DEPARTMENT OF COMMERCE

BUREAU OF STANDARDS

S. W. STRATTON, Director

TECHNOLOGIC PAPERS OF THE BUREAU OF STANDARDS, No. 92

[Issued June 30, 1917]

[NOTE.—In publishing the present paper it is desired to state explicitly that, while it is a part of the Bureau's proper duties to furnish upon request technical advice such as is given in this paper, the Bureau expresses no opinion in regard to the advisability, propriety, or justice of any proposed legislation incorporating this specification.—S. W. STRATTON, *Director*.]

MEASUREMENT AND SPECIFICATION OF THE PHYSICAL FACTORS WHICH DETERMINE THE SATURATION OF CERTAIN TINTS OF YELLOW

By Irwin G. Priest, Associate Physicist, and Chauncey G. Peters, Assistant Physicist

CONTENTS

		Page
I.	Introduction	1
II.	Considerations governing the choice of form of the specification	2
III.	Fundamental principles of color	2
	1. Properties of the illumination	3
	2. Properties of the substance illuminated	4
	3. Effect of the observer's color sense	4
IV.	Nature and form of the proposed specification	4
V.	General description of apparatus and fundamental principles of the method of test	7
VI.	Explicit directions for making test	9
	1. Preparation of sample	9
	2. Apparatus adjustments	9
	3. Observations	9
	4. Computation	10

I. INTRODUCTION

Frequent and persistent demands have been made on the Bureau of Standards to draft a form of specification which would be suitable to define rigorously in law a limiting value of what, in common parlance, may be called the "color," the "depth of color," the "strength of color," or the "yellowness" of butter and oleomargarine. More specifically stated, it is desired to define a

line of demarcation between the paler tints of yellow and those of a more pronounced color.[1]

The purposes of this paper are:

1. To outline the rational principles which should govern the formulation of such a specification.

2. To present and explain the form of specification recommended by the Bureau, together with the methods and apparatus used to make the necessary measurements for testing in terms of the specification.

An attempt will be made to present the subject in such a way as to make it intelligible to interested persons who may have little or no previous knowledge of the scientific principles or the technique involved.[2]

II. CONSIDERATIONS GOVERNING THE CHOICE OF FORM OF THE SPECIFICATION

It is evident that the desired specification should have the following characteristics:

1. It should be absolutely definite and unambiguous, its terms affording as small basis as possible for any difference of opinion among experts.

2. It should be valid for an indefinite time, and accordingly must not depend upon the assumed permanency of the color of material samples.

3. It should not be dependent upon reference to so-called color scales which themselves have never been defined in scientific terms and which have neither definition nor warrant of validity other than their maker's or originator's name.

4. Its terms should be capable of simple explanation to persons not previously acquainted with the principles involved, and should admit of convenient incorporation in the text of the law.

III. FUNDAMENTAL PRINCIPLES OF COLOR[3]

The apparent color of a substance is determined by three factors, viz: (1) The color of the illumination (as, e. g., sunlight, diffuse daylight, gaslight, electric light, etc.), (2) the reflecting properties of the substance, and (3) the color vision of the observer.

---

[1] In the accepted terms of scientific terminology of color theory, we may say that it is the "saturation" or "purity" of the color which it is desired to limit. (See Rood: Modern Chromatics.)

[2] On this account it has been necessary to adopt in some places a certain laxity of statement which would not otherwise be permissible in a scientific paper. We believe, however, that such statements will not be subject to criticism in respect to any fact essential to the matter in hand.

[3] Under this heading are given some elementary principles relating to spectroscopy, selective absorption, color, and color vision, which may be omitted by readers already familiar with such subjects.

1. PROPERTIES OF THE ILLUMINATION

Sunlight, daylight, and, in general, the light from all incandescent solids (e. g., carbon particles in the flame of a gas or oil lamp or the filament of an incandescent electric lamp) consist of a mixture of lights any one of which alone causes a sensation of color, while all acting jointly on the eye cause the sensation of white.[4] By suitable means composite white light may be resolved into its elements—red, orange, yellow, green, blue, violet, and their intermediate hues.[5] Elementary colored light is conveniently specified by its wave length.[6]

The color of a composite light is determined (1) by the wave lengths of its constituents and (2) by the relative intensities of its constituents. A specification of wave length is a perfectly definite thing which can not be misconstrued. Therefore, in describing the color of a light it is more definite and unambiguous to specify its wave length or its range of wave lengths with their relative intensities than to describe it by color names, and this is the accepted practice in physics. As already mentioned, the "whiteness" of light from our ordinary artificial light sources (incandescent solids) is a purely relative matter, all of them being yellowish compared with sunlight, while some are "yellower" than others. The physical basis of this difference in color is the fact that the relative intensities of blue and yellow are different in different sources. The source which is relatively weak in its blue constituent appears yellowish when compared with one in which the ratio of the intensity of blue to the intensity of yellow is higher. While there is no universally accepted definition of "white light," probably the most rational definition of it is "average direct noon summer sunlight."

---

[4] While sunlight, daylight, and several artificial lights are loosely described as "white," their whiteness is a purely relative matter. It is, for example, commonly recognized that all artificial lights are decidedly yellowish when compared with daylight and that some of them are more yellowish than others.

[5] The rainbow is caused by just such a resolution of sunlight into its elements, and the same phenomenon may be seen by viewing a small white object through a triangular glass prism.

[6] The most convenient unit of measurement for wave length for our present purpose is one one-millionth of a millimeter $\left(\frac{1 \text{ mm}}{1\,000\,000}\right)$. The following table gives the wave lengths of light to which the human eye is commonly sensitive, with the corresponding commonly accepted color names:

Wave length, millionths of 1 mm	Color	Wave length, millionths of 1 mm	Color
397 to 424	Violet	575 to 585	Yellow
424 to 492	Blue	585 to 647	Orange
492 to 575	Green	647 to 723	Red

2. PROPERTIES OF THE SUBSTANCE ILLUMINATED

A substance, such as chalk, which reflects equally well all of the colored constituents of white light is white. If illuminated by white light, a substance having a slightly lower reflecting power for red, yellow, and orange than for blue will appear of a bluish tint, and, conversely, one defective in its reflecting power for blue will appear yellowish. But a substance which would appear yellowish in white light may be made to appear white if illuminated by a suitable bluish light, simply because the relatively low reflecting power for blue is compensated by the excessive blue illumination.

3. EFFECT OF THE OBSERVER'S COLOR SENSE

To a totally color-blind person all objects appear only black and white and various shades of gray. Such cases are, however, exceedingly rare. On the other hand, partial color blindness of various types and degrees is quite common. Because of the infinite variety of aberrations of color vision it is quite impossible to make any a priori general statement as to their effect in colorimetric specifications. Each observer's vision must be individually tested in order to make his observations significant. Any method of testing the validity of which involves any question of the observer's color vision is accordingly to be avoided if possible.

IV. NATURE AND FORM OF THE PROPOSED SPECIFICATION

In the present case it is obvious that we should limit our task strictly to specifying the property of the substance which determines its color. By so doing we at once eliminate all the unsettled, debatable questions of color vision and color of illumination which would greatly embarrass the enforcement of any law in which they might be involved. In order to obtain data on the property of butter and oleomargarine which determines their color, we have determined the relative diffuse reflecting power [7] for different colors for a number of samples.[8] The values obtained are shown graphically in Fig. 1. From the data shown in this figure we draw the following conclusions:

1. In all the samples there is a rapid rise in reflecting power between about wave length $\frac{500}{1\,000\,000}$ mm and $\frac{540}{1\,000\,000}$ mm.

[7] Ratio of the brightness of the illuminated surface to the illumination falling on that surface. For example, imagine a white card and a similar gray card illuminated by the same light. The white card will be the brighter. The ratio of the brightness of the gray card to the brightness of the white will be its diffuse reflecting power relative to the white one.

[8] Submitted by William T. Creasy, May 1, 1915.

2. For any sample the reflecting power for wave lengths less than $\frac{490}{1\,000\,000}$ mm is nearly constant.

3. For any sample the reflecting power for wave lengths greater than about $\frac{540}{1\,000\,000}$ mm or $\frac{560}{1\,000\,000}$ mm is nearly constant.

4. The ratio of the reflecting power for blue to the reflecting power for yellow varies widely for different samples.

This ratio is large for the pale samples and small for the more intensely colored ones. For a perfectly white sample it would equal exactly 1. As pointed out before, the "yellowness" of the butter and oleomargarine is due to their relatively low reflecting power for blue. The essence of our recommendation is that the desired color limitation be stated in terms of the ratio of the reflecting power for blue to the reflecting power for yellow. It is desirable, however, that the specification be worded somewhat more definitely than this by specifying the wave lengths of the light for which the reflecting powers are measured. As a matter of convenience we propose to use the blue light of wave length $\frac{436}{1\,000\,000}$mm and the yellow of wave length $\frac{578}{1\,000\,000}$mm, because light of these wave lengths can readily be obtained in sufficient purity from the mercury arc lamp by using selected color glasses [9] to absorb the other light emitted by the lamp. Definitely, then, the form recommended is: [10]

The diffuse reflecting power for light of wave length $\frac{436}{1\,000\,000}$ *mm shall not be less than — per cent of the diffuse reflecting power for light of wave length* $\frac{578}{1\,000\,000}$ *mm, the temperature of the sample being between 18° and 22° C.*

The following characteristics of this specification should be particularly noted:

1. Strictly speaking, it does not specify color, but merely specifies a property which, in practice, will not allow of saturated tints of yellow. Its sole purpose is to state a simple physical requirement, the fulfillment of which is practically incompatible with the substance appearing of a very saturated yellow tint. For example, oleomargarine or butter conforming to this specification might have any of a variety of colors, including green and violet.

2. The validity of this specification is conditioned upon the assumption that, for any sample in question, the relation between diffuse reflecting power and wave length will be approximately

[9] To be hereafter described under "General description of apparatus and fundamental principles of the method of test."

[10] Form essentially equivalent to this was first recommended in a letter to William T. Creasy, secretary National Dairy Union, May 27, 1915.

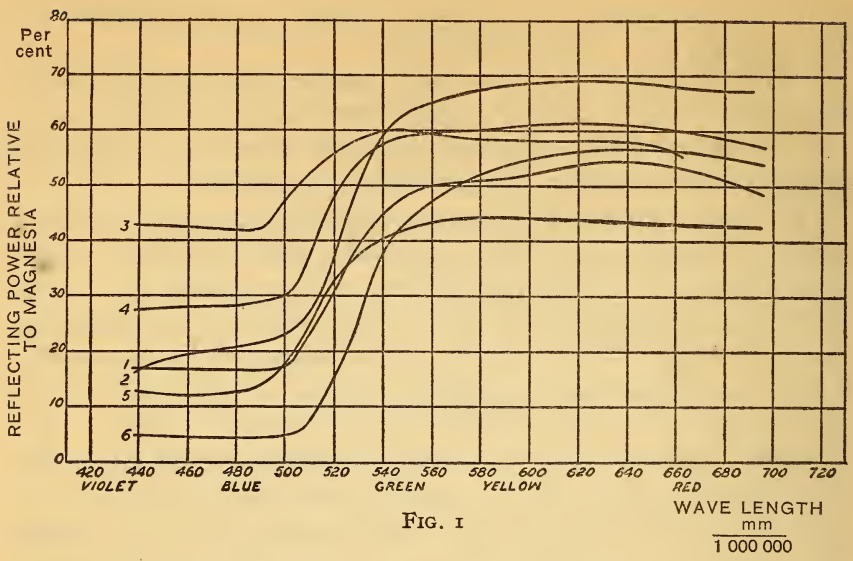


FIG. 1

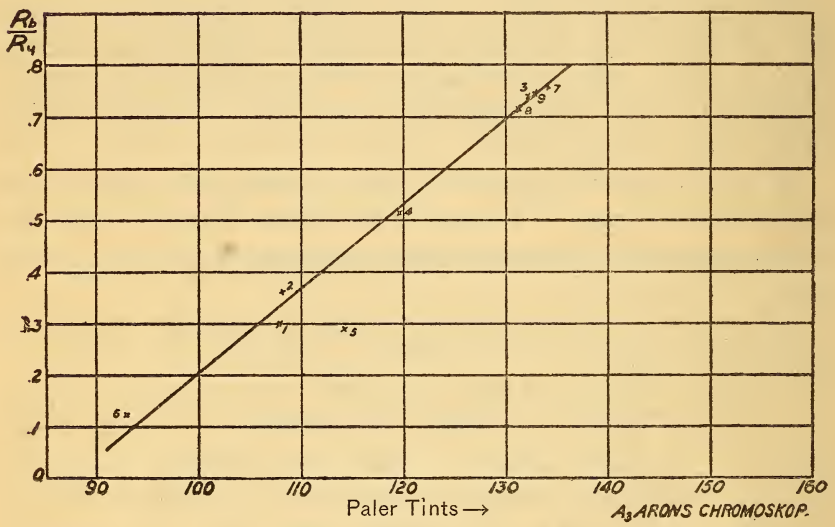


FIG. 2

The numbers attached to the curves in Fig. 1 and the points in Fig. 2 refer to the samples listed below, which were submitted by Wm. T. Creasy, Secretary National Dairy Union.

Submitted	Sample No.	Label on sample as submitted	Description as submitted
May 1, 1915	1	SMR 11520	Print butter.
	2	SMR 11521	Colored oleo.
	3	SMR 11522	Jelkey oleo.
	4	SMR 11523	White butter.
	5	SMR 11519	Oleo Duncan, 18 ¢.
	6	SMR 11524	Highly colored butter.
May 23, 1915	7		Capital City oleo.
	8		Daisy oleo.
	9		Good Luck oleo.

of the type shown in Fig. 1. It is of course possible to imagine a substance for which the relation between reflecting power and wave length is of such a type as to enable it to conform to this specification and still appear of a saturated tint of yellow. However, we do not believe it possible in practice to prepare edible fats having such properties.[11]

While no rigorously quantitative relation can be stated between "color" and the ratio of reflecting powers specified above, still we can illustrate this relation in a way sufficiently definite for all practical purposes. This is done in Fig. 2. Distance from left to right represents color readings on the Arons chromoscope,[12] the readings for the paler tints falling toward the right. Distance from the bottom up is proportional to the ratio of reflecting powers. The relation of "color" to this ratio is indicated for each sample by the position of the point plotted. This diagram illustrates clearly the fact that, in the case of these representative samples, paleness of tint is caused by a high value of the ratio of the reflecting power for blue to the reflecting power for yellow.

3. The measurements required to test in terms of this specification involve no question of the observer's color vision.

4. It is unambiguous. Its terms will afford little basis for expert disagreement as to its significance, interpretation, or meaning.

V. GENERAL DESCRIPTION OF APPARATUS AND FUNDAMENTAL PRINCIPLES OF THE METHOD OF TEST

From what has been previously said, it is evident that we need an apparatus by means of which we can measure the diffuse reflecting power for light of wave length $\frac{436}{1\,000\,000}$ mm in terms of its diffuse reflecting power for light of wave length $\frac{578}{1\,000\,000}$ mm. The apparatus used for this purpose at the Bureau of Standards [13] is shown diagrammatically in Fig. 3 and in perspective in Fig. 4. (Consult these figures before reading further.) Its utility for the present purpose is due to the following facts and principles:

1. The ratio of reflecting powers can be measured by means of the Martens photometer *M* (Fig. 3). A section of this instrument in the line of sight is shown in Fig. 5. For the complete descrip-

[11] The specification might be made more rigorous by adding to it the phrase "Provided also that the reflecting power for light of wave length $\frac{578}{1\,000\,000}$ mm shall not be less than that for light of wave length $\frac{546}{1\,000\,000}$ mm."

[12] For description of this instrument see Annalen der Physik, **39**, p. 545. It is not necessary that one be familiar with this instrument in order to understand the present discussion. It is only necessary to realize that increasing distance toward the right represents paler and paler tints of yellow.

[13] This particular apparatus is not essential to the test. The ratio of reflecting powers desired might be determined in many different ways. This apparatus is, however, quite suitable and convenient.

tion and theory of this instrument the original paper by Martens must be consulted.[14] For our present purpose, however, it is sufficient merely to observe the following facts:

(*a*) One sees on looking into the instrument in the direction *AB* (Fig. 3) a circular field, divided into two halves, one half of which is illuminated by light reflected by the sample *S* (Fig. 3), while the other half is illuminated by light reflected by the magnesia *W* (Fig. 3).

(*b*) By rotating the nicol prism *N* (Fig. 5) about the axis *AB* (Fig. 3), the brightness of one half of the field is made to increase while that of the other half simultaneously decreases. A position may be found for which the two halves are "matched" (i. e., are of equal brightness).

(*c*) If a_b is the angle read by pointer *J* on circular scale *K* (Fig. 5) for a matched field when the illumination is blue and a_y the corresponding angle when the illumination is yellow, then the ratio of the reflecting power for blue to the reflecting power for yellow may be computed from the observed values of these angles in degrees.

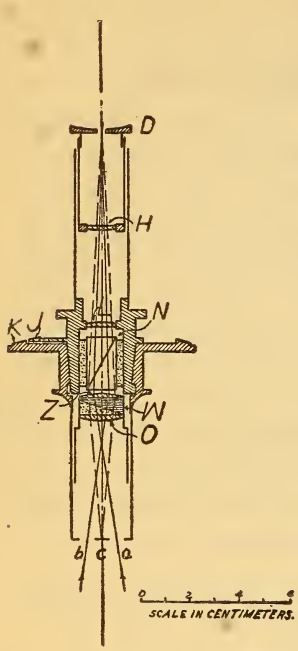


FIG. 5.—*Martens photometer*

2. Illumination by light of wave length $\frac{436}{1\,000\,000}$ mm (blue) may be obtained from the mercury lamp by placing between the photometer and the eye a blue glass screen which absorbs sufficiently all the other light from the lamp.[15]

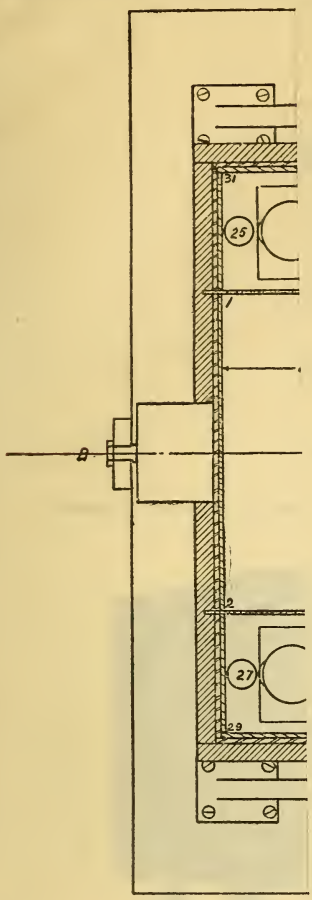
3. Illumination by light of wave length $\frac{578}{1\,000\,000}$ mm (yellow) may be obtained from the mercury lamp by placing between the photometer and the eye a glass absorbing the other light from the mercury lamp.[16]

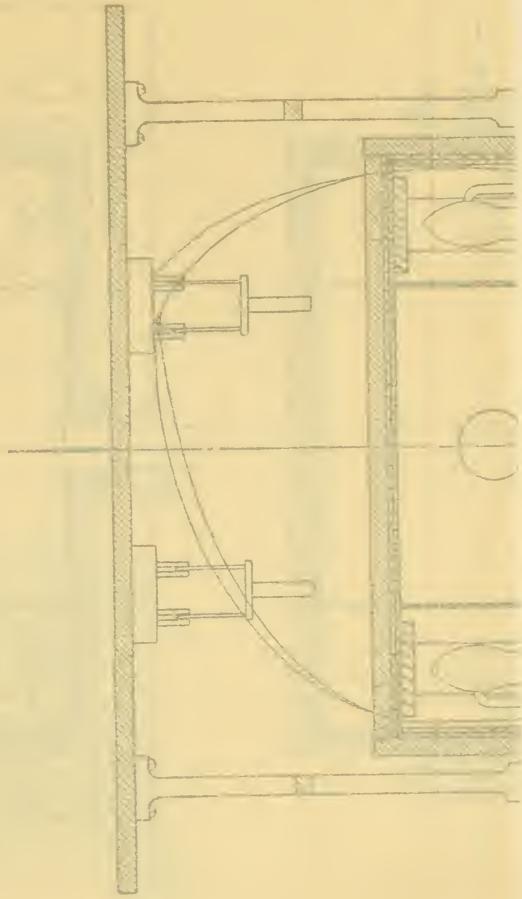
---

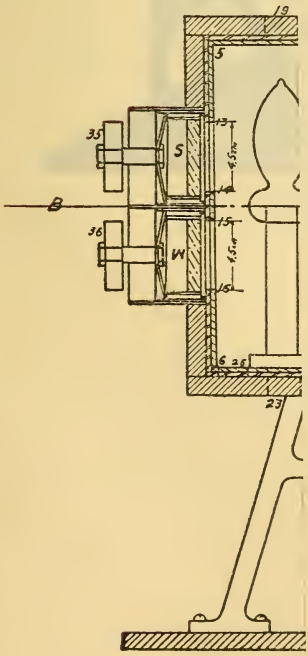
[14] Phys. Zeits., I, p. 299; 1900.

[15] When the samples under consideration are very pale, as in the present case, it is not necessary that this glass absorb the comparatively faint violet light from the mercury lamp. We have found a plate of Jena glass No. 3873, of thickness 1.88 mm, to be suitable for this purpose. The spectral transmission of the screen used is shown in Fig. 6.

[16] It is not necessary when dealing with samples like the above to absorb the slight amount of red emitted by the mercury lamp. We have used a plate of Corning glass G–36, of thickness 5.67 mm, the spectral transmission of which is shown in Fig. 6.







C and *D*, trunnion supports prov
S, sample; *W*, white standar
photometer; 35 and 36, remo

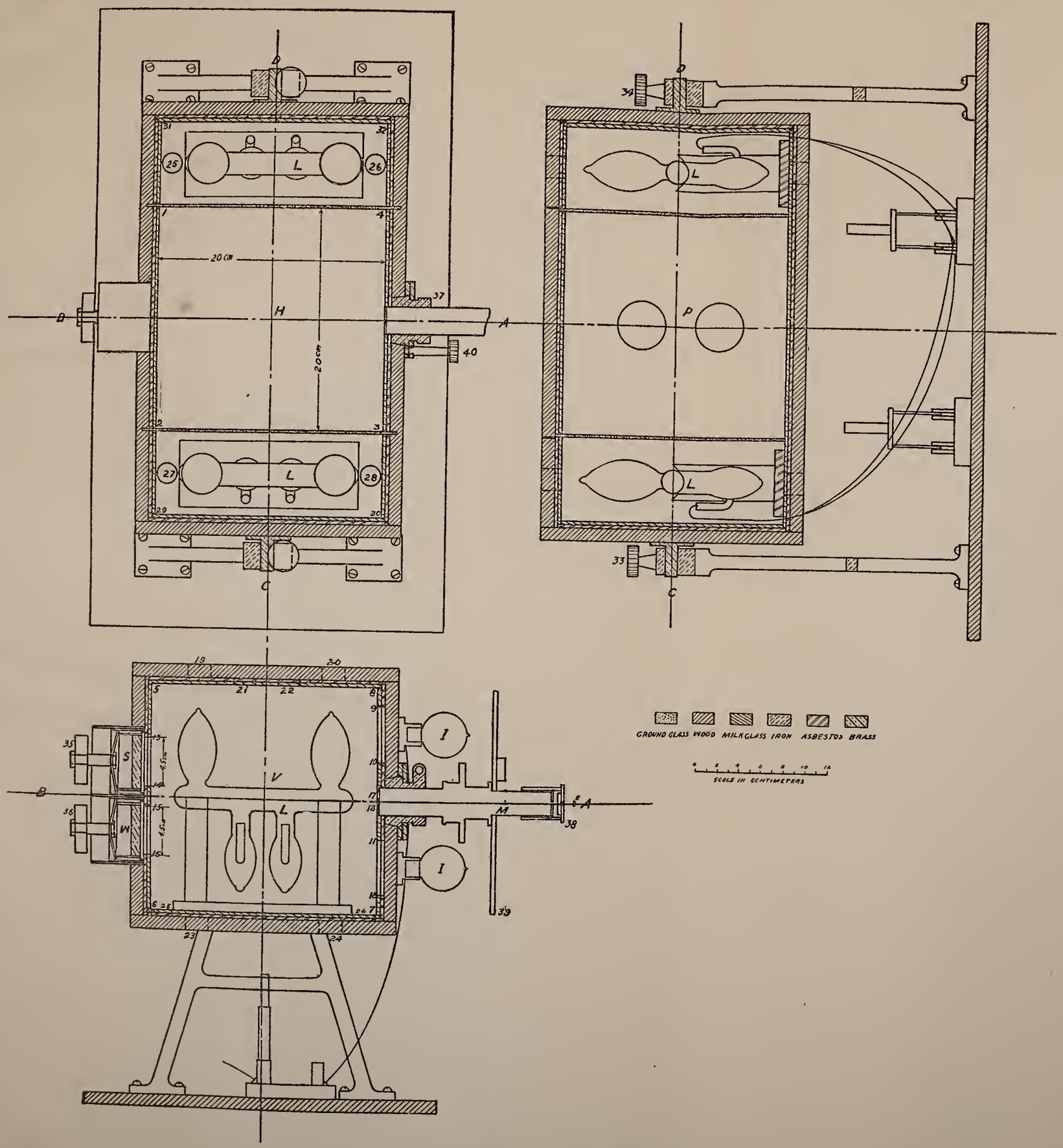


FIG. 3.—*Apparatus for measuring relative reflecting power*

C and *D*, trunnion supports providing for rotation about axis *C* and *D*; 29, 30, 32, and 31, white lined box; 1 to 4 and 2 to 3, diffusion screens; *L* and *L*, mercury lamps; *S*, sample; *W*, white standard (magnesia); 9 to 10 and 11 to 12, black spots to prevent regular reflection into the photometer; *M*, Matens photometer; 37, mount for the photometer; 35 and 36, removable cups; *I* and *I*, lamps to illuminate photometer scale; 38, color screen; *E*, observer's eye; 39, screen for shading eye and illuminating photometer scale, and carrying lens to read scale

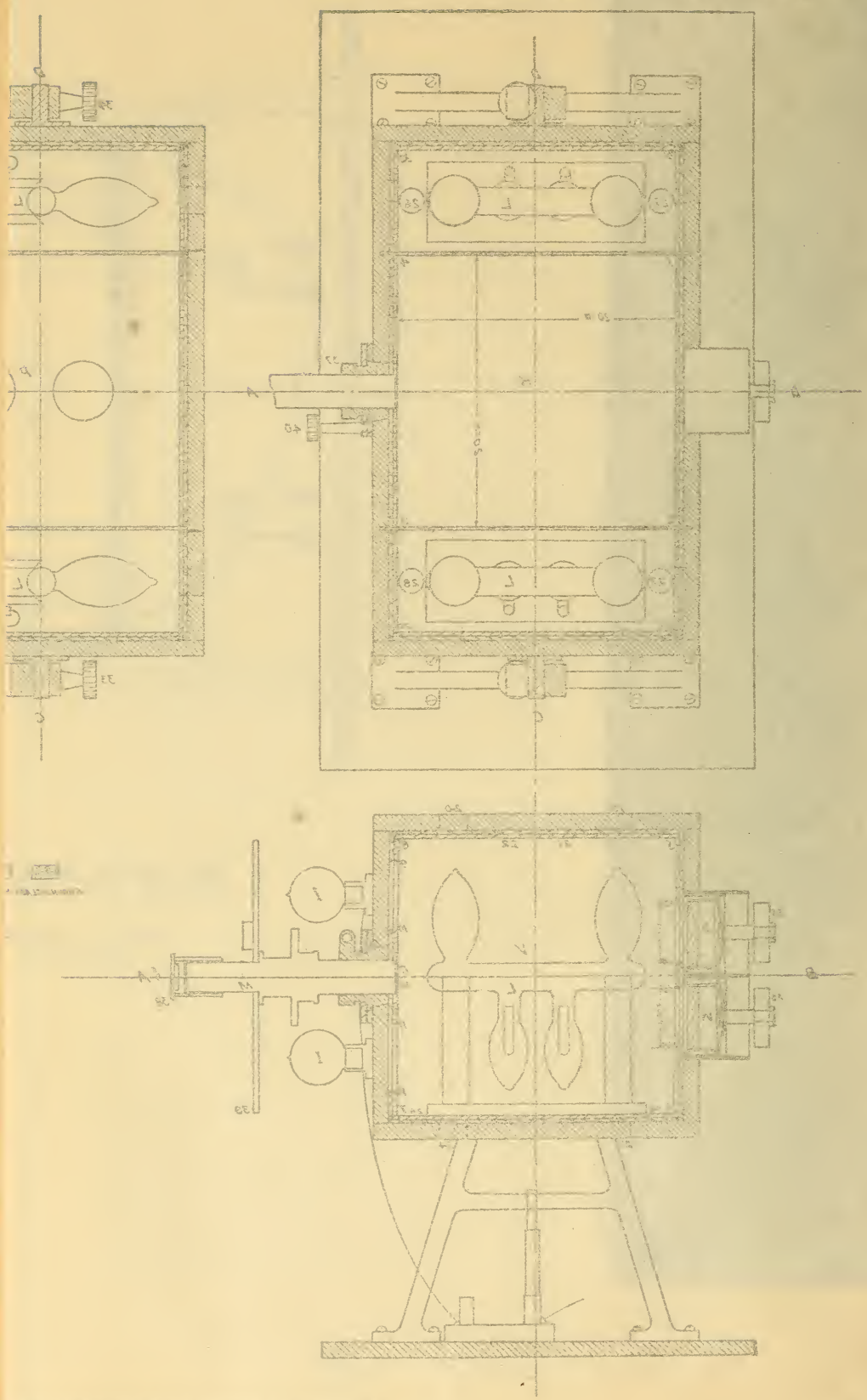


FIG. 3.—Apparatus for measuring relative reflecting [illegible]

C and D, trunnion supports providing for rotation about axis C and D; 25, 30, 34, and 41, white lined box; 1 to 4 [illegible] S, sample; W, white standard (magnesia); 9 to 10 and 11 to 12, black screw to prevent regular reflection into the photometer; 35 and 36, removable cups; I and I, lamps to illuminate photometer scale; 38, color screen; 39, [illegible]

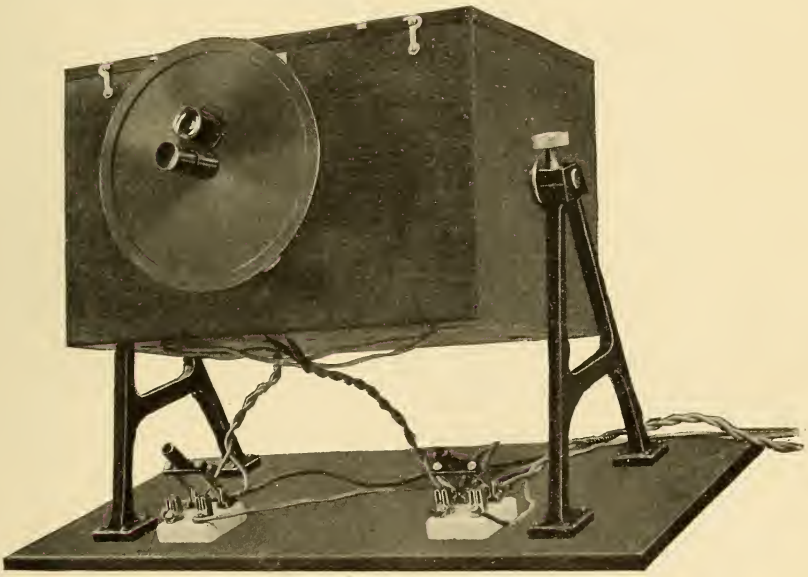


FIG. 4.—*Apparatus for measuring relative reflecting power*

VI. EXPLICIT DIRECTIONS FOR MAKING TEST

1. PREPARATION OF SAMPLE

Pack the sample firmly in the container shown in Fig. 7 to a depth of at least 20 mm,[17] so that the surface against the glass is smooth and uniform.[18] If it is desired to preserve the sample for some time, the cell may be sealed, but otherwise this is unnecessary.

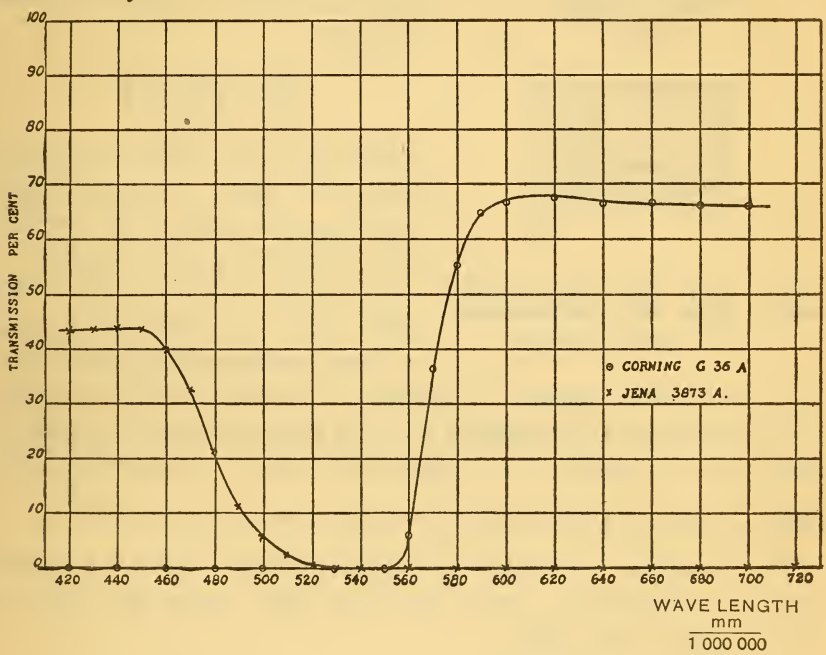


FIG. 6.—*Spectral transmission of color screens used in making the tests*

2. APPARATUS ADJUSTMENTS

Place the photometer so that the part of the field illuminated by the white surface *W* becomes dark when the index on the photometer head points to zero. Clamp the photometer in this position. Place the sample at *S*. Start the mercury lamps by tipping the box on its axis *CD*.

3. OBSERVATIONS

With the blue glass over the ocular, turn the photometer head until the two halves of the field are of equal brightness. (The

[17] The thickness of the sample must, of course, be so great that an increase in thickness will make no difference in the result.

[18] It is convenient but not necessary to have the sample under a glass cover. Experiment has shown that the same value will be obtained with covered and uncovered samples. The glass cover itself must, of course, be colorless.

division line should disappear.) Read the angle a_b indicated by the index on the photometer head.[19] Place the yellow glass over the ocular and similarly obtain the angle a_y.

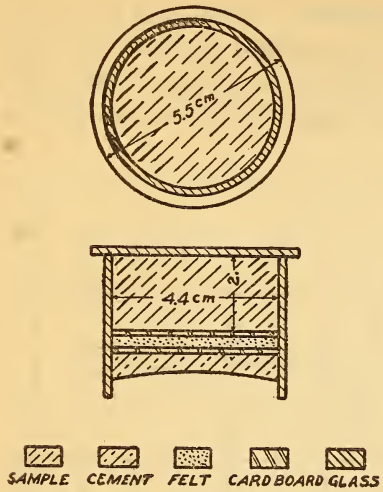


FIG. 7.—*Cell for sample*

4. COMPUTATION

The desired ratio of diffuse reflecting powers is given by the formula:

$$\frac{R_b}{R_y}=\left(\frac{\tan a_b}{\tan a_y}\right)^2,$$

where R_b is the diffuse reflecting power for light of wave length $\frac{436}{1\,000\,000}$ mm and R_y is the diffuse reflecting power for light of wave length $\frac{578}{1\,000\,000}$ mm. This ratio may be computed by use of the accompanying table giving values of the squares of tangents, or more readily by means of a special slide rule designed for such computations.[20] Approximate values (usually as accurate as will be required) of the ratio $\frac{R_b}{R_y}$ may be read directly from the chart shown in Fig. 8.

The preceding method was first formulated and tried at this Bureau in December, 1913, and has been tested and used at various times since then.

WASHINGTON, July, 1916.

---

[19] It is possible to make the two halves of the field equally bright at four different settings of the photometer head. For convenience, use the setting which falls between 0° and 90°.

[20] Made by Keuffel and Esser after design by Bureau of Standards.