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AN EXAMINATION OF THE MUNSELL COLOR SYSTEM

I. SPECTRAL AND TOTAL REFLECTION AND THE MUNSELL SCALE OF VALUE

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AN EXAMINATION OF THE MUNSELL COLOR SYSTEM

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I. INTRODUCTION

A signal and practical contribution to the classification and specification of colors for the purposes of art was made by A. H. Munsell in his book, A Color Notation,[2] and The Atlas of the Munsell Color System.[3] The limits of this paper will not permit of a detailed review of these books, and readers unfamiliar with the subject are referred to the citations just given. It must suffice here to point out that Munsell has adopted the only natural and logical method of color classification, as has, indeed, been expounded by Bezold, Rood, Abney, Nutting,[4] and others. In this natural method a color is specified completely by three characteristics which have been designated by various terms, the meanings of which, as used by different authorities, are shown in Table 1.

[1] This paper is an amplification of report on Bureau of Standards Test No. 23998 to Munsell Color Co., June, 1919.

[2] A. H. Munsell, A Color Notation, Boston, Geo. H. Ellis Co.; 1905. Later editions, 1907, 1913, 1916.

[3] Boston, Wadsworth, Howland & Co.; 1915.

[4] Bezold, Theory of Color, English Translation by Koehler, Am. Ed., p. 100; 1876. Rood, Modern Chromatics, New York; 1879. Abney, Color Measurement and Mixture, London; 1891. Nutting, B. S. Bulletin, 9, p. 1: 1913. For the concept of colors arranged in a sphere, consult particularly: (1) Philip Otto Runge, Die Farbenkugel, Hamburg; 1810. (Reprinted in Runge's Hinterlassene Schriften, p. 112; Hamburg, 1840. Copy in Boston Public Library.) (2) Parsons, Introduction to Study of Color Vision, p. 38. (3) Külpe, Outlines of Psychology (1893), English translation by Titchener, p. 311; 1901. Cf. also: (1) Chevreul, Exposé d 'un moyen de définir et de nommer les coleurs . . . , Mem. de l'Academie, Paris, 33; 1861. (2) Höfler. Zeit. fur Physiol. und Psyc. der Sinnesorg. Abt. 1, 58, pp. 356–371; 1910–1911.

TABLE 1.—The Three Characteristics of Color, and the Names by which These Characteristics are Designated by Various Authorities

Authority	The species of color. The characteristic by virtue of which it may be referred with more or less accuracy to the spectral colors, red, orange, yellow, green, blue, violet	The characteristic in which colors vary from gray (a color having no hue) to colors having a pronounced hue	The characteristic by which grays may be arranged in series between white and black
Bezold [a]	Hue	Purity	Brightness.
Rood [b]	Hue	Purity	Luminosity or brightness.
Abney [c]	Hue	Purity	Luminosity.
Century Dictionary [d]	Color tone or hue	Chroma or saturation	Brightness, luminosity, value, or tone.
Webster's Dictionary [e]	Hue or color tone	Chroma, purity, intensity, or saturation.	Value or luminosity.
Standard Dictionary [f]	Color tone or quality	Purity or saturation	Brightness.
MUNSELL	HUE	CHROMA	VALUE.

[a] The Theory of Color, English translation by Koehler, American Ed., p. 100; 1876.
[b] Modern Chromatics, p. 30 ff.; 1879.
[c] Color Measurement and Mixture, p. 15; 1891.
[d] Century Dictionary (1902 and Revised Ed., 1911) under "Color," "Value," and "Tone."
[e] Webster's International Dictionary (1910) under "Color."
[f] Standard Dictionary (1916) under "Color."

Munsell has expounded this system in an elementary and practical way for students of art and has accomplished the colossal task of producing an altas of charts in which actual colored samples are shown arranged according to this natural system. That the system is valuable in practice is demonstrated by the fact that it has been used for several years with great satisfaction and success in connection with the business of one of the foremost manufacturers of colored printing inks.[5] From the point of view of precise colorimetry, however, the system, as it exists to-day, is faulty because of its lack of fundamental accurate specification. Much of the knowledge and methods of measurement that are available now were not available to Mr. Munsell, whose death has prevented the improvements and revision which it is to be presumed he would have made had he lived. After Mr. Munsell's death the Munsell Color Co.[6] requested the Bureau of Standards to undertake this fundamental standardization,[7] and submitted for this purpose the set of cards herein considered. We have no extensive information as to the uniformity of various sets which the company may have issued.

This paper is a partial report upon this task. It deals only with (1) the diffuse spectral reflection of the nine neutral grays and three samples of each of the hues red, yellow, green, blue, and

[5] By Arthur S. Allen, with a corporation having headquarters in New York City.
[6] Then at 220 West Forty-second Street, New York City, since removed to 120 Tremont Street, Boston, Mass.
[7] Letters of July 19 and Aug. 8, 1918, Munsell Color Co. to Bureau of Standards.

purple; (2) a discussion of the Munsell value scale; (3) recommendations on the improvement of the system and its establishment upon a more secure foundation. A complete report would comprehend experimental determinations of the hue, value, and chroma of all the standards, a task which it has not been possible to undertake as yet. The results here reported are considered of prime importance (*a*) as regards the basis of the system and (*b*) as being logically the first part of the standardization.

II. ELEMENTARY THEORY INVOLVED IN THIS REPORT

Light is radiant power which, impinging on the retina of the eye, excites the sensation called color.[8] The radiant energy may be considered as traveling through the space between the light source and the retina in the form of a vibration or wave motion in a hypothetical intervening medium. If the vibration has some one definite frequency, the color produced will have a pronounced hue, which may be described as red, orange, yellow, green, blue, or violet, depending upon that frequency. (See Table 2.) The

TABLE 2.—Approximate Frequencies and Wave Lengths[a] of Spectral Hues

Hue	Frequency in vibrations per trillionth of one second	Wave length[b] in millimicrons
Red	429	700
Orange	502	597
Yellow	516	581
Green	570	527
Blue	634	473
Violet	739	406

[a] Cf. Rood, Modern Chromatics, p. 26; 1879.

[b] One millimicron $= \frac{\text{micron}}{1\,000} = \frac{1}{1\,000\,000}$ millimeter = about $\frac{1}{25\,400\,000}$ inch.

color will also be very saturated; that is, of high chroma. If the energy is distributed according to a law not yet determined with precision, but (in one case) approximately represented in sunlight, among many vibrations of different frequencies, the color will be recognized as white (or gray) and will have no distinguishing hue. If the energy is distributed among vibrations of different frequencies according to some law other than that required to produce white or gray, it may produce any of a vast number of colors of various hues and chromas, depending upon the relative amounts

[8] Rigorously, light is radiant power multiplied by a factor proportional to its visibility. This factor varies with the frequency or wave length of the energy. Power is the time rate of transfer of energy.

of energy of different frequencies. In Fig. 1 are shown typical examples of the distribution of energy among various wave lengths required to produce various colors. The horizontal scale is a scale of wave lengths. The vertical scale is a scale of relative energy. Note, in the figure, that red is produced by a preponderance of energy of wave lengths about 600 to 700 mμ;[9] green, 500 to 600 mμ; blue, 400 to 500 mμ. These curves are intended merely to illustrate a few typical cases of spectral-energy distributions which produce certain colors. It will be understood readily that the possible variety of such curves is infinite. To each curve there corresponds a color of a certain hue and chroma, and such a curve

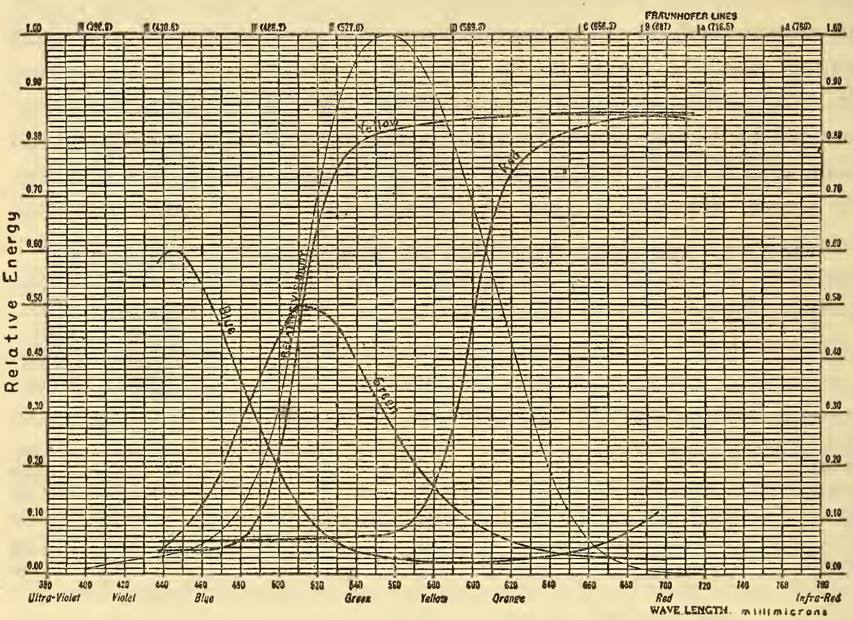

Fig. 1

is therefore sufficient to determine uniquely hue and chroma, although the process of deriving these characteristics from such curves is very laborious and has not yet been sufficiently standardized[10] for practical use. Nevertheless, such a curve of spectral-energy distribution, together with total luminosity or value, completely specifies a color by specifying its stimulus. (The converse is not true; that is, a given color may be excited by energy represented by any of a considerable number of distribution curves. The number of possible colors is therefore not infinite.)

[9] mμ≡one millimicron≡0.001 micron=one millionth of one millimeter=about $\frac{1}{25\ 400\ 000}$ inch.

[10] Methods have been indicated by H. E. Ives, Jour. Frank. Inst., p. 673; Dec., 1915.

Keeping in mind the conception of a spectral-energy distribution curve as discussed above, let us now consider the color of a diffusely reflecting surface such as one of the cards in the Munsell Atlas.[11] Let this card be illuminated by diffuse white light. If it reflects light of all frequencies equally well, it will appear gray, or, in the extreme cases, white or black, the luminosity and the Munsell value being determined by the total light reflected. (See Fig. 2.) If, on the other hand, the card is selective in its reflection—that is, reflects light of some frequencies or wave lengths much better than others—its color will, in general, be distinguished by some hue. The saturation or chroma of the color will be roughly indicated by the shape of the spectral-reflection curve; if its reflection is small or zero for a large range of wave lengths and large for another small range, the color will be very saturated—that is, of high chroma—while only a slight variation in the reflection for different wave lengths will indicate a pale color; that is, one slightly saturated or of low chroma.

It is possible to measure, with a spectrophotometer, for each wave length, the light reflected by the card relative to that reflected by a standard white substance such as magnesium carbonate. This ratio is the *reflection* relative to magnesium carbonate. The absolute reflection equals this ratio multiplied by the absolute reflection (that is, the ratio of reflected to incident light) of magnesium carbonate. (The value of the absolute reflection of magnesium carbonate is not very certainly established.)

For the reason that the least perceptible increment in stimulus is directly proportional to the stimulus, it is better to plot reflection to a logarithmic scale, as is done in Figs. 2*a* to 7*a*, inclusive. As will be pointed out in the discussion of the value scale below, value should naturally be directly proportional to the logarithm of reflection, although this is not accurately the case with the Munsell values.

III. EXPERIMENTAL DATA

The primary data of the present investigation are shown in the curves of spectral reflection in Figs. 2 to 7 and 2*a* to 7*a*, inclusive. In Figs. 2 and 2*a* the numbers attached to the curves indicate value on the Munsell scale. The fractions $^7/_5$, $^5/_5$, $^3/_2$, etc., in other figures, indicate value and chroma according to the Munsell designations, the numerator indicating value and the denominator chroma.

[11] A *perfect* diffusely reflecting surface would appear equally bright from all directions, regardless of the direction of the incident light. These cards only approximate this condition.

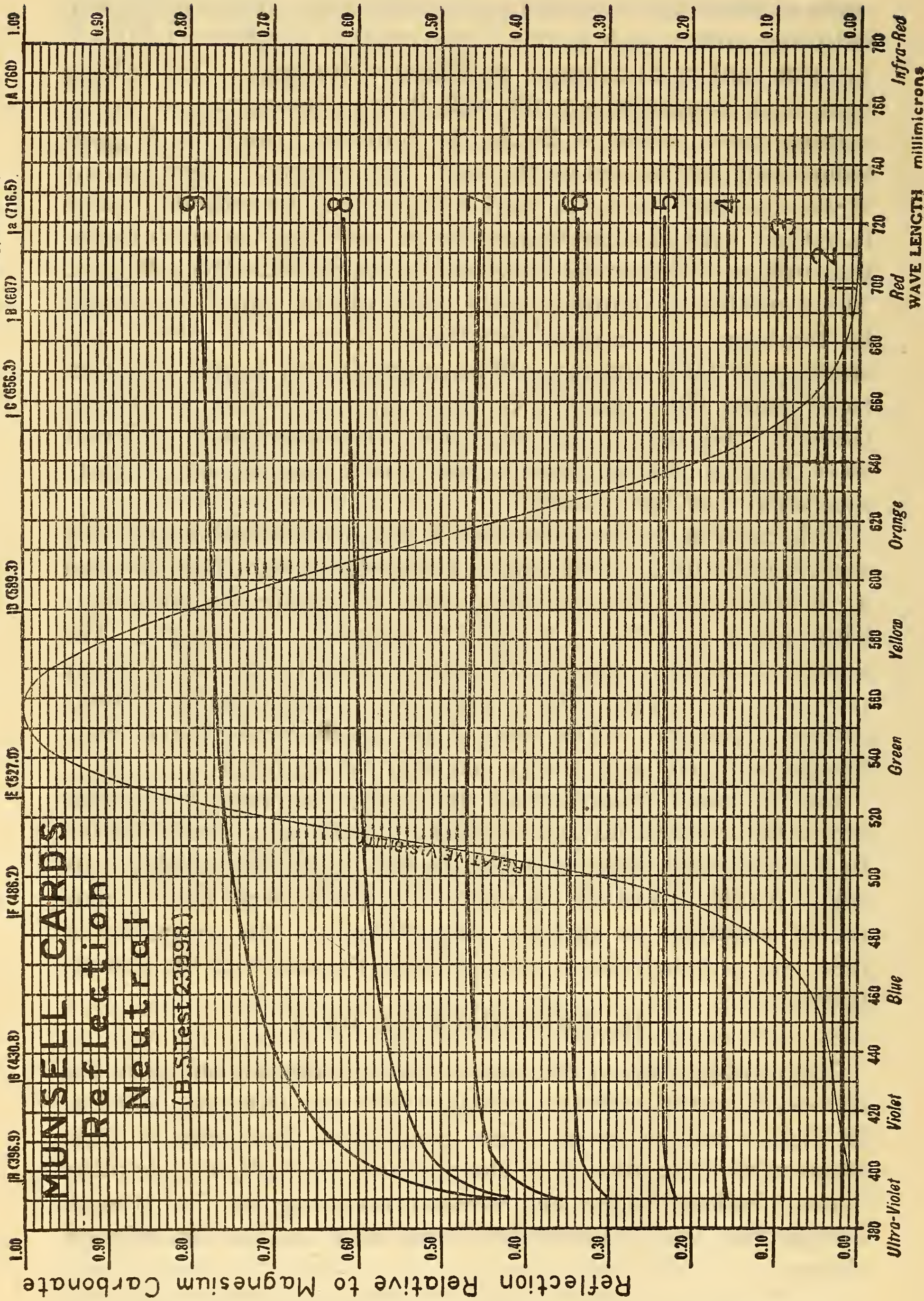
MUNSELL CARDS
Reflection
Neutral
(B. S. test 23998)
FRAUNHOFER LINES
H (396.9)
G (430.8)
F (486.2)
E (527.0)
D (589.3)
C (656.3)
B (687)
a (716.5)
A (760)
RELATIVE VISIBILITY
Ultra-Violet
Violet
Blue
Green
Yellow
Orange
Red
Infra-Red
WAVE LENGTH millimicrons
Reflection Relative to Magnesium Carbonate
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
380
400
420
440
460
480
500
520
540
560
580
600
620
640
660
680
700
720
740
760
780
9
8
7
6
5
4
3
2
1

FIG. 2

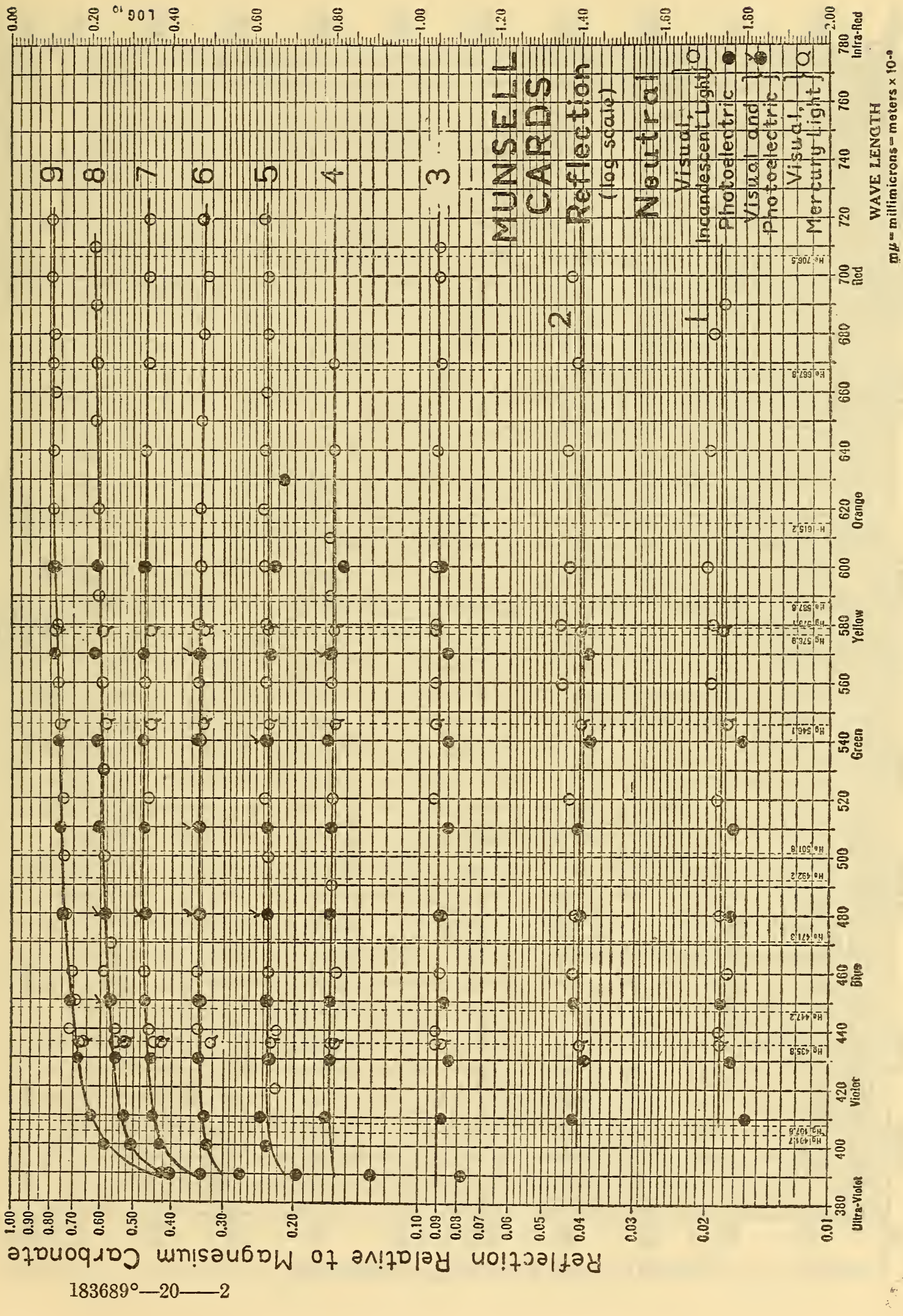
MUNSELL CARDS
Reflection (log scale)
Neutral
Visual, Incandescent Light
Photoelectric
Visual and Photoelectric
Visual, Mercury Light
9
8
7
6
5
4
3
2
1
LOG10
WAVE LENGTH
mμ = millimicrons = meters × 10-9
Ultra-Violet
Violet
Blue
Green
Yellow
Orange
Red
Infra-Red
Reflection Relative to Magnesium Carbonate

Fig. 2a

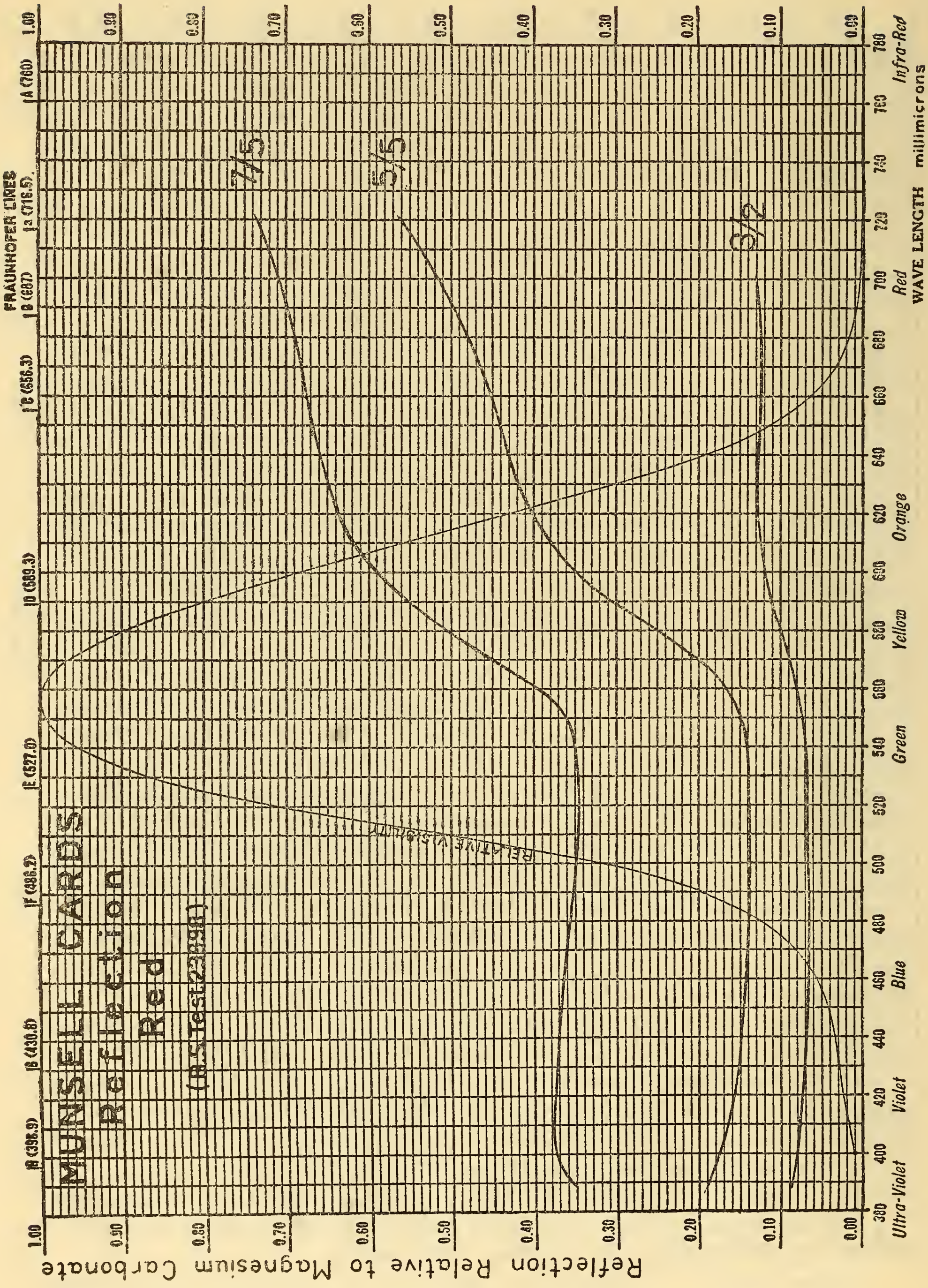
MUNSELL CARDS
Reflection
Red
7/5
5/5
3/2
RELATIVE VISIBILITY
FRAUNHOFER LINES
WAVE LENGTH millimicrons
Ultra-Violet
Violet
Blue
Green
Yellow
Orange
Red
Infra-Red
Reflection Relative to Magnesium Carbonate

FIG. 3

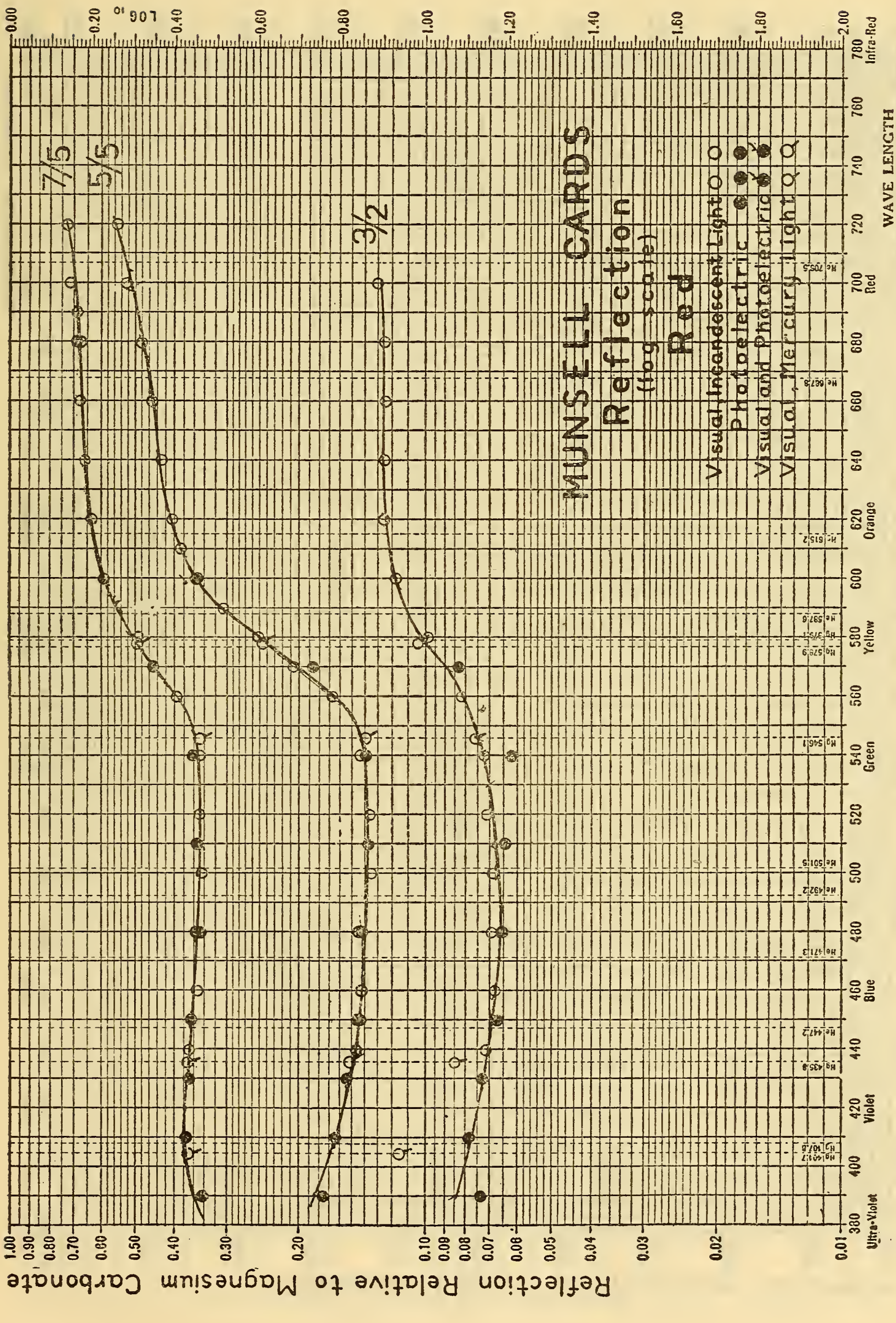
MUNSELL CARDS
Reflection
(log scale)
Red
Visual, Incandescent Light
Photoelectric
Visual and Photoelectric
Visual, Mercury Light
7/5
5/5
3/2
Reflection Relative to Magnesium Carbonate
LOG 10
WAVE LENGTH
$m\mu$ = millimicrons = meters x 10^{-9}
Ultra-Violet
Violet
Blue
Green
Yellow
Orange
Red
Infra-Red

FIG. 3a

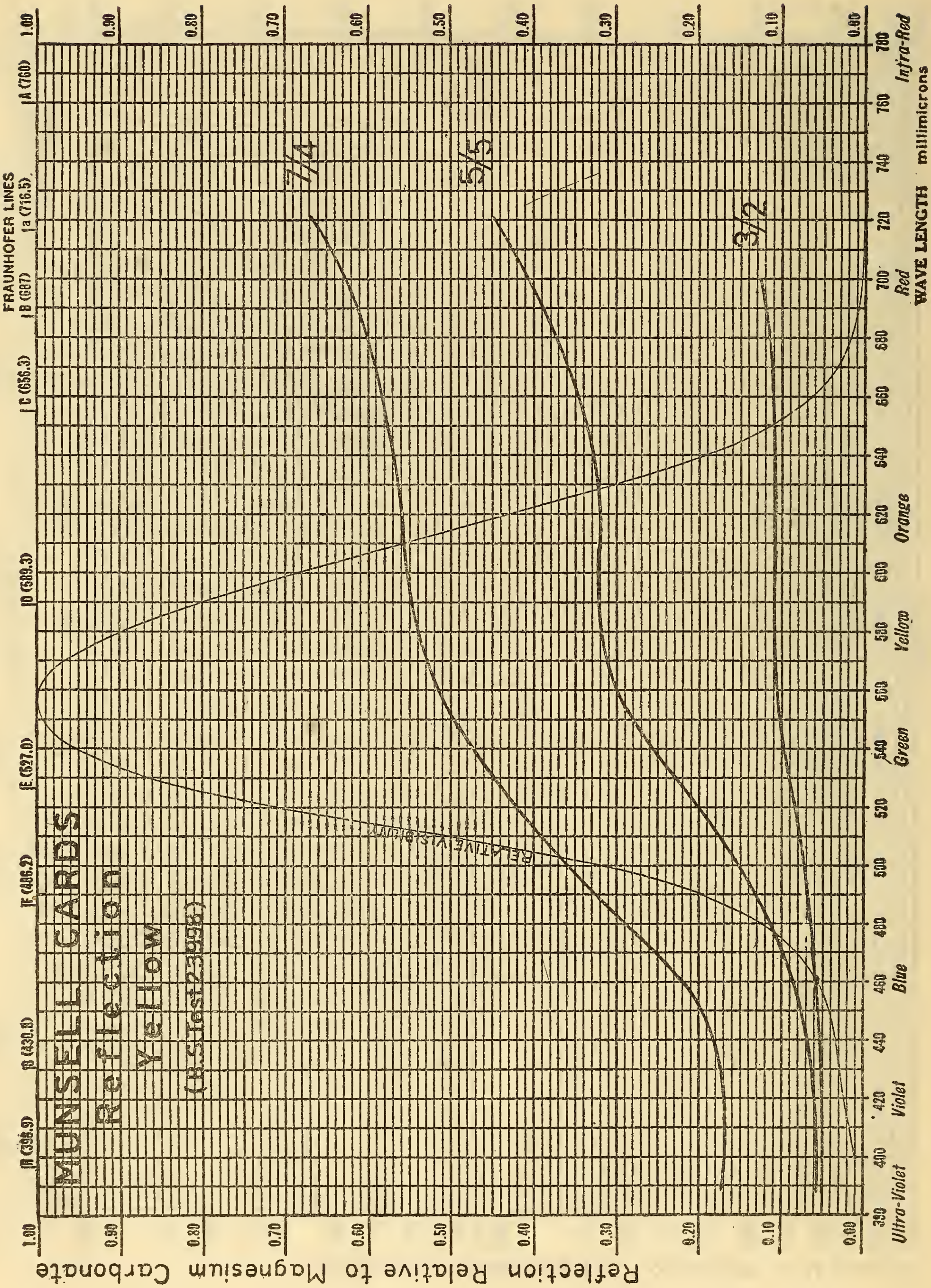
MUNSELL CARDS
Reflection
Yellow
FRAUNHOFER LINES
7/4
5/5
3/2
RELATIVE VISIBILITY
Ultra-Violet
Violet
Blue
Green
Yellow
Orange
Red
Infra-Red
WAVE LENGTH millimicrons
Reflection Relative to Magnesium Carbonate

FIG. 4

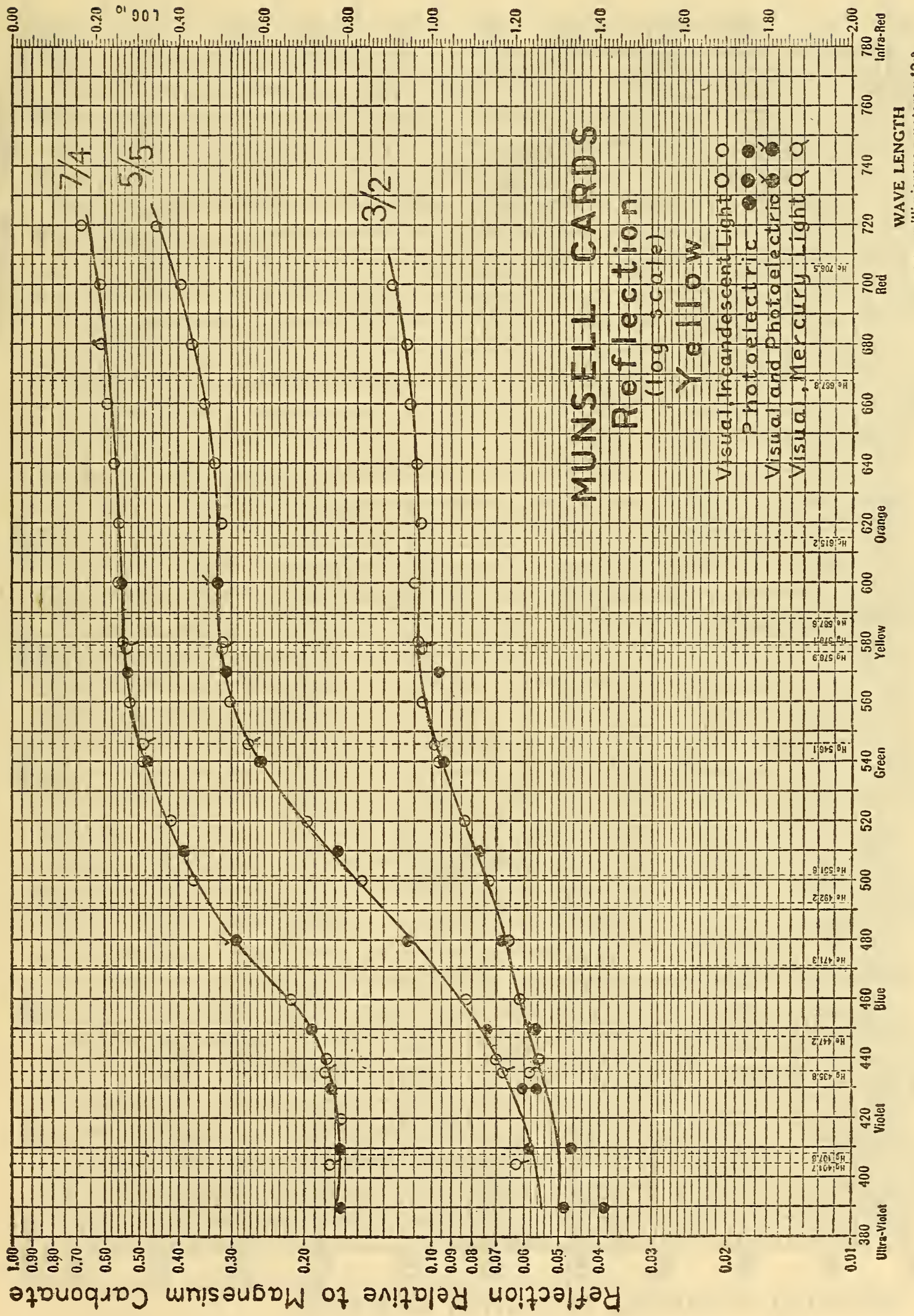
MUNSELL CARDS
Reflection
(log scale)
Yellow
Visual, Incandescent Light
Photoelectric
Visual and Photoelectric
Visual, Mercury Light
7/4
5/5
3/2
LOG ρ
WAVE LENGTH
mμ = millimicrons = meters x 10^{-9}
Reflection Relative to Magnesium Carbonate

FIG. 4*a*

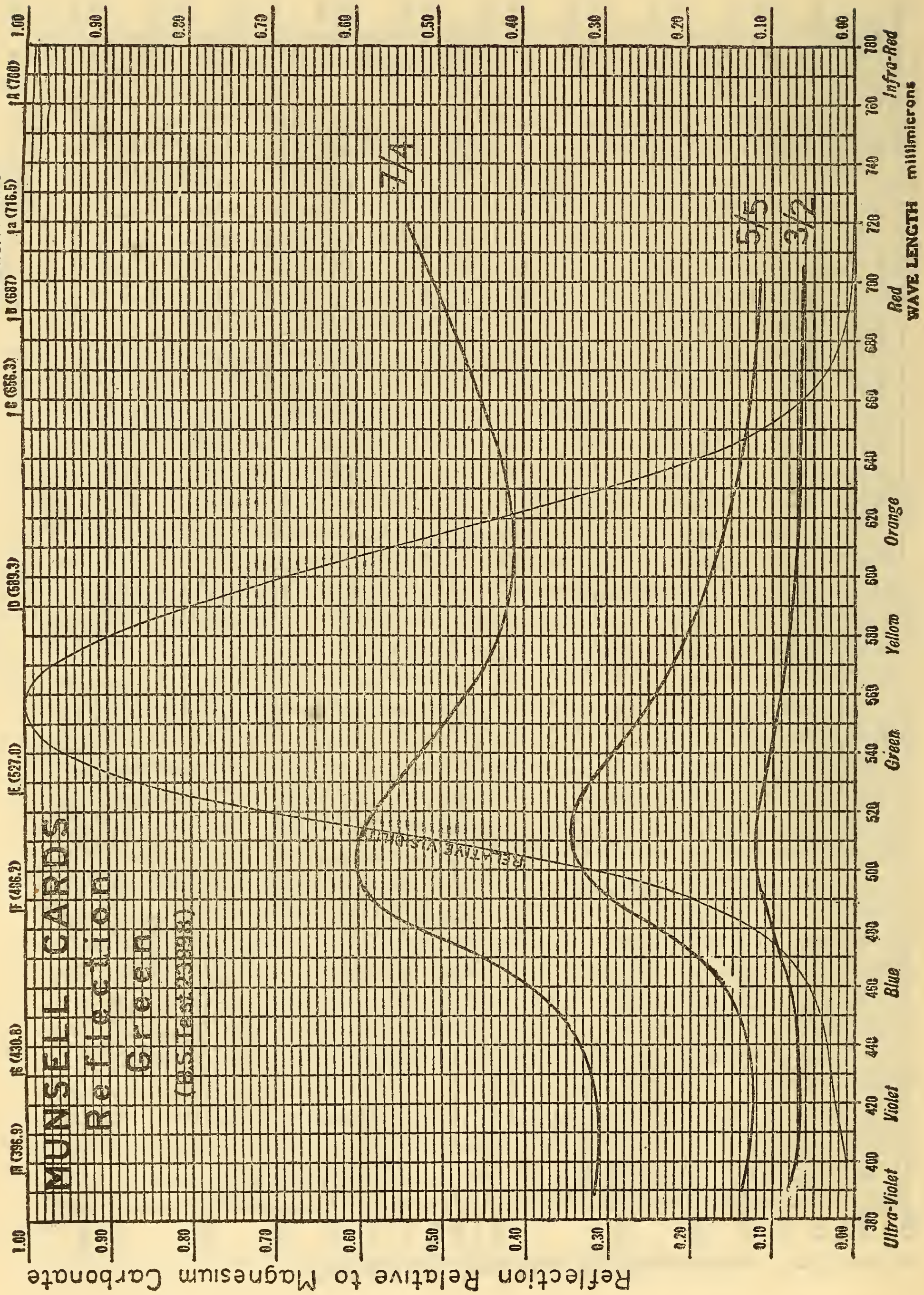
MUNSELL CARDS
Reflection
Green
Reflection Relative to Magnesium Carbonate
FRAUNHOFER LINES
WAVE LENGTH millimicrons
Ultra-Violet
Violet
Blue
Green
Yellow
Orange
Red
Infra-Red
7/4
5/5
3/2
RELATIVE VISIBILITY

FIG. 5

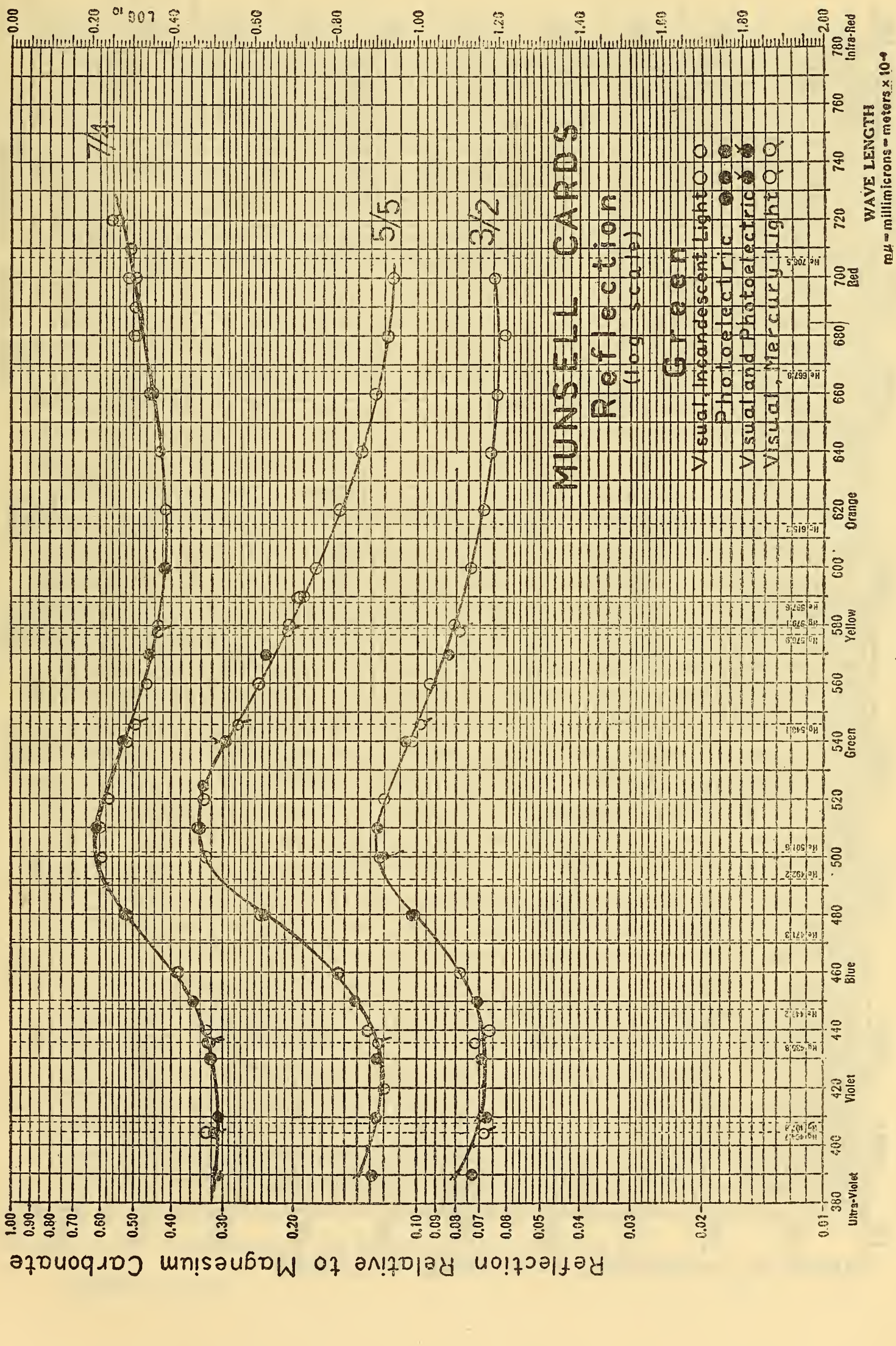
MUNSELL CARDS
Reflection
(log scale)
Green
Visual, Incandescent Light
Photoelectric
Visual and Photoelectric
Visual, Mercury Light
7/4
5/5
3/2
Log
WAVE LENGTH
mμ = millimicrons = meters x 10⁻⁹
Ultra-Violet
Violet
Blue
Green
Yellow
Orange
Red
Infra-Red
Reflection Relative to Magnesium Carbonate

Fig. 5a

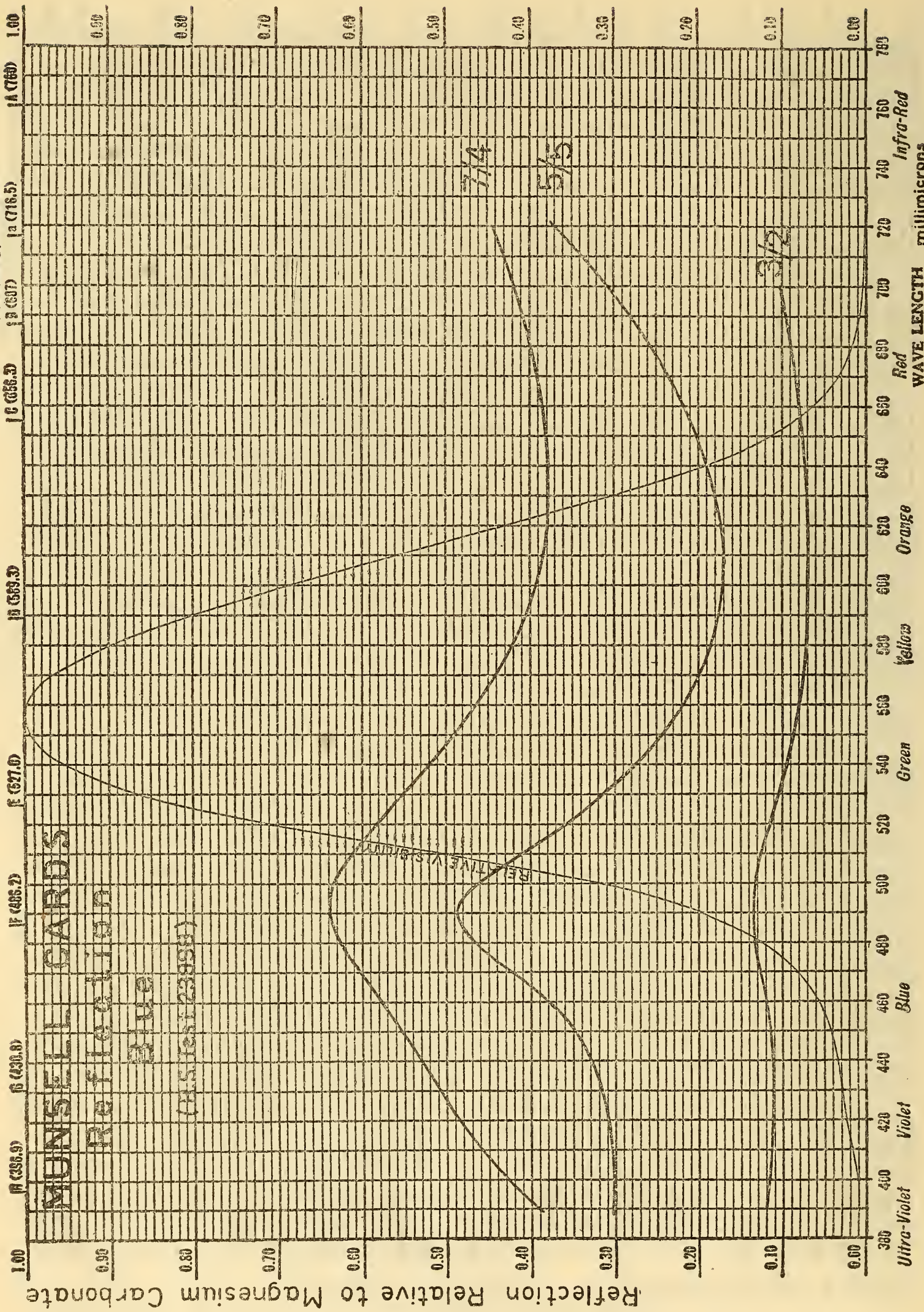
MUNSELL CARDS
Reflection
Blue
FRAUNHOFER LINES
7/4
5/5
3/2
Ultra-Violet
Violet
Blue
Green
Yellow
Orange
Red
Infra-Red
WAVE LENGTH millimicrons
Reflection Relative to Magnesium Carbonate

FIG. 6

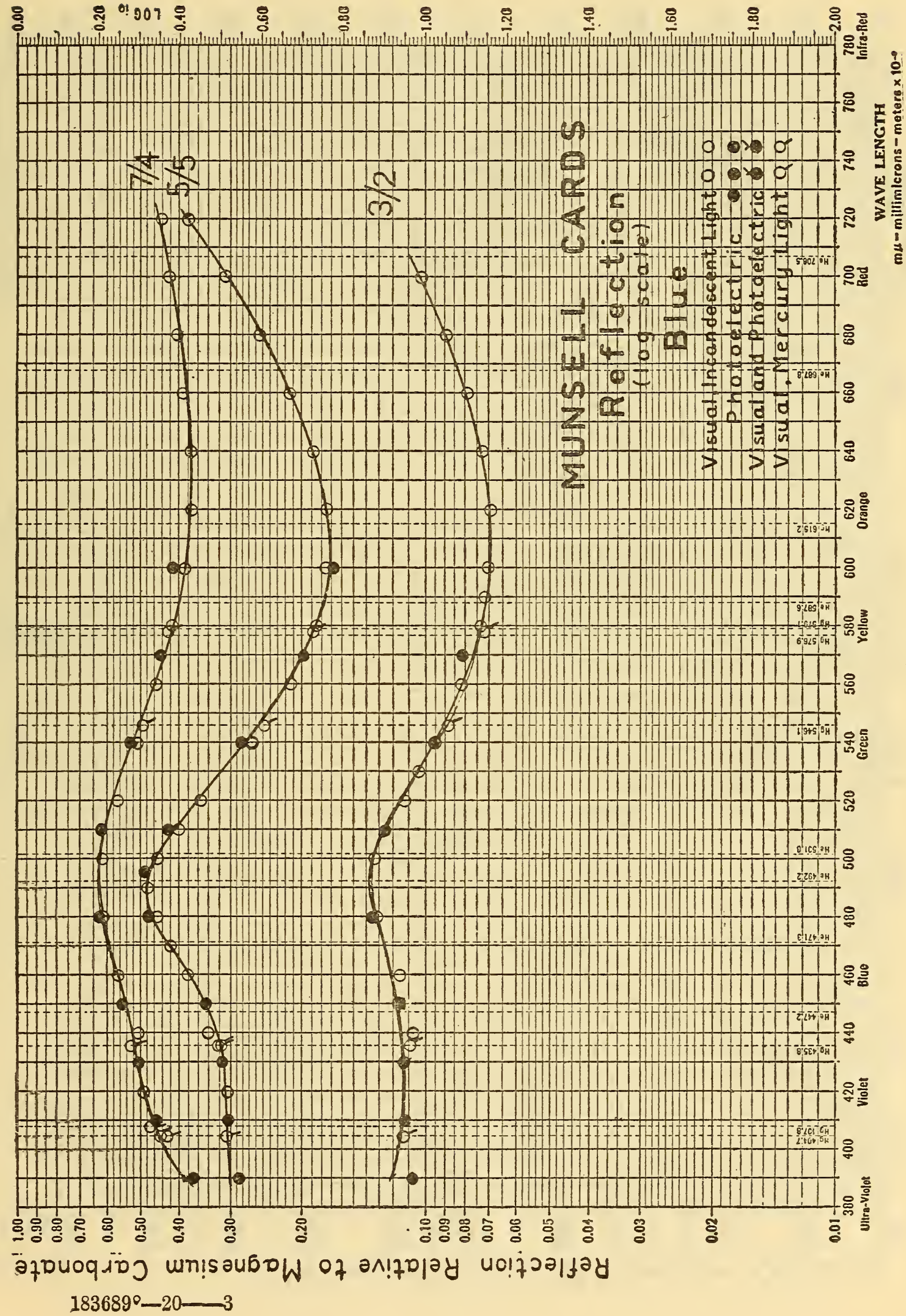

Fig. 6*a*

183689°—20——3

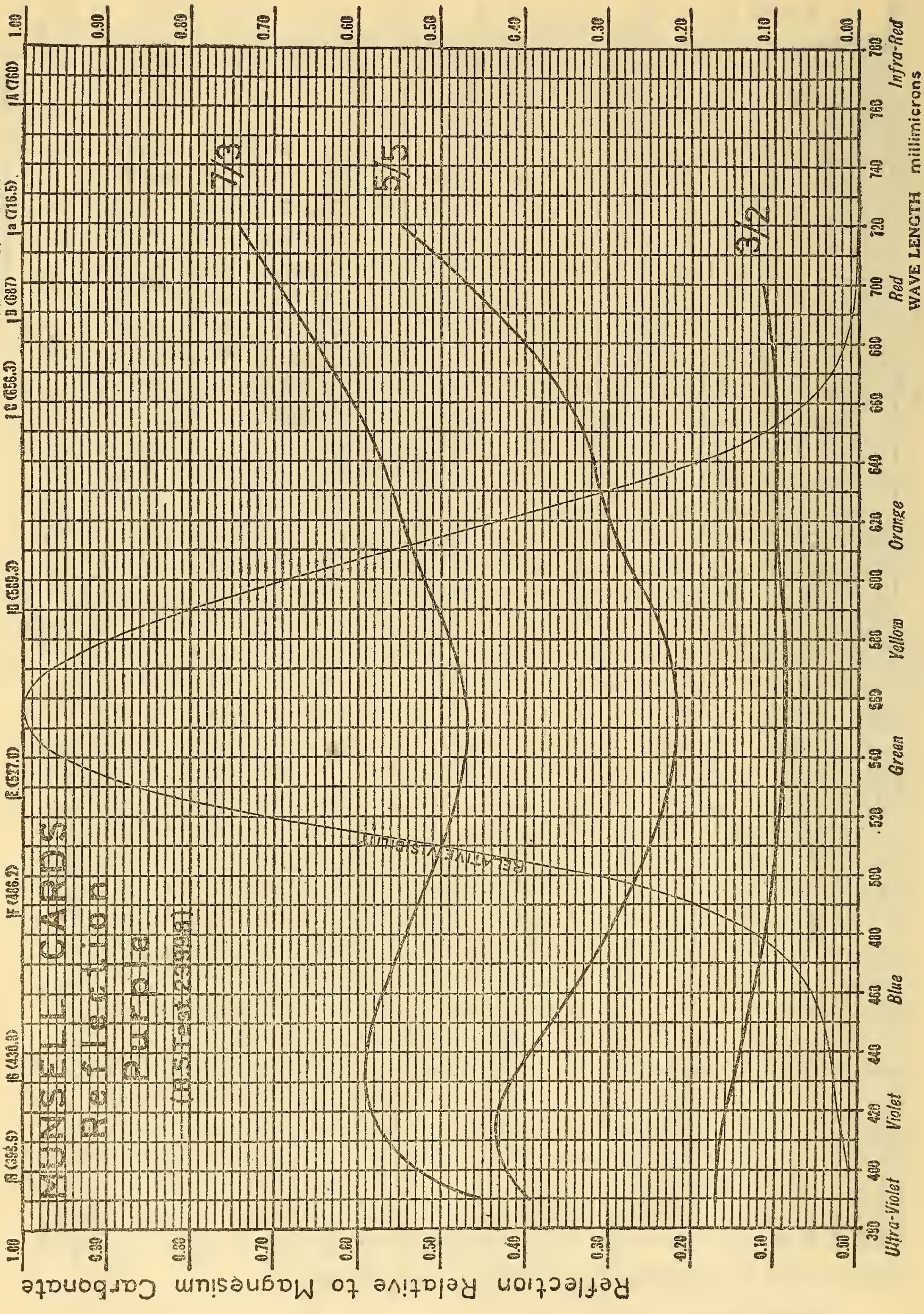
MUNSELL CARDS
Reflection
Purple
FRAUNHOFER LINES
7/3
5/5
3/2
RELATIVE VISIBILITY
Ultra-Violet
Violet
Blue
Green
Yellow
Orange
Red
Infra-Red
WAVE LENGTH millimicrons
Reflection Relative to Magnesium Carbonate

Fig. 7

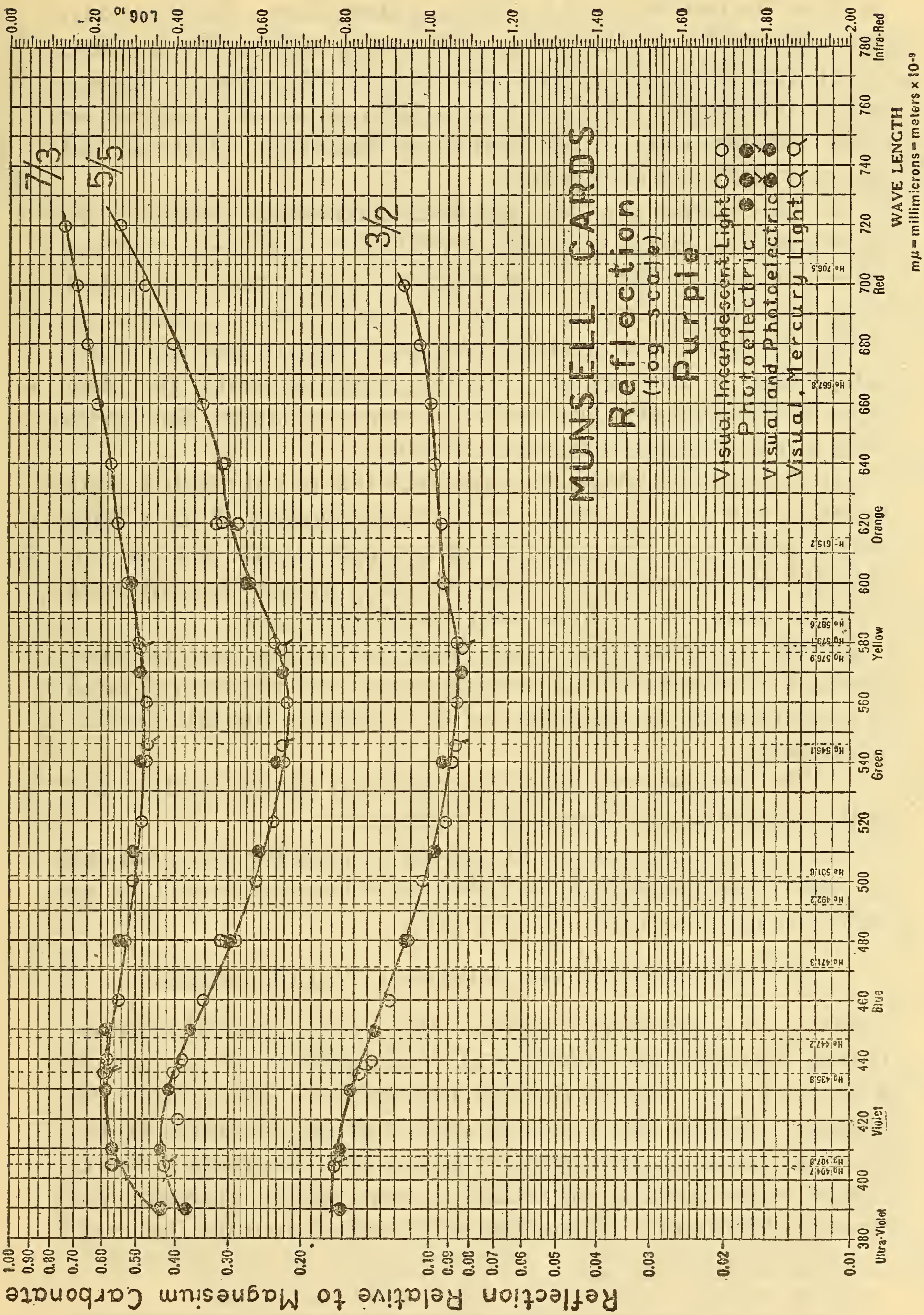
MUNSELL CARDS
Reflection
(log scale)
Purple
Visual, Incandescent Light
Photoelectric
Visual and Photoelectric
Visual, Mercury Light
7/3
5/5
3/2
WAVE LENGTH
mμ = millimicrons = meters x 10⁻⁹
Ultra-Violet
Violet
Blue
Green
Yellow
Orange
Red
Infra-Red
LOG₁₀
Reflection Relative to Magnesium Carbonate

Fig. 7*a*

It is not necessary for the purpose of this report to describe in detail the methods used in obtaining these data. For those who are interested in the methods the following information is given:

(1) The visual data were obtained by the Koenig-Martens spectrophotometer,[12] with an illumination apparatus designed for such measurements at the Bureau of Standards. The essential features of this apparatus are:

(*a*) The sample and the standard magnesium carbonate are illuminated by lamps in a white-lined box in such a way that the illumination is, so far as these samples are concerned, equivalent to perfectly diffuse; that is, of equal intensity from all directions. Either the light from gas-filled tungsten lamps or mercury-vapor lamps may be used at will. In the graphs herewith, the plain open circles indicate data with the tungsten lamps, the circles with a tail, data with the mercury lamps.

(*b*) The spectrophotometer looks into this box through a small aperture and in a direction normal to the surfaces of the sample and standard, so that one-half of the photometric field is illuminated by light reflected by the standard magnesium carbonate and the other half by light from the Munsell card.

(*c*) The magnesium-carbonate block and the card can be interchanged conveniently by a rotating device, and relative reflection is computed by the standard *tan* × *cot* formula for this spectrophotometer.

(2) The photoelectric data were obtained by the method and apparatus previously described by Gibson.[13]

The very close agreement throughout between the data obtained by these entirely different methods is convincing evidence that no serious errors of methods are involved.

IV. DISCUSSION OF MUNSELL VALUE SCALE

In Fig. 8 is shown the approximate average spectral distribution of light from the noon sun at Washington.[14] If, for each of a series of wave lengths through the spectrum, we multiply the ordinates of this curve by the corresponding ordinates of the spectral reflection curve of any sample, and plot these products against wave lengths, we obtain a curve which represents the spectral distribution of sunlight after reflection from the card.

---

[12] Ann. der Phys. (4), 12, p. 984; 1903.

[13] Jour. Op. Soc. of Am., p. 23; Jan.–Mar., 1919. B. S. Sci. Paper No. 349; Oct., 1919.

[14] Representative curve based on visibility data by Coblentz and Emerson (B. S. Scientific Paper No. 303) and energy distribution adopted by Priest (Phys. Rev. (2), 11, p. 504, Fig. 1) from the data of Abbot.

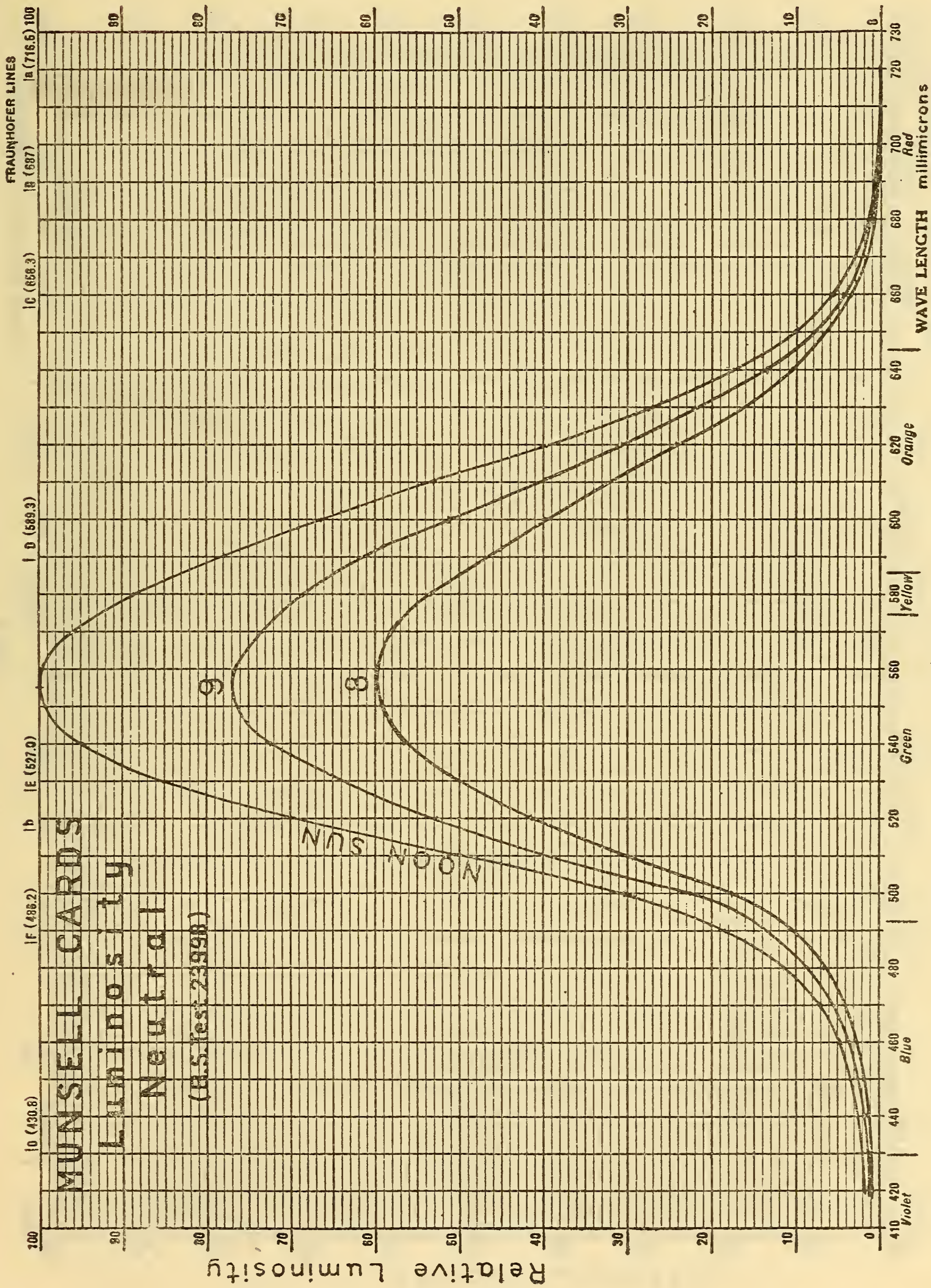
FRAUNHOFER LINES
MUNSELL CARDS
Luminosity
Neutral
NOON SUN
9
8
Relative Luminosity
Violet
Blue
Green
Yellow
Orange
Red
WAVE LENGTH millimicrons

Fig. 8

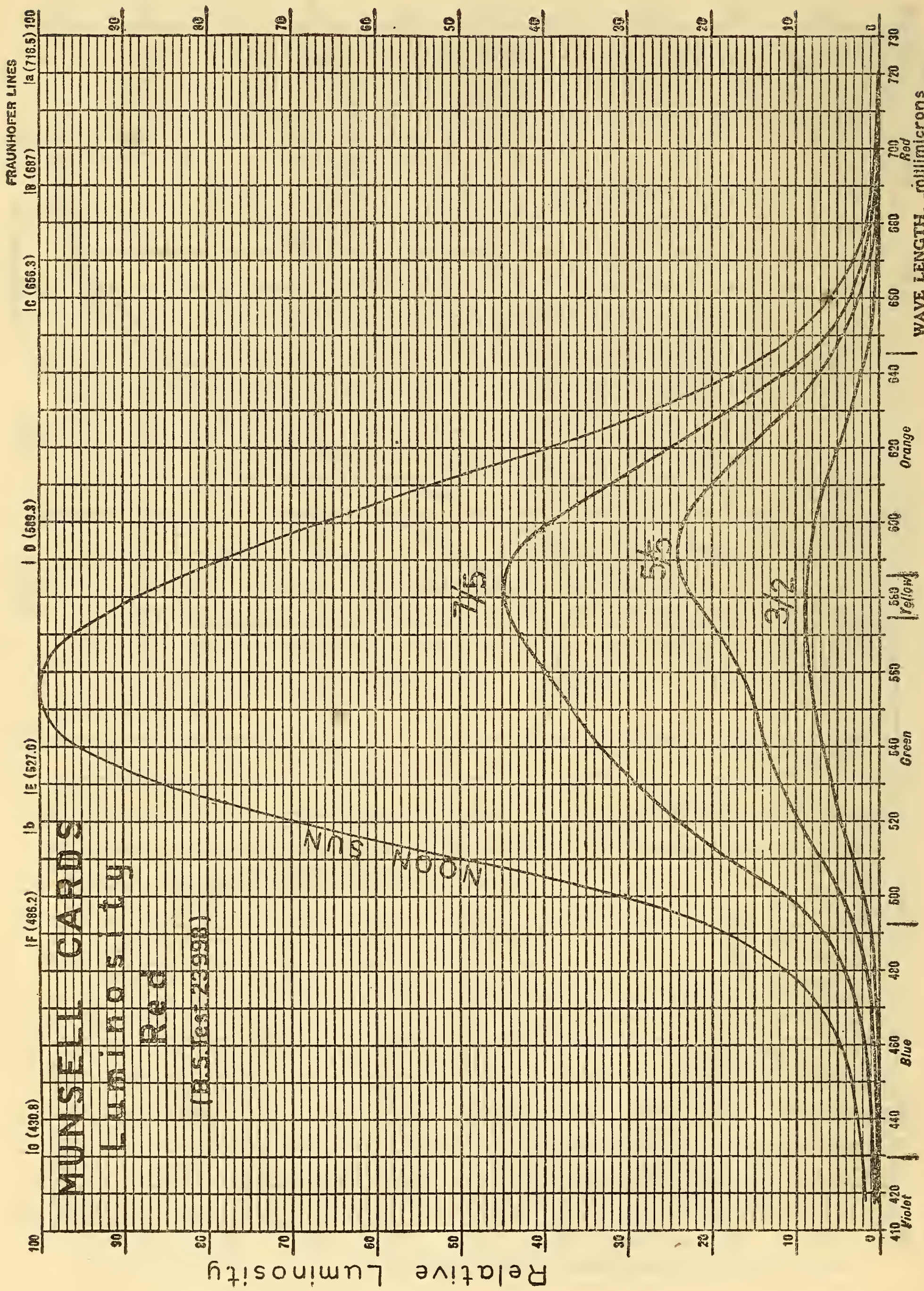
MUNSELL CARDS
Luminosity
Red
(B.S. Test 23998)
NOON SUN
7/5
5/5
3/2
FRAUNHOFER LINES
WAVE LENGTH—millimicrons
Relative Luminosity

Fig. 9

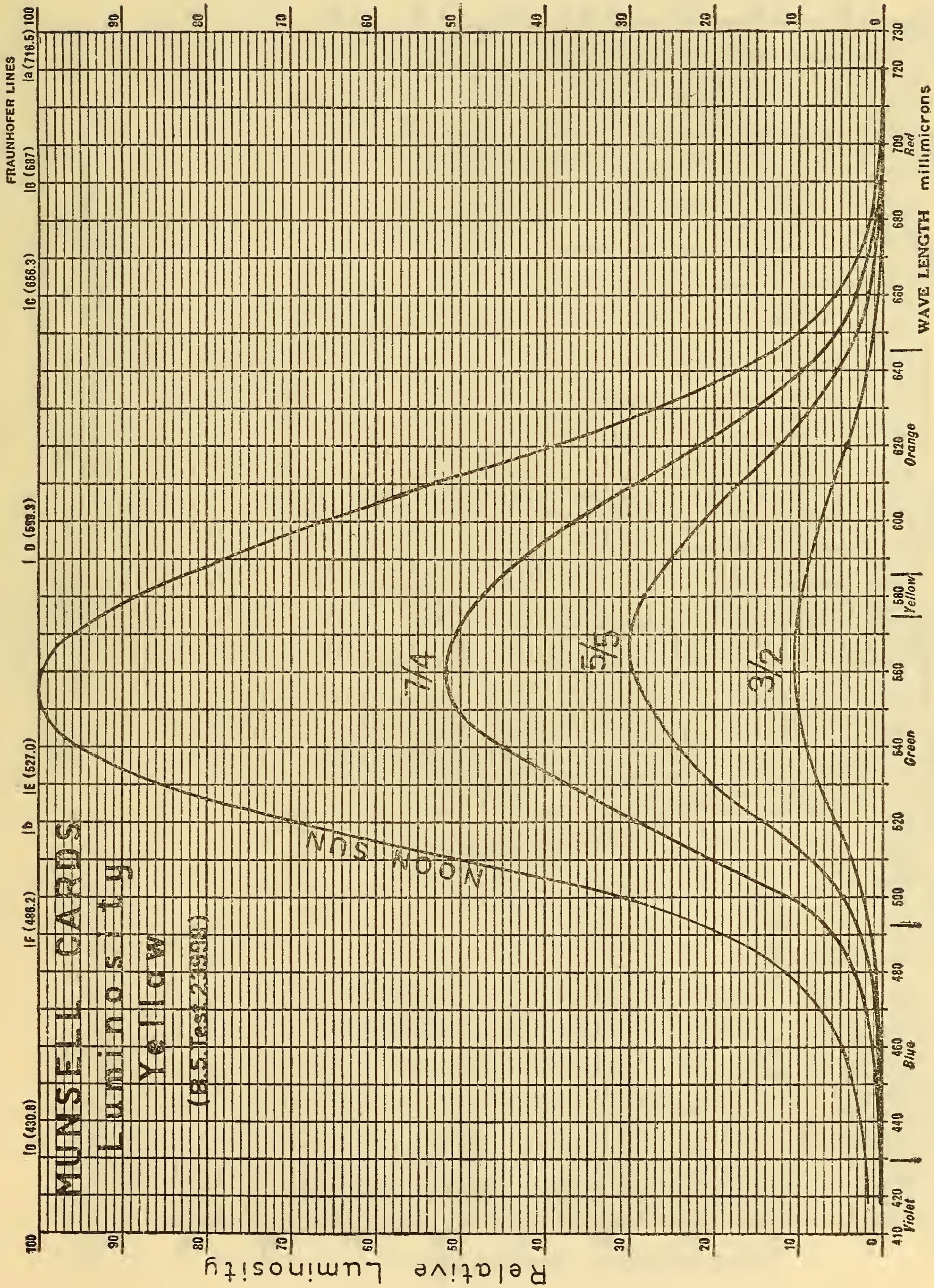
FRAUNHOFER LINES
MUNSELL CARDS
Luminosity
Yellow
NOON SUN
7/4
5/5
3/2
WAVE LENGTH millimicrons
Violet
Blue
Green
Yellow
Orange
Red
Relative Luminosity

Fig. 10

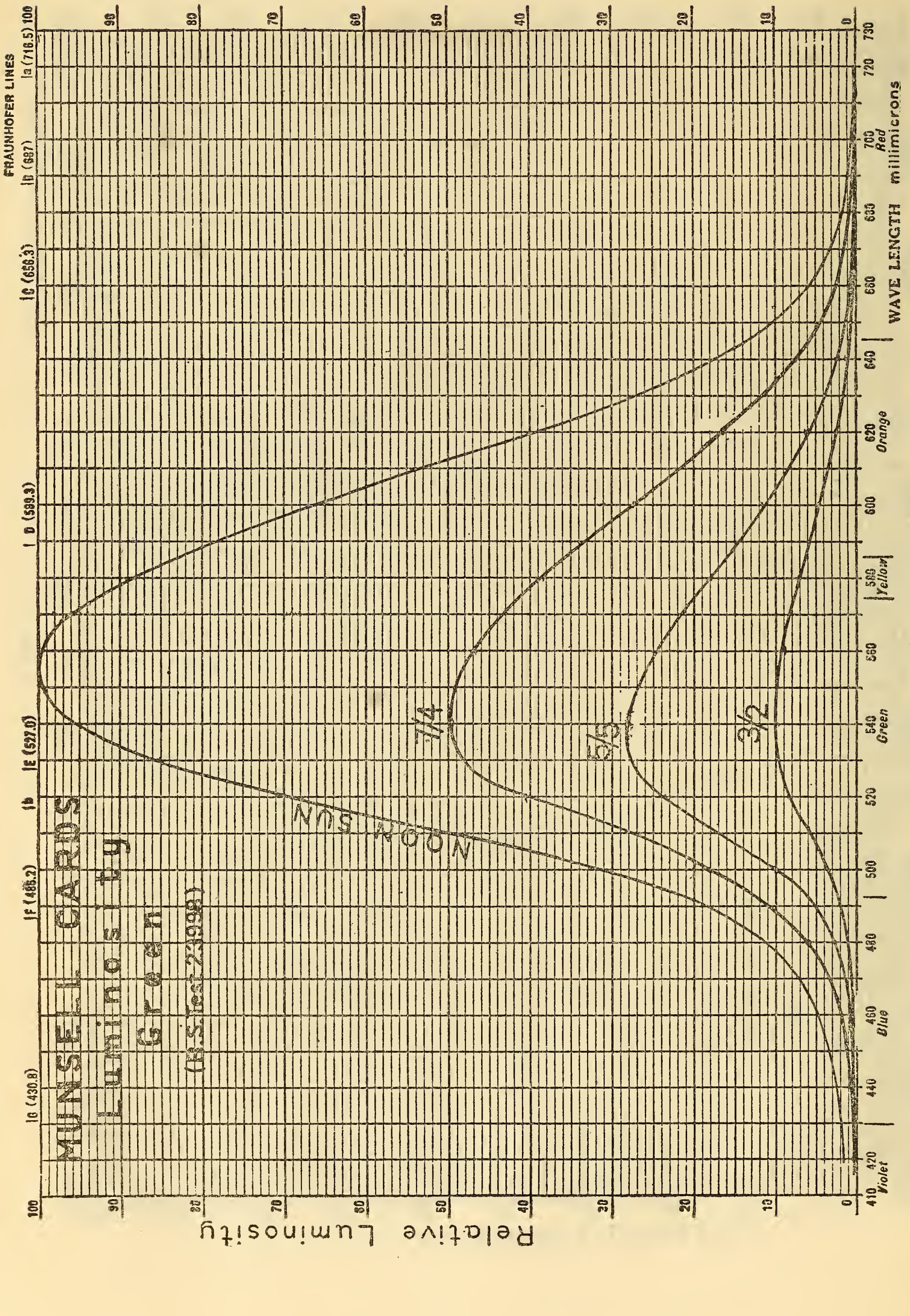
FRAUNHOFER LINES
MUNSELL CARDS
Luminosity
Green
NOON SUN
7/4
5/5
3/2
Violet
Blue
Green
Yellow
Orange
Red
WAVE LENGTH millimicrons
Relative Luminosity

FIG. 11

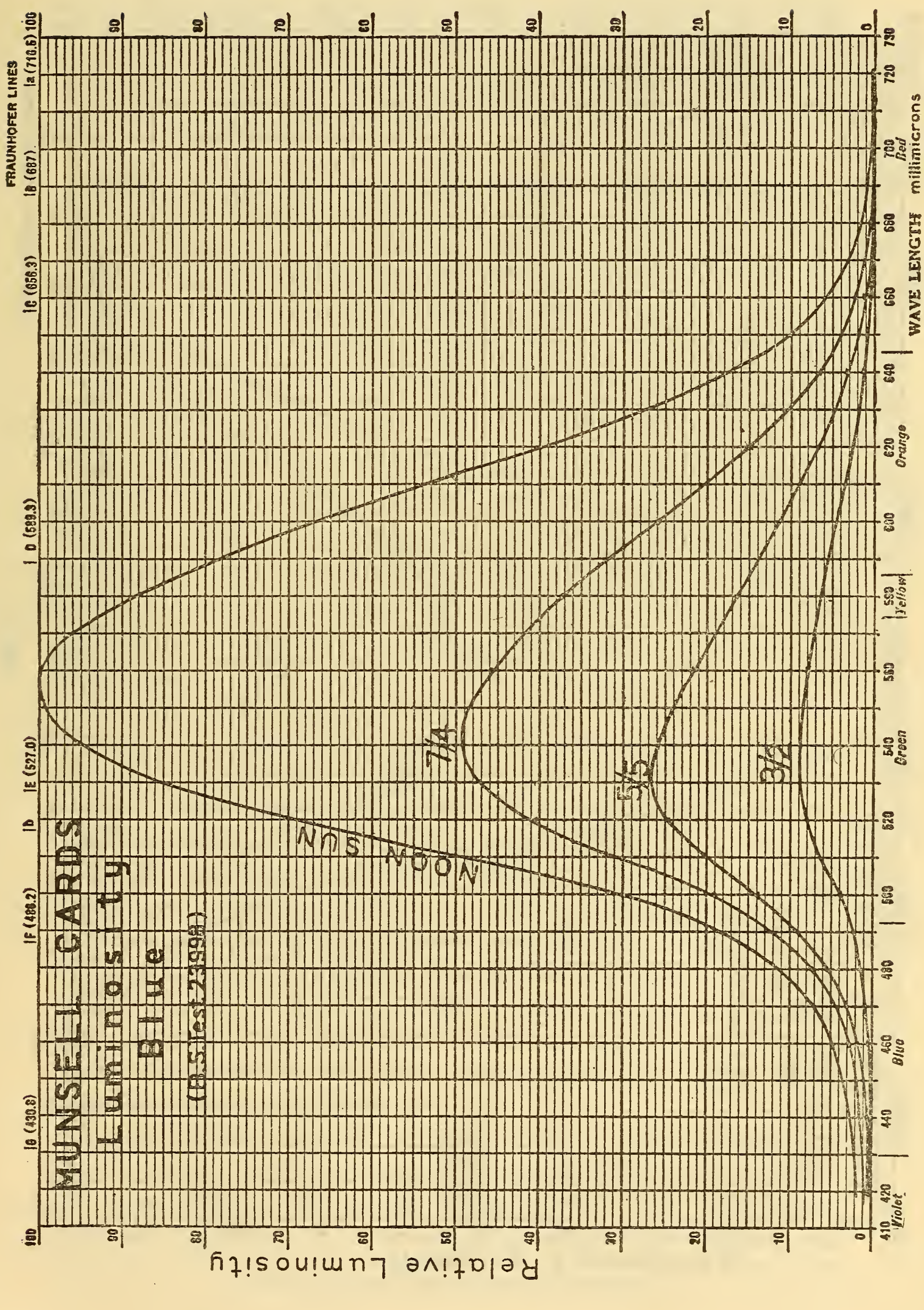
MUNSELL CARDS
Luminosity
Blue
FRAUNHOFER LINES
NOON SUN
7/4
5/5
3/2
Relative Luminosity
WAVE LENGTH millimicrons
Violet
Blue
Green
Yellow
Orange
Red

Fig. 12

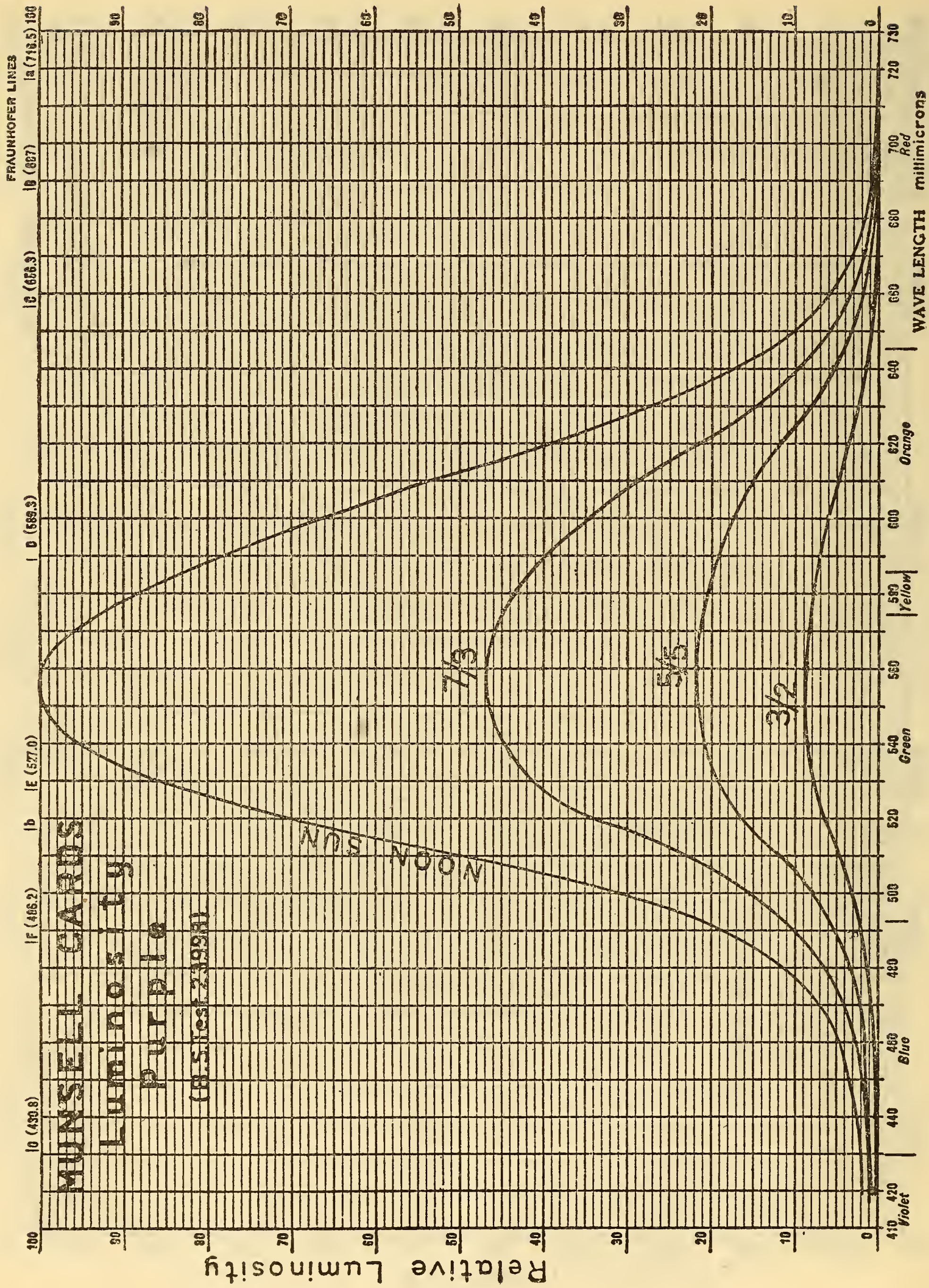
FRAUNHOFER LINES
MUNSELL CARDS
Luminosity
Purple
NOON SUN
7/3
5/5
3/2
WAVE LENGTH millimicrons
Violet
Blue
Green
Yellow
Orange
Red
Relative Luminosity

Fig. 13

(See Figs. 8 to 13, inclusive.) Such curves are known as spectral luminosity curves. Moreover, the area of this curve [15] divided by the area of the sunlight curve gives the total reflection of the card for sunlight. The total sunlight reflections obtained by this method, the areas having been measured with a planimeter, are shown in Table 3.

TABLE 3.—Diffuse Reflection for Sunlight Relative to Magnesium Carbonate

	Gray	Red	Yellow	Green	Blue	Purple
Number	N 9					
Reflection	0.722					
Number	N 8					
Reflection	.602					
Number	N 7	R 7/5	Y 7/4	G 7/4	B 7/4	P 7/3
Reflection	.465	0.451	0.488	0.477	0.476	0.496
Number	N 6					
Reflection	.343					
Number	N 5	R 5/5	Y 5/5	G 5/5	B 5/5	P 5/5
Reflection	.234	.222	.270	.239	.249	.242
Number	N 4					
Reflection	.161					
Number	N 3	R 3/2	Y 3/2	G 3/2	B 3/2	P 3/2
Reflection	.090	.087	.100	.091	.085	.089
Number	N 2					
Reflection	.041					
Number	N 1					
Reflection	.018					

Now, the Munsell value numbers are obviously some function of this total reflection. Indeed, it is explicitly stated on the charts in the Munsell Atlas that these numbers indicate the reflection of the cards in the sense that 1 means that 10 per cent of the incident light is reflected; 2 means 20 per cent; 3, 30 per cent; etc. *The results of our measurements, as given in Table 3, show conclusively that these statements in the Atlas are in error, and that the Munsell value numbers have no directly proportional relation to the reflections.* The actual relation existing between the Munsell values and the reflections is shown graphically in Fig. 14. From this curve one may read the reflection of sunlight corresponding to any Munsell value.

A very simple relation has been found to exist between the Munsell values and the reflections, viz, *the squares of the Munsell value numbers are directly proportional to the reflection of sunlight.* (See Fig. 15.) It seems likely that this relation has

[15] Included between the curve and the wave-length axis.

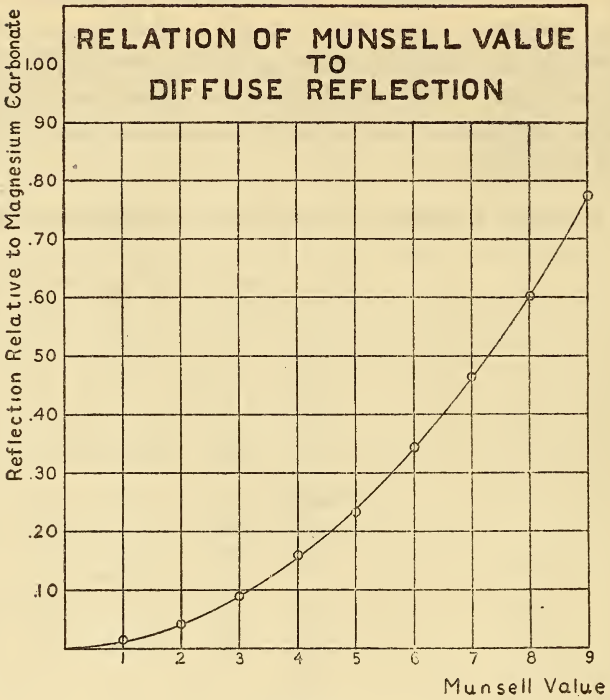
RELATION OF MUNSELL VALUE
TO
DIFFUSE REFLECTION
Reflection Relative to Magnesium Carbonate
1.00
90
.80
.70
.60
50
.40
.30
.20
.10
1
2
3
4
5
6
7
8
9
Munsell Value

Fig. 14

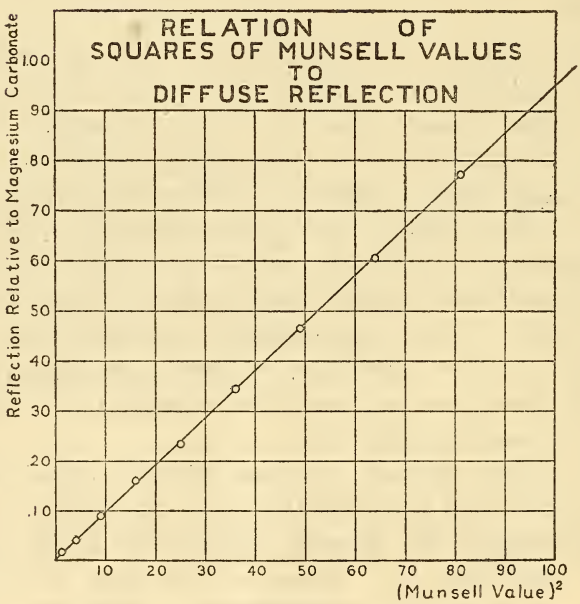
RELATION OF
SQUARES OF MUNSELL VALUES
TO
DIFFUSE REFLECTION
Reflection Relative to Magnesium Carbonate
1.00
90
.80
70
60
50
40
30
.20
.10
10
20
30
40
50
60
70
80
90
100
(Munsell Value)²

Fig. 15

been introduced into the system by an oversight in the use of the Munsell photometer.[16] Taking values as directly proportional to the diagonal of the opening of the diaphragm (valve) in the instrument would lead to just this result, for the reflection by the sample is evidently proportional to the square of this diagonal.

Whether this relation of value to actual light reflection was selected purposely or inadvertently by Munsell is not quite clear.[17] We may be sure that, as an artist, he would not have been satisfied with a value scale in which the reflections of the successive steps actually formed an arithmetical series, as 10 per cent, 20 per cent, 30 per cent, 40 per cent, etc. (even though it is stated in the Atlas that this is the interpretation of the value scale), for in such a scale the apparent contrast of different intervals would not be equal; for example, the contrast between 10 per cent and 20 per cent would be much greater than between 80 per cent and 90 per cent.

It will probably be agreed by all who are interested in the subject and consider it carefully, that the steps in the value scale should be apparently equal; that is, the visual contrast between the cards of any two adjacent numbers should equal that between any other adjacent two. Now, there is a well-known natural law which enables us to formulate mathematically (at least to a good approximation) the relation which must exist between the reflections of the members of the series of values in order that this condition may be satisfied. A scale conforming to this law may be called a natural value scale. This law may be stated in several forms, but probably the simplest and most

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[16] Munsell, Color Notation, Second Ed., pp. 39–41.

[17] In an advertising circular issued by A. H. Munsell and entitled, "The New Munsell Photometer (patented Nov. 19, 1901)," etc., we find the following paragraph:

"Intermediate positions of the shutter give *a regularly increasing scale of light from black to white—self-registered on a dial* at the back wall by a gear shaft and index hand. The dial registers 100 when the shutter is open and 0 when it is shut, the intermediate degrees following Fechner's law of sensation. This calibration is easily verified, by comparing the area of opening at any position of the shutter, with the corresponding reading on the dial."

This paragraph is, however, covered by a pasted insert which reads as follows:

"The dial bears two scales, the inner of which may be used for comparing the intensity of light sources. Thus, with a standard 10-c. p. lamp opposite the fixed half, and a 40-c. p. lamp opposite the variable half, the shutter is choked down to one-fourth its full area to procure a balance. The outer scale differs from the usual photometric scale in that it measures *sensation* of light rather than intensity. It is divided into 100 equal values (sensations of increase of luminosity), from complete blackness (0), to pure white illuminated to the full extent of the instrument. These sensation values read directly as the diagonal of the variable shutter in millimeters, and are used in this description."

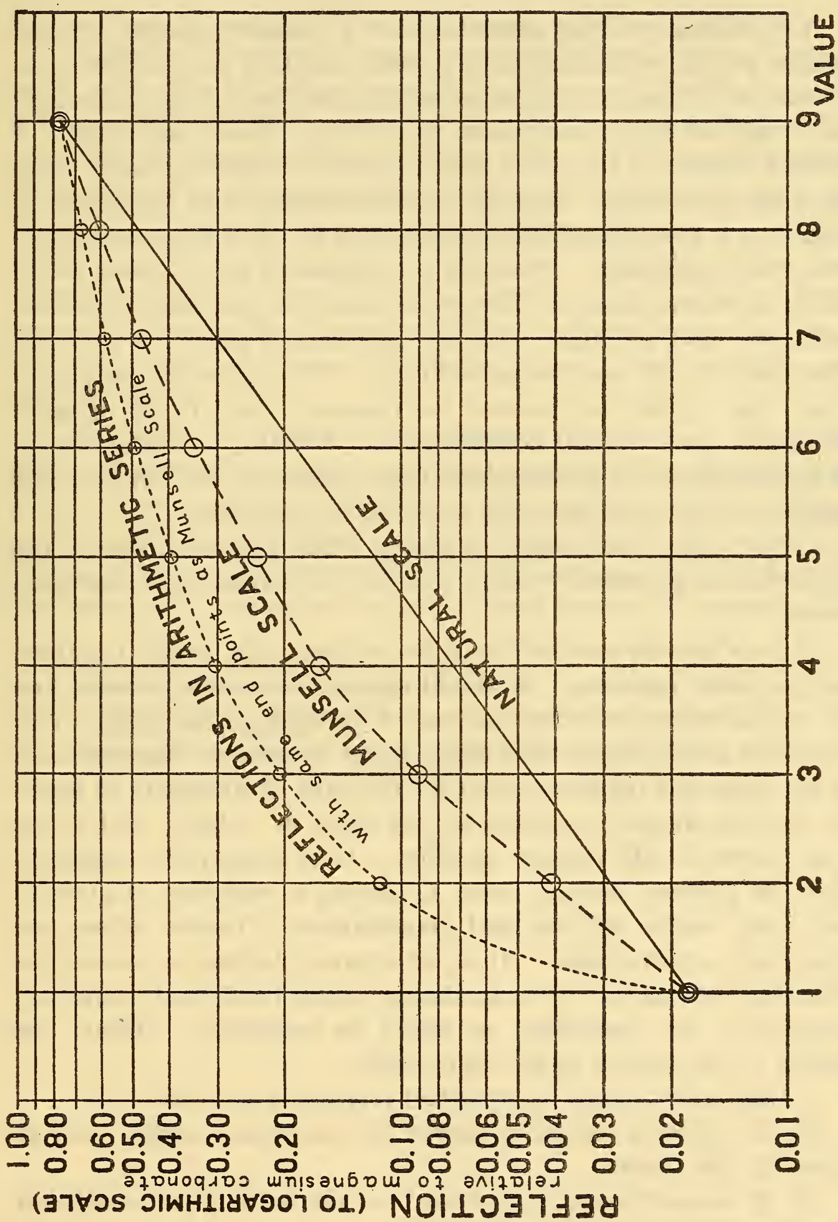
The treatment here is somewhat more definite than in the "Color Notation," and apparently verifies our previous conclusion that Munsell values are directly proportional to the diagonals of the shutter opening, However, the whole treatment of the photometer and its use in measuring value is rather indefinite; and the implication that values, read directly as the diagonal of the shutter, are proportional to sensation in the sense of Fechner's law is quite wrong.

easily comprehended is: The reflections of the various members of the series of cards should form a geometric series; that is, the ratio of the reflections of any two adjacent cards in the series should be constant throughout the series.[18] This leads to a simple graphical relation which must exist between the value-scale numbers and the reflections; viz, the graph relating the value-scale numbers and the logarithms of the reflections must be a straight line. (See Fig. 16.) In this figure the logarithms of the measured reflections of the Munsell cards are plotted against their Munsell value numbers (dashed curve). It appears that while considerable parts of this curve are sensibly straight, it does not conform rigorously to the law stated above. *The curve indicates that the lower intervals of the Munsell scale are two great relative to the higher intervals. In our opinion this conclusion is verified by qualitative examination* of the cards submitted and tested. The lower intervals, 1–2, 2–3, 3–4, 4–5, look greater than the higher intervals, 5–6, 6–7, 7–8, 8–9.

However, the Munsell scale approximates much more nearly to the natural scale than a scale in which the reflections of the series form an arithmetical series. In Fig. 16 the dotted curve shows the relation between value numbers and the logarithms of reflections for a series of cards having the same end members as the Munsell cards but assumed to have their reflections in an arithmetical series. It will be noted that this curve departs much farther from a straight line than the Munsell curve. We may, perhaps, assume that Munsell, fully realizing the unsuitability of a value scale with reflections in arithmetical series, adopted his scale merely from artistic considerations and really approximated to the true natural scale of value by adopting his value numbers as proportional to the square roots of the reflections.

Our sunlight reflections for the different hues given in Table 3 verify in a remarkable manner the consistency of the Munsell values for different hues. It will be noted that the reflections for sunlight are nearly constant for the same Munsell values for all the hues and the neutral. Considering the uncertainties of heterochromatic photometry which were necessarily involved in Munsell's work, it seems remarkable that he obtained such consistent results for the values of different hues.

[18] This relation is based on Weber's law, often erroneously called Fechner's law. See Webster's International Dictionary, 1910 ed., under "Weber's law," and "Fechner's law." See also Ostwald, Farbenfibel, Leipzig, pp. 9–10; 1917. Külpe, Outlines of Psychology, Eng. Trans. by Titchener, p. 122; 1901.



REFLECTIONS IN ARITHMETIC SERIES
with same end points as Munsell Scale
MUNSELL SCALE
NATURAL SCALE
VALUE
1
2
3
4
5
6
7
8
9
REFLECTION (TO LOGARITHMIC SCALE)
relative to magnesium carbonate
1.00
0.80
0.60
0.50
0.40
0.30
0.20
0.10
0.08
0.06
0.05
0.04
0.03
0.02
0.01

Fig. 16

V. PROPOSALS FOR THE IMPROVEMENT OF THE SYSTEM AND ITS ESTABLISHMENT UPON A MORE RELIABLE FOUNDATION

It is obviously highly desirable that a standard system, at least similar to that of Munsell in its general outlines, be established for the use of artists, art students, and others, including the makers and users of paints and inks, and other colored materials. A revised edition of the Atlas and The Color Notation, based upon the best present-day methods of measurement and specification, would be a most important contribution to the science and art of chromatics generally. That the production of such a work would be an enormous task, involving the hearty cooperation of artists, scientists, and practical colorists, is obvious; and it is not now clear just how it may be undertaken. It is, however, an opportune time to point out some of the features which, in our opinion, should be given careful consideration. Pending a further study of all the phases of the problem, these proposals can not be made exhaustive, but the following occur to us at present:

1. The value scale should be one in which the reflections of the cards form a geometric series; that is, the natural scale discussed above.

As to what the end points of the actual scale should be, there may be some question. It would appear reasonable to make 100 per cent absolute reflection one end of the scale (value=10). This would of course be an ideal limit, never attainable, but desirable as the ideal end reference point for the sake of simplicity of ideas. As to what should be chosen for the other or "black" end of the scale, there is still greater question. It is tentatively suggested that the present Munsell value 1, having a reflection of about 2 per cent, meets all practical requirements. Lower values are practically unattainable. It is, of course, obvious on consideration that we can not, even in theory, make the lowest value correspond to zero reflection, as might be suggested, without due regard to the nature of the value scale.

2. Each color should be specified physically in three ways:

(*a*) By spectral reflection curves (of the actual cards), such as given in this report.

(*b*) By monochromatic analysis,[19] *on the basis of an established standard white* (not yet established).

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[19] Nutting, B. S. Bulletin, 9, p. 1; 1913.

(*c*) By its constants under prescribed conditions on the Arons chromoscope.[20]

3. The colorimetric and photometric specifications of the cards should accompany the Atlas, and should refer in clear terms to fundamental standards about which there can be no ambiguity.

4. Relative reflection or value measurements on different colors must be made with light of specified quality, and for this purpose it is reasonable to select average noon sunlight. Measurements of value can be made with the greatest convenience and reliability by means of the Martens photometer [21] and a hollow hemisphere arranged to illuminate the samples with diffuse light.[22] By a slight addition to the Martens photometer, it may be made to give true standard sunlight values, using gas-filled tungsten lamps as light sources. This can be accomplished by inserting between the eye and the present nicol prism in the instrument a quartz plate and another nicol.[23]

5. In order to avoid further confusion of terms, it would be highly desirable to secure a general agreement in nomenclature among those experts interested in this subject, before issuing another edition of this work. Steps toward the general standardization of the nomenclature of colorimetry are now being taken by the Bureau of Standards and the Optical Society of America.

WASHINGTON, November 11, 1919.

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[20] Ann. der Phys. (4), **39**, p. 545; 1912.

[21] Phys. Zeit., **1**, p. 299; 1900.

[22] Cf. Luckiesh: "Measurement of Reflection Factor," Electrical World, May 19, 1917.

[23] Priest, Phys. Rev. (2), **11**, p. 502; June, 1918.