.40
CU3 SE2	A	0.4533	0.3780	-565.64	11.64	14.28 Y_ω	546	16.60	12.60
TETRAGONAL	C	0.2916	0.2965	476.47	8.99	16.57 Y_ε	589	15.70	12.80
	C	0.2997	0.2757	-561.78	14.40	14.59 Y_ω	650	15.40	20.40

REF. FOR R: VON GEHLEN, FRANKFURT

REMARKS: LOC: SIERRA DE UMANGO,ARGENTINA

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_ε)	(R_ω)
UMANGITE	A	0.4317	0.4003	486.82	4.10	16.00 Y_ε	470	18.60	15.80
CU3 SE2	A	0.4592	0.3798	-556.16	12.00	13.60 Y_ω	546	16.00	12.00
TETRAGONAL	C	0.2926	0.2961	474.82	8.75	16.27 Y_ε	589	16.00	12.10
	C	0.3058	0.2814	-556.86	12.76	13.34 Y_ω	650	14.60	20.10

REF. FOR R: BURKE, FREE UNIV.,AMSTERDAM

REMARKS: LOC: EAGLE GROUP,LAKE ATHABASCA,CANADA

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MINERAL NAME                            CHROMATICITY  DOMINANT              BRIGHTNESS
COMPOSITION                      SOURCE COORDINATES    (COMPL.)   PURITY  (VISUAL R)  LAMBDA    REFLECTIVITY
CRYSTAL SYSTEM                            X        Y   WAVELENGTH  (P%)        Y        (NM)    (Rε )  (Rω )

STARINGITE                         A   0.4427 0.4054    487.28     1.26     13.83 Yε     470     14.50  12.80

(FE,MN)0.5(SN,TI)4.5(TA,NB).O12
                                   A   0.4418 0.4047    486.24     1.51     12.07 Yω     546     13.90  12.10

HEXAGONAL                          C   0.3044 0.3101    476.00     2.80     13.90 Yε     589     13.70  12.00

                                   C   0.3033 0.3084    474.67     3.41     12.15 Yω     650     13.60  11.80

REF. FOR R: BURKE, FREE UNIV.,AMSTERDAM

REMARKS:    LOC: SERICCZINHO,BRAZIL



                                                                                                  Rp     Rg
KLOCKMANNITE                       A   0.4045 0.3933    489.10    10.81     10.99 Yp     470     15.50  37.40

CU SE                              A   0.4359 0.4065    493.33     2.80     34.50 Yg     546     11.90  35.60

HEXAGONAL                          C   0.2678 0.2754    478.02    20.04     11.55 Yp     589      9.80  33.80

                                   C   0.2987 0.3081    481.73     5.04     34.98 Yg     650      9.30  32.00

REF. FOR R: BURKE, FREE UNIV.,AMSTERDAM

REMARKS:    LOC: EAGLE GROUP,LAKE ATHABASCA,CANADA
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MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_ε)	(R_ω)
CASSITERITE	A	0.4408	0.4054	489.48	1.70	12.26 Y_ε	470	13.00	11.30
SN O2	A	0.4421	0.4061	490.44	1.36	10.79 Y_ω	546	12.40	10.90
TETRAGONAL	C	0.3027	0.3091	477.85	3.50	12.35 Y_ε	589	12.10	10.70
	C	0.3042	0.3108	478.57	2.77	10.86 Y_ω	650	11.90	10.50

REF. FOR R: BURKE ET AL (1969)

REMARKS: LOC: UNKNOWN

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_ε)	(R_ω)
GEIKIELITE	A	0.4422	0.4061	490.36	1.34	11.76 Y_ε	470	12.30	14.90
MG TI O3	A	0.4431	0.4068	492.14	1.09	14.40 Y_ω	546	11.90	14.50
TRIGONAL	C	0.3042	0.3110	479.10	2.74	11.83 Y_ε	589	11.60	14.40
	C	0.3055	0.3123	479.54	2.12	14.47 Y_ω	650	11.50	13.90

REF. FOR R: CERVELLE (1967)

REMARKS: LOC: CREST MORE,CALIFORNIA. MG O=29.4;FE O=3.8;TI O2=66.5

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_ε)	(R_ω)
COVELLITE	A	0.4251	0.3944	484.25	5.99	23.06 Y_ε	470	29.10	13.40
CU S	A	0.3581	0.3588	485.03	23.61	6.34 Y_ω	546	23.70	7.15
HEXAGONAL	C	0.2837	0.2856	474.65	13.24	23.66 Y_ε	589	21.15	4.20
	C	0.2284	0.2236	475.17	40.63	7.06 Y_ω	650	23.00	5.90

REF. FOR R: SIMPSON; LONDON

REMARKS: LOC: UNKNOWN. S=32.6;CU=65.5;FE=0.05;SI=0.01;AL=0.03

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_ε)	(R_ω)
COVELLITE	A	0.4195	0.3948	486.83	7.25	22.15 Y_ε	470	28.70	13.60
CU S	A	0.3666	0.3504	481.57	22.30	6.30 Y_ω	546	23.10	6.90
HEXAGONAL	C	0.2795	0.2836	476.31	14.92	22.87 Y_ε	589	20.30	3.70
	C	0.2301	0.2177	473.33	40.97	6.96 Y_ω	650	20.90	7.40

REF. FOR R: CERVELLE (1968)

REMARKS: LOC: BOR,YOUGOSLAVIA. CU=66.2;FE=0.3;S=33.2

MINERAL NAME COMPOSITION CRYSTAL SYSTEM	SOURCE	CHROMATICITY COORDINATES X	Y	DOMINANT (COMPL.) WAVELENGTH	PURITY (P%)	BRIGHTNESS (VISUAL R) Y	LAMBDA (NM)	REFLECTIVITY (R_ω)	(R_ε)
COVELLITE	A	0.3673	0.3673	485.89	20.96	6.37 Y_ω	486	11.30	27.50
CU S	A	0.4248	0.3993	488.55	5.76	23.25 Y_ε	546	7.20	24.30
HEXAGONAL	C	0.2355	0.2343	475.79	36.70	7.01 Y_ω	589	4.50	21.70
	C	0.2857	0.2923	477.52	11.50	23.87 Y_ε	656	5.90	21.80

REF. FOR R: VON GEHLEN & PILLER (1965)

REMARKS: LOC. ALGHERO, SARDINIA, ITALY

Table XI 1. Mean Transmittance Values of Some Cut Gemstones

Wavelength (nm)	440	460	480	500	520	540	560	580	600	620	640	660	
Citrine	11.8	16.2	21.5	27.4	33.6	39.7	45.4	50.8	55.3	59.1	62.6	66.0	
Amethyst	33.9	38.7	38.7	36.2	33.4	31.9	32.0	33.7	36.5	40.2	44.1	47.5	
Chrysoberyl	39.2	42.9	43.4	42.5	47.3	56.0	66.5	75.0	80.5	83.5	84.8	86.2	Sp_1
Chrysoberyl	9.2	11.8	12.6	13.1	17.4	25.8	36.9	48.5	57.4	63.1	67.0	70.1	Sp_2
Spinel	0.0	0.1	0.1	0.1	0.1	0.6	2.3	6.6	13.8	21.9	29.9	37.9	
Syn. Ruby(1)	0.4	2.2	3.2	1.8	0.6	0.2	0.3	1.7	8.9	24.2	41.7	51.5	
Syn. Ruby(2)	6.0	8.6	6.5	4.7	4.1	4.5	6.8	13.7	29.0	48.1	61.6	68.0	
Almandine(1)	26.2	27.9	24.1	14.2	11.1	15.8	19.6	20.2	28.8	38.7	47.6	53.9	
Almandine(2)	31.8	33.6	29.9	18.8	15.0	20.1	24.1	24.2	31.7	40.3	47.6	51.3	

Matching Liquid

Di-iodo Methane R.I. = 1.74 for Chrysoberyl & Synthetic Ruby

Rayner = 1.70 for Spinel

Rayner = 1.55 for Citrine & Amethyst

Cargille = 1.78 for Almandine

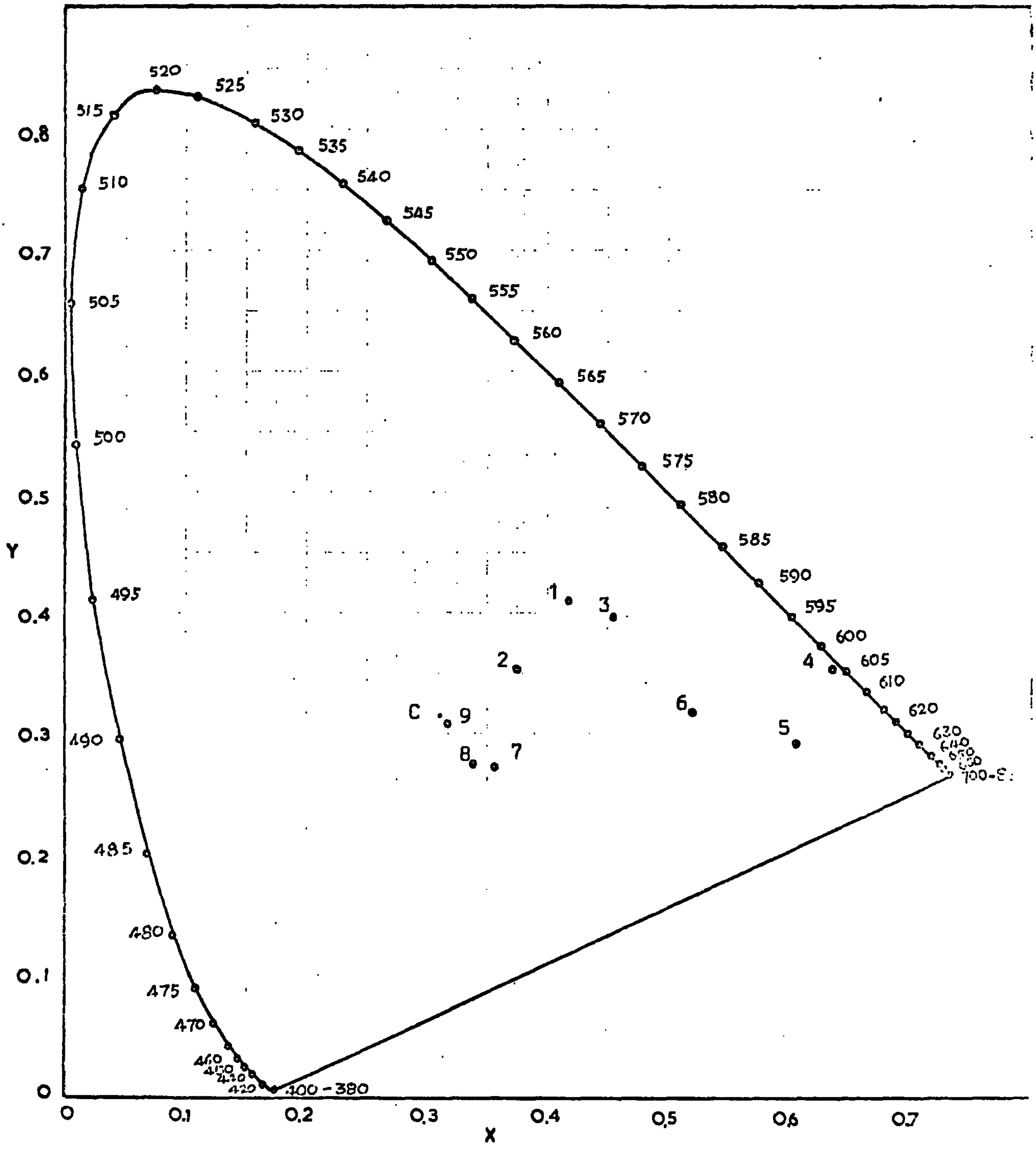
Table XI 2.

QUANTITATIVE COLOUR VALUES OF SOME CUT GEMSTONES.

	Chromaticity coordinates x	Chromaticity coordinates y	Dominant or Complementary Wavelength	Excitation purity (Pe %)
Under Tungsten Light (Source A)				
Citrine	0.5203	0.4245	588.21	62.19
Chrysoberyl Sp1	0.5006	0.3940	591.88	38.31
Chrysoberyl Sp2	0.5556	0.4050	593.59	71.57
Spinel	0.6595	0.3397	608.32	99.65
Synthetic Ruby Sp1	0.6711	0.3064	633.26	84.55
Synthetic Ruby Sp2	0.6189	0.3417	615.97	72.92
Almandine Sp1	0.5163	0.3573	-508.66	29.80
Almandine Sp2	0.4969	0.3643	-512.05	23.99
Amethyst	0.4635	0.3940	-511.39	7.58
Under Average Daylight (Source C)				
Citrine	0.4.72	0.4100	579.46	53.86
Chrysoberyl Sp1	0.3745	0.3537	585.19	27.30
Chrysoberyl Sp2	0.4641	0.3955	586.86	62.54
Spinel	0.6407	0.3567	603.60	99.38
Synthetic Ruby Sp1	0.6063	0.2945	634.35	73.46
Synthetic Ruby Sp2	0.5197	0.3185	614.82	56.30
Almandine Sp1	0.3560	0.2731	-502.74	26.00
Almandine Sp2	0.3387	0.2746	-509.91	22.15
Amethyst	0.3186	0.3087	-502.11	4.65

* – sign indicates complementary wavelength.

Figure XI 1. Chromaticity diagram showing the colour distributions of some cut gemstones under average daylight (CIE source C).



Legen for Figure XI 1.

	Gemstones	Weight
1.	Citrine; brilliant cut,circular	1.22 carat
2.	Chrysoberyl Sp 1; mixed cut	0.58 "
3.	Chrysoberyl Sp 2; cushion-shaped cut	1.42 "
4.	Spinel; trap cut, 8-sided	1.30 "
5.	Synthetic ruby Sp 1; brilliant cut,circular	0.91 "
6.	Synthetic ruby Sp 2; mixed cut,oval	1.28 "
7.	Almandine Sp 1; cabochon with a concave base	0.99 "
8.	Almandine Sp 2; " " " " "	0.91 "
9.	Amethyst; fancy cut, hart-shape	3.01 "

Figure XI 2.

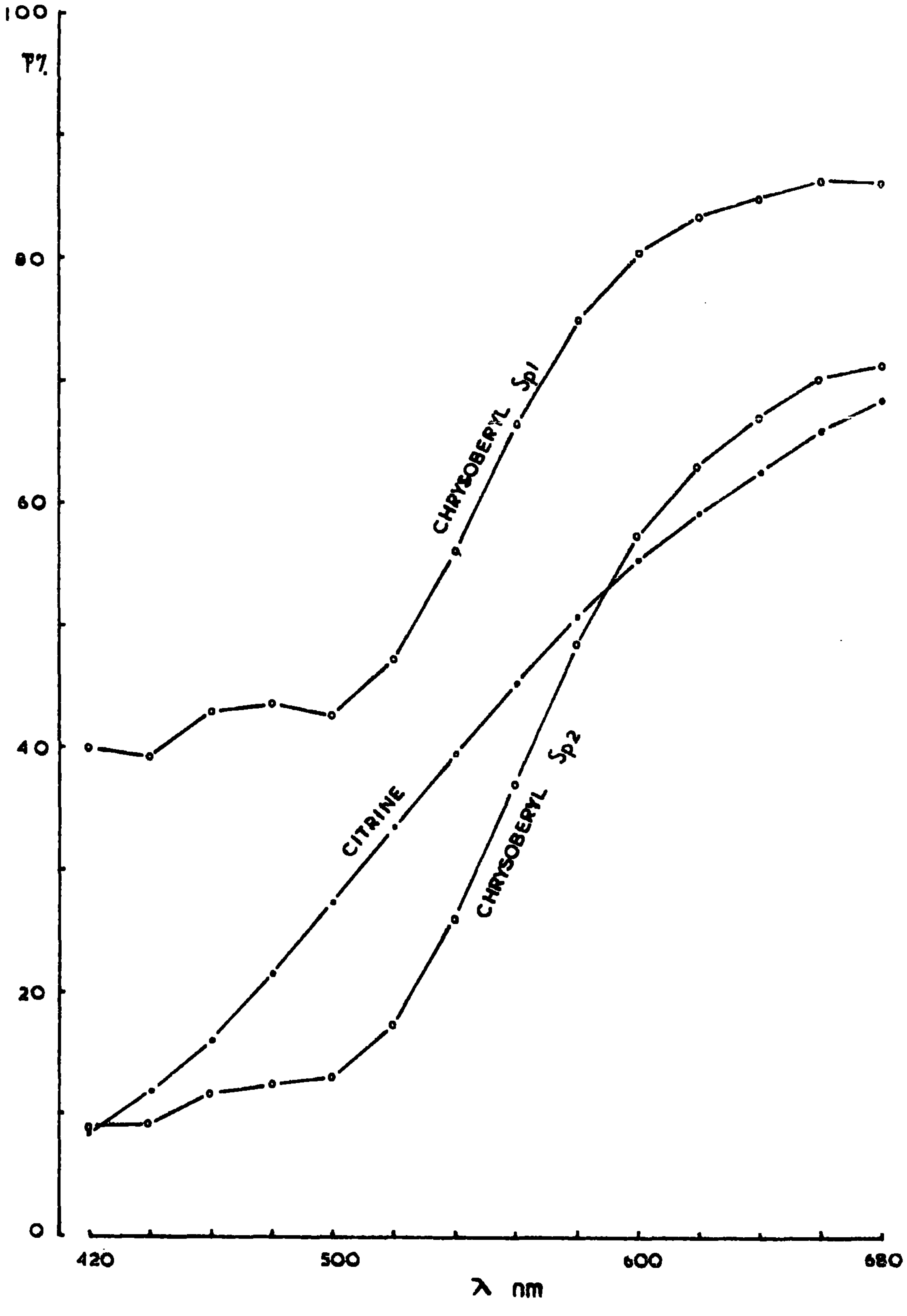

100
T%
80
60
40
20
0
420
500
600
680
λ nm
CHRYSOBERYL Sp1
CITRINE
CHRYSOBERYL Sp2

Figure XI 3.

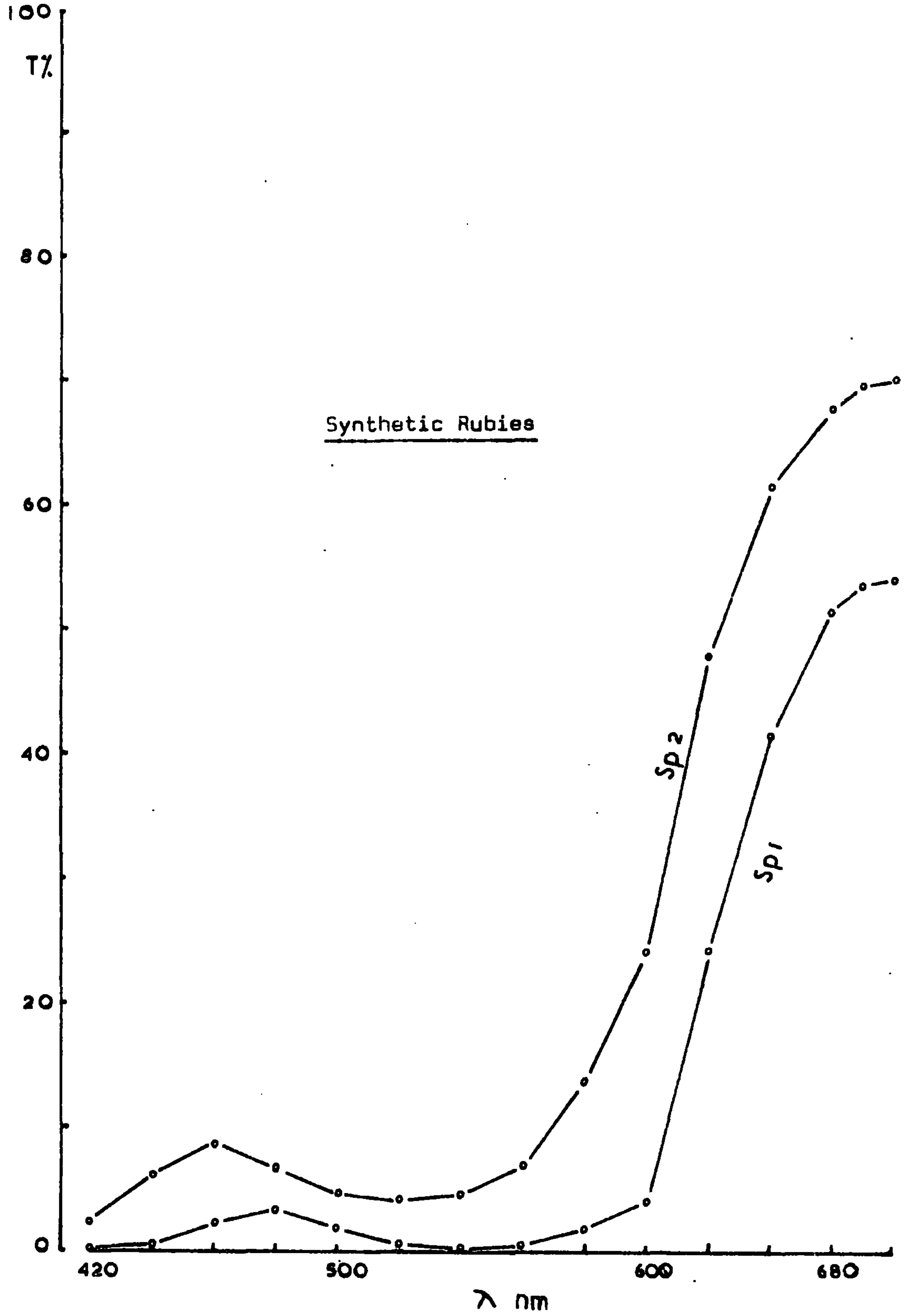
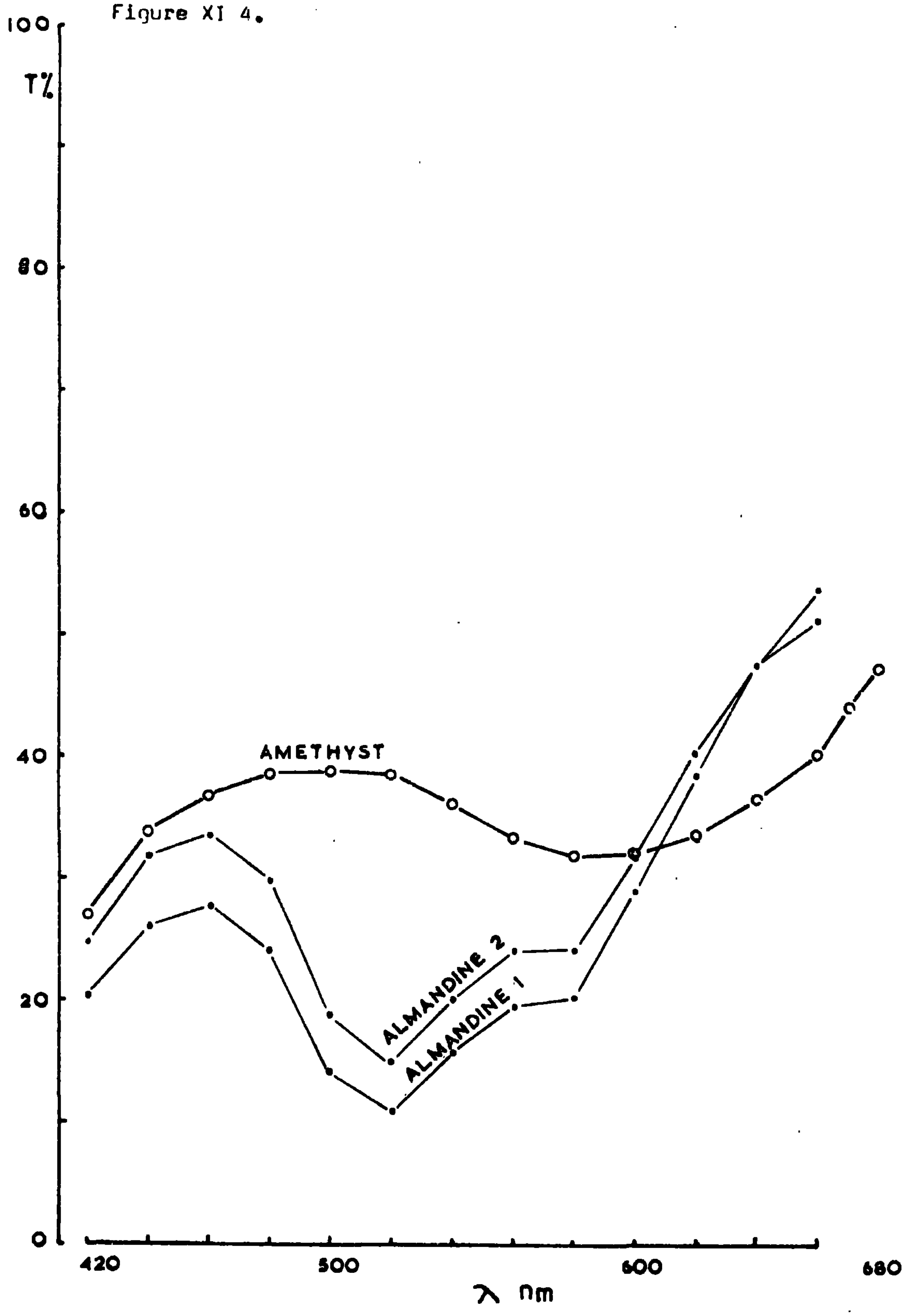
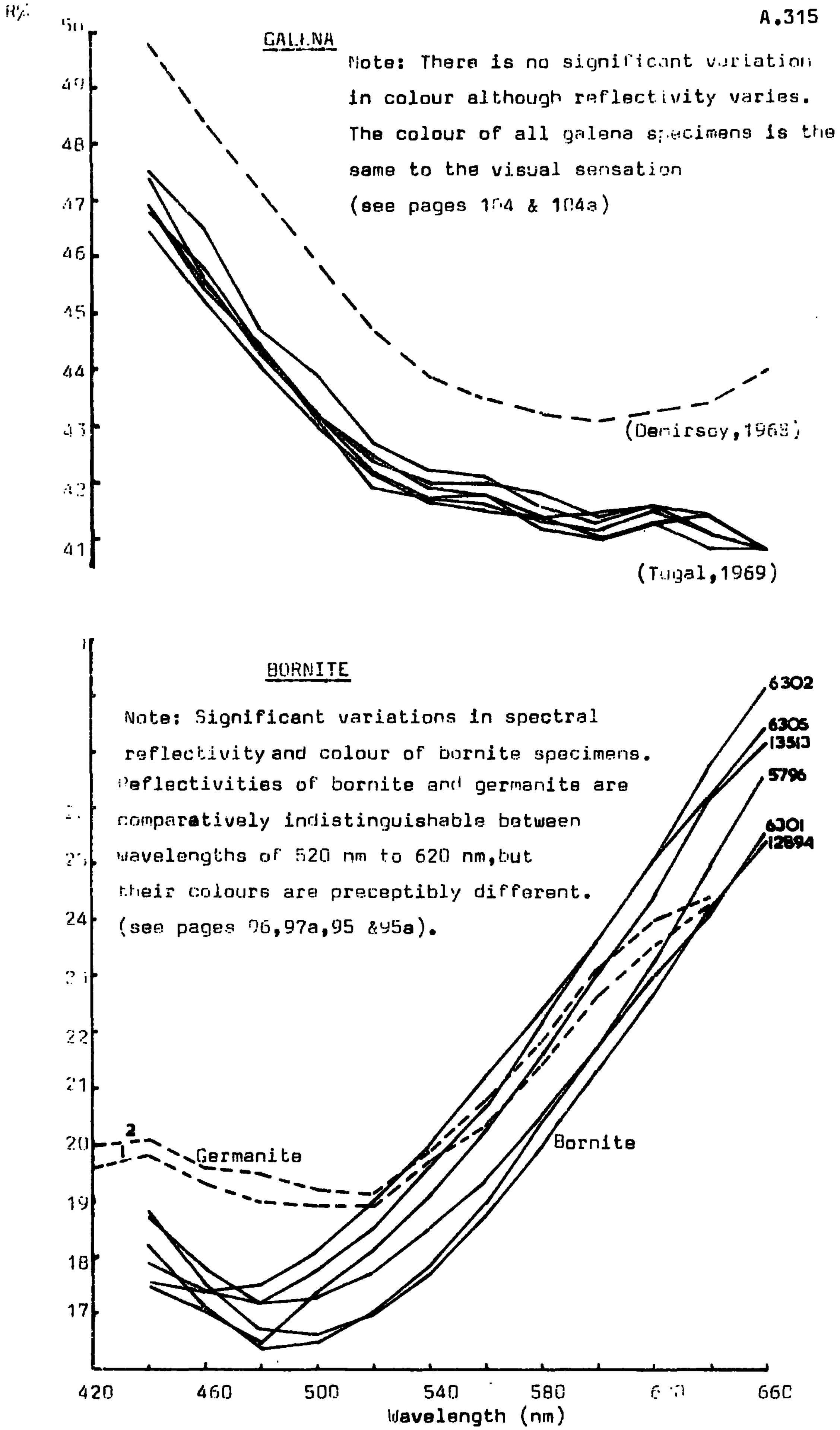


Figure XI 4.


100
T%
80
60
40
20
0
420
500
600
680
λ nm
AMETHYST
ALMANDINE 2
ALMANDINE 1



Note: There is no significant variation in colour although reflectivity varies. The colour of all galena specimens is the same to the visual sensation (see pages 104 & 104a)

Note: Significant variations in spectral reflectivity and colour of bornite specimens. Reflectivities of bornite and germanite are comparatively indistinguishable between wavelengths of 520 nm to 620 nm, but their colours are preceptibly different. (see pages 96,97a,95 &95a).

Figure XII 1. Showing marked variations in spectral reflectivity values quoted for specific minerals. (see pages 112 & 46).

Appendix III 1.

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CR:PROC OPTIONS(MAIN);


       SPECR:PROC OPTIONS(MAIN);
             /*SPECR IS A PROGRAM TO COMPUTE SPECTRAL REFLECTIVITY OF        */
             /*MINERAL FROM GALVO READINGS.                                   */
              DCL(R(N),S(N),W(N),A(N),B(N),G(T),GG(T))CONTROLLED FLOAT;
              DCL(I,J,SUM,GO)FIXED BIN;
             DCL(M,TITLE)CHAR(50)VAR;
       TAKE:GET LIST(TITLE);
             GET LIST(N);
             ALLOCATE R,S,W,A,B;
             DO I=1 TO N;
             GET LIST(S(I));
             END;
             GET LIST(T);
             GET LIST(W);
              PUT EDIT(TITLE,'SPECTRAL REFLECTIVITY')(SKIP(2),A,SKIP(2),COL
                        (50),A);
             PUT EDIT('WAVELENGTH NM',W)(SKIP(2),A,COL(22),(N)(F(5,1),X(3)))
                        ;
      START:GET LIST(M);
             ON ENDFILE(SCARDS)GOTO FIN;
             DO I=1 TO N;
              ALLOCATE G,GG;
             DO J=1 TO T;
             SUM=0;
             GET LIST(G(J));
             SUM=SUM+G(J);
             A(I)=SUM/T;
             END;
             DO J=1 TO T;
             SUM=0;
             GET LIST(GG(J));
             SUM=SUM+GG(J);
             B(I)=SUM/T;
             END;
              GET LIST(GO);
              R(I)=(A(I)-GO)/(B(I)-GO)*S(I);
             END;
              PUT EDIT(M,R)(SKIP(2),A,COL(22),(N)(F(5,2),X(3)));
             GOTO START;
        FIN:END;
```

```
ECT:PROC OPTIONS(MAIN);


ST
      REFLECT:PROC OPTIONS(MAIN);
             /*REFLECT IS A PROGRAM TO COMPUTE TRISTIMULUS VALVES AND      */
             /*CHROMATICITY COORDINATES OF OBJECT COLOURS BY WEIGHTED     */
             /*ORDINATE METHOD.                                            */
             DCL(K(M),R(M),A(N),B(N),H(N,C),D(N,C))CONTROLLED FLOAT;
             DCL(TOT(3),V(3),Q(3),T,P)FLOAT;
             DCL(I,J,C,Z,M,N)FIXED BIN,(X,Y)CHAR(100)VAR;
             ON ENDFILE(SCARDS)GOTO LAST;
             /*READ IN MEASURED SPECTRAL REFLECTIVITY VALUES               */
         RESET:GET LIST(M,X);
               ALLOCATE K,R;
                   GET LIST(K,R);
                    PUT SKIP(4);
                    PUT PAGE EDIT('MEASURED REFLECTIVITY','WAVELENGTH')(COL
                             (49),A,SKIP(2),COL(18),A,SKIP);
                   IF M<=6 THEN DO;
1                   PUT EDIT((K(I) DO I=1 TO M))(COL(38+7*I),F(3));
1                   PUT EDIT(X)(COL(18),A);
1                   PUT EDIT((R(I) DO I=1 TO M))(COL(38+7*I),F(5,2));
1                  END;
                  ELSE DO;
1                   PUT EDIT((K(I) DO I=1 TO 6))(COL(38+7*I),F(3));
1                   PUT EDIT(X)(COL(18),A);
1                   PUT EDIT((R(I) DO I=1 TO 6))(COL(38+7*I),F(5,2));
1                  IF M<=12 THEN DO;
2                   PUT SKIP(2);
2                   PUT EDIT((K(I) DO I=7 TO M))(COL(45+7*MOD(I-1,6)),F(3));
2                   PUT EDIT((R(I) DO I=7 TO M))(COL(45+7*MOD(I-1,6)),
                             F(5,2));
2                  GOTO L1;
2                  END;
1                  IF (M>12)&(M<19) THEN DO;
2                   PUT SKIP(2);
2                   PUT EDIT((K(I) DO I=7 TO 12))(COL(45+7*MOD(I-1,6)),
                             F(3));
2                   PUT EDIT((R(I) DO I=7 TO 12))(COL(45+7*MOD(I-1,6)),
                             F(5,2));
2                   PUT SKIP(2);
2                   PUT EDIT((K(I) DO I=13 TO M))(COL(45+7*MOD(I-1,6)),
                             F(3));
2                   PUT EDIT((R(I) DO I=13 TO M))(COL(45+7*MOD(I-1,6)),
                             F(5,2));
2                  END;
1                  ELSE DO;
2                   PUT SKIP(2);
2                   PUT EDIT((K(I) DO I=7 TO 12))(COL(45+7*MOD(I-1,6)),
                             F(3));
2                   PUT EDIT((R(I) DO I=7 TO 12))(COL(45+7*MOD(I-1,6)),
                             F(5,2));
2                   PUT SKIP(2);
2                   PUT EDIT((K(I) DO I=13 TO 18))(COL(45+7*MOD(I-1,6)),
                              F(3));
2                   PUT EDIT((R(I) DO I=13 TO 18))(COL(45+7*MOD(I-1,6)),
                              F(5,2));
2                   PUT SKIP(2);
2                   PUT EDIT((K(I) DO I=19 TO M))(COL(45+7*MOD(I-1,6)),
```

```
CT:PROC OPTIONS(MAIN);
```

```
,T
                              F(3));
                   PUT EDIT((R(I) DO I=19 TO M))(COL(45+7*MOD(I-1,6)),
                              F(5,2));
                  END;
                 END;
           L1:GET LIST(N,C,Z);
              ALLOCATE A,B,H,D;
              GET LIST(A);
             DO I=1 TO N;
                IF A(I)<K(1) THEN
              DO;
                B(I)=R(1)+((A(I)-K(1))*(R(2)-R(1))/(K(2)-K(1)));
                GOTO KWINT;
              END;
             J=2;
        ZWOGE:IF A(I)=K(J) THEN
              DO;
                B(I)=R(J);
                GOTO KWINT;
              END;
                IF A(I)<K(J) THEN
              DO;
                B(I)=R(J-1)+((A(I)-K(J-1))*(R(J)-R(J-1))/(K(J)-K(J-1)));
                GOTO KWINT;
              END;
             J=J+1;
                IF J<=M THEN
                GOTO ZWOGE;
                IF A(I)>K(M) THEN
              DO;
                B(I)=R(M)+((A(I)-K(M))*(R(M)-R(M-1))/(K(M)-K(M-1)));
              END;
        KWINT:END;
        PLONK:TOT=0;
        SPLUD:GET LIST(P,Y);
              DO I=1 TO N;
              GET LIST(H(I,1),H(I,2),H(I,3));
              DO C=1 TO 3;
                D(I,C)=B(I)*H(I,C);
              END;
              END;
                      PUT SKIP(3);
                     PUT EDIT(X,'WAVELENGTH','REFLECTIVITY','ENERGY ',
                             'DISTRIBUTION')(COL(25),A,SKIP(2),COL(23),A,
                              COL(34),A,COL(58),A,A);
              DO I=1 TO N;
                  PUT FDIT(A(I),B(I),(D(I,C) DO C=1 TO 3))(COL(24),
                         F(3),COL(37),F(6,3),COL(52),F(8,4),2(F(12,4)));
              DO C=1 TO 3;
                 TOT(C)=TOT(C)+D(I,C);
              FND;
              END;
              DO C=1 TO 3;
                 V(C)=TOT(C)/P;
```

```
CT:PROC OPTIONS(MAIN);
```

```
        END;
           T=SUM(V);
        DO C=1 TO 3;
           Q(C)=V(C)/T;
        END;
           PUT EDIT('SUMS',(TOT(C) DO C=1 TO 3))(COL(30),A,COL(53),
                    F(6,4),3(F(12,4)));
          PUT EDIT(Y,'X','Y','Z','TRISTIMULUS VALUES',(V(C) DO C=1 TO
                    3),'CHROMATICITY COORDINATES',(Q(C) DO C=1 TO 3))
                    (SKIP(3),COL(20),A,SKIP(2),COL(53),A,COL(65),A,
                    COL(77),A,SKIP(2),COL(27),A,3(F(12,4)),SKIP(2),
                    COL(23),A,3(F(12,4)));
           Z=Z-1;
           IF Z=0 THEN
           DO;
            FREE A,B,K,P;
            GOTO RESET;
           END;
           ELSE GOTO BLANK;
LAST:END REFLECT;
```

Appendix VI 1 b.

Example of listing of the programme "REFLECT" of Appendix VI 1 a.

```
12              (number of wavlengths used in the measurement of R% or T%)
'BORNITE SP. 6305(W.H, 1971)'
440 460 480    to    620 640 660
17.55 17.42 17.53               etc.
81              (number of weighted ordinates from 380 to 780 nm)
3               (for tristimulus values X,Y,Z)
2               (for two light sources)
380 385 390     to    770 775 780
'1931 CIE STANDARD SOURCE A'
0.0006 0.0000 0.0029
0.0011 0.0000 0.0053
0.0024 0.0000 0.0113        (colour-matching functions weighted by
                            relative spectral distribution of CIE
        etc.                source A)

0.0011 0.0000 0.0000
0.0011 0.0000 0.0000
0.0000 0.0000 0.0000
0.0000 0.0000 0.0000
'1931 CIE STANDARD SOURCE C'
0.0022 0.0000 0.0101
0.0041 0.0002 0.0197        (colour-matching functions weighted by
                            relative spectral distribution of CIE
        etc.                source C)

0.0003 0.0000 0.0000
0.0000 0.0000 0.0000
14
'BORNITE SP.NGD 6(TUGAL, 1969)'
440 460 480    to    660 680 700
16.70 16.60 17.26              etc.
81
3
2
380 385 390 395     to      770 775 780
```

```
'1931 CIE STANDARD SOURCE A'
0.0006 0.0000 0.0029
0.0011 0.0000 0.0053
```

etc.

```
0.0000 0.0000 0.0000
'1931 CIE STANDARD SOURCE C'
0.0022 0.0000 0.0101
0.0041 0.0002 0.0197
```

and so on.

```
        [illegible]: PROC OPTIONS(MAIN);
             /*[illegible] OF [illegible] CONSTANT*/
             /*DOMINANT WAVELENGTHS                                           */
              DCL(W(N),A(N),B(N),R(N),S(N))CONTROLLED FLOAT;
              DCL(X,Y)FLOAT;
             DCL(TITLE)CHAR(100)VAR;
             DCL(P(N))CONTROLLED FIXED BIN;
             DCL(N,I)FIXED BIN;
              ON ENDFILE(SYSIN)GOTO FIN;
        [illegible]: GET LIST(TITLE,X,Y);
             /*READ IN NUMBER OF WAVELENGTH                                   */
              GET LIST(N);
             ALLOCATE W,A,B,R,S,P;
             /*READ IN WAVELENGTHS AND COORDINATES                            */
              DO I=1 TO N;
1             GET LIST(W(I),A(I),B(I));
1            P(I)=0;
1             IF ABS(A(I)-X)<ABS(B(I)-Y) THEN DO;
2             R(I)=(A(I)-X)/(B(I)-Y);
2            P(I)=2;
2             END;
1             ELSE DO;
2             S(I)=(B(I)-Y)/(A(I)-X);
2            P(I)=1;
2             END;
1             END;
           PUT SKIP EDIT('SLOPES OF LINES OF CONSTANT DOMINANT WAVELENGTH')
                         (COL(23),A,SKIP(2));
             PUT EDIT(TITLE)(COL(23),A);
             PUT EDIT('WAVELENGTH','(X-XS)/(Y-YS)','(Y-YS)/(X-XS)')(SKIP(2
                     ),COL(17),A,COL(43),A,COL(60),A);
              DO I=1 TO N;
1             PUT SKIP EDIT(W(I))(COL(17),F(3));
1            IF P(I)=2 THEN
1             PUT EDIT(R(I))(COL(41),F(9,5));
1            ELSE PUT EDIT(S(I))(COL(61),F(9,5));
1            END;
          FIN:END;
```

```
'SOURCE A COMBINED WITH NEUTRAL FILTER(20%)(x=0.4473,y=0.4196)'

0.4473  0.4196

320              (number of wavelengths)

380  0.17411  0.00496

381  0.17409  0.00496

382  0.17407  0.00497


          etc.    (wavelength & chromaticity coordinates of
                                      equal-energy spectrum)


697  0.73465  0.26535

698  0.73467  0.26533

699  0.73469  0.26531
```

Table VI 1. Slopes of Lines of Constant Dominant Wavelength for C.I.E. Standard Sources A,B,C and Source E (Equal-energy, Wavelength basis) (from Judd 1933)

Source A		Source B		Wave-length (nm)	Source C		Source E	
r_1	r_2	r_1	r_2		r_1	r_2	r_1	r_2
+0.67950		+0.50303		380	+0.43688		+0.48508	
0.67954		0.50307		381	0.43693		0.48513	
0.67957		0.50311		382	0.43698		0.48517	
0.67963		0.50319		383	0.43706		0.48525	
0.67968		0.50326		384	0.43714		0.48532	
+0.67972		+0.50330		385	+0.43719		+0.48537	
0.67980		0.50340		386	0.43731		0.48548	
0.67986		0.50347		387	0.43739		0.48555	
0.67991		0.50355		388	0.43747		0.48563	
0.68000		0.50365		389	0.43759		0.48574	
+0.68008		+0.50375		390	+0.43770		+0.48584	
0.68016		0.50385		391	0.43782		0.48595	
0.68024		0.50395		392	0.43793		0.48606	
0.68035		0.50408		393	0.43808		0.48620	
0.68046		0.50421		394	0.43822		0.48633	
+0.68052		+0.50430		395	+0.43832		+0.48643	
0.68066		0.50445		396	0.43850		0.48659	
0.68076		0.50458		397	0.43865		0.48673	
0.68087		0.50471		398	0.43879		0.48687	
0.68102		0.50489		399	0.43899		0.48705	
+0.68115		+0.50504		400	+0.43917		+0.48722	
0.68130		0.50522		401	0.43936		0.48740	
0.68143		0.50538		402	0.43954		0.48757	
0.68157		0.50553		403	0.43971		0.48774	
0.68171		0.50571		404	0.43991		0.48792	
+0.68189		+0.50591		405	+0.44013		+0.48813	
0.68202		0.50607		406	0.44031		0.48830	
0.68222		0.50630		407	0.44057		0.48854	
0.68241		0.50651		408	0.44081		0.48877	
0.68265		0.50679		409	0.44111		0.48906	
+0.6829		+0.5071		410	+0.4414		+0.4893	
0.6831		0.5074		411	0.4417		0.4897	
0.6834		0.5076		412	0.4421		0.4900	
0.6836		0.5079		413	0.4424		0.4903	
0.6839		0.5082		414	0.4427		0.4906	
+0.6841		+0.5085		415	+0.4430		+0.4909	
0.6846		0.5089		416	0.4435		0.4913	
0.6848		0.5092		417	0.4438		0.4916	
0.6855		0.5100		418	0.4446		0.4924	
0.6857		0.5102		419	0.4449		0.4927	
+0.6864		+0.5110		420	+0.4457		+0.4935	
0.6870		0.5117		421	0.4465		0.4942	
0.6877		0.5124		422	0.4473		0.4950	
0.6886		0.5133		423	0.4482		0.4959	
0.6892		0.5140		424	0.4490		0.4966	

Table VI 1 (continued)

r_1	r_2	r_1	r_2		r_1	r_2	r_1	r_2
+0.6903		+0.5152		425	+0.4502		+0.4979	
0.6914		0.5163		426	0.4515		0.4991	
0.6923		0.5172		427	0.4524		0.5000	
0.6933		0.5184		428	0.4537		0.5012	
0.6944		0.5196		429	0.4550		0.5024	
+0.6957		+0.5209		430	+0.4564		+0.5038	
0.6972		0.5225		431	0.4581		0.5055	
0.6988		0.5241		432	0.4598		0.5072	
0.7000		0.5254		433	0.4613		0.5086	
0.7020		0.5275		434	0.4635		0.5108	
+0.7037		+0.5293		435	+0.4654		+0.5126	
0.7056		0.5314		436	0.4676		0.5148	
0.7074		0.5332		437	0.4695		0.5167	
0.7095		0.5354		438	0.4719		0.5190	
0.7115		0.5375		439	0.4742		0.5212	
+0.7140		+0.5402		440	+0.4771		+0.5240	
0.7165		0.5428		441	0.4798		0.5267	
0.7191		0.5455		442	0.4827		0.5296	
0.7215		0.5481		443	0.4855		0.5323	
0.7244		0.5511		444	0.4888		0.5354	
+0.7277		+0.5546		445	+0.4926		+0.5391	
0.7310		0.5581		446	0.4964		0.5428	
0.7345		0.5617		447	0.5002		0.5465	
0.7382		0.5657		448	0.5045		0.5507	
0.7424		0.5702		449	0.5094		0.5555	
+0.7465		+0.5746		450	+0.5141		+0.5600	
0.7508		0.5791		451	0.5190		0.5648	
0.7556		0.5842		452	0.5244		0.5701	
0.7602		0.5891		453	0.5297		0.5753	
0.7655		0.5947		454	0.5358		0.5811	
+0.7708		+0.6003		455	+0.5419		+0.5871	
0.7766		0.6065		456	0.5486		0.5935	
0.7826		0.6129		457	0.5555		0.6003	
0.7894		0.6201		458	0.5633		0.6079	
0.7963		0.6273		459	0.5711		0.6155	
+0.8036		+0.6351		460	+0.5796		+0.6236	
0.8110		0.6429		461	0.5881		0.6319	
0.8192		0.6516		462	0.5975		0.6410	
0.8281		0.6611		463	0.6073		0.6510	
0.8382		0.6717		464	0.6192		0.6622	
+0.8490		+0.6831		465	+0.6317		+0.6743	
0.8610		0.6958		466	0.6455		0.6877	
0.8747		0.7103		467	0.6612		0.7030	
0.8899		0.7263		468	0.6788		0.7200	
0.9062		0.7435		469	0.6976		0.7382	
+0.9251		+0.7635		470	+0.7195		+0.7594	
0.9455		0.7852		471	0.7434		0.7825	
0.9682		0.8094		472	0.7702		0.8084	
0.9954	+1.0066	0.8364		473	0.8002		0.8372	
+1.0217	0.9788	0.8669		474	0.8342		0.8699	

Table VI 1 (continued)

r1	r2	r1	r2		r1	r2	r1	r2
	[illegible]	+0.9018		475	+0.8736		+0.9075	
	0.9168	0.9421		476	0.9193		0.9510	+1.0515
	0.8832	0.9879	+1.0122	477	0.9719	[illegible]	+1.0009	0.9991
	0.8479	+1.0405	0.9611	478	+1.0328	0.9542		0.9449
	0.8107		0.9076	479		0.9050		0.8883
	+0.7713		+0.8515	480		+0.8391		+0.8290
	0.7296		0.7927	481		0.7705		0.7670
	[illegible]		0.7322	482		0.7002		0.7033
	[illegible]		0.6695	483		0.6277		0.6374
	[illegible]		0.6056	484		0.5543		0.5704
	+0.5358		0.5397	485		+0.4789		+0.5013
	0.4953		0.4717	486		+0.4015		+0.4302
	0.4433		0.4023	487		+0.3227		+0.3577
	0.3899		0.3315	488		+0.2428		+0.2838
	0.3353		0.2596	489		+0.1619		+0.2089
	+0.2797		+0.1871	490		+0.0805		+0.1323
	+0.2224		+0.1127	491		−0.0026		+0.0560
	+0.1638		+0.0371	492		−0.0869		−0.0225
	+0.1051		−0.0382	493		−0.1706		−0.1008
	+0.0461		−0.1131	494		−0.2537		−0.1765
	−0.0123		−0.1877	495		−0.3361		−0.2559
	−0.0708		−0.2619	496		0.4185		0.3329
	−0.1287		−0.3350	497		0.4993		0.4087
	−0.1860		−0.4074	498		0.5793		0.4838
	−0.2423		−0.4784	499		0.6579		0.5574
	−0.2979		−0.5486	500		−0.7357		−0.6304
	0.3519		0.6169	501		0.8114		0.7013
	0.4050		0.6842	502		0.8863		0.7714
	0.4569		0.7504	503	−1.0415	0.9601		0.8403
	0.5075		0.8153	504	0.9681	−1.0330		0.9081
	−0.5571		−0.8796	505	[illegible]		−1.0252	−0.9754
	0.6062	−1.0601	0.9433	506	0.8490		0.9594	−1.0423
	0.6539	0.9939	−1.0061	507	0.8072		0.9021	
	0.7006	0.9359		508	0.7567		0.8516	
	0.7459	0.8850		509	0.7178		0.8068	
	−0.7902	−0.8396		510	−0.6826		−0.7666	
	0.8329	0.7992		511	0.6507		0.7304	
	0.8742	0.7629		512	0.6216		0.6977	
	0.9143	0.7298		513	0.5947		0.6677	
	0.9530	0.6998		514	0.5699		0.6403	
−1.0104	−0.9897	−0.6726		515	−0.5471		−0.6153	
0.9767	−1.0239	0.6483		516	0.5263		0.5928	
0.9473		0.6262		517	0.5072		0.5722	
0.9206		0.6057		518	0.4890		0.5528	
0.8969		0.5865		519	0.4718		0.5347	
−0.8757		−0.5688		520	−0.4557		−0.5178	
0.8568		0.5522		521	0.4403		0.5019	
0.8399		0.5368		522	0.4258		0.4870	
0.8244		0.5221		523	0.4117		0.4726	
0.8101		0.5079		524	0.3979		0.4587	

Table VI 1 (continued)

r_1	r_2	r_1	r_2		r_1	r_2	r_1	r_2
[illegible]		−0.4938		525	[illegible]		[illegible]	
[illegible]		0.4802		526	[illegible]		0.6313	
[illegible]		[illegible]		527	0.3772		[illegible]	
[illegible]		0.4531		528	[illegible]		0.4045	
0.7367		0.4398		529	0.3306		0.3913	
−0.7[illegible]		−0.4267		530	−0.3174		−0.3762	
[illegible]		0.4137		531	0.3643		0.3652	
0.7179		0.4008		532	0.2913		0.3523	
0.7021		0.3879		533	[illegible]		0.3391	
0.6913		0.3749		534	0.2650		0.3263	
−0.6758		−0.3619		535	−0.2519		−0.3135	
[illegible]		0.3490		536	0.2356		0.3005	
[illegible]		0.3357		537	0.2252		0.2872	
0.6493		0.3225		538	[illegible]		0.2737	
0.6369		0.3088		539	0.1977		0.2602	
[illegible]		−0.2953		540	−0.1858		−0.2466	
[illegible]		0.2812		541	[illegible]		0.2325	
0.6073		0.2671		542	[illegible]		[illegible]	
0.5962		0.2523		543	[illegible]		[illegible]	
0.5851		0.2373		544	[illegible]		0.1894	
−0.5739		−0.2220		545	[illegible]		−0.1729	
0.5625		0.2063		546	[illegible]		[illegible]	
0.5504		0.1899		547	[illegible]		[illegible]	
0.5387		0.1730		548	[illegible]		[illegible]	
0.5257		0.1558		549	−0.0140		[illegible]	
[illegible]		−0.1377		550	[illegible]		[illegible]	
0.4989		−0.1189		551	[illegible]		[illegible]	
0.4849		−0.0996		552	[illegible]		[illegible]	
0.4705		−0.0792		553	[illegible]		[illegible]	
0.4547		−0.0583		554	+0.0575		[illegible]	
−0.4387		−0.0365		555	+0.0771		[illegible]	
0.4217		−0.0133		556	0.1025		[illegible]	
0.4036		[illegible]		557	0.1265		[illegible]	
0.3847		[illegible]		558	0.1512		+0.0533	
0.3642		+0.0626		559	0.1774		+0.1095	
−0.3433		+0.0902		560	[illegible]		+0.1364	
0.3219		0.1193		561	0.2327		0.1647	
[illegible]		0.1503		562	0.2627		[illegible]	
[illegible]		0.1826		563	[illegible]		[illegible]	
0.2433		0.2168		564	[illegible]		[illegible]	
−0.2136		+0.2530		565	[illegible]		[illegible]	
[illegible]		0.2915		566	[illegible]		[illegible]	
−0.1469		0.3323		567	[illegible]		[illegible]	
−0.1092		0.3757		568	[illegible]		[illegible]	
−0.0681		0.4221		569	0.5177		[illegible]	
[illegible]		+0.4709		570	[illegible]		[illegible]	
[illegible]		0.5227		571	[illegible]		[illegible]	
+0.0760		0.5768		572	[illegible]		[illegible]	
+0.1377		0.6394		573	0.7119		0.6564	
+0.2033		0.7039		574	0.7679		0.7154	

Table VI 1 (continued)

r_1	r_2	r_1	r_2		r_1	r_2	r_1	r_2
+0.2768		+0.7733		575	+0.8276		+0.7784	
0.3688		0.8479		576	0.8964		0.8456	
0.4521		0.9290	+1.0764	577	0.9580	+1.0139	0.9180	
0.5574		+1.0162	0.9841	578	+1.0294	0.9714	0.9952	+1.0045
0.6791			0.8996	579		0.9039	+1.0788	0.9269
+0.8205			+0.8226	580		+0.8114		+0.8554
0.9862	[illegible]		0.7521	581		0.7633		0.7894
+1.1818	[illegible]		0.6877	582		0.7295		0.7289
	0.7053		0.6285	583		0.6793		0.6729
	[illegible]		0.5737	584		0.6322		0.6207
	[illegible]		+0.5232	585		+0.5884		+0.5724
	[illegible]		0.4765	586		0.5475		0.5276
	0.3157		0.4332	587		[illegible]		0.4857
	0.2463		0.3925	588		0.4721		[illegible]
	0.1859		0.3552	589		0.4392		0.4163
	+0.1309		+0.3198	590		+0.4076		[illegible]
	[illegible]		0.2869	591		0.3769		[illegible]
	[illegible]		0.2566	592		0.3490		[illegible]
	[illegible]		0.2277	593		0.3222		0.2862
	−0.0380		0.2011	594		0.2974		[illegible]
	−0.0708		+0.1761	595		+0.2739		[illegible]
	−0.1011		0.1530	596		0.2521		[illegible]
	−0.1276		0.1316	597		0.2318		0.1899
	−0.1516		0.1114	598		0.2125		[illegible]
	−0.1744		0.0923	599		0.1943		0.1508
	−0.1951		+0.0747	600		+0.1773		+0.1332
	0.2148		+0.0576	601		0.1609		0.1161
	0.2336		[illegible]	602		0.1455		0.1002
	[illegible]		+0.0266	603		0.1306		0.0847
	0.2656		+0.0122	604		0.1167		[illegible]
	−0.2797		−0.0010	605		+0.1038		0.0572
	0.2926		−0.0132	606		0.0918		[illegible]
	0.3051		−0.0251	607		[illegible]		[illegible]
	0.3166		−0.0360	608		0.0693		[illegible]
	0.3271		−0.0462	609		0.0593		[illegible]
	−0.3368		−0.0558	610		[illegible]		[illegible]
	0.3461		0.0649	611		[illegible]		−0.0079
	0.3549		0.0736	612		+0.0321		−0.0162
	0.3628		0.0815	613		+0.0241		−0.0243
	0.3703		0.0891	614		+0.0166		−0.0320
	−0.3776		−0.0965	615		[illegible]		−0.0395
	[illegible]		0.1033	616		[illegible]		0.0464
	0.3902		0.1094	617		[illegible]		0.0526
	0.3961		0.1154	618		−0.0098		0.0588
	0.4016		0.1211	619		−0.0156		0.0646
	−0.4067		−0.1265	620		−0.0210		−0.0701
	0.4111		0.1313	621		0.0258		0.0750
	0.4157		0.1361	622		0.0306		0.0798
	0.4199		0.1405	623		0.0351		0.0844
	0.4238		0.1447	624		0.0394		0.0886

Table VI 1 (continued)

r_1	r_2	r_1	r_2		r_1	r_2	r_1	r_2
	−0.4277		[illegible]	625		−0.0435		−0.0929
	0.4313		0.1527	626		0.0471		[illegible]
	0.4346		0.1562	627		0.0511		0.1005
	0.4377		0.1596	628		0.0544		0.1038
	[illegible]		0.1631	629		0.0580		0.1074
	−0.4437		−0.1664	630		−0.0611		−0.1105
	0.4465		0.1691	631		0.0641		0.1136
	0.4492		0.1721	632		0.0672		0.1167
	0.4517		0.1748	633		0.0700		0.1195
	0.4542		0.1776	634		0.0727		0.1223
	−0.4565		−0.1803	635		−0.0753		−0.1248
	0.4587		0.1825	636		0.0778		0.1273
	0.4607		0.1847	637		0.0800		0.1296
	0.4627		0.1869	638		0.0823		0.1319
	0.4647		0.1891	639		0.0846		0.1341
	−0.4665		−0.1911	640		−0.0866		−0.1362
	0.4682		0.1931	641		0.0886		0.1382
	0.4696		0.1947	642		0.0903		0.1399
	0.4712		0.1965	643		0.0921		0.1417
	0.4725		0.1980	644		0.0936		0.1432
	−0.4739		−0.1995	645		−0.0952		−0.1448
	0.4752		0.2010	646		0.0967		0.1463
	0.4763		0.2022	647		0.0980		0.1476
	0.4775		0.2035	648		0.0993		0.1489
	0.4786		0.2048	649		0.1006		0.1502
	−0.4795		−0.2058	650		−0.1017		−0.1513
	0.4805		0.2069	651		0.1028		0.1524
	0.4814		0.2079	652		0.1039		0.1535
	0.4821		0.2088	653		0.1047		0.1543
	0.4831		0.2098	654		0.1058		0.1554
	−0.4838		−0.2106	655		−0.1066		−0.1562
	0.4845		0.2115	656		0.1075		0.1571
	0.4851		0.2121	657		0.1081		0.1577
	0.4858		0.2129	658		0.1090		0.1586
	0.4864		0.2135	659		0.1096		0.1592
	−0.4869		−0.2142	660		−0.1103		−0.1599
	0.4873		0.2146	661		0.1107		0.1603
	0.4878		0.2152	662		0.1113		0.1609
	0.4882		0.2156	663		0.1117		0.1613
	0.4885		0.1260	664		0.1122		0.1618
	−0.4889		−0.2164	665		−0.1126		−0.1622
	0.4892		[illegible]	666		0.1130		0.1626
	0.4896		[illegible]	667		0.1134		0.1630
	0.4900		[illegible]	668		0.1139		0.1634
	0.4901		0.2178	669		0.1141		0.1637
	−0.4905		−0.2183	670		−0.1145		−0.1641
	0.4907		0.2185	671		0.1147		0.1643
	0.4910		0.2189	672		0.1151		0.1647
	0.4912		0.2191	673		0.1153		0.1649
	0.4916		0.2195	674		0.1157		0.1653

Table VI 1 (continued)

r_1	r_2	r_1	r_2		r_1	r_2	r_1	r_2
	−0.4918		−0.2197	675		−0.1159		−0.1655
	0.4921		0.2201	676		0.1164		0.1660
	0.4923		0.2203	677		0.1166		0.1662
	0.4925		0.2205	678		0.1168		0.1664
	0.4928		0.2209	679		0.1172		0.1668
	−0.49300		−0.22110	680		−0.11741		−0.16700
	0.49321		0.22134	681		0.11766		0.16725
	0.49343		0.22158	682		0.11791		0.16750
	0.49362		0.22180	683		0.11814		0.16773
	0.49382		0.22203	684		0.11837		0.16796
	−0.49401		−0.22225	685		−0.11860		−0.16819
	0.49419		0.22245	686		0.11881		0.16839
	0.49435		0.22263	687		0.11899		0.16858
	0.49451		0.22281	688		0.11918		0.16877
	0.49465		0.22297	689		0.11935		0.16893
	−0.49477		−0.22311	690		−0.11949		−0.16908
	0.49488		0.22324	691		0.11962		0.16920
	0.49496		0.22334	692		0.11972		0.16931
	0.49503		0.22342	693		0.11980		0.16939
	0.49510		0.22350	694		0.11987		0.16947
	−0.49514		−0.22354	695		−0.11993		−0.16951
	0.49519		0.22360	696		0.11999		0.16957
	0.49521		0.22362	697		0.12001		0.16960
	0.49523		0.22364	698		0.12003		0.16962
	−0.49525		−0.22366	699		−0.12005		−0.16964

(see pages 74 to 76, Chapter VI)

```
OM:PROC OPTIONS(MAIN);


EST
        CHROM:PROC OPTIONS(MAIN);
               /*CHROM IS A PROGRAM TO CALCULATE DOMINANT WAVELENGTH,          */
               /*CHROMATICITY COORDINATES AND EXCITATION PURITY PERCENTAGE.   */
               DCL(X(M),Y(M),T(N,2),W(N),C(N),D(N),R(M),Z(M),E(M),F(M),P(M),
                Q(M),V(M),G(M),H(M))CONTROLLED FLOAT;
                DCL(A,B,IND,SX,SY,PX,PY,VV,GG,HH)FLOAT;
               DCL(M,N,I,J,K)FIXED BIN;
               DCL(COL(M))CONTROLLED FIXED BIN;
               DCL(NAME CHAR(100))VAR;
               DCL(TITLE(M)CHAR(50))CONTROLLED VAR;
               ON UNDERFLOW PUT DATA;
               GET LIST(NAME);
               PUT PAGE EDIT(NAME)(COLUMN(20),A);
               /* READ IN NUMBERS OF MINERAL SAMPLES                           */
               GET LIST(M);
               /* READ IN CHROMATICITY COORDINATES OF STANDARD SOURCE          */
               GET LIST(A,B);
               /* ALLOCATE ARRAY STORAGE                                       */
               ALLOCATE X,Y,R,Z,E,F,P,Q,TITLE,COL;
               /* READ IN CHROMATICITY COORDINATES OF MINERAL SAMPLES AND      */
               /* TITLES                                                       */
               PUT EDIT('CHROMATICITY COORDINATES')(COLUMN(60),A);
               PUT EDIT('SAMPLE','X','Y')(COLUMN(20),A,COLUMN(66),A,COLUMN(76)
                    ,A);
               DO I=1 TO M;
 1             GET LIST(TITLE(I));
 1             GET LIST(X(I),Y(I));
 1             PUT EDIT(TITLE(I),X(I),Y(I))(SKIP(2),COLUMN(20),A,COLUMN(63),F
                    (6,4),COLUMN(76),F(6,4));
 1             END;
               /* COMPUTE COORDINATE RATIOS                                    */
               DO I=1 TO M;
 1             IF ABS(X(I)-A)<ABS(Y(I)-B) THEN DO;
 2             R(I)=(X(I)-A)/(Y(I)-B);
 2             COL(I)=1;
 2             END;
 1             ELSE DO;
 2            R(I)=(Y(I)-B)/(X(I)-A);
 2             COL(I)=2;
 2             END;
 1             PUT SKIP EDIT(I,R(I))(X(5),F(2),X(5),F(7,3));
 1             END;
               /* READ IN NUMBER OF TABULATED COORDINATE RATIOS,WAVELENGTH     */
               /* VALUES, AND CHROMATICITY COORDINATES                         */
               GET LIST(N);
               /* ALLOCATE ARRAY STORAGE                                       */
               ALLOCATE T,W,C,D;
               /* READ IN WAVELENGTHS ETC                                      */
               DO J=1 TO N;
 1             GET LIST(T(J,1),T(J,2),W(J),C(J),D(J));
 1             END;
               /* COMPUTE WAVELENGTH OF CALCULATED MINERAL COORDINATE RATIOS*/
               /* FROM TABULATED VALUES                                        */
               Z=0;
               DO I=1 TO M;
 1             K=COL(I);
```

```
ST

1             DO J=1 TO N-1;
2             IF T(J,K)>R(I)& T(J+1,K)<R(I) THEN GOTO L1;
2             ELSE IF T(J,K)<R(I)& T(J+1,K)>R(I) THEN GOTO L1;
2             ELSE GOTO L2;
2          L1:Z(I)=(R(I)-T(J,K))/(T(J+1,K)-T(J,K));
2             Z(I)=Z(I)+W(J);
2          L2:IF T(J,K)=R(I) THEN Z(I)=W(J);
2             END;
1             PUT SKIP EDIT(I,Z(I))(X(5),F(2),X(5),F(7,3));
1             END;
              DO I=1 TO M;
1             IF Z(I)=0 THEN
1             DO;
2             DO J=I TO M;
3             TITLE(J)=TITLE(J+1);
3             Z(J)=Z(J+1);
3             X(J)=X(J+1);
3             Y(J)=Y(J+1);
3             END;
2             END;
1             END;
              J=0;
              DO I=1 TO M;
1             IF Z(I)=0 THEN
1             J=J+1;
1             END;
              M=M-J;
              /* COMPUTE DOMINANT WAVELENGTH COORDINATES                        */
              DO I=1 TO M;
1             IF ABS(Z(I)-TRUNC(Z(I)))>0 THEN DO;
2             E(I)=Z(I)-TRUNC(Z(I));
2             J=TRUNC(Z(I))-W(1)+1;
2             E(I)=E(I)*(C(J+1)-C(J))+C(J);
2             F(I)=Z(I)-TRUNC(Z(I));
2             F(I)=F(I)*(D(J+1)-D(J))+D(J);
2             END;
1             IF ABS(Z(I)-TRUNC(Z(I)))=0 THEN DO;
2             E(I)=C(J);
2             F(I)=D(J);
2             END;
1             END;
              /* COMPUTE EXCITATION PURITY PERCENTAGE                           */
              IND=0;
           L3:DO I=1 TO M;
1             P(I)=(X(I)-A)*100/(E(I)-A);
1             Q(I)=(Y(I)-B)*100/(F(I)-B);
1             PUT SKIP EDIT(I,P(I),Q(I),E(I),F(I))(X(5),F(2),X(5),F(7,3),
              X(5),F(7,3),X(5),F(7,3),X(5),F(7,3));
1             END;
              IF IND=1 THEN GOTO L4;
               GET LIST(SX,SY,PX,PY);
              ALLOCATE V,G,H;
              DO I=1 TO M;
1          IF (P(I)>0) & (Q(I)>0) THEN GOTO L5;
```

```
1           ELSE DO;
             /*COMPUTE COORDINATES OF COMPLEMENTARY WAVELENGTHS             *
2            VV=SX-PX;
2            GG=(SY-PY)/VV;
2            HH=(SX*PY-PX*SY)/VV;
2            V(I)=A-X(I);
2            G(I)=(B-Y(I))/V(I);
2            H(I)=(A*Y(I)-B*X(I))/V(I);
2            E(I)=(H(I)-HH)/(GG-G(I));
2            F(I)=GG*E(I)+HH;
2           END;
1        L5:END;
            IND=1;
            GOTO L3;
            /* PRINT OUT RESULTS                                             */
         L4:PUT PAGE;
            PUT SKIP(6);
            PUT EDIT('WEIGHTED ORDINATE METHOD')(COL(10),A);
            PUT EDIT(NAME)(COL(10),A);
            PUT SKIP(2);
            PUT EDIT('WAVELENGTH','COORDINATES','EXCITATION PURITY')
                     (COL(50),A,COL(69),A,COL(89),A);
            PUT EDIT('NM','X','Y','P','Q')(COL(54),A,COL(69),A,COL(79),A,CO
                     (93),A,COL(103),A);
            PUT SKIP(2);
            DO I=1 TO M;
1           PUT EDIT(TITLE(I),Z(I),E(I),F(I),P(I),Q(I))(SKIP(2),COL(10),A,
                      COL(52),F(6,2),COL(66),F(6,4),COL(76),F(6,4),COL(90),
                      F(6,2),COL(100),F(6,2));
1           END;
            PUT SKIP(5);
            PUT EDIT('PROBLEM COMPLETED')(COLUMN(3),A);
            END CHROM;
```

```
M:PROC OPTIONS(MAIN);
```

ATTRIBUTE AND CROSS-REFERENCE TABLE

Appendix VI 4 b.

Example of listing of the programme "CHROM" of Appendix VI 4 a.

```
      '1931 CIE STANDARD SOURCE A (0.4476, 0.4075)'
 10             (number of specimens)
 0.4476  0.4075
 'BORNITE SP. 6305(W.H, 1971)'
 0.4774  0.4066
 'BORNITE SP.NGD 6(TUGAL, 1969)'
 0.4751  0.4113

     and so on

 'GERMANITE SP. 1(LEVY, 1966)'
 0.4666  0.4026
 184             (number of wavelengths from 516 to 699 nm)
 -0.9769    1          516    0.04533    0.81939
 -0.9473    1          517    0.05218    0.82516

                 etc.

 +0.9862    1          581    0.51906    0.48003     (see Table VI 1)
  1         +0.8462    582    0.52560    0.47353
  1         +0.7053    583    0.53207    0.46709

                 etc.

  1         -0.49525   699    0.73469    0.26531
 0.17411  0.00496  0.73469  0.26531 (chromaticity coordinates of 380 nm
                                     and 830 nm of the spectrum)
```

```
LOR:PROC OPTIONS(MAIN);

1
        COLOR:PROC OPTIONS(MAIN);
              DCL(W(N),T(N),E(N),F(N,3),P(N,3),PP(N,3),CMF(N,3))CONTROLLED
                  FLOAT;
              DCL(S(3),TOT(3),TOTAL(3),X(3),Y(3),A(3),B(3),K(3),NK,Q,V,R(2),
                 NF,YY(3))FLOAT;
              DCL(I,J,N)FIXED BIN(31),(TITLE)CHAR(100)VAR;
                 ON ENDFILE(SCARDS)GOTO DONE;
        BEGIN:GET LIST(TITLE,N);
               ALLOCATE W,T,E,F,P,PP,CMF;
         GET LIST(T,E);
           L1:DO I=1 TO N;
               GET LIST(W(I),F(I,1),F(I,2),F(I,3));
           L2:DO J=1 TO 3;
               P(I,J)=E(I)*F(I,J);
               PP(I,J)=T(I)*P(I,J);
             END L2;
             END L1;
             PUT PAGE EDIT('FILTER','WAVELENGTH','SOURCE-ENERGY',
                              '1931 CIE CM FUNCTIONS','PRODUCTS','PRODUCTS',
                             'T','H','X','Y','Z','XH','YH','ZH','XHT','YHT',
                             'ZHT')(COL(2),A,COL(9),A,COL(20),A,COL(34),A,COL
                            (73),A,COL(103),A,SKIP,COL(4),A,COL(25),A,COL(34)
                           ,A,COL(44),A,COL(54),A,COL(65),A,COL(76),A,COL(87)
                            ,A,COL(96),A,COL(106),A,COL(116),A);
             PUT SKIP(2);
          L3:DO I=1 TO N;
             PUT EDIT(T(I),W(I),E(I),(F(I,J) DO J=1 TO 3),
                     (P(I,J) DO J=1 TO 3),(PP(I,J) DO J=1 TO 3))
                     (COL(3),F(4,2),COL(13),F(3),COL(21),F(6,2),
                     3(F(10,4)),3(F(11,2)),3(F(10,2)));
             END L3;
               S=0;  TOT=0;
          L4:DO I=1 TO N;
          L5:DO J=1 TO 3;
               S(J)=S(J)+P(I,J);
               TOT(J)=TOT(J)+PP(I,J);
          END L5;
          END L4;
             PUT EDIT('SUMS',(S(J) DO J=1 TO 3),(TOT(J) DO J=1 TO 3))
                      (SKIP(2),COL(55),A,F(9,2),2(F(11,2)),3(F(9,2)));
             /*COMPUTE NORMALIZED TRISTIMULUS VALUES AND COORDINATES OF  */
             /*THE SOURCE                                                */
          L6:DO J=1 TO 3;
             K(J)=100.0/S(J);
             IF J=2 THEN
             GOTO BUR;
          END L6;
        BUR:DO;
               NK=K(J);
            END;
          L7:DO J=1 TO 3;
               X(J)=NK*S(J);
               Y(J)=NK*TOT(J);
          END L7;
               Q=SUM(X);
               V=SUM(Y);
```

OR:PROC OPTIONS(MAIN);

Appendix VIII 1. (continued)

```
/*CHROMATICITY COORDINATES OF SOURCE AND FILTER.                     */
L8:DO J=1 TO 3;
      A(J)=X(J)/Q;
      B(J)=Y(J)/V;
END L8;
     PUT EDIT('NORMALIZING FACTOR K = ',NK,'X','Y','Z',
              'NORMALIZED TRISTIMULUS','(SOURCE)',(X(J) DO J=1 TO
              3),'(FILTER)',(Y(J) DO J=1 TO 3))(SKIP(2),COL(20),A,
              COL(44),F(7,5),SKIP,COL(59),A,COL(69),A,COL(79),A,
              SKIP,COL(20),A,COL(46),A,3(F(11,4)),SKIP(2),COL(46),
             .A,3(F(11,4)));
     PUT EDIT('CHROMATICITY COORDINATES','(SOURCE)',(A(J) DO J=1
              TO 3),'(FILTER)',(B(J) DO J=1 TO 3))(SKIP(2),COL(20)
              ,A,COL(46),A,3(F(10,4)),SKIP(2),COL(46),A,3(F(10,4))
              );
L9:DO J=1 TO 3;
      R(J)=100.0/TOT(J);
       IF J=2 THEN
      GOTO DUR;
   END L9;
DUR:DO;
      NF=R(J);
   END;
/*COMPUTE NORMALIZED TRISTIMULUS VALUES OF FILTER                     */
L10:DO J=1 TO 3;
      YY(J)=NF*TOT(J);
   END L10;
/*COMPUTE NORMALIZED COLOUR-MATCHING FUNCTIONS OF FILTER              */
/*COMBINED WITH CIE SOURCE.                                           */
    DO I=1 TO N;
    DO J=1 TO 3;
      CMF(I,J)=YY(J)*PP(I,J)/TOT(J);
    END;
    END;
      PUT PAGE EDIT(TITLE,'WAVELENGTH','COLOR MATCHING FUNCTIONS')
                     (COL(10),A,SKIP(2),COL(15),A,COL(35),A);
      TOTAL=0;
     PUT SKIP(2);
L11:DO I=1 TO N;
       PUT EDIT(W(I),(CMF(I,J) DO J=1 TO 3))(COL(19),F(3),
              3(F(15,4)));
L12:DO J=1 TO 3;
     TOTAL(J)=TOTAL(J)+CMF(I,J);
END L12;
END L11;
    PUT EDIT('SUMS',(TOTAL(J) DO J=1 TO 3))(SKIP(2),COL(38),A,
              3(F(14,4)));
DONE:END COLOR;
```

OR:PROC OPTIONS(MAIN);

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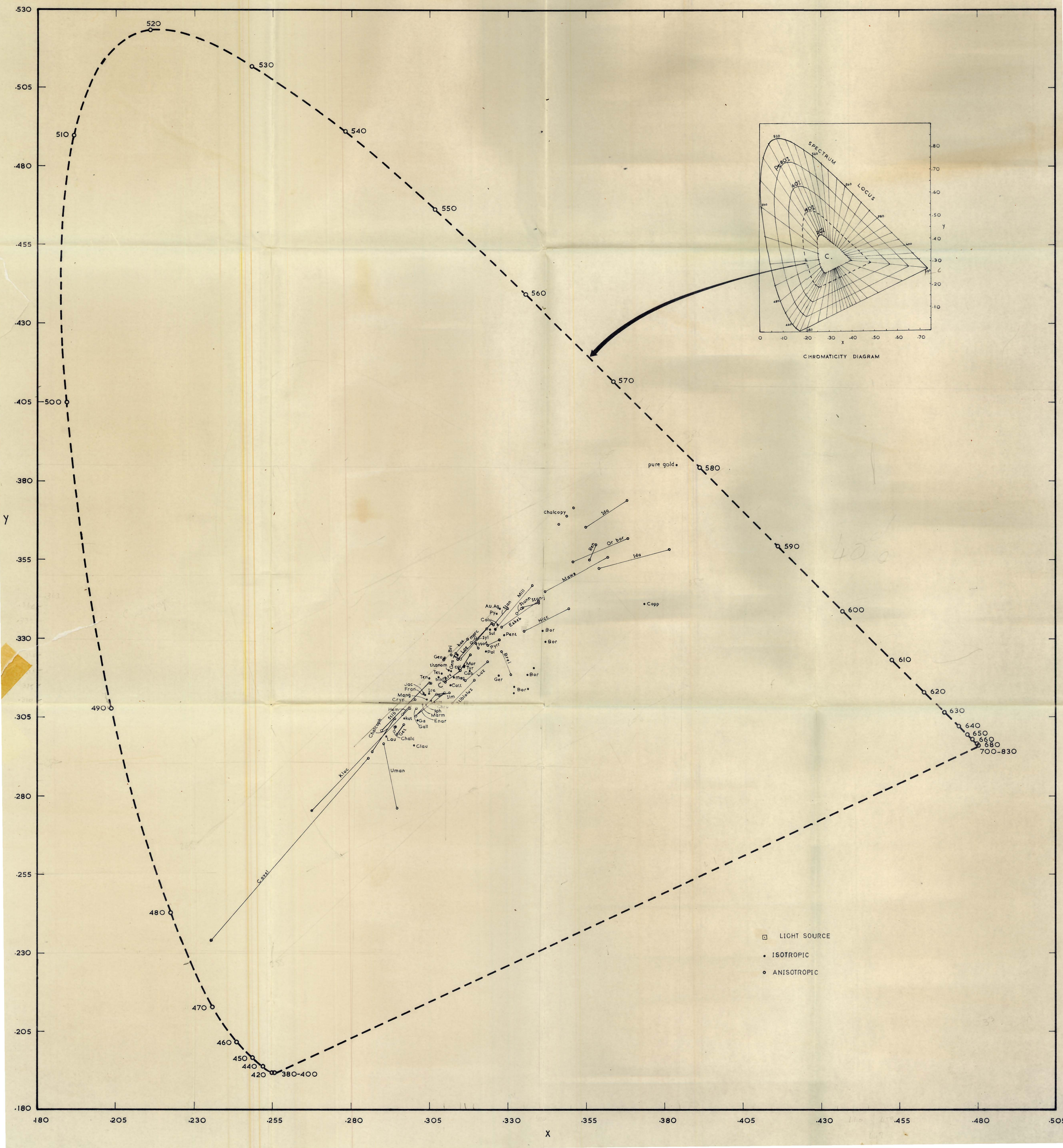
Figure 1.a. PART OF THE C.I.E. CHROMATICITY DIAGRAM SHOWING THE COLOURS OF SOME ORE MINERALS UNDER THE C.I.E. SOURCE C (average daylight)



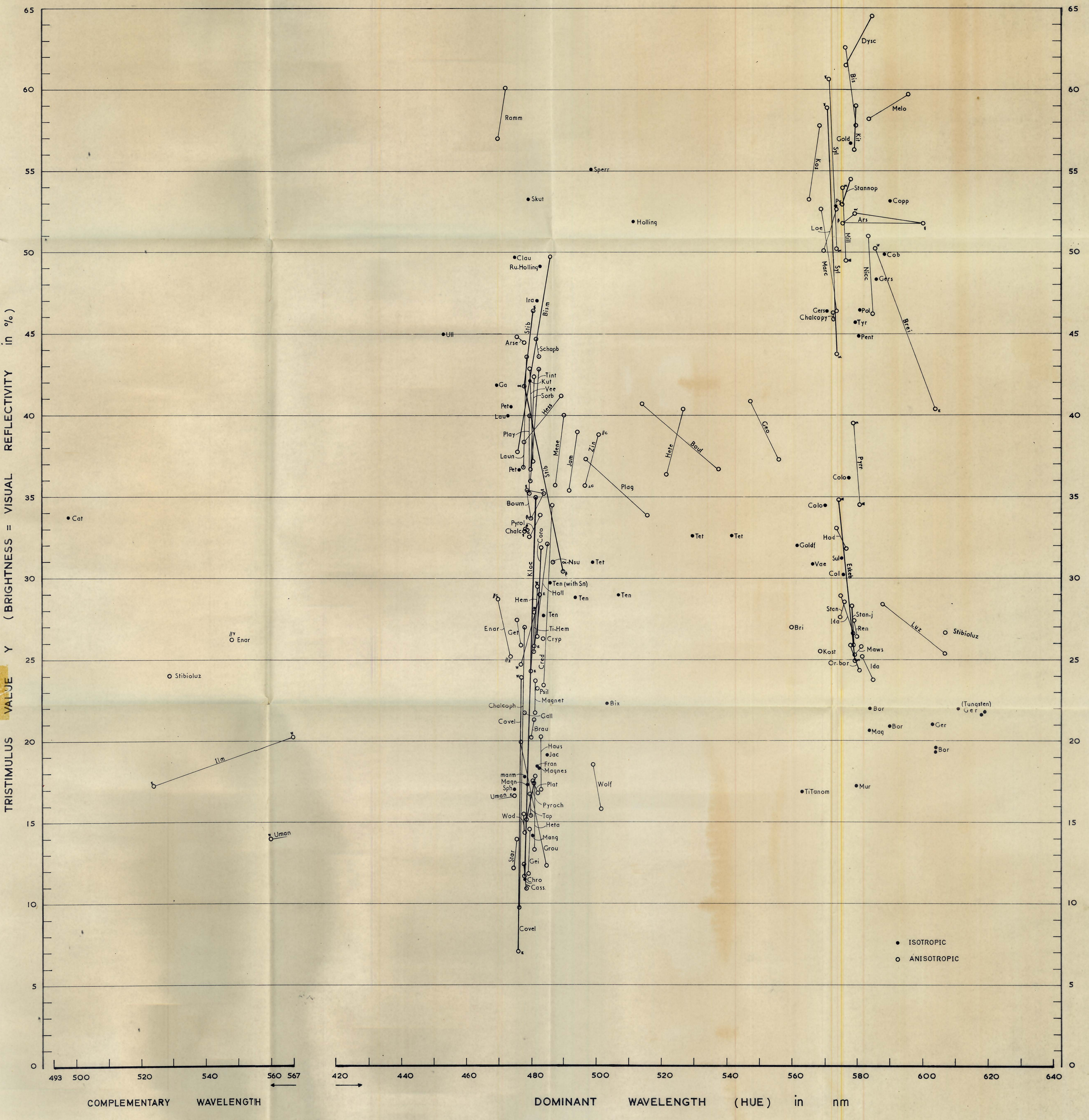


Figure 1.b. RELATIVE BRIGHTNESS AND HUE OF ORE MINERALS UNDER THE C·I·E· SOURCE C (average daylight)