THE EFFECT OF THE HEIGHT AND YARN SIZE OF A PILE TEXTURE ON COLOR

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ABSTRACT

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by Lorraine Haugk Gross

This study was concerned with pile texture and was especially designed to investigate two independent variables, pile height and yarn size, to determine their textural effect on color.

Three types of texture, a tapestry, a low pile and a high pile, were handwoven in each of the ten basic Munsell colors. Five low pile samples were also woven in the complementary hues. These samples and the findings of a previous study, from which interest in this work originated, furnished the data for this research.

The color of each sample was analyzed by both subjective and objective colorimetry. The Macbeth-Munsell Colorimeter, Type #1, and the Munsell Color Standards in high gloss surface were used in subjective colorimetry. Objective colorimetry utilized the Gardner Color Difference Meter. All data were reported in terms of Munsell notations.

The combined use of objective and subjective methods of color analysis seemed to be more valuable in this study than either method would have been if used alone, for each method had its strengths and weaknesses. Through subjective analysis, which involved the human eye, the samples were notated at a higher value and a brighter saturation level than they were through objective analysis.

The changes in color due to a change in texture from a non-pile, tapestry texture, to a pile texture were analyzed. The change in texture was found to cause a decrease in the value level. The change in type of texture affected color more than did changes of either of the variables, yarn size or pile height, of the pile texture.

In the low pile samples of this study and the samples of the previous study yarn size was the major variable. These samples were compared to determine the effect of yarn size on color. Yarn size affected the color of a pile texture primarily by lowering its saturation. Analysis of the two-colored samples showed that not only yarn size, but also the value and saturation of the complements selected, influenced the success of complementary mixtures in pile texture.

The samples of the two pile heights were compared to determine the effect of pile height on color. Pile height was found to affect the color of a pile texture only to a minor degree in the particular pile density used in this study. The importance of this factor in color prediction would depend upon the accuracy of color match desired.

This research was undertaken to add further knowledge to the little explored area concerning the effect of texture on color. There are many other aspects of texture's effect on color which need to be investigated.

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By

Lorraine Haugk Gross

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CHAPTER I

INTRODUCTION

The world surrounding us is filled with color. The designer, attempting to utilize this color, often finds that the color of the finished product as seen by the observer is not always the color he intended, for apparent color is affected by many things such as the surrounding colors and the illumination. Texture, which is an important element in all design, also appears to have some effect on color. In discussing color comparisons of two samples of different textures and area sizes Evans suggests that texture affects color, but that we do not know <u>how</u> it affects color:

> So little is known about them (texture and area size) quantitatively that only suggestive remarks are possible. In regard to the latter factor, differences in texture, there seems to be only one statement that can be made, namely if the textures are very different, no direct comparison can be made. Presence of a large texture difference may so change the appearance of two samples that, although they would match exactly if they had the same surfaces, only an expert can decide whether they match or not, sometimes only if he has available other samples that vary slightly from the match.[1]

This investigator was interested in determining what the actual effect of texture was on color.

Interest in this study was first stimulated by a presentation of a pilot study on "The Effect of the Texture of a Pile Weave on Color" by Mary L. Shipley.[2] Remarkable visual proof that pile texture

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[1]Ralph M. Evans, <u>An Introduction to Color</u> (New York: John Wiley & Sons, Inc., 1948), p. 322.

[2]Mary L. Shipley, "The Effect of the Texture of a Pile Weave on Color" (unpublished study, Western Reserve University, Cleveland, Ohio, July, 1960).

affects color had been offered in that presentation. This study was then undertaken:

1. To determine how pile height affects solid colors.
2. To determine how yarn size affects solid and complementary colors of a pile texture.
3. To attempt to utilize scientific color testing instruments in the area of aesthetics and design.

It was felt that an investigation of these attributes of pile texture, yarn size and pile height, would contribute new knowledge toward the greater understanding of the effect of texture on color. The investigator hoped that applying scientific color measurement to aesthetic aspects of color would open new avenues for the designer-investigator. Wright has written: "If a practical system of subjective colour measurement were eventually developed, its most lively application would most probably be found in the realm of design."[1] In 1925 Luckiesh reminded the reader of the attitude of the artist toward science when he stated: "Many artists contend that, aside from a few general principles of color harmony, the realization of satisfactory color arrangements depends upon an aesthetic instinct. The attitude of science is naturally that the facts of aesthetics are discoverable."[2] At the present time the designer still has little contact with the scientific aspects of his work.

The greatest value of this research should be in bringing to the designer a stronger awareness that texture does affect color and in helping the designer to predetermine the effect of height and yarn size of a pile texture on its color.

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[1]W. D. Wright, "The Needs and Prospects of Subjective Colour Measurement," Visual Problems of Colour, Volume II (London: Her Majesty's Stationery Office, 1958), p. 374.

[2]Matthew Luckiesh, The Language of Color (New York: Dodd, Mead & Co., 1925), p. 228.

CHAPTER II

REVIEW OF LITERATURE

Color

The first question that arises in a study of color is "What is Color?" The physicist, the psychologist, and the psychophysicist each have different, valid answers to this question. Color to the physicist is light and its wavelength as modified by objects and substances. The psychophysicist adds a third factor to the definition of color, the eye. The psychologist expands the definition of color still further to include the mind's interpretations.[1] Watson explains color by saying:

> The colour of an object is not inherent in the matter itself, but all bodies have the property of selective absorption, i.e., the power to break up the light that falls upon them, and to absorb or reflect the different waves or colour rays of which the light is composed. The colour of a body is determined by the character and intensity of the light rays that it reflects.[2]

Since this is purely a physical definition of color and color appreciation is a visual reaction, it was felt that the human eye needed to be added to this definition. The Committee on Colorimetry of the Optical Society of America formulated the definition of color that was used throughout this study:

> Color consists of the characteristics of light other than spatial and temporal inhomogeneities; light being that aspect

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[1]Evans, pp. 2-3.

[2]William Watson, Textile Design and Colour (New York: Longmans Green & Co., 1949), p. 132.

> of radiant energy of which a human observer is aware through the visual sensations which arise from the stimulation of the retina of the eye.[1]

Color is generally associated with three attributes: hue, value or lightness, and saturation. However, David Katz's theories concerning the modes of appearance of color[2] have raised unanswered questions. The Committee on Colorimetry, taking recognition of the importance of the modes of appearance felt that, "On a perceptual basis the modes of appearance of color should logically be considered as additional attributes."[3] The committee then quotes Troland:

> Hue, saturation and brilliance do not exhaust all possible attributes of colors, since it is possible for them to vary in dimensions distinct from any of these three . . . . Other color attributes which are of importance in perceptual studies include the so-called 'modes of appearance', or Erscheinungsweisen. Thus, color may appear as 'body', 'surface', or 'film'. They may also be lustrous or non lustrous.[4]

Although some members of the group agreed with this concept of color, the committee as a whole did not feel that the modes of appearance were attributes of color on an equal level with those attributes of hue, value, and saturation. "Terms implying a dependence of color on some of the other attributes of visual appearance should be avoided."[5] Again they state, "The sensed color is one thing and the mode is something else."[6]

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[1]Optical Society of America, Committee of Colorimetry, The Science of Color (New York: Thomas Y. Crowell Company, 1953), pp. 220-221. Cited hereafter as Optical Society Committee on Colorimetry.

[2]David Katz, The World of Color (London: Kegan Paul, Trench, Trubner & Co. Ltd., 1935).

[3]Optical Society Committee of Colorimetry, p. 7.

[4]Ibid., p. 7, quoting L. T. Troland, Psychophysiology (New York: Van Nostrand, 1929), I, p. 254.

[5]Ibid., p. 58.

[6]Ibid., p. 145.

They did, however, recognize and analyze the modes of appearance of color as perceptual processes.[1] Since in this thesis the texture changes (which are changes in the surface mode of appearance) caused changes in color, the preceding theories of color attributes were of special interest to the investigator.

Color and Texture

The purpose of this study was to determine the effect of pile texture on color, therefore, the relationship of texture and color was investigated.

> Texture may be defined as visible nonuniformities in the reflectance of a surface which are obviously a physical property of the surface. It may vary from a roughness so fine that it appears simply as a matte surface to irregularities such as exist in coarse textiles. . . . Texture of any kind makes the position and existence of the surface a visible fact quite aside from the fact that the surface reflects light.[2]

The word pile "refers to a nap surface made up of erect hairs or fibers on the surface of the cloth."[3]

Very few studies have been done on the effect of texture on color. Studies on the relationship of color and non-pile textiles were conducted at the British Textile Institute.[4] A study on "The Effect of Texture on Additive Color Mixture in Fabric" was conducted at Michigan State University.[5] The only study relating pile texture to color known to this

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[1]*Ibid.*, p. 151.

[2]Evans, p. 122.

[3]Osma Couch Gallinger and Josephine Couch Del Deo, *Rug Weaving for Everyone* (Milwaukee: Bruce Publishing Co., 1957), p. 31.

[4]P. Warburton and G. V. Lund, "Colour and Textiles," *Journal of the Textile Institute*, XLVII (May, 1956), pp. 305-361; and P. Warburton and P. H. Oliver, "Colour and Textiles, The Blending of Coloured Fibres," *Journal of the Textile Institute*, XLVII (May, 1956), pp. 361-373.

[5]Gay Wright Vela, "The Effect of Texture on Additive Color Mixture in Fabric" (unpublished Master's Thesis, College of Home Economics, Michigan State University, 1961).

investigator is the one by Mary L. Shipley which inspired this work.[1]

Other authors, such as Watson, do briefly mention and generalize concerning the effect of texture on color, although they have not conducted extensive experiments on this subject.

> The following factors tend to modify colours in their application to textile fabrics: a) The physical structure of the material; b) The mechanical construction of the yarn; c) The structure of the cloth; d) The finish applied to the cloth after weaving.[2]

A suggestion that there is something "special" about the color of pile fabrics due to their cloth structure is given by Richards: "The chief aesthetic characteristic of pile fabrics is the beauty of color obtained by the play of light through the upstanding pile."[3] Horsfall also seems to be aware of this for he suggests that the color matching for pile rugs should be done with the cut yarns.[4] In discussing color matching for textile yarn dyeing Wright says:

> Allowance has to be made for the effect which the texture of a surface has on its colour quality, since the manner in which the light is reflected from say the woven fibres in a piece of silk will be radically different from the reflection off the surface of a carpet where the cross-section of the fibres is visible.[5]

Wright begins to explain why the light reflection of pile textures affects color:

> Similarly, with a dyed fabric the multiple reflections and scattering between and within the fibres cause successive absorption of some part or other of the spectrum, and the emergent light will thus appear coloured. The depth of colour of a surface

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[1]Shipley.

[2]Watson, p. 147.

[3]Charles R. Richards, Art in Industry (New York: The Macmillan Company, 1929), p. 89.

[4]R. S. Horsfall and L. G. Lawrie, The Dyeing of Textile Fibres (Bouverie House, Fleet Street: Ernest Benn Limited, 1927), p. 237.

[5]W. D. Wright, The Measurement of Colour (New York: The Macmillan Company, 1958), p. 206.

> will depend in part on the extent to which the light penetrates into the surface, and this in turn will be governed by the dimensions, structure and refractive index of the material of which the surface is composed.[1]

The effect of wool yarns, which are the "physical structure of the material," on color was investigated. One study had been conducted concerning wool color changes, but the study concerned only wool processing into yarn and did not consider color changes due to the weaving process.[2] Luckiesh discussed the effect of wool surface on color:

> The surface character of a fabric plays an important part in the appearance of the color. A colored fabric is ordinarily seen by reflected light, the light falling upon it being robbed of some of its rays by the selective absorption of the dye. If the surface is porous like wool, the light can penetrate deeply and will therefore suffer more internal reflections, finally reaching the eye quite pure in color. The degree of transparency of the fiber also exerts an influence. . . . Wool and silk fibers are transparent, but those of cotton are not, hence light cannot penetrate as far into the latter as into silk or wool.[3]

Later Luckiesh discussed this again:

> In a loose fabric of porous surface the light penetrates more deeply and is colored by many multiple reflections. . . . Wool fibers are more transparent than cotton, and therefore permit a deeper penetration of the light. This means a greater number of multiple reflections, and, for example, as in the case of a dichroic[4] dye, it results in a color corresponding to that which would be obtained with a cotton fabric dyed in a denser solution of this dye.[5]

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[1]Ibid., p. 22.

[2]E. P. Mersereau and L. W. Rainard, "Color Changes in Wool During Processing," Textile Research Journal, XXI (April, 1951), pp. 239-247.

[3]Matthew Luckiesh, Color and Its Applications (New York: D. Van Nostrand Company, Inc., 1927), pp. 302-303.

[4]Dichromatic materials are materials that have one color in thin layers and quite another in thick.

[5]Luckiesh, Color and Its Application, p. 308.

The wool yarns used in this study exhibited a luster. "The luster of wool is largely a property of the epidermal scales, and in general, the smoother these scales, the greater the luster."[1] When discussing luster as an attribute of the modes of appearance, Evans explains it by writing: "It (luster) corresponds to the perception of a surface whose reflection characteristics change sufficiently with the angle of view so that different intensities or qualities of light reach the two eyes of the observer."[2] Judd also speaks of gloss (which seems to be used interchangeably with luster and fluorescence) and textiles:

> Textiles because of their weave give complicated variations in angular distribution of reflected light with rotation in their own plane. The fiber itself has a gloss; the textile because of its weave introduces characteristic variations, and the processing of the textile . . . affects its gloss.[3]

Judd later suggests the exact effect that this gloss will have on textile color:

> The effect is to raise the directional reflectance, decrease the purity of the light reaching the eye of the inspector from the specimen, and leave the dominant wavelength nearly constant. . . . The abrading of the surface (and thus making it less glossy) has caused the color perceived to belong to the specimen to become lighter and less saturated but has left the hue nearly unchanged.[4]

It is interesting to note that, contrary to the gloss resulting from the yarn, the texture of the pile samples produces what Judd calls "negative gloss":

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[1]Louis A. Olney, Textile Chemistry and Dying: Part I, Chemical Technology of the Fibers (Lowell, Mass.: Lowell Textile Associates, 1945), p. 79.

[2]Evans, p. 170.

[3]Deane B. Judd, Color in Business, Science, and Industry (New York: John Wiley & Sons, Inc., 1952), p. 303.

[4]*Ibid.*, pp. 305-306.

> A 'surface' having a pronounced tridimensional micro-structure, like white velvet, or that of a forest viewed from an airplane, is likely to show the peak of directional reflectance along the angle of incidence instead of near that of mirror reflection. Such a surface is composed of cavities, some of which are lit up by light falling in any one direction into the surface. Whatever light leaves these cavities by reflection must necessarily leave them more or less in the direction of the source. These surfaces are sometimes said to have negative gloss.[1]

Color Measurement

Colorimetry, which is the measurement of color when color is defined in the psychophysical sense, is based on the premise that a relationship can be found between physical specifications of color stimuli (such as the wavelength) and the sense perceptions that arise from them.[2] There are two basic methods of color measurement:

> We can divide the instruments and methods (for colorimetry) into two main groups: objective or physical colorimetry, which is chiefly based on purely physical measurements, and subjective or visual colorimetry in which ample use is made of the properties of the eye of the observer for colour vision.[3]

Bouma then establishes a regulation for colorimetry:

> In practice we must insist that both subjective and objective colorimetry furnish results in agreement with the C.I.E. system.
>
> It is of course self-evident that in principle it is easier for objective colorimetry to comply with this requirement than for subjective.[4]

Both subjective and objective methods of colorimetry, however, have strengths and weaknesses.

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[1] Ibid., p. 303.

[2] Optical Society Committee of Colorimetry, pp. 40-44 and pp. 254-316.

[3] P. T. Bouma, Physical Aspects of Colour (Eindhoven, The Netherlands: N. V. Philips Gloeilampenfabrieken, 1947), p. 144.

[4] Ibid., p. 145.

Subjective methods involve the human eye which is indeed a marvelous instrument. The discrimination of the eye, especially in relation to hue, is superior to the best photoelectric devices, and is rarely surpassed in spectrophotometry.[1] Wonderful as the eye is, it does cause problems in color measurement. The eyes of different people see the same color differently, and the same person may see the same color differently at various times.[2] There is also a change in color vision with age.[3] For these reasons a standard observer has been adopted for color measurement. Adaptation of the eye is another important factor in visual color discrimination. Because of adaptation, what we do see is not what we should see. However this is a process of human vision and must be considered even when analyzing instrumental data.[4]

Other factors affecting the fineness of discrimination of color involving the observer include: normality of vision, retinal fatigue, attention, attitude or purpose, training in discrimination, and technique of observation.[5] The mode of appearance of a color also gives rise to problems in visual color matching:

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[1]Dorothy Nickerson, Color Measurement and Its Application to the Grading of Agricultural Products, U.S. Dept. of Agriculture Misc. Pub. 580 (Washington: U. S. Government Printing Office, 1946), p. 23; and Optical Society Committee of Colorimetry, pp. 123-124 and p. 219.

[2]Wright, The Measurement of Colour, p. 47.

[3]F. L. Wurburton, "Variations in Normal Colour Vision in Relation to Practical Colour Matching," Physical Society of London - Proceedings, LXVII, n 414B (June, 1954), pp. 477-484.

[4]Optical Society Committee of Colorimetry, p. 119; and Wright, The Measurement of Colour, pp. 46-47.

[5]Luckiesh, Color and Its Applications, p. 163 and p. 302; and Optical Society Committee of Colorimetry, p. 126.

> The mode of appearance of a color gave rise to a distinct type of perception, different for each mode, and it has already been noted that aperture and surface colors follow their own rules, each quite independently of the energy distribution involved. The matter, however, goes even deeper than this in that the average observer is quite incapable of comparing any two colors if they have markedly different 'attributes.'[1]

An instrument eliminates the problems inherent in visual color matching due to the human eye and to the mode of appearance. All samples are reduced to the same mode of appearance with the same attributes. Usually this is the film or aperture mode as seen in unrelated viewing.[2] This does not, however, make instrumental color analysis the perfect answer. Evans reminds us: "It should always be kept in mind as a sobering thought, however, that every one of these (the visual phenomena) will return immediately the moment anyone looks at the sample.[3]

In color analysis, certain factors having to do with the stimuli also affect the fineness of discrimination. These include closeness or contiguity of the colors in space, contiguity in time, duration, shape, size, surface character, dominant wavelength, purity, luminance (its spectral character, intensity and distribution), and environment (surround color and size).[4]

The Munsell color chips, used as a comparative standard for the subjective comparison, fulfilled the requirements of a good color atlas as listed by Bouma. A color atlas must have a complete range of colors, exhibit very little difference between neighboring colors, be reproducible and unchanging with the passing of time.[5]

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[1]Evans, p. 184.

[2]Ibid., p. 202.

[3]Ibid.

[4]Luckiesh, Color and Its Applications, p. 163 and p. 302; and Optical Society Committee of Colorimetry, p. 126.

[5]Bouma, pp. 160-162.

The ideal instrument for use in objective colorimetric analysis of the samples in this study is not yet developed. Preliminary plans have been developed for a colorimetric goniophotometer which would accurately measure the color changes.[1]

Since the color analysis instruments are not perfect, readings of different instruments do not always give the same results. This problem has been studied and reported by a number of people.[2]

The discrepancies in the color notation obtained in this study by using the Gardner Color Difference Meter and those of the Munsell chips are explained by three facts. The first two would be common to any color study using this instrument. The third discrepency primarily concerned this study because of the inavailability of equipment.

1. The source--filter photocell of the difference meter used did not duplicate, spectrally, the C.I.E. standard observer.
2. The instrumental color solid did not exactly duplicate the Munsel spacing.
3. There was a great difference between the reference standard and the color of the specimens used in this study.[3]

More accurate readings could be obtained if there were few differences between the standard and the sample in spectral composition. Because there should be little difference between sample and standard, the suggestion was given that, when using a color difference meter, standards

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[1]Letter from Mary Spicer, Instrument Sales, Hunter Associates Laboratory, Inc., McLean, Virginia.

[2]Judd, pp. 163-170; and H. D. Murray, Colour: In Theory and Practice (London: Chapman & Hall, Ltd., 1952), p. 280; Optical Society Committee of Colorimetry, p. 176; and Genevieve Reimann, Deane B. Judd, and Harry J. Keegan, "Spectrophotometric and Colorimetric Determination of the Colors of the TCCA Standard Color Cards," JOSA, XXXVI (March, 1946), p. 144.

[3]Richard S. Hunter, Photoelectric Tristimulus Colorimetry with Three Filters, National Bureau of Standards, United States Department of Commerce, Circular C 429 (Washington: U.S. Government Printing Office, 1942).

be established with the spectrophotometer.[1] Because of the above shortcomings, the Gardner Color Difference Meter was recommended as a color difference meter rather than as a color meter.[2]

Problems involved in color measurement due to the fiber and fabric texture were also investigated. Two studies[3] gave detailed reports of the problems and possible solutions involved in textile color analysis. Standards for measuring textile samples have been determined by the C.I.E. These include the standard observer, standard illuminants, standard angular conditions and a reflectance standard.[4]

> The angular conditions recommended for the colorimetry of opaque specimens are that the light shall strike the specimen at 45° and that the light shall be viewed along the perpendicular to its surface. Since, as in the inspection of the glossy and semi-glossy materials making up the bulk of commerce, these conditions avoid by a wide margin the inclusion of the main beam of specularly reflected light, they should be used particularly when appearance is the chief concern.[5]

Additional directions were given for visual color matching:

> Care should be taken to hold the surface of the sample in the horizontal plane and close to the plane of the standards; errors in Munsell value by as much as a whole step are possible through inadvertent tilting or raising of the sample surface. . . . In glossy

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[1]Judd, pp. 153-154.

[2]Gardner Laboratory, Instruction Manual for Gardner Automatic Color and Color Difference Meter (Bethesda, Md.: Gardner Laboratory, Inc.), p. 5.

[3]Olsen Bent Buchmann, "The Objective Measurement of Colour and Colour Changes," Contributions from the Danish Institute for Textile Research, No. 11, Transactions of the Danish Academy of Technical Sciences, A.T.S. No. 4 (1950); and Reimann, Judd and Keegan, pp. 128-159.

[4]Commission Internationale de l'Eclairage, Proceedings of the Eighth Session, Cambridge, England (Sept., 1931), pp. 19-29.

[5]Deane B. Judd, Colorimetry, National Bureau of Standards, United States Department of Commerce, Circular 478 (Washington: U. S. Government Printing Office, 1950), p. 6.

> surfaces . . . the characteristic color of the sample is obtained only when specularly reflected light is prevented from reaching the eye of the observer.[1]

The luster of the yarn introduced still other problems into the color measurements.[2] Although some of the writers felt that color measurement of glossy samples was impossible, the committee on colorimetry states:

> Materials, such as cloth with a pronounced luster or sheen, will produce noticeable polarization effects. Errors arising from such effects can be eliminated in some photometric instruments by rotating the sample rapidly in its own plane. In other instruments the error is most conveniently avoided by averaging the reflectances observed when the sample is placed alternately in each of the two beams entering the photometer, with unchanged orientation of the sample. In general, for all polarizing photometers, the average between the maximum and minimum observed reflectances or between any two reflectances observed in two orientations of the sample differing by exactly 90 degrees is the reflectance for unpolarized energy.[3]

After the color of every sample had been measured, it was the purpose of this study to determine what color change had taken place. How much color change was acceptable? How should color difference be reported? Much has been written, but no agreement reached on the amount and type of color difference permissible in textiles.[4] A number of

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[1]The ISCC-NBS Method of Designating Colors and A Dictionary of Color Names. National Bureau of Standards, United States Department of Commerce, Circular 553 (Washington: U. S. Government Printing Office, 1955), p. 7.

[2]Judd, Color in Business, Science, and Industry, pp. 154-169; and Optical Society Committee of Colorimetry, p. 218.

[3]Optical Society Committee of Colorimetry, p. 189.

[4]American Society for Testing Materials, Symposium on Color Difference Specification, Presented at a meeting of Committee E-12 on Appearance, Cleveland, Ohio, March, 1952 (Philadelphia, Pa.: American Society for Testing Materials, 1952); Judd, Color in Business, Science, and Industry, pp. 276-277; and F. T. Simon and E. I. Stearns, "Why Small Color Differences are Important in Textiles," Proceedings of the American Association of Textile Chemists and Colorists, American Dyestuff Reporter, XXXIII (May, 1944), pp. 232-235.

formulas have been developed and used for specifying the amount of this color difference.[1] However: "it seems doubtful whether any formula can have more than a limited validity."[2]

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[1]Judd, Color in Business, Science, and Industry, pp. 260-267; and Dorothy Nickerson, "Summary of Available Information on Small Color Difference Formulas," American Dyestuff Reporter, XXXIII (June, 1944), pp. 252-256.

[2]Wright, The Measurement of Color, pp. 178-179.

CHAPTER III

PROCEDURE

Instrument Development

The data for this study were derived from thirty-five textured samples. One phase of the study involved the comparison of findings from this study with the results of a similar study at Western Reserve University.[1] The samples of the two studies varied in yarn size used. The difference in color due to the change in this variable, yarn size, was analyzed. In the present study the samples were woven in two pile heights. Another phase of this investigation involved the study of difference in color due to the change in this second variable, pile height. Tapestry samples were also woven. These were compared to the low pile samples to determine the effect of a variation in type of texture on color.

Color System

The Munsell Color System[2] was used as the basis for this research because of its standardization, widespread use, ease of notation, and convertability from and to other color measurement systems.

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[1]Since this study by Mary L. Shipley will be referred to throughout this paper, it will be listed as the "Shipley," "first," or "previous" study without footnoting.

[2]For a comprehensive description of the Munsell Color System see A Color Notation, 10th ed., by Albert H. Munsell (Baltimore: Munsell Color Company, 1954).

Yarns

Persian rug yarns purchased from Paternayian Brothers of New York, New York, were used for the textured samples of both studies. The yarn was of three ply, "Z" twist construction; each of these three ply were composed of two yarns combined with a "S" twist.

Seven of the colors (red, yellow-red, yellow, green, blue, purple-blue and red-purple) were purchased directly from the manufacturer, and three of the colors (blue-green, green-yellow, and purple) were dyed using the same wool in white. Although the dye lots of the previous study could not be matched, it was felt that the dye formulas of the commercially dyed yarns probably were not altered. The commercially dyed yarns of both studies seemed to match visually. The hand dyed yarns could not be as perfectly matched. Because of the impossibility of repeating dye formulas, the colors exhibited some metamerism. The blue-green of the original study seemed to have faded; therefore, the Munsell color chip, rather than the yarn was matched.

Because the variable between the two studies was to be yarn size, the three major ply of the yarns were separated and each new yarn (which still consisted of two ply) was considered as an individual unit in this study. Thus, three yarns used in this study were equal to one yarn of the previous study. The effect of this variable was tested in this study.

Texture Samples

The samples were hand-woven on a floor loom. A heavy 5/10 medium twist, bleached linen yarn was used for warp. The wool previously described was used for weft. The pile samples were woven with the flossa knot technique (a half ghiordes knot).[1] The samples

[1]For more information on the mechanics of this method of weaving see Callinger and Del Deo.

consisted of ten rows of eighteen knots each. Between each row of knots three rows of filler weft of heavy, white wool were thrown. This made each sample approximately four and three-eighth inches by three and one-half inches. Each knot consisted of eighteen of the separated yarns in comparison with the previous study in which each knot consisted of six yarns. The knots were tied over flossa bars and then the pile was cut.

Three types of samples were woven:

1. Tapestry samples in which the weft completely covered the warp. These were compared to the low pile samples to determine the effect of pile texture on color.
2. Low pile samples which were knotted over a flossa bar three-eighths inch by one-eighth inch and then cut to form a pile of one-half inch. These corresponded to the samples of the Shipley study in pile height and were compared with the Shipley samples to determine the effect of yarn size on color.
3. High pile samples which were knotted over a flossa bar one-half inch by one-fourth inch and then cut to form a pile of three-fourths inch. These were compared to the low pile samples of this study to determine the effect of pile height on color.

All three types of samples were woven in each of the ten basic Munsell Colors. The low pile samples were also woven in the five complementary color combinations: red and blue-green, red-purple and green, yellow-green and purple, blue and yellow-red, and purple-blue and yellow. The two colors of the complementary pair were used in equal amounts in each knot.

After the weaving process was completed the samples were coated on the back with a rubberized compound. They were then cut apart and the excess warp and filling yarns removed. The pile samples were also sheared to provide a more uniform surface.

Color Analysis

Because the investigator wanted to delve into the possibility of combining science and aesthetics, both subjective and objective methods of color analysis were used. It was felt that the use of both visual and instrumental color analysis techniques would strengthen the study since no one perfect method or instrument has been developed in this field. Visual methods were used because design analysis and appearance is a visual and mental process. An instrumentation method was used because it gave repeatable, unbiased results.

Subjective Color Analysis

Subjective judgment was done by a panel of three judges: Miss Mary Shipley (who also judged the color changes in the previous study by the same subjective method), Mrs. Betty Monroe, and Mr. Robert Bullard. All three judges are faculty members of Michigan State University who work in the area of interior design; they are knowledgeable in the field of color.

The Macbeth-Munsell Colorimeter, Type #1, was used for this color analysis. This colorimeter consists of an arrangement of two Spinning Disks mounted directly beneath a color corrected light source with controlled viewing conditions. The light source is composed of two R40 300-watt Reflector Flood lamps used with two 7-1/4" Macbeth daylight filters. The light source-filter combination produces the closest duplication of North Sky daylight (7500° Kelvin) that is commercially available. The viewing area is enclosed by two hinged doors which are opened to approximately a 45° angle with the sides of the unit to act as a blind to shield out extraneous light while using the instrument. The interior of the viewing area is painted a light neutral gray (Munsell N8/) in order to standardize the surrounding conditions when color judgments are made. A mask is mounted on a bar before the samples; this mask has four equal-sized rectangular apertures for viewing equal areas of the sample and standard.

The 1225 chips from the Munsell Color Standards in high-gloss surface were used as comparative standards.

The steps involved in subjective color judging were:

1. The colorimeter was readied (the doors positioned, the mask put in place, the lights turned on).
2. The textured sample was placed on the spinner and spun to fuse the color and texture, this gave a film mode of appearance.
3. The judges matched the textured sample to the nearest gloss chip. The chips were held under the lights in such a way that no light reflection was directed from them.
4. The Munsell book notation of the sample was estimated by each judge by interpolation and extrapolation between the chips in this series. Each judge gave his own estimate of the color. No attempt was made to agree on a single color notation for the sample.

Objective Color Analysis

Objective color judging was done with the Gardner Color Difference Meter which is an automation of the Hunter Color Difference Meter. This color difference meter was selected in preference to a spectrophotometer (which is usually considered the ideal measuring instrument) because of the larger area of the sample that could be presented to the instrument. All spectrophotometers available to the investigator had small fields. It was felt that in a small field one tiny facet of the texture might influence the entire reading.

In the Gardner Color Difference meter a circular field of the sample of approximately two inches in diameter is presented to the instrument. The light source is so set up that the beam is divided and each section strikes the sample at a 45° angle of incidence. The light diffused perpendicularly from the sample is passed out to each of three filter photocell combinations. This light creates a current proportional to its intensity that can be measured. The readings obtained give the colorimetric specification of the sample. This specification comes from three dials, the Rd, a, and b. "Rd" gives a luminous reflectance reading commensurate to Munsell's value. The "a" indicates redness when plus and greenness when minus. A plus value of "b" indicates yellowness, a minus value blueness. Thus, the a and b readings are the rectangular coordinates of the color on the color solid.

A white tile standard secured from Gardner Laboratory was used to standardize the instrument[1] because it was thought desirable to have the instrument on the same standardization for all hues. The instrument was restandardized after every set of samples was analyzed. Each set of samples consisted of the chip, yarn, tapestry, low pile, and high pile of one hue.

Because of the texture of the samples, each sample was presented to the instrument in four positions; the sample was given a 90° turn after each reading. The four readings taken were averaged.

Not only were the tapestry and pile samples analyzed, but unlike the visual analysis, the standard hue chip, the yarn (wrapped on a card) and the complementary colored low pile samples were also analyzed.

Data Conversion

All data was reported in or converted to Munsell notations for

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[1]On this tile Rd = 83.0, a = -2.0, and b = +2.5.

analysis, because it was felt that such notation would be more meaningful to the reader.

The decisions of the judges as to the color of each sample by subjective color matching were averaged to obtain one usable figure.

The values from the color difference meter were converted to Munsell notations by the method recommended by the O. S. A. subcommittee report.[1] The following steps were used in this conversion:

1. Y was found from Rd (Rd = 100 Y)
2. Munsell value (V) was found from Y by the use of the "I. C. I. (Y) equivalents of the recommended Munsell value scale (V) from 0/ to 10/" table.[2]
3. Munsell hue and saturation were found with the help of the Hunter to Munsell conversion charts.[3] Hue and saturation were found by interpolation between the proper value level charts.[4]

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[1]Sidney M. Newhall, Dorothy Nickerson, and Deane B. Judd, "Final Report of the O. S. A. Subcommittee on the Spacing of the Munsell Colors," JOSA 33:7 (July, 1943), pp. 385-418.

[2]*Ibid.*

[3]A series of these charts will be found in Appendix B.

[4]Sample problems showing the method of interpolation are found in many references including that of the subcommittee listed above.

CHAPTER IV

FINDINGS AND INTERPRETATIONS

Color Analysis

Results of Subjective Color Analysis

The results of the subjective color analysis are recorded in Table I, page 25. Although the judges' determinations of the Munsell notations did not vary widely, the analysis of the individual judge did not always agree with that of the other judges. Much of the discrepancy seemed to occur when value or saturation levels of the samples appeared to go beyond those of the chips. In the thirty samples analyzed disagreement on hue was notated only seven times. Value notations varied nineteen times and saturation notations varied twenty-three times. It was not possible to find any pattern in these variations.

Results of Objective Color Analysis

Table II, page 27, shows the results of the objective color analysis. The primary differences in the instrument readings of any given sample were due to the position of the sample.[1] Although the readings at the various positions were not the same, they did not exhibit the differences found between the various judges' color notations. A second reading at the same position at the same time gave the same results. It was felt, that if these samples could have been spun while

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[1]The Gardner Color Difference Meter readings of the various positions of each sample are recorded in Appendix A.

Key for Tables[1]

R	red
YR	yellow-red
Y	yellow
GY	green-yellow
G	green
BG	blue-green
B	blue
PB	purple-blue
P	purple
RP	red-purple
N	neutral
H	hue
V	value
S	saturation
C	Munsell gloss chip
Y	yarn (when listed under texture)
T	tapestry woven sample
LP	low pile sample
HP	high pile sample
>	color moved in a clockwise direction around the color wheel
<	color moved in a counter-clockwise direction around the color wheel
-	a decrease in value or saturation
+	an increase in value or saturation
o	no change

[1]This key applies to all the tables in this study.

Table I. Judges' Munsell Notations by Subjective Color Analysis Using the Macbeth-Munsel Colorimeter and Munsell High Gloss Color Chips

Sample		Determination of the Judges				
		Hue	Value and Saturation			
Color	Texture	All Judges	Bullard	Monroe	Shipley	Average
R	T	5 R	$\frac{4}{12}$	$\frac{4}{12}$	$\frac{3}{10}$	5 R $\frac{3.67}{11.33}$
	LP	7.5 R	$\frac{3}{11}$	$\frac{3}{11}$	$\frac{2}{11}$	7.5 R $\frac{2.67}{11}$
	HP	6 R	$\frac{3}{10}$	$\frac{3}{12}$	$\frac{3}{12}$	6 R $\frac{3}{11.33}$
YR	T	2.5 YR	$\frac{6}{14}$	$\frac{6}{12}$	$\frac{6}{14}$	2.5 YR $\frac{6}{13.33}$
	LP	2.5 YR	$\frac{5}{14}$	$\frac{4}{10}$	$\frac{4.5}{12}$	2.5 YR $\frac{4.5}{12}$
	HP	2.5 YR	$\frac{6}{14}$	$\frac{4}{12}$	$\frac{4.5}{13}$	2.5 YR $\frac{4.83}{13}$
Y	T	2.5 Y	$\frac{8}{12}$	$\frac{8}{11}$	$\frac{8}{11}$	2.5 Y $\frac{8}{11.33}$
	LP	2.5 Y	$\frac{7}{11}$	$\frac{7}{11}$	$\frac{7}{12}$	2.5 Y $\frac{7}{11.33}$
	HP	2.5 Y	$\frac{8}{14}$	$\frac{7}{12}$	$\frac{7.5}{12}$	2.5 Y $\frac{7.5}{12.67}$
GY	T	→ [a]	5 GY $\frac{7}{10}$	3.5 GY $\frac{8}{10}$	5 GY $\frac{7}{10}$	4.5 GY $\frac{7.33}{10}$
	LP	5 GY	$\frac{7}{10}$	$\frac{7}{12}$	$\frac{5}{10}$	5 GY $\frac{6.33}{10.67}$
	HP	5 GY	$\frac{7}{11}$	$\frac{7}{11}$	$\frac{5}{10}$	5 GY $\frac{6.33}{10.67}$
G	T	2.5 G	$\frac{5}{8}$	$\frac{4}{8}$	$\frac{4}{8}$	2.56 G $\frac{4.33}{8}$
	LP	5 G	$\frac{3}{6}$	$\frac{3}{6}$	$\frac{3}{7}$	5 G $\frac{3}{6.33}$
	HP	→	5 G $\frac{3}{7}$	4 G $\frac{3}{6}$	5 G $\frac{3}{7}$	4.66 G $\frac{3}{6.67}$

[a] This arrow → indicates that the hue determination varied among the various judges. Their determinations of hue are given with their value and saturation determinations.

Table I - Continued

Sample Color	Sample Texture	Hue All Judges	Bullard	Monroe	Shipley	Average
		Determination of the Judges				
			Value and Saturation			
BG	T	5 BG	$\frac{5}{6}$	$\frac{5}{6}$	$\frac{5}{8}$	5 BG $\frac{5}{6.67}$
	LP	→	5 BG $\frac{3}{6}$	6 BG $\frac{4}{8}$	5 BG $\frac{3.5}{6}$	5.33 BG $\frac{3.5}{6.67}$
	HP	→	5 BG $\frac{4}{8}$	6 BG $\frac{4}{8}$	5 BG $\frac{4.5}{8}$	5.33 BG $\frac{4.17}{8}$
B	T	→	7.5 B $\frac{4}{8}$	7.5 B $\frac{4}{8}$	8.5 B $\frac{3}{6}$	7.83 B $\frac{3.67}{7.33}$
	LP	10 B	$\frac{2}{8}$	$\frac{3}{8}$	$\frac{2}{8}$	10 B $\frac{2.33}{8}$
	HP	10 B	$\frac{2}{8}$	$\frac{3}{7}$	$\frac{2}{8}$	10 B $\frac{2.33}{7.33}$
PB	T	5 PB	$\frac{3}{10}$	$\frac{4}{12}$	$\frac{3}{10}$	5 PB $\frac{3.33}{10.67}$
	LP	5 PB	$\frac{2}{10}$	$\frac{2}{10}$	$\frac{2}{10}$	5 PB $\frac{2}{10}$
	HP	→	5 PB $\frac{2}{8}$	5 PB $\frac{2}{8}$	6 PB $\frac{2}{8}$	5.33 PB $\frac{2}{8}$
P	T	7.5 P	$\frac{5}{10}$	$\frac{5}{9}$	$\frac{5}{10}$	7.5 P $\frac{5}{9.67}$
	LP	7.5 P	$\frac{3}{10}$	$\frac{3}{10}$	$\frac{3}{11}$	7.5 P $\frac{3}{10.33}$
	HP	7.5 P	$\frac{4}{12}$	$\frac{3}{10}$	$\frac{3.5}{11}$	7.5 P $\frac{3.5}{11}$
RP	T	5 RP	$\frac{4}{11}$	$\frac{4}{10}$	$\frac{3}{7}$	5 RP $\frac{3.67}{9.33}$
	LP	→	7.5 RP $\frac{3}{11}$	10 RP $\frac{2}{8}$	7.5 RP $\frac{2}{8}$	8.33 RP $\frac{2.67}{9.67}$
	HP	7.5 RP	$\frac{3}{8}$	$\frac{3}{10}$	$\frac{2}{8}$	7.5 RP $\frac{2.67}{8.67}$

Table II. "Rd," "a" and "b" Averages of Objective Color Analysis Using the Gardner Color Difference Meter and Their Conversion into Munsell Notations

Sample		Averages			Munsell
Color	Texture	Rd	a	b	Notation
R	C	10.0	+64.8	+15.7	4.25 R $\frac{3.68}{13.04}$
	Y	4.7	38.18	11.83	7.35 R $\frac{2.53}{8.81}$
	T	4.05	33.99	11.1	8.38 R $\frac{2.32}{8.01}$
	LP	9.88	17.5	6.1	4.34 R $\frac{3.66}{3.76}$
	HP	10.08	16.63	5.9	3.9 R $\frac{3.68}{3.7}$
YR	C	29.7	+31.2	+31.9	3.05 YR $\frac{5.97}{10.54}$
	Y	17.6	32.78	26.25	2.38 YR $\frac{4.75}{9.83}$
	T	14.18	28.43	28.83	5.02 YR $\frac{4.32}{11.36}$
	LP	6.93	26.73	19.1	2.28 YR $\frac{3.09}{7.93}$
	HP	6.68	25.93	18.95	2.66 YR $\frac{3.03}{7.87}$
Y	C	59.3	+0.0	+45.3	3.74 Y $\frac{8.01}{9.99}$
	Y	39.53	5.75	35.98	2.11 Y $\frac{6.78}{8.72}$
	T	34.53	4.15	33.04	2.63 Y $\frac{6.37}{7.82}$
	LP	20.75	7.73	29.23	1 Y $\frac{5.11}{7.8[illegible]}$
	HP	19.15	7.88	28.58	1.5 Y $\frac{4.93}{7.54}$
GY	C	44.1	-22.5	+36.6	4.19 GY $\frac{7.07}{8.74}$
	Y	24.7	14.9	29.7	2.51 GY $\frac{5.51}{7.04}$
	T	23.38	13.23	29.03	2 GY $\frac{5.38}{6.87}$
	LP	10.6	11.63	22.48	2.89 GY $\frac{3.78}{5.61}$
	HP	11.33	12.78	22.83	3.45 GY $\frac{3.89}{5.82}$

Continued

Table II - Continued

Sample Color	Sample Texture	Averages Rd	Averages a	Averages b	Munsell Notation
G	C	20.5	-30.5	+11.5	4.04 G $\frac{5.08}{5.52}$
	Y	7.73	19.75	10.53	1.75 G $\frac{3.25}{5.38}$
	T	7.4	18.6	9.85	1.85 G $\frac{3.19}{4.99}$
	LP	2.58	11.43	5.3	1.98 G $\frac{1.77}{4.5}$
	HP	2.15	10.58	4.98	1.49 G $\frac{1.57}{4.32}$
BG	C	12.3	-22.5	-3.5	4.05 BG $\frac{4.05}{5.78}$
	Y	11.13	19.3	4.30	4.89 BG $\frac{3.86}{4.9}$
	T	9.15	18.75	5.0	5.26 BG $\frac{3.52}{5.04}$
	LP	3.65	13.2	4.95	6.10 BG $\frac{2.19}{5.12}$
	HP	3.6	13.33	4.93	6.09 BG $\frac{2.18}{5.13}$
B	C	12.3	-14.7	-17.8	3.91 B $\frac{4.05}{5.69}$
	Y	5.43	7.63	26.23	8.1 B $\frac{2.73}{5.99}$
	T	5.05	6.63	23.03	8.43 B $\frac{2.62}{5.38}$
	LP	1.68	2.63	16.75	9.47 B $\frac{1.31}{4.75}$
	HP	1.43	2.18	15.88	9.98 B $\frac{1.15}{4.85}$
PB	C	6.0	+2.1	-58.7	3.7 PB $\frac{2.87}{9.83}$
	Y	4.2	1.28	42.45	3.69 PB $\frac{2.37}{7.85}$
	T	4.08	1.85	41.83	3.27 PB $\frac{2.34}{7.09}$
	LP	1.35	2.25	28.6	3.6 PB $\frac{1.1}{6.91}$
	HP	1.28	2.2	26.9	3.57 PB $\frac{1.05}{6.75}$

Continued

Table II - Continued

Sample Color	Sample Texture	Averages Rd	Averages a	Averages b	Munsell Notation
P	C	10.3	+25.4	-29.1	$4.37\ P\ \frac{3.73}{7.73}$
	Y	10.15	29.60	30.7	$5.85\ P\ \frac{3.7}{8.42}$
	T	8.15	25.35	27.6	$5\ P\ \frac{3.34}{7.27}$
	LP	2.65	24.43	28.43	$3.79\ P\ \frac{1.57}{9.03}$
	HP	3.2	24.58	28.0	$4.02\ P\ \frac{2.03}{7.91}$
RP	C	11.0	+40.4	-5.6	$5.16\ RP\ \frac{3.84}{8.89}$
	Y	5.2	30.1	4.9	$5.85\ RP\ \frac{2.66}{6.68}$
	T	5.28	26.73	3.95	$6.48\ RP\ \frac{2.69}{6.03}$
	LP	1.78	19.13	1.93	$1.21\ R\ \frac{1.37}{5.76}$
	HP	1.55	18.2	1.4	$1.81\ R\ \frac{1.23}{5.72}$
COMPLEMENTARIES					
R & BG	LP	1.85	-.65	+.625	$N\ \frac{1.41}{0}$
RP & G	LP	1.73	+1.88	+1.78	$N\ \frac{1.34}{.20}$
GY & P	LP	5.53	+2.45	+7.93	$10\ YR\ \frac{2.74}{1.85}$
B & YR	LP	2.43	+5.53	+3.63	$0.9\ YR\ \frac{1.7}{1.86}$
PB & Y	LP	5.33	-2.38	+6.33	$1\ GY\ \frac{2.7}{1.65}$

the instrumental reading was being taken, the same results could have been reaffirmed many times. Slight differences for various positions were attributed to the movement of the pile due to the heat of the lamps and to the lay of the pile.

The instrument, in an unbiased way, showed color is affected by texture, for never did any of the textures in the same color obtain the same notation. That is, the reading from the yarn never matched the reading from the tapestry, low pile, or high pile sample. Thus, it might be said that texture's influence on color was more than an illusion of the eye.

Comparison of Analysis Methods

A comparison of the results of the subjective and objective methods of color measurement was compiled on Table III, page 31. When reading this table, consideration must be made of the fact that the instrument was standardized on a white tile. Because of this method of standardization, instrumental reading of the chips of the ten Munsel hues at their most saturated level when converted to Munsell notations by the proper method, did not agree with the given notations for those chips.[1] The discrepancy found is recorded under "C" in the texture column of the table; this is the first recording for each color on the table. If attribute discrepancies of the chips were added to the same attributes of the various textures, the instrumental figures would more nearly show the instruments determination of the Munsell notation. When using this figure to determine how much the color differed in subjective and objective colorimetry the direction or type of difference must also be considered. Because of this discrepancy in notations for the same chip and samples, the subjective analysis of the color was considered to be more nearly what people saw.

[1]The Review of Literature on page 12 explained the reasons for this discrepancy.

Table III. The Color Differences between the Results of Subjective and Objective Color Analysis

Sample Color	Sample Texture	Analysis Method: Subjective	Analysis Method: Objective	Color Differences: H		Color Differences: V	Color Differences: S
R	C	4.7 R 4.05[a]/13.6	4.25 R 3.68/13.04	.45	<	-.37	-.54
	T	5 R 3.67/11.33	8.38 R 2.33/8.01	3.38	>	-1.34	-3.32
	LP	7.5 R 2.67/11	4.34 R 3.66/3.76	3.16	<	+.99	-7.24
	HP	6 R 3/11.33	3.9 R 3.68/3.7	2.1	<	+.68	-7.63
YR	C	4.8 YR 5.97/12	3.05 YR 5.97/10.54	1.75	<	0	-1.46
	T	2.5 YR 6/13.33	5.02 YR 4.32/11.36	2.52	>	-1.68	-1.97
	LP	2.5 YR 4.5/12	2.28 YR 3.09/7.93	.22	<	-1.41	-4.07
	HP	2.5 YR 4.83/13	2.66 YR 3.03/7.87	.16	>	-1.8	-5.13
Y	C	4.9 Y 7.95/12.1	3.74 Y 8.01/9.99	1.16	<	+.06	-2.11
	T	2.5 Y 8/11.33	2.63 Y 6.37/7.82	.13	>	-1.63	-3.51
	LP	2.5 Y 7/11.33	1 Y 5.11/7.8	1.5	<	-1.89	-3.53
	HP	2.5 Y 7.5/12.67	1.5 Y 4.93/7.54	1.0	<	-2.57	-5.13
GY	C	5.1 GY 6.98/9.9	4.19 GY 7.07/8.74	.91	<	+.09	-1.16
	T	4.5 GY 7.33/10	2 GY 5.38/6.87	2.5	<	-1.95	-3.13
	LP	5 GY 6.33/10.67	2.89 GY 3.78/5.61	2.11	<	-2.55	-5.06
	HP	5 GY 6.33/10.67	3.45 GY 3.89/5.82	1.55	<	-2.44	-4.85
G	C	4.9 G 5.03/7.9	4.04 G 5.08/5.52	.86	<	+.05	-2.38
	T	2.5 G 4.33/8	1.85 G 3.19/4.99	.7	<	-1.14	-3.01
	LP	5 G 3/6.33	1.98 G 1.77/4.50	3.02	<	-1.23	-1.83
	HP	4.66 G 3/6.67	1.49 G 1.57/4.32	3.17	<	-1.43	-2.35

[a]The Munsell re-notation of the chip is used in this table.

Table III - Continued

Sample		Analysis Method		Color Differences		
Color	Texture	Subjective	Objective	H	V	S
BG	C	5.3 BG $\frac{3.97}{6.05}$	4.05 BG $\frac{4.05}{5.78}$	1.25 <	+.08	-.27
	T	5 BG $\frac{5}{6.67}$	5.26 BG $\frac{3.53}{5.04}$	.26 >	-1.47	-1.63
	LP	5.33 BG $\frac{3.5}{6.67}$	6.1 BG $\frac{2.19}{5.12}$	.77 >	-1.31	-1.55
	HP	5.33 BG $\frac{4.17}{8}$	6.09 BG $\frac{2.18}{5.13}$	.76 >	-1.99	-2.87
B	C	4.1 B $\frac{4.09}{5.8}$	3.91 B $\frac{4.05}{5.69}$	.19 <	-.04	-.11
	T	7.83 B $\frac{3.67}{7.33}$	8.43 B $\frac{2.62}{5.38}$	.6 >	-1.05	-1.95
	LP	10 B $\frac{2.33}{8}$	9.47 B $\frac{1.31}{4.75}$	.53 <	-1.02	-3.25
	HP	10 B $\frac{2.33}{7.33}$	9.98 B $\frac{1.15}{4.85}$	.02 <	-1.18	-2.48
PB	C	5.1 PB $\frac{3.04}{9.6}$	3.7 PB $\frac{2.87}{9.83}$	1.40 <	-.17	+.23
	T	5 PB $\frac{3.33}{10.67}$	3.27 PB $\frac{2.34}{7.09}$	1.73 <	-.99	-3.58
	LP	5 PB $\frac{2}{10}$	3.6 PB $\frac{1.10}{6.91}$	1.40 <	-.90	-3.09
	HP	5.33 PB $\frac{2}{8}$	3.57 PB $\frac{1.05}{6.75}$	1.76 <	-.95	-1.25
P	C	5.7 P $\frac{4.05}{9.2}$	4.37 P $\frac{3.73}{7.73}$	1.33 <	-.32	-1.47
	T	7.5 P $\frac{5}{9.67}$	5 P $\frac{3.34}{7.27}$	2.5 <	-1.66	-2.4
	LP	7.5 P $\frac{3}{10.33}$	3.79 P $\frac{1.57}{9.03}$	3.71 <	-1.43	-1.3
	HP	7.5 P $\frac{3.5}{11}$	4.02 P $\frac{2.03}{7.91}$	3.48 <	-1.47	-3.09
RP	C	4.9 RP $\frac{4.06}{9.5}$	5.16 RP $\frac{3.84}{8.89}$	.26 >	-.22	-.61
	T	5 RP $\frac{3.67}{9.33}$	6.48 RP $\frac{2.69}{6.03}$	1.48 >	-.98	-3.3
	LP	8.33 RP $\frac{2.67}{9.67}$	1.21 R $\frac{1.37}{5.76}$	2.88 >	-1.3	-3.91
	HP	7.5 RP $\frac{2.67}{8.67}$	1.81 R $\frac{1.23}{5.72}$	4.31 >	-1.44	-2.95

The results of objective analysis, however, were felt to be more accurate, less biased, determinations of the amounts and kinds of differences between the various textures of a given color. This was due to the fact that individual judge's notations varied widely while the Gardner Color Difference Meter gave a number of closely comparable readings when considering any given sample.

The color difference meter recorded duller saturations for the samples than did the judges. When the discrepancies in the notations are considered, the green low and high pile and the purple low pile have brighter saturation readings; however, these readings were very close to those obtained by the judges. The instrument also recorded darker values for all textured samples but the red low and high pile. These lower recordings of value and saturation may be partially due to the spinning of the sample which could have enhanced reflectivity. Whether the differences were due to variations in what the eye perceived and what the instrument "perceived" or to the fact that the sample was spun in one instance and not in the other could not be determined. Although the hue of the samples as determined by the judges and by the instrument differed, no set pattern as to direction of hue difference could be ascertained.

Effect of Pile Texture on Color

The Shipley study showed that pile texture affects color. Since that study involved only visual judging, the question remained--Was the change in color only a visual illusion due to the change in attributes of the surface mode of appearance, or was this truly a color change? The results of this study reaffirm and strengthen the findings of the previous study, for pile texture again was found to affect color. Table II on which the color difference meter determinations of the yarn, tapestry, low pile and high pile were recorded showed that by objective analysis no two of these were the same color. Thus, the effect of pile texture on color was not a visual illusion, for the color difference meter also recorded this color change.

Table II shows that the yarn color was different from the color of either tapestry or pile texture woven from it. Table IV, page 35, gives the difference in hue, value, and saturation between the pile and tapestry weaves of both studies to show the difference in color that can be expected when a yarn is woven into a cut pile rather than a non-pile texture.

The results of the Shipley study were reported as found by subjective color analysis because this was the only analysis method used. The results of the present study were reported as found in both subjective and objective analysis since the findings differed in each method of color analysis.

Unlike the previous tables, the figures in this table were rounded off to compare with those of the previous study which were reported in whole numbers. On Table IV the zero means only that no whole number difference in the attribute being considered was found. However, as can be seen from Tables I and II, there were small differences in all of these attributes.

The value level decreased from one to two steps between the tapestry and the pile textured samples in both studies. An exception in this study was the red samples as analyzed by the color difference meter where the value level increased one step. The subjective analysis of these same red samples showed no change in value. The exceptions in the Shipley study were yellow-red and yellow in which the value level was unchanged.

The hues of the red, yellow-red and yellow samples moved in a counterclockwise direction around the color wheel according to the objective analysis. All other hues moved in a clockwise direction with

Table IV. Differences in Color as Found Through the Analysis Methods Used in Shipley and Gross Studies Due to Change in Type of Texture

Sample Color	Sample Study	Analysis Method	Type of Texture: Tapestry	Type of Texture: Low Pile	Color Differences: H	Color Differences: V	Color Differences: S
R	SS[a]	S[b]	$5R\frac{5}{15}$	$7.5\ R\frac{3}{15}$	2.5 >	-2	0
	GS[c]	S	$5\ R\frac{4}{11}$ [a]	$7.5\ R\frac{4}{12}$	2.5 >	0	+1
	GS	O[e]	$8.4\ R\frac{3}{8}$	$4.3\ R\frac{4}{4}$	4.1 <	+1	-4
YR	SS	S	$2.5\ YR\frac{5}{15}$	$2.5\ YR\frac{5}{15}$	0	0	0
	GS	S	$2.5\ YR\frac{6}{13}$	$2.5\ YR\frac{5}{12}$	0	-1	-1
	GS	O	$5.0\ YR\frac{4}{11}$	$2.3\ YR\frac{3}{8}$	2.7 <	-1	-3
Y	SS	S	$2.5\ Y\frac{8}{12}$	$2.5\ Y\frac{8}{14}$	0	0	+2
	GS	S	$2.5\ Y\frac{8}{11}$	$2.5\ Y\frac{7}{11}$	0	-1	0
	GS	O	$2.6\ Y\frac{6}{8}$	$1\ Y\frac{5}{8}$	1.6 <	-1	0
GY	SS	S	$5\ GY\frac{7.5}{12}$	$4\ GY\frac{6}{12}$	1 <	-1.5	0
	GS	S	$4.5\ GY\frac{7}{10}$	$5\ GY\frac{6}{11}$	.5 >	-1	+1
	GS	O	$2\ GY\frac{5}{7}$	$2.9\ GY\frac{4}{6}$	.9 >	-1	-1
G	SS	S	$2.5\ G\frac{5}{10}$	$5\ G\frac{3}{8}$	2.5 >	-2	-2
	GS	S	$2.5\ G\frac{4}{8}$	$5\ G\frac{3}{6}$	2.5 >	-1	-2
	GS	O	$1.9\ G\frac{3}{5}$	$2.G\frac{2}{5}$	.1 >	-1	0

[a]SS = Shipley study
[b]S = Subjective Color Analysis
[c]GS = Gross study
[d]Because the results in the Shipley study were reported in whole numbers, the decimals of the Gross study were rounded off for this table.
[e]O = Objective Color Analysis

Table IV - Continued

Sample Color	Sample Study	Analysis Method	Type of Texture: Tapestry	Type of Texture: Low Pile	Color Differences: H	Color Differences: V	Color Differences: S
BG	SS	S	7.5 BG $\frac{5}{6}$	4.5 BG $\frac{3}{6}$	2.5 <	-2	0
	GS	S	5 BG $\frac{5}{7}$	5.3 BG $\frac{4}{7}$	.3 >	-1	0
	GS	O	5.3 BG $\frac{4}{5}$	6.1 BG $\frac{3}{5}$	.8 >	-1	0
B	SS	S	7.5 B $\frac{4}{8}$	10 B $\frac{3}{14}$	2.5 >	-1	+6
	GS	S	7.8 B $\frac{4}{7}$	10 B $\frac{2}{8}$	2.2 >	-2	+1
	GS	O	8.4 B $\frac{3}{5}$	9.5 B $\frac{1}{5}$	1.1 >	-2	0
PB	SS	S	5 PB $\frac{4}{12}$	5 PB $\frac{3}{14}$	0	-1	+2
	GS	S	5 PB $\frac{4}{11}$	5 PB $\frac{2}{10}$	0	-2	-1
	GS	O	3.3 PB $\frac{2}{7}$	3.6 PB $\frac{1}{7}$	.3 >	-1	0
P	SS	S	7.5 P $\frac{4}{12}$	7.5 P $\frac{3}{10}$	0	-1	-2
	GS	S	7.5 P $\frac{5}{10}$	7.5 P $\frac{3}{10}$	0	-2	0
	GS	O	5 P $\frac{3}{7}$	3.8 P $\frac{2}{9}$	1.2 <	-1	+2
RP	SS	S	2.5 RP $\frac{4}{12}$	10 RP $\frac{2}{8}$	7.5 >	-2	-4
	GS	S	5 RP $\frac{4}{9}$	8.3 RP $\frac{3}{10}$	3.3 >	-1	+1
	GS	O	6.5 RP $\frac{3}{6}$	1.21 R $\frac{1}{5}$	4.7 >	-2	-1

this method of analysis. Subjective analysis of the samples of this study showed that in all cases where a change of hue occurred this change was in a clockwise direction. No pattern of hue change was exhibited in the samples of the previous study. In both studies, the greatest hue changes were exhibited by the red-purple samples. The red, green and blue samples also exhibited strong hue changes by more than one method of analysis.

Saturation, which had shown a remarkable increase from the yarn to the pile texture in the previous study, did not seem to show a definite pattern of change from the tapestry to the pile texture. When visually inspected without controlled conditions the pile texture samples, however, seemed brighter and more lively than the tapestry samples.

When considering all dimensions of color, the yellow, purple-blue and purple samples exhibited the least amount of change while the red, blue and red-purple samples exhibited the greatest changes in color from tapestry to pile texture.

The Effect of Yarn Size of Pile Texture on Color

Solid Colors

The one-half inch pile textured samples of this study were compared with the samples of the previous study on Table V, page 38, to determine the effect of yarn size on color. The notations from the subjective colorimetry were used because this was the only method of analysis used in the first study.

When comparing the samples of the two studies, the only attribute which changed in any important degree was saturation. The decrease in yarn size caused the saturation to decrease in all colors except blue-green, purple and red-purple. Purple showed no change while blue-green exhibited a one step increase and red-purple a two step increase in

Table V. Comparison of the Shipley and Gross Studies Showing the Differences in the Color of Pile Texture Due to Change in Yarn Size as Determined by Subjective Color Analysis

Sample Color	Yarn Size: Heavier Yarn of Shipley Study	Yarn Size: Finer Yarn of Gross Study	Color Differences H		V	S
R	$7.5\ R\ \frac{3}{15}$	$7.5\ R\ \frac{3}{11}$[a]	0		0	-4
YR	$2.5\ YR\ \frac{5}{15}$	$2.5\ YR\ \frac{4}{12}$	0		-1	-3
Y	$2.5\ Y\ \frac{8}{14}$	$2.5\ Y\ \frac{7}{11}$	0		-1	-3
GY	$4\ GY\ \frac{6}{12}$	$5\ GY\ \frac{6}{11}$	1	>	0	-1
G	$5\ G\ \frac{3}{8}$	$5\ G\ \frac{3}{6}$	0		0	-2
BG	$4.5\ BG\ \frac{3}{6}$	$5\ BG\ \frac{4}{7}$	.5	>	+1	+1
B	$10\ B\ \frac{3}{14}$	$10\ B\ \frac{2}{8}$	0		-1	-6
PB	$5\ PB\ \frac{3}{14}$	$5\ PB\ \frac{2}{10}$	0		-1	-4
P	$7.5\ P\ \frac{3}{10}$	$7.5\ P\ \frac{3}{10}$	0		0	0
RP	$10\ RP\ \frac{2}{8}$	$8\ RP\ \frac{3}{10}$	2	<	+1	+2

[a] Because the results in the Shipley study were reported in whole numbers, the decimals in this study were rounded off for this table.

saturation with the finer yarn. Since the blue-green and purple yarns were hand-dyed, some of this change might be attributed to this factor. The red-purple yarn was not hand-dyed, therefore the reason for its change could not be attributed to this.

Value change was also found between the samples of different yarn sizes. As in the saturation, there was either no change or a decrease in value in all but the blue-green and red-purple samples. The value change, however, was never greater than one step.

The judges indicated that only three colors showed change in hue: the two colors that showed change in the other color attributes, blue-green and red-purple, as well as green-yellow. Since the green-yellow is another of the hand-dyed yarns and the dye formulas of the hand-dyed yarns were different this may account for the change.

When considering all three attributes of color, the blue, purple-blue and red-purple samples showed the greatest change due to yarn size. The purple samples exhibited no change in color from one yarn size to the next.

Complementary Colors

The previous study also analyzed analogous and complementary color mixtures in pile texture. Because the complementary colors proved to be unsuccessful mixtures, this investigator was interested in determining what affect the smaller yarn size would have on similar combinations.

As in the previous study, the samples of this study did not spin to a gray which they would if they were a perfect combination of complementary colors. There was, however, a great difference in the amount of color blending in the samples of the same color combinations but of different yarn sizes. The complements of red and blue-green, and of red-purple and green were rated nearest to gray; nevertheless, since they exhibited rings of color when spun, no color notation could be made.

The samples from this study were also analyzed with the Gardner Color Difference Meter. Since these mixtures were composed of two colors whose combination should, theoretically, produce gray by additive color mixture in the eye, the writer was interested in discovering what color the instrument would "see." The colors of these combinations as determined by the difference meter all fell in the gray range. Their readings are recorded on Table II. Complementary color mixtures rated as the best grays by subjective analysis were the same mixtures recorded as the better grays by objective analysis.

Yarn size alone appeared not to be the solution when combining complementary colors. The most successful complementary color combinations were those composed of colored yarns whose value and/or saturation levels varied to a smaller degree.

The changes in color of the solid and complementary colored samples due to yarn size can perhaps be attributed to a change in light reflectance due to the difference in the size of the spaces between yarns and to a change in light penetration of the yarns due to a change in the size of the yarns.[1]

Effect of Height of Pile Texture on Color

The data illustrating the effect of pile height on color was compiled into Table VI, page 41. Both subjective and objective analysis were given, for they recorded varying amounts of difference in color due to pile height.

By using subjective analysis, saturation changes were found to be greater than either value or hue changes; more samples also exhibited a change in saturation than in any other color attribute. Yellow-red, yellow, blue-green, purple-blue and red-purple all changed one or more steps in saturation; the saturation changes were increases in some

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[1]Discussion on these two factors as they influence color in textiles is included in the Review of Literature, pp. 6-7.

Table VI. Differences in Color Due to Changes in Pile Height in this Study as Determined by Subjective and Objective Color Analysis

Subjective Analysis					
Sample Color	Pile Height Low 1/2"	Pile Height High 3/4"	Color Differences H	V	S
R	$7.5\ R\ \frac{2.67}{11}$	$6\ R\ \frac{3}{11.33}$	1.5 >	+.33	+.33
YR	$2.5\ YR\ \frac{4.5}{12}$	$2.5\ YR\ \frac{4.83}{13}$	0	+.33	+1
Y	$2.5\ Y\ \frac{7}{11.33}$	$2.5\ Y\ \frac{7.5}{12.67}$	0	+.5	+1.34
GY	$5\ GY\ \frac{6.33}{10.67}$	$5\ GY\ \frac{6.33}{10.67}$	0	0	0
G	$5\ G\ \frac{3}{6.33}$	$4.66\ G\ \frac{3}{6.67}$	.34 <	0	+.34
BG	$5.33\ BG\ \frac{3.5}{6.67}$	$5.33\ BG\ \frac{4.17}{8}$	0	+.67	+1.33
B	$10\ B\ \frac{2.33}{8}$	$10\ B\ \frac{2.33}{7.33}$	0	0	-.67
PB	$5\ PB\ \frac{2}{10}$	$5.33\ PB\ \frac{2}{8}$	.33 >	0	-2
P	$7.5\ P\ \frac{3}{10.33}$	$7.5\ P\ \frac{3.5}{11}$	0	+.50	+.67
RP	$8.33RP\ \frac{2.67}{9.67}$	$7.5\ RP\ \frac{2.67}{8.67}$	.83 <	0	-1

Table VI - Continued

Sample Color	Objective Analysis: Pile Height, Low - 1/2 "	High - 3/4"	Color Differences: H	V	S
R	$4.34\ R\ \frac{3.66}{3.76}$	$3.9\ R\ \frac{3.68}{3.7}$	.44 <	+.02	-.06
YR	$2.28\ YR\ \frac{3.09}{7.93}$	$2.66\ YR\ \frac{3.03}{7.87}$	.38 >	-.06	-.06
Y	$1.0\ Y\ \frac{5.11}{7.80}$	$1.5\ Y\ \frac{4.93}{7.54}$	.5 >	-.18	-.26
GY	$2.89\ GY\ \frac{3.78}{5.61}$	$3.45\ GY\ \frac{3.89}{5.82}$	.56 >	+.11	+.21
G	$1.98\ G\ \frac{1.77}{4.50}$	$1.49\ G\ \frac{1.57}{4.32}$	.49 <	-.2	-.18
BG	$6.10\ BG\ \frac{2.19}{5.12}$	$6.09\ BG\ \frac{2.18}{5.13}$	.01 <	-.01	+.01
B	$9.47\ B\ \frac{1.31}{4.75}$	$9.98\ B\ \frac{1.15}{4.85}$	.51 >	+.16	+.1
PB	$3.6\ PB\ \frac{1.10}{6.91}$	$3.57\ PB\ \frac{1.05}{6.75}$	.03 <	-.05	-.16
P	$3.79\ P\ \frac{1.57}{9.03}$	$4.02\ P\ \frac{2.03}{7.91}$	.23 >	+.46	-1.12
RP	$1.21\ R\ \frac{1.37}{5.76}$	$1.81\ R\ \frac{1.23}{5.72}$	.6 >	-.14	-.04

samples and decreases in others. The hue was found to change over one full step in only the red sample. Red-purple changed .83 of one step. The change of the red-purple, however, was in a counterclockwise direction which was opposite from that of the red sample. Value levels either remained the same or increased. The largest value change was only .67 of a step in the blue-green. Red, yellow-red, yellow and purple also exhibited value changes.

By using objective color analysis small changes were found for every sample in every attribute. No full step hue changes were found. Only two samples, blue-green and purple-blue exhibited almost non-existent hue changes. No value changes of a whole step were found, and only one color, purple, had a sizeable value change (.46 of a step). Purple was also the only color which exhibited an important saturation change. In objective analysis, no pattern of change could be found in hue, value or saturation.

The importance of visual color difference is often due to the combination of the changes in hue, value and saturation. Through visual analysis only, green exhibited no change even when considering the three attributes together.

The pile texture used in this study was very dense and therefore did not allow deep light penetration even in the higher pile. What the effect of height change would be on a less dense pile is as yet undetermined.

Although there was a slight difference in color due to pile height, the amount of this difference seemed small enough to make height changes of one-fourth inch in a dense pile, as analyzed in this study, a minor factor in color prediction. Pile height cannot, however, be discounted for it does affect color. The importance of this factor of pile texture depends on the accuracy of a color match desired.

CHAPTER V

SUMMARY AND CONCLUSIONS

This research was designed to study the effect of the height and yarn size of a pile texture on color. An attempt was made to involve the instruments and methods of science in the field of aesthetics.

Procedure

Thirty-five textured samples woven by the investigator and the findings of an earlier study by Mary L. Shipley furnished the data for this research. Because this study was designed to be compared with the one by Mary L. Shipley, an effort was made to duplicate that study as closely as possible with only one significant variable, the size of the yarn. In addition, there was an introduction of differences in pile height and type of texture within this study.

The samples were hand-woven on a floor loom. Three types of texture, a tapestry, a low pile of one-half inch and a high pile of three-fourths inch were woven in each of the ten basic Munsell colors. Five low pile samples were also woven in the complementary hues. A wool yarn obtained by untwisting similar three ply yarn to that used in the previous study was used; the yarn of this study was, therefore, one-third the size of that used in the previous study. Yarn in seven of the ten hues was purchased, while yarn had to be dyed to match three hues, the blue-green, green-yellow and purple.

The color of each sample was analyzed by both subjective and objective colorimetry. Subjective color analysis was done by a panel of three judges using the Macbeth-Munsell Colorimeter, Type #1, and the Munsell Color Standards in high-gloss surface. The judges' decisions as to the color of each sample were averaged to obtain the notation of the subjective color analysis for each sample. Objective color analysis was done with the Gardner Color Difference Meter. Every sample was presented to the instrument in four different positions. The four sets of readings were averaged to obtain the Gardner Color Difference Meter reading for the sample. This reading was then converted to its equivalent Munsell notation.

Findings, Interpretations and Conclusions

Color Analysis

The subjective and objective methods of colorimetry were compared. In subjective colorimetry the individual judges' notations, especially of value and saturation, often varied from those of the other judges. These variations were much greater than were the variations between color difference meter readings of the same sample. Because of the reproducibility of the instrumental data in comparison to that of subjective colorimetry, the results of the objective color analysis were considered truer indications of the color differences between the various textures of the same basic color.

It was difficult to compare accurately the color notations of both methods of analysis due to the fact that the Munsell notations of the chips as determined by conversion of color difference meter data, and the official Munsell notations for those chips did not agree. This seemed to indicate that in future studies every effort should be made to obtain spectrophotometric readings of one of the textures in every color used to serve as standards to use in standardizing the Gardner Color Difference Meter. If this is not possible (as it was not in this study) an alternate method might be to standardize the instrument with Munsell chips.

Because of the discrepancies between the converted color difference meter notations and the official notations, the results of subjective colorimetry were considered to be closer to what the observer would perceive.

To the human eye, as determined by the subjective analysis, the samples generally appeared higher in value and brighter in saturation than the color difference meter indicated. How much of this could be attributed to differences in what the human eye and the instrument "saw," and how much was due to differences in methods of sample presentation[1] could not be determined. In a future study it might be enlightening to spin the sample under an objective colorimeter or spectrophotometer and then compare this to the findings obtained with the Macbeth-Munsell Colorimeter.

Although both subjective and objective colorimetry were used, no second analysis of either type was made to reaffirm the findings. An interesting addition to this study might have been to have had the judges individually reanalyze the samples at a later time. It might also have been interesting to compare the findings of a color difference meter with those of a spectrophotometer. Both objective and subjective methods of color analysis were found to have strengths and weaknesses. From this study no one method could be said to be superior to the other.

Effect of Pile Texture on Color

The results of the Shipley study, indicating that pile texture affects color, were reaffirmed and strengthened in this study. Not only subjective analysis, as was also used in the previous study, but the objective analysis confirmed the Shipley findings. Especially because of the

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[1]In subjective colorimetry the sample was spun, while in objective colorimetry it was presented in four, different, stationary positions.

confirmation by objective color analysis, the effect of texture on color can be said to be more than a visual illusion.

The changes in color between a non-pile and a pile texture were analyzed. In many instances texture change caused hue change. Most of the hues that changed due to difference in texture moved in a clockwise direction, except the very warm hues, red, yellow-red, and yellow which moved in a counter-clockwise direction. When comparing a pile texture to a non-pile texture the pile texture generally caused the value level of a color to decrease. No pattern of change could be found in saturation. When considering all the attributes of color, the red, red-purple and blue samples exhibited the greatest change in color due to the change in texture from the non-pile to the pile. Yellow, purple-blue and purple exhibited the least change due to this textural difference.

Effect of Yarn Size on Color

The one-half inch pile textured samples of this study were compared to similar samples of the previous study to determine the effect that yarn size had on color. Only three hue changes were found. Decreases in value were found, but these decreases were never greater than one value step. Yarn size appeared to affect, to any important degree, only one attribute of color: saturation. In all colors except blue-green, purple, and red-purple the saturation decreased. The blue, purple-blue and red-purple showed the greatest changes in color due to yarn size when all attributes of color were considered together.

Five samples, each woven with one pair of complementary colors evenly distributed throughout, were compared to similar samples from the previous study. In none of the complementary colored samples of either fine or heavier yarns did the colors spin to perfect gray in the Macbeth-Munsell Colorimeter. Samples woven of finer yarns did blend closer to gray than those woven of heavier yarns. The samples composed of colors with fairly equal value and saturation levels were more successful combinations. This seemed to indicate that the choice of complements, rather than yarn size alone, determines the success of complementary colored combinations. The complementary colored samples were also analyzed on the Gardner Color Difference Meter to determine the possibility of using this instrument for future studies involving combinations of colors. The color difference meter appeared to give reliable readings of the degree of neutrality achieved by each sample.

Since the samples from both studies, although analyzed by a similar subjective method, could not be analyzed at the same time, further investigation needs to be done to determine what, if any, of the changes discovered were due to time lag. Only two yarn sizes were used in these studies. Further study to determine what effect other yarn sizes have on color would be a valuable addition to this field of knowledge.

Effect of Pile Height on Color

The study of the effect of pile height on color seemed to indicate that pile height was a minor factor in color determination. Although color differences were found in all attributes of color between the one-half inch pile samples and the three-fourth inch pile samples, these differences did not present a consistent pattern. In most cases these differences were also less than one whole hue, value or saturation step. Since, however, the importance of color difference is due to the combination of hue, value and saturation changes, the small differences in each attribute can not be discounted completely. The importance of a pile height difference of one-fourth inch on color appears therefore to depend on the accuracy of color match desired. The one-half and three-fourths inch pile heights had been selected because it was felt that these were possible carpet thicknesses in the home furnishings industry. It would be useful to determine if a greater difference in pile height would cause a more definite color change. The pile used was very dense; a change in this attribute of pile texture might also affect the color change between varying pile heights.

Conclusions Restated

Stated briefly, the findings of this study which are the most important to the designer-investigator were:

1. Change in texture affects color more than a change in the attributes of a given texture.
2. Change in texture from a non-pile to a pile affects color primarily by decreasing its value level.
3. Change in yarn size from a heavier to a finer yarn affects the color of a pile texture primarily by lowering its saturation.
4. Change in pile height from a lower to a higher pile has little or no effect on color. None of the color attributes showed any pattern of change. However, if an absolutely perfect color match were necessary, the change in the textural attribute of pile height would have to be considered.
5. The use of both subjective and objective methods of color analysis in a study involving aesthetics is better than the use of either method alone.

Further Research Suggestions

Many avenues for further study presented themselves as this research progressed. Some, such as the effects of other pile heights and yarn sizes on color, have already been mentioned. Other areas which need study include:

1. The effects of other variations of pile texture on color.
2. The effects of other types of texture on color.

3. The influence of various types of dyes on the color changes in textiles.
4. The spectrophotometric analysis of textural color changes to determine exactly what is happening to the wavelengths of the samples due to texture changes.

As this work progressed, the investigator observed two other variations of pile texture which influenced the color of the samples. A great color change took place when the uncut pile was cut during the weaving process. The density of the pile as it was hand manipulated also appeared to be a factor affecting its color. For unexplained reasons, the red-purple and the blue-green samples in this study were the ones that consistently showed the greatest change in color or deviated the most from the color changes of the other samples. Why was this so? Was the type of dye used an important influence in these reactions? The possibilities for future investigation of the effect of texture on color appear endless and fascinating.

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APPENDIX A

APPENDIX A.--"Rd," "a" and "b" Readings of the Samples in Four Positions through Objective Color Analysis Using the Gardner Color Difference Meter.

Sample		Gardner Color Difference Meter Readings											
		Position I			Position II			Position III			Position IV		
Color	Texture	Rd	a	b	Rd	a	b	Rd	a	b	Rd	a	b
R	Y	4.2	36.8	11.3	5.2	39.4	12.1	4.3	36.9	11.9	5.1	39.6	12.0
	T	3.9	34.0	11.1	4.3	33.9	11.1	3.8	34.0	11.1	4.2	33.9	11.1
	LP	9.0	16.9	6.1	10.1	16.7	5.9	10.2	16.9	6.0	10.2	19.5	6.4
	HP	10.0	16.2	5.9	10.1	16.2	5.9	10.1	17.2	5.9	10.1	16.9	5.9
YR	Y	16.5	32.7	25.8	19.3	32.8	26.8	15.8	32.7	25.7	18.8	32.9	26.7
	T	14.7	28.2	23.9	14.0	28.4	23.8	14.4	28.5	23.9	13.6	28.6	23.7
	LP	6.9	26.6	19.2	7.0	26.8	19.1	6.8	26.6	19.0	7.0	26.9	19.1
	HP	6.7	26.0	19.1	6.8	26.1	19.2	6.5	25.8	18.7	6.7	25.8	18.8
Y	Y	37.4	6.3	35.5	41.9	5.2	36.6	37.3	6.2	35.4	41.5	5.3	36.4
	T	35.2	4.1	33.5	35.2	4.1	33.5	33.9	4.2	33.3	33.8	4.2	33.3
	LP	20.6	7.9	29.2	21.0	7.6	29.3	20.4	7.9	29.2	21.0	7.5	29.2
	HP	18.9	7.8	28.5	19.5	7.8	28.6	19.2	8.0	28.6	19.0	7.9	28.6

Continued

APPENDIX A. - Continued

		Gardner Color Difference Meter Readings											
		Position I			Position II			Position III			Position IV		
Color	Texture	Rd	a	b	Rd	a	b	Rd	a	b	Rd	a	b
GY	Y	24.3	15.7	29.2	28.0	14.9	30.5	24.2	14.5	29.5	28.0	14.2	30.7
	T	23.1	13.6	28.8	23.7	13.1	29.2	23.7	13.0	29.1	23.0	13.2	29.0
	LP	10.3	11.2	22.3	10.8	12.1	22.9	10.7	11.7	22.4	10.6	11.5	22.3
	HP	11.5	13.8	22.9	11.5	13.4	22.9	10.9	12.7	22.4	11.4	11.2	23.1
G	Y	7.2	19.2	10.7	8.5	20.4	10.6	6.9	19.2	10.1	8.3	20.2	10.7
	T	7.9	18.9	9.8	6.9	18.3	9.8	7.9	18.8	9.8	6.9	18.4	10.0
	LP	2.6	11.6	5.4	2.5	11.2	5.2	2.7	11.8	5.4	2.5	11.1	5.2
	HP	2.2	10.8	6.0	2.1	10.5	5.0	2.2	10.5	5.0	2.1	10.5	4.9
BG	Y	10.5	19.5	4.4	11.0	19.5	4.4	10.0	19.9	5.4	13.0	18.3	3.0
	T	9.3	18.9	5.0	9.4	18.8	5.0	9.0	18.7	5.0	8.9	18.6	5.0
	LP	3.8	13.5	5.0	3.8	13.5	5.0	3.6	13.1	4.9	3.4	12.7	4.9
	HP	3.7	13.4	4.9	3.9	13.4	4.9	3.2	13.5	5.0	3.6	13.0	4.9

Continued

APPENDIX A. - Continued

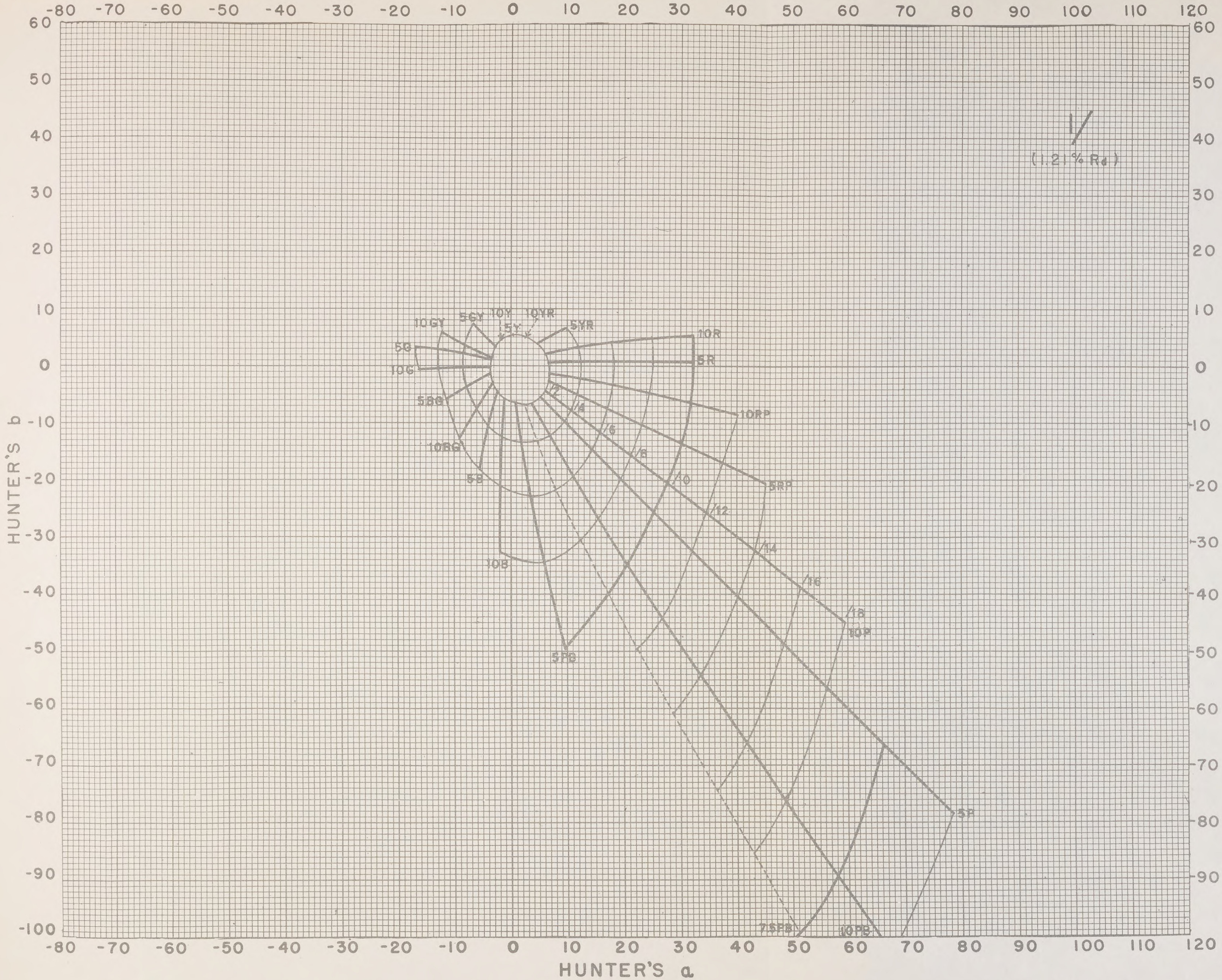
Sample		Gardner Color Difference Meter Readings											
		Position I			Position II			Position III			Position IV		
Color	Texture	Rd	a	b	Rd	a	b	Rd	a	b	Rd	a	b
B	Y	4.7	6.8	23.7	6.3	8.4	27.7	4.6	7.0	25.8	6.1	8.3	27.7
	T	5.4	6.7	23.6	5.2	6.7	23.2	4.8	6.5	22.7	4.8	6.6	22.6
	LP	1.6	2.6	16.6	1.6	2.6	17.0	1.7	2.7	16.6	1.8	2.6	16.8
	HP	1.5	2.2	15.8	1.5	2.2	15.8	1.3	2.2	15.8	1.4	2.1	16.1
PB	Y	3.8	1.4	42.0	4.7	1.2	43.8	3.7	1.4	41.4	4.6	1.1	42.6
	T	4.3	1.9	41.2	4.2	1.8	42.1	3.9	1.8	41.8	3.9	1.9	42.2
	LP	1.2	2.2	29.1	1.4	2.3	29.2	1.4	2.3	29.1	1.4	2.2	27.0
	HP	1.2	2.2	26.3	1.4	2.2	28.4	1.3	2.2	26.4	1.2	2.2	26.5
P	Y	9.2	29.9	29.9	11.4	29.2	30.4	8.8	30.1	31.7	11.2	29.2	30.8
	T	8.4	25.5	28.0	8.3	25.3	27.7	7.9	25.3	28.0	8.0	25.3	26.7
	LP	2.6	24.5	28.3	2.6	24.5	28.4	2.8	24.2	28.5	2.6	24.5	28.5
	HP	3.2	24.6	27.9	3.3	25.0	28.3	3.1	24.3	27.9	3.2	24.4	27.9

Continued

APPENDIX A. - Continued

Sample		Gardner Color Difference Meter Readings											
		Position I			Position II			Position III			Position IV		
Color	Texture	Rd	a	b	Rd	a	b	Rd	a	b	Rd	a	b
RP	Y	5.7	31.8	4.1	7.3	32.8	5.2	5.6	30.6	4.6	7.2	32.2	5.1
	T	5.5	27.3	4.0	5.1	26.6	3.9	5.4	26.6	3.9	5.1	26.4	4.0
	LP	1.8	20.0	1.9	1.8	19.3	2.0	1.7	18.6	2.0	1.8	18.6	1.8
	HP	1.7	18.7	1.2	1.5	18.0	1.5	1.5	17.7	1.5	1.5	18.4	1.4
R&BG	LP	1.9	-0.9	+0.6	1.9	0.4	0.6	1.8	0.4	0.7	1.8	0.9	0.6
RP&G	LP	1.8	+1.7	+1.6	1.7	1.7	1.8	1.6	1.6	1.8	1.8	2.5	1.9
GY&P	LP	5.5	+1.6	+8.3	5.7	2.7	8.0	5.3	2.8	7.3	5.6	2.7	8.1
B&YR	LP	2.5	+5.5	+3.6	2.4	5.6	3.6	2.3	5.5	3.6	2.5	5.5	3.7
PB&Y	LP	5.6	-2.5	+7.8	5.4	2.6	9.0	4.8	2.2	7.2	5.5	2.2	1.3

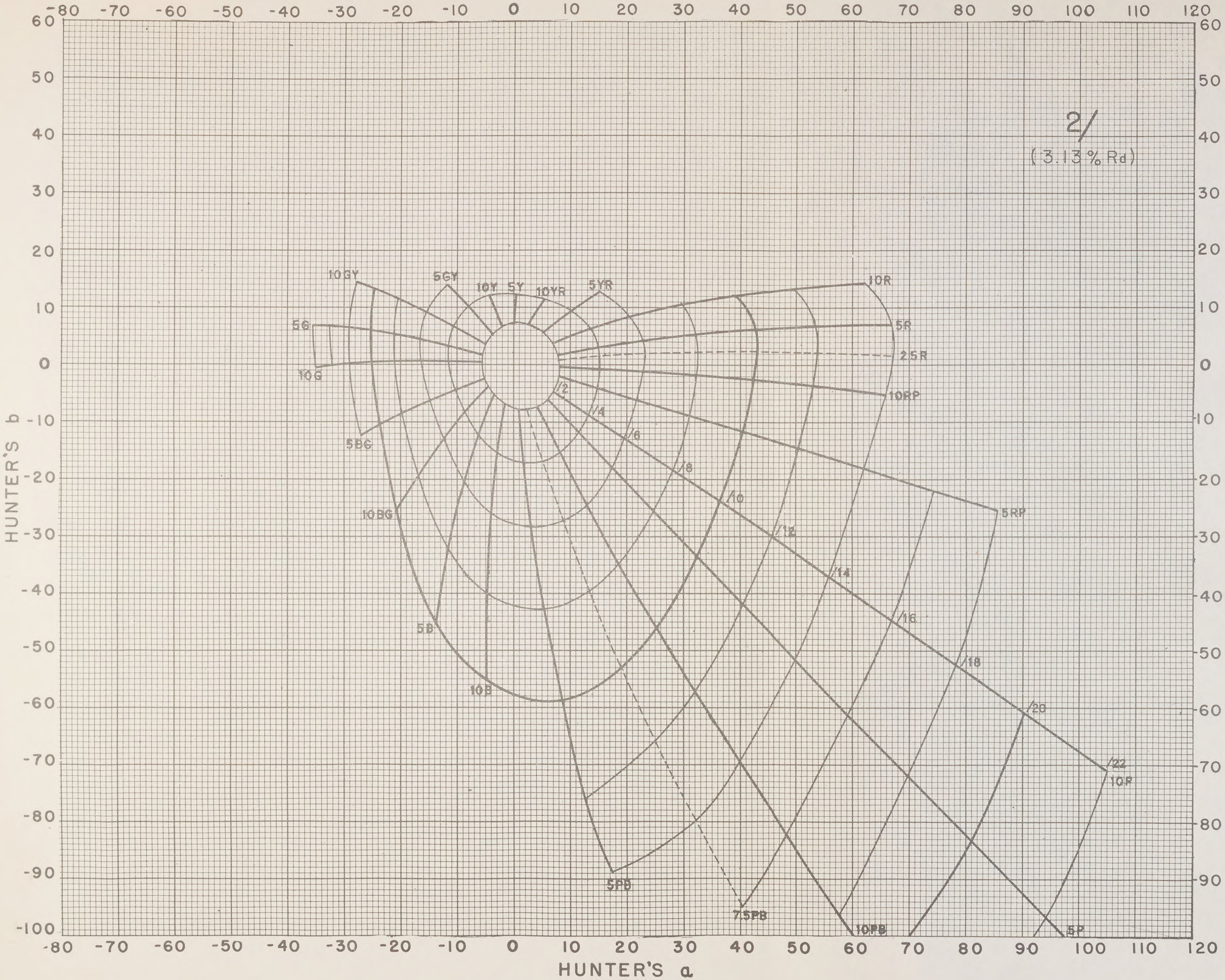
APPENDIX B



Munsell hue and chroma renotations for I. C. I. Illuminant C for the value indicated on diagram. Hue is indicated near end of each radiating hue line. Chroma is indicated in steps of 2, the inner ovoid being /2.

$a = 175\, f_y\, (1.02X - Y)$

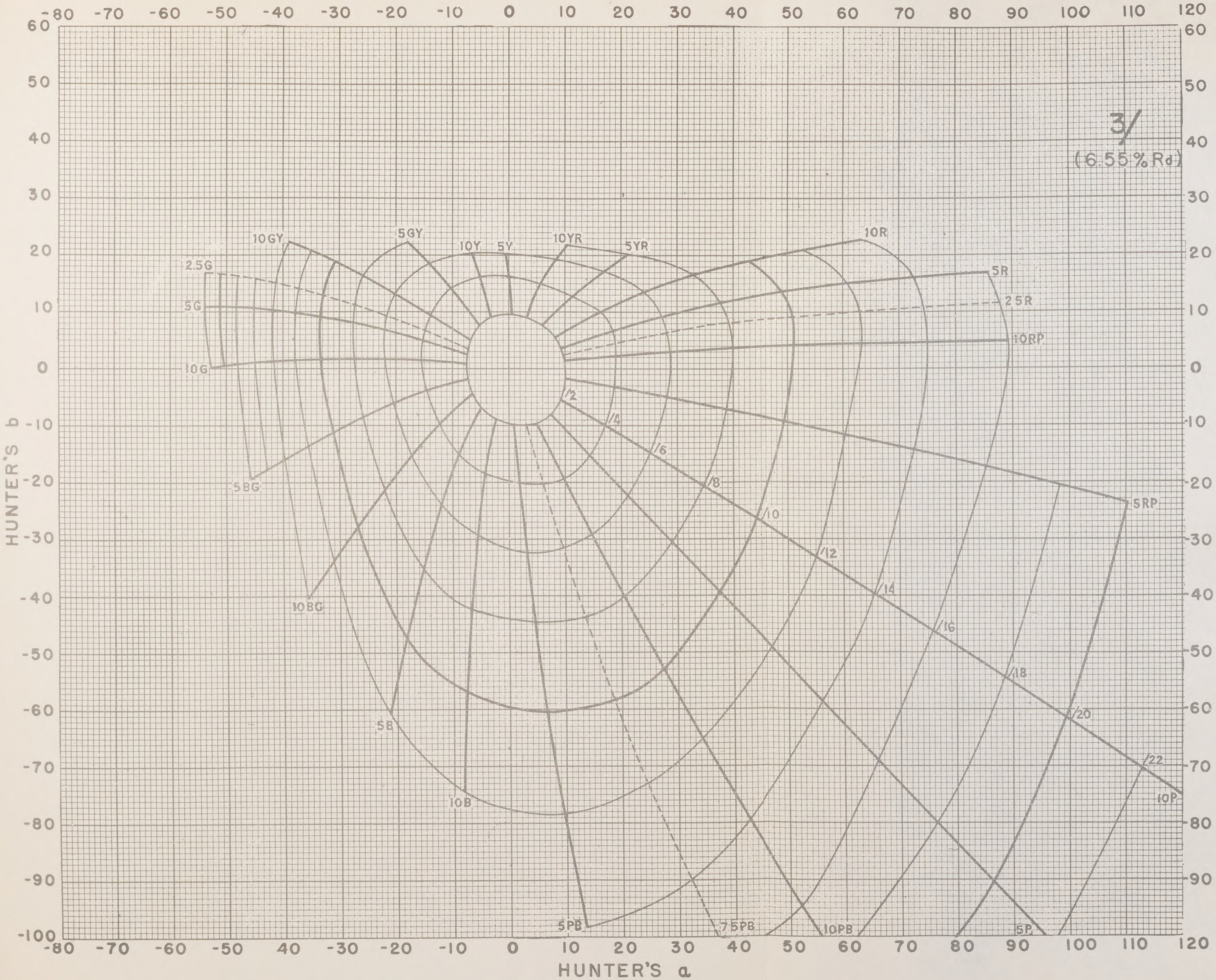
$b = 70\, f_y\, (Y - .847Z)$



Munsell hue and chroma renotations for I. C. I. Illuminant C for the value indicated on diagram. Hue is indicated near end of each radiating hue line. Chroma is indicated in steps of 2, the inner ovoid being /2.

$a = 175\, f_y\, (1.02\,X - Y)$

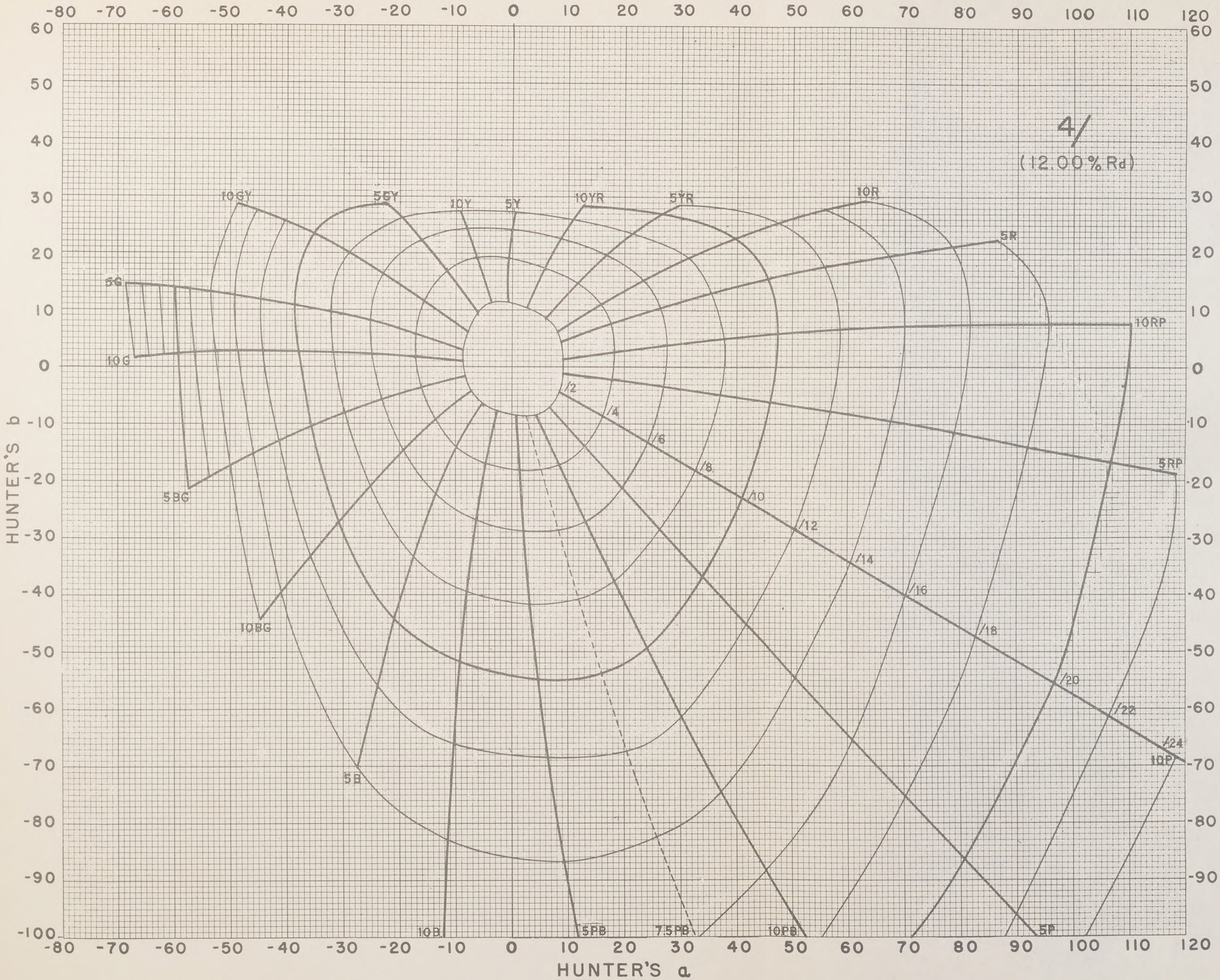
$b = 70\, f_y\, (Y - .847\,Z)$



Munsell hue and chroma renotations for I. C. I. Illuminant C for the value indicated on diagram. Hue is indicated near end of each radiating hue line. Chroma is indicated in steps of 2, the inner ovoid being /2.

$a = 175\ f_y\ (1.02\ X - Y)$

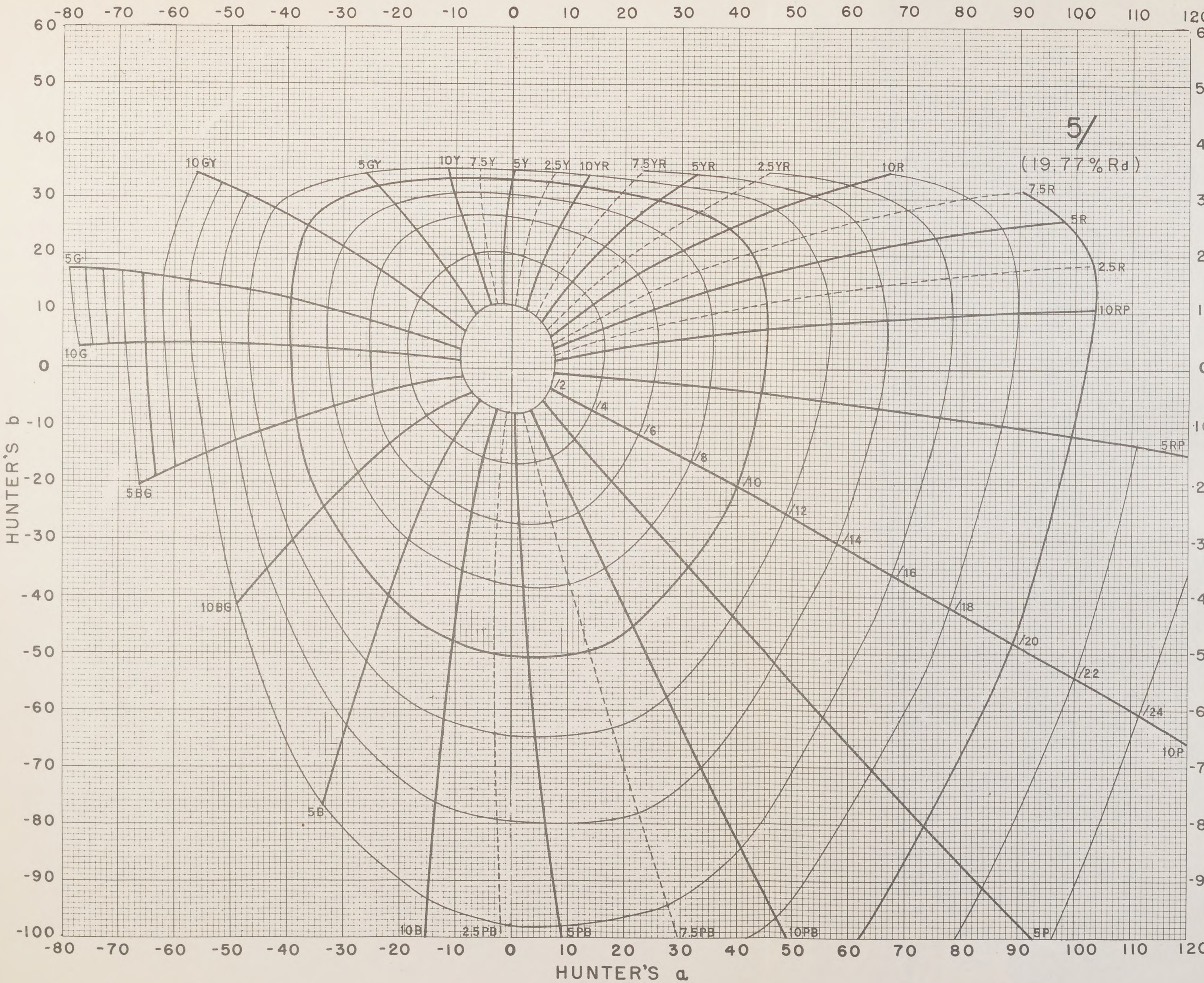
$b = 70\ f_y\ (Y - .847\ Z)$



Munsell hue and chroma renotations for I. C. I. Illuminant C for the value indicated on diagram. Hue is indicated near end of each radiating hue line. Chroma is indicated in steps of 2, the inner ovoid being /2.

$a = 175\, f_y\,(1.02X - Y)$

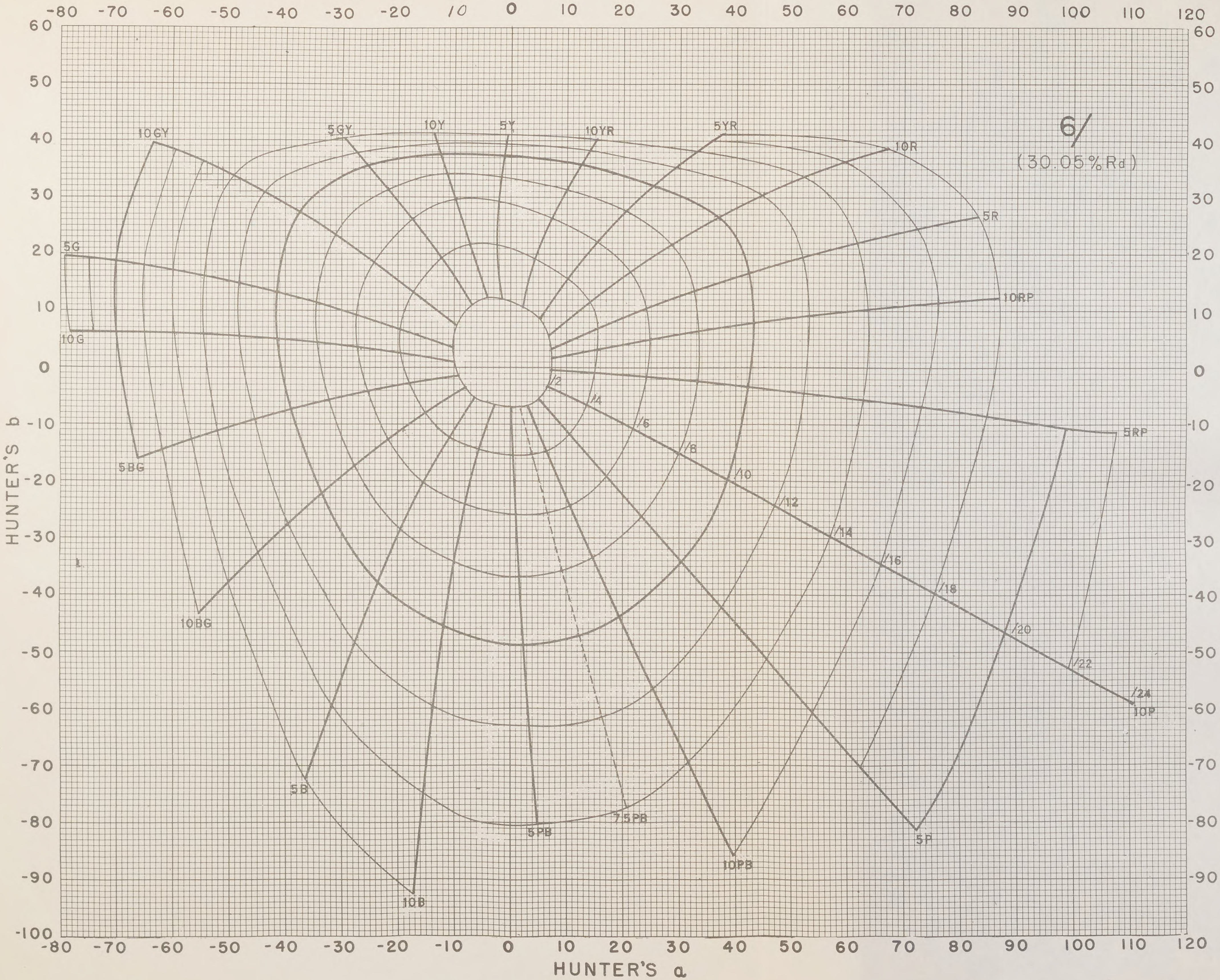
$b = 70\, f_y\,(Y - .847Z)$



Munsell hue and chroma renotations for I. C. I. Illuminant C for the value indicated on diagram. Hue is indicated near end of each radiating hue line. Chroma is indicated in steps of 2, the inner ovoid being /2.

$a = 175\, f_y\, (1.02X - Y)$

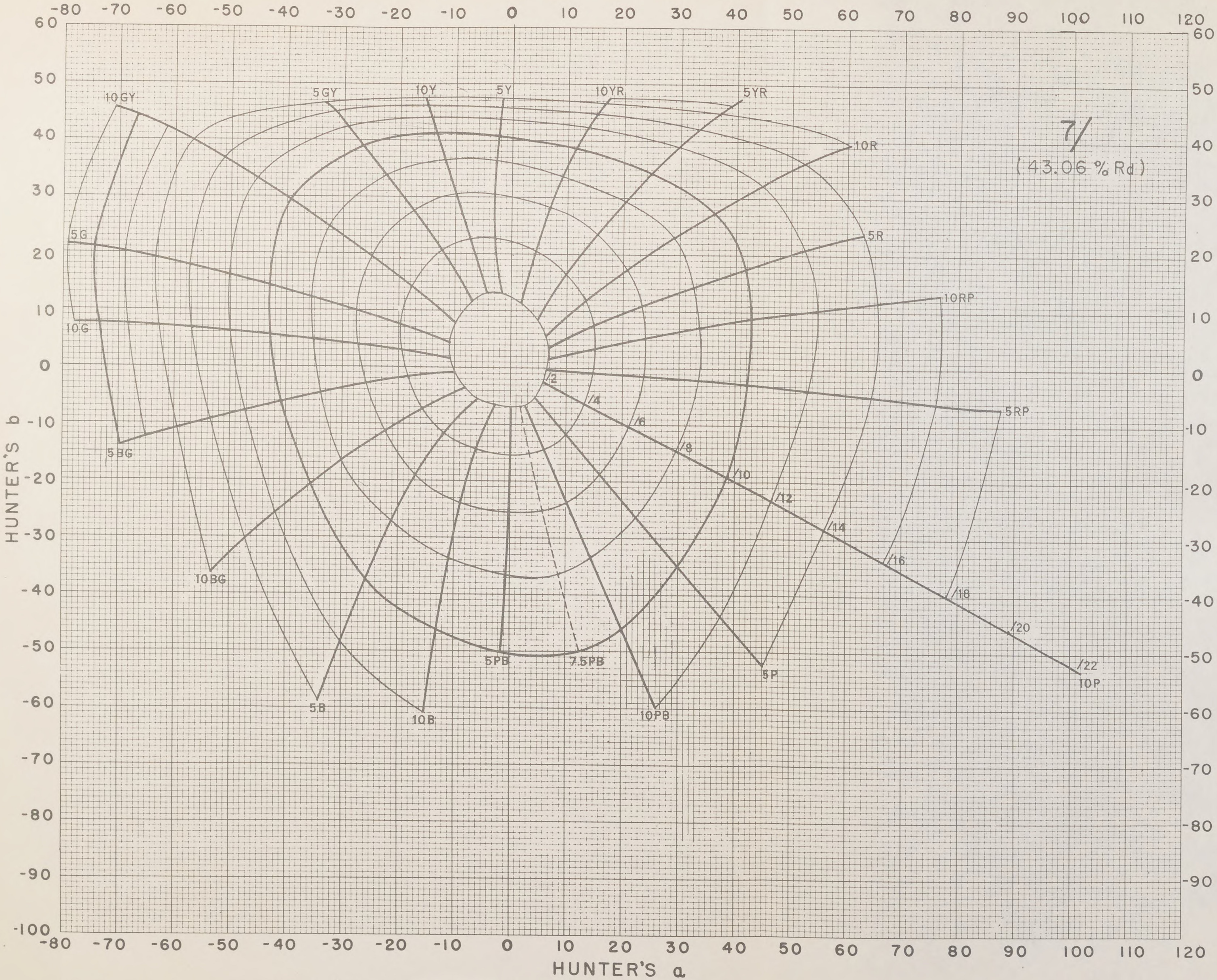
$b = 70\, f_y\, (Y - .847Z)$



Munsell hue and chroma renotations for I. C. I. Illuminant C for the value indicated on diagram. Hue is indicated near end of each radiating hue line. Chroma is indicated in steps of 2, the inner ovoid being /2.

$a = 175\, f_y\, (1.02\, X - Y)$

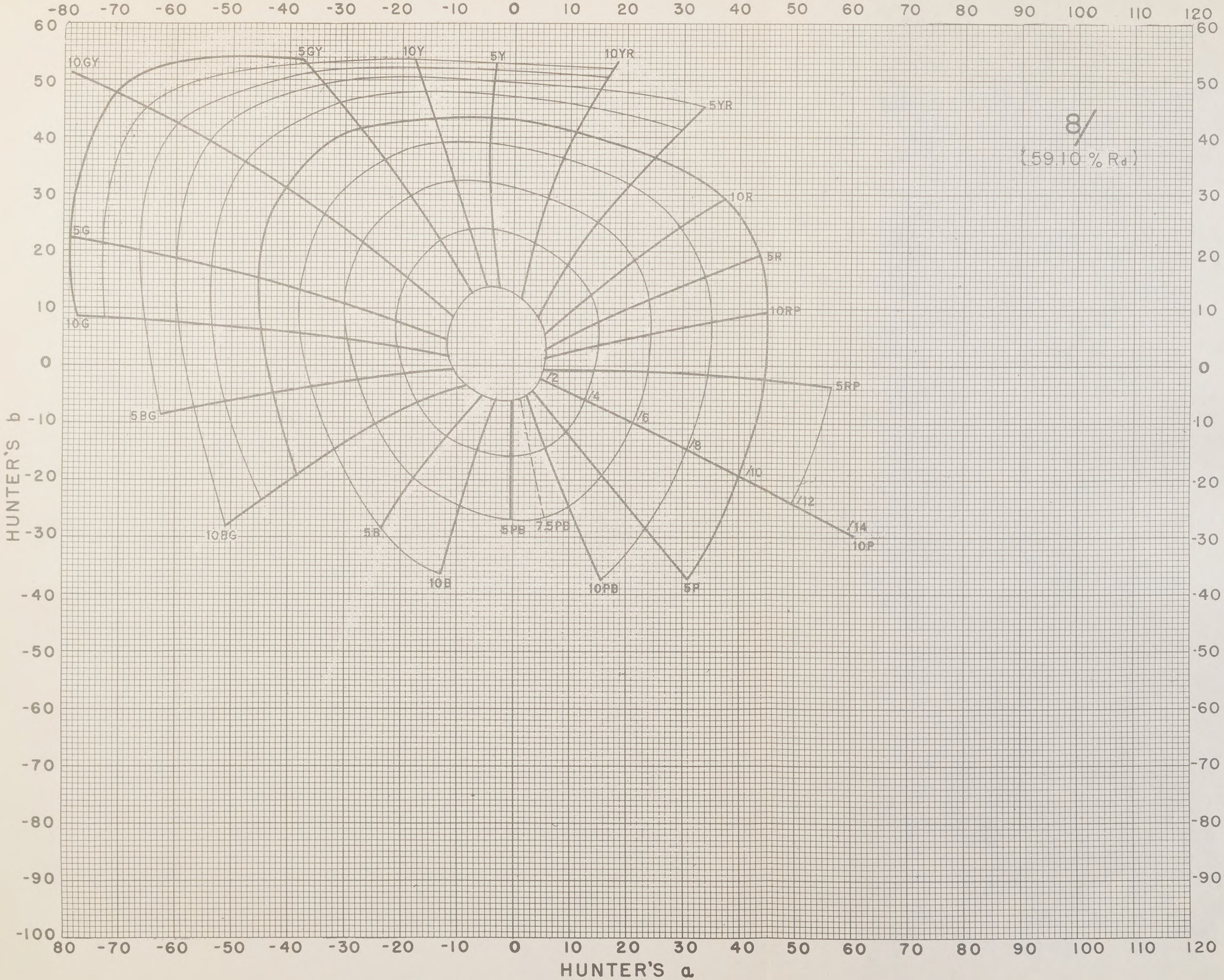
$b = 70\, f_y\, (Y - .847\, Z)$



Munsell hue and chroma renotations for I. C. I. Illuminant C for the value indicated on diagram. Hue is indicated near end of each radiating hue line. Chroma is indicated in steps of 2, the inner ovoid being /2.

$a = 175\, f_y\,(1.02\,X - Y)$

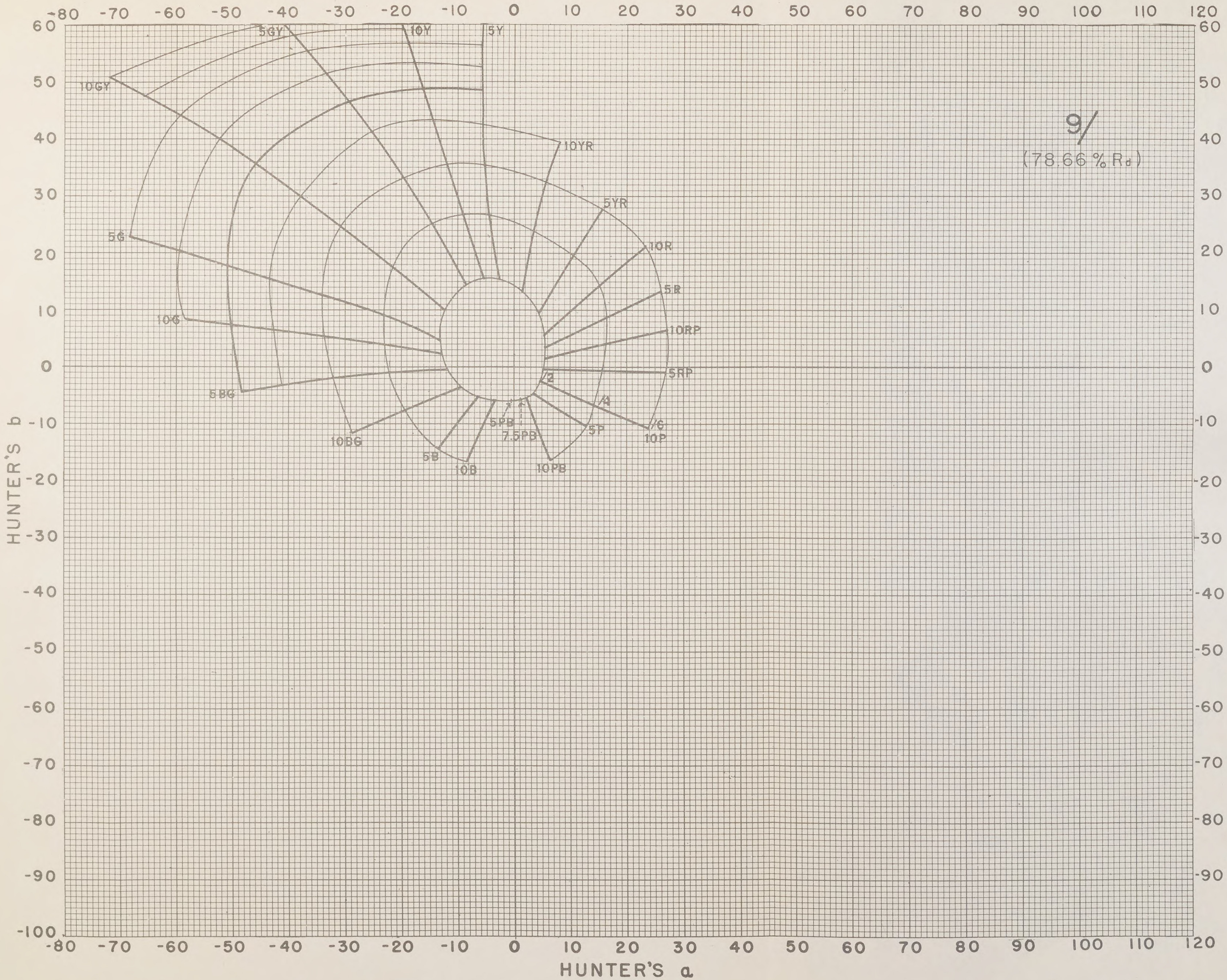
$b = 70\, f_y\,(Y - .847\,Z)$



Munsell hue and chroma renotations for I. C. I. Illuminant C for the value indicated on diagram. Hue is indicated near end of each radiating hue line. Chroma is indicated in steps of 2, the inner ovoid being /2.

$a = 175\, f_y\, (1.02\, X - Y)$

$b = 70\, f_y\, (Y - .847\, Z)$



Munsell hue and chroma renotations for I. C. I. Illuminant C for the value indicated on diagram. Hue is indicated near end of each radiating hue line. Chroma is indicated in steps of 2, the inner ovoid being /2.

$a = 175\, f_y\, (1.02\,X - Y)$

$b = 70\, f_y\, (Y - .847\,Z)$