# A MEASURE OF THE COLOR CHARACTERISTICS OF WHITE PAPERS.

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ABSTRACT

Since the color differences between white papers are usually relatively small, it is obvious that a method capable of giving a measure of these differences must be quite sensitive to very small color increments, and that a method which makes use of the principle of multiple reflections will be much more sensitive to small color differences than any method which makes use of a single reflection. The principle of multiple reflections is employed in the Pfund colorimeter, which colorimeter was used to measure the color characteristics of 21 commercial papers.

The color characteristics of each paper were determined by finding the coefficients of diffuse reflection for red (wave length 625 m$\mu$), green (wave length 550 m$\mu$), and blue (wave length 460 m$\mu$) light. It was found that none of the papers tested was truly white, but that each was more or less deficient in blue and less so in green.

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## I. INTRODUCTION.

It is common experience that there is a wide variation in the color of so-called white papers. Any material is commonly said to be white when it reflects all colors of the spectrum highly and with little selectivity.[1] There are yellow-white and green-white (less common) papers, produced usually by insufficient cooking or insufficient bleaching, or both, or by improper handling of the pulp during the bleaching process. These tones are most common with chemical wood papers. There are also red-white and blue-white papers, generally produced by the addition of red or blue dyes to the furnish in the beater or stuff chests to overcome the natural yellowish or greenish tones of the pulp. Not all red tones

[1] For a thorough discussion of light and color see the report of the colorimetry committee (Leonard T. Troland, chairman) of the Optical Society of America; Jour. Opt. Soc. of Am. and Review of Scientific Instruments, 6, p. 527; 1922.

in white papers are due to the addition of dye, however, as pulp from certain trees has a natural and decidedly reddish color.

White papers vary not only in having slight color differences, but they vary considerably in the proportion of incident light diffusely reflected.[2] Pulps and papers which reflect the greater proportion of incident light are said to be more brilliant, while those which reflect the least light and have the appearance of containing invisible dirt are called "dirty white" or gray.

Because of the variation of the human eye in the perception of light and color, and of the confusion of language in describing the colors perceived, and because of other personal factors which can not be avoided in grading materials for color it is desirable to carry out all color grading and measurements in some system which eliminates, as far as possible, personal factors and which gives a numerical value to any variations from a chosen standard. For these reasons various representatives of the paper industry have expressed a desire at different times during the past two years that the study of the color of white papers be undertaken by this bureau and at the same time have offered their cooperation in every way possible.

## II. METHODS AND RESULTS.

In initiating this investigation the apparatus used consisted of an integrating sphere and a spectrophotometer. Illumination of the sample was effected by means of four incandescent lamps arranged symmetrically around the center of the sphere, which was enameled white inside and coated with magnesium oxide. The paper being investigated and a standard white surface consisting of a block of magnesium carbonate were held on the bottom of the sphere. No direct rays of light could reach the paper sample or the magnesium carbonate surface. Diffused light from the two surfaces was reflected by a prism, placed on the outer top surface of the sphere into the spectrophotometer. The upper half of the field of view at the ocular slit of the spectrophotometer was lighted by reflection through the prism from the standard surface, while the lower half was lighted by reflection from the sample being tested. By rotating a screw to which was fastened a drum bearing a wave-length scale the constant deviation prism of the spectrophotometer was so adjusted that any wave length of the visible spectrum

[2] In all cases in this investigation where reflection of light is mentioned, diffuse reflection is to be understood.

could be brought into the field of view. By means of a variable sector the ratio of the quantity of light of a given wave length reflected by the sample of paper to that reflected by the magnesium carbonate surface was determined directly. A graph of the results was then plotted, using wave lengths as abscissas and ratios as ordinates, which should have given a curve characteristic of the color of the sample of paper tested.

While this instrument was satisfactory, however, for most colored materials, it was not found very satisfactory for determinations of the color characteristics of whites or near whites, because the photometric error in setting the sector, by which the ratio of light reflected by the two surfaces is determined, was often greater than the actual color differences between the two surfaces; that is, the departure from white of most "white" papers is so small that this departure can not be readilv measured by means of an instrument of this type.

After experimenting a short time with this type of colorimeter the writer's attention was called to an instrument of quite different type, designed and built by A. H. Pfund, of Johns Hopkins University, for the study of white pigments. An instrument of this type is being used by the paint section of the chemical division of the Bureau of Standards for the determination of the color characteristics of white pigments. It was found upon examination that this colorimeter could be readily adapted to the study of the color characteristics of white papers.

(1) The Pfund Method.—The unique feature of this colorimeter is that by its use the color characteristics of a material are not determined from a single reflection from the material but from several reflections. The advantage of multiple reflections over a single reflection in problems of this nature is stated by Pfund, as follows: [3]

> If white light be allowed to fall on a surface that is slightly greenish, it is obvious that the diffusely reflected light will contain an excess of green. If, now, this light be allowed to fall on a second surface, identical with the first, the light reflected will be relatively still richer in green. By allowing, similarly, a third and fourth reflection to take place it is possible to accentuate the green tint very pronouncedly. If a surface be truly white—that is, nonselective—multiple reflections wi l affect only the intensity of the light, not its spectral distribution.

The construction of the colorimeter is shown in Figure 1. *L* is a 100-watt incandescent lamp. *A* and *B* are circular disks,

[3] "A new colorimeter for white pigments and some results obtained by its use," A. H. Pfund; Proc. Am. Soc. Test. Materials 20, (1920), Pt. II, p. 441. (See this article for a complete description of Pfund's colorimeter.)

approximately $3\frac{13}{16}$ and $2\frac{1}{4}$ inches in diameter, respectively, of the paper being investigated. The disk *B* has a circular opening ½ inch in diameter cut in the center, so that the rays of light reflected from *A* can enter the optical cube *P*, by which they are reflected horizontally into the eyepiece *E*. At the same time a beam of light *R* from the source *L* is reflected by the glass disk *G* (roughly ground on both sides) along the tube *T*, through the optical cube *P* and into the eyepiece *E*. The field of view through *E* is divided horizontally, and its lower half is lighted by diffuse reflection from the samples *A* and *B*. Connected with the horizontal axis of the mirror *G* are a lever arm and pointer (not shown in illustration). By means of the lever arm the ground-glass mirror *G* can be rotated about its horizontal axis so as to

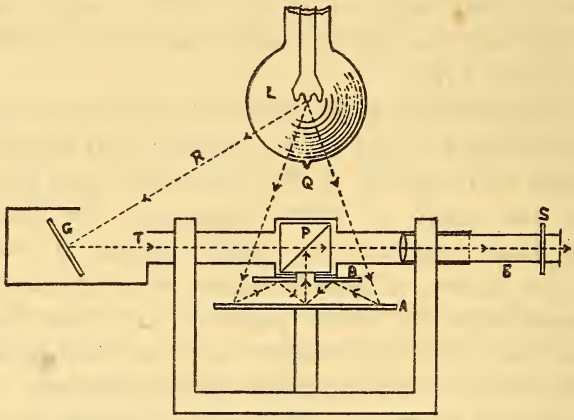


FIG. 1.—*Diagrammatic sketch of Pfund's colorimeter.*

direct any proportion of its total reflection along the tube *T* and into the eyepiece *E*. The pointer moves along an arbitrary scale which has been graduated in terms of light intensities.

The examination of the paper for its color properties is made by matching the two half fields as they appear when viewed through each of three colored glasses when placed at the point *S* in the eyepiece tube. Pfund's reasons for using colored glasses rather than some other means of controlling the wave lengths of light for which the two half fields are matched are as follows: [4]

While this colorimeter lends itself admirably to the methods of monochromatic colorimetry, this method has not been used because it demands a standard source of white light and a highly trained observer. At the present time no such standard source of light has been agreed upon. It therefore seemed advisable to determine the color characteristics simply in terms of the brightness for blue, green, and red

[4] See footnote 3, p. 669.

light. Accordingly, color screens of dominant hue, 460 $\mu\mu$ (blue), 550 $\mu\mu$ (green), and 625 $\mu\mu$ (red), were successively placed in the eyepiece tube of *S* and photometric balances were established. The readings thus obtained led eventually to a numerical value of the brightness for the above colors of known wave length. These numbers established the color characteristics of the paper uniquely and standard samples may therefore be discarded.

(2) Test Procedure.—For the purpose of carrying out this investigation 21 samples, including newsprint, machine-finished printing, book, bond, and ledger paper, were obtained from various sources. Each of these samples is designated in Figures 2 to 6 by a number and the class of paper to which it belongs.

Certain precautions must be observed in preparing any samples for tests of this nature. The test samples were taken from areas of the sheet free from folds, wrinkles, or surface dirt. Care was taken to place the samples in position in the instrument in two parallel planes, but on account of the nature of paper this was sometimes impossible and was probably the cause of considerable variation at times in the results for the two sides (felt and wire) of the same paper. It was also found very necessary, as might have been expected, to place a sufficient number of test sheets of each sample in the holders to prevent any light from the source from passing through the samples and being reflected back by the holders, since such a circumstance causes the sample to show to disadvantage by giving too low coefficients of reflection.[5]

After a little experience one can readily make settings on the scale through the red and green filters with a difference between the maximum and minimum of 5 settings of not more than 2 or 3 divisions on the scale, so that the average of the 5 observations is correct to about ½ scale division in extreme cases, which when converted to coefficient of diffuse reflection is correct to less than ¼ unit. The settings through the blue filter, however, can usually not be made so accurately, and the difference between the maximum and minimum of 5 settings may sometimes be as much as 5 scale divisions.

(3) Results of Tests.—A graph is furnished with this colorimeter which may be used to convert the scale readings as found to coefficients of diffuse reflection. In Figures 2 to 6 the coefficients of diffuse reflection form the vertical axes, while the colors or wave lengths of light for which the papers were tested form the horizontal axes. For laboratory use, however, the scale settings might be used to form the vertical axes instead of the coefficients

[5] By "coefficient of diffuse reflection" Pfund means "relative brightness." (See footnote 3, p. 669.)

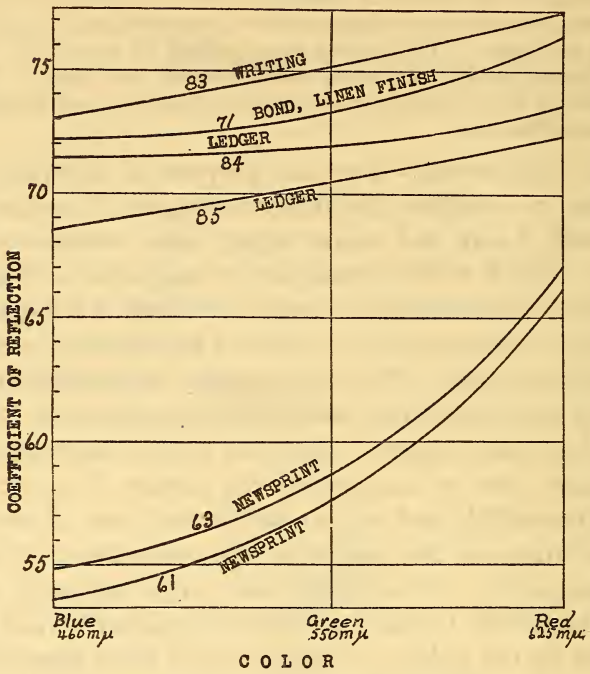


FIG. 2.—*Color curves of various papers.*

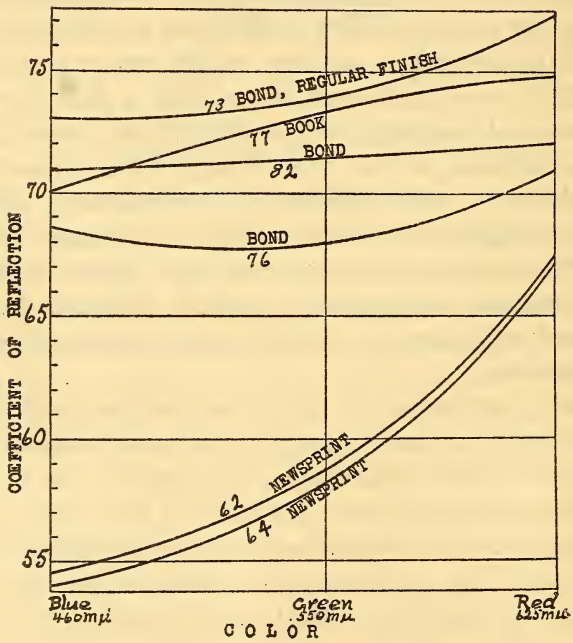


FIG. 3.—*Color curves of various papers.*

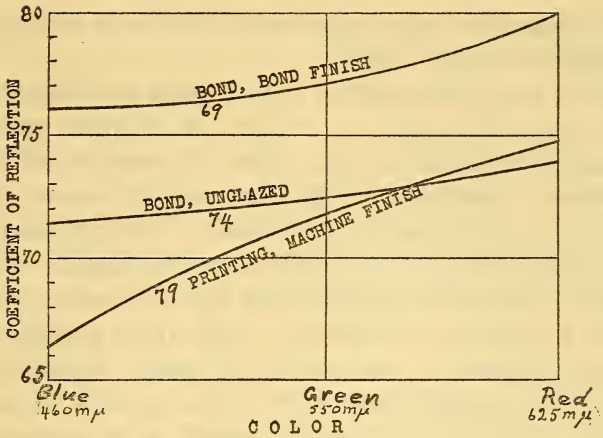


FIG. 4.—*Color curves of various papers.*

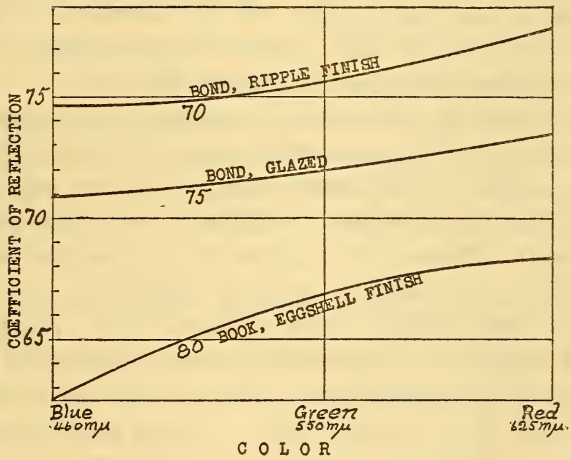


FIG. 5.—*Color curves of various papers.*

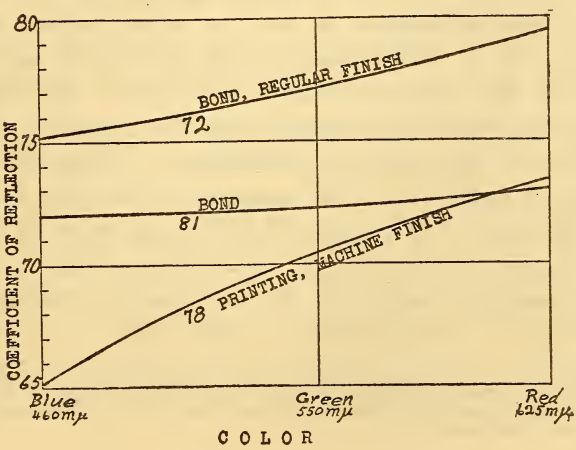


FIG. 6.—*Color curves of various papers.*

of diffuse reflection, since they are of the same order and do not differ greatly from the latter.

Figures 2 to 6 show that of the 21 papers examined all reflect less blue light than green or red light, or, in other words, that all the papers are deficient in blue color. To correct such deficiency it is common manufacturing practice to add a small quantity of a blue dye to the furnish in the beater. The papers represented by the graphs lying at all points near the parallels to the horizontal axes, such as 82 (fig. 3) and 81 (fig. 6), most nearly approach the ideal of nonselective reflection, while those papers represented by graphs, such as 62 and 64 (fig. 3), which lie considerably off the horizontal position are poor in the quality of nonselective reflection. The paper in this series which most nearly approaches the ideal of nonselective reflection is No. 81 (fig. 6), which from blue to red is less than 1 point off the horizontal position, while the poorest papers in this respect show a difference of about 13 points between the blue and red coefficients.

Another detail to be noted in examining the graphs, such as 62 and 76 (fig. 3), is that some lie relatively higher on the vertical scale than others. This would seem to indicate that the samples vary considerably in relative brightness or in the proportion of incident light reflected, the graphs highest on the vertical scale representing papers which are most brilliant. No. 69 (fig. 4) would thus seem to be the most brilliant of the 21 papers.

Pfund's method for determining relative brightness is to divide the product of the coefficients of reflection for the red and blue by the coefficient for the green light. In this connection, however, the relation of finish of the paper to brightness as determined by the Pfund colorimeter must be taken into consideration.

The relative brightness of two or more papers differing in finish can not be determined, it seems, by an instrument of this type if the degree of finish is properly indicated by the amount of light specularly reflected by the sample, as claimed by the inventor of the Ingersoll glarimeter.[6] While the number of reflections of light from the sample in the Pfund colorimeter must be at least 3, the number of reflections must be some whole number plus a fraction, as, for example, 3.6, since only diffuse reflection from the paper can be employed in making color determinations. It seems obvious, then, that a sample of paper

[6] For a description of the Ingersoll glarimeter and the physical principles upon which it is constructed, see "The glarimeter: An instrument for measuring the gloss of paper," by L. R. Ingersoll, Jour. Opt. Soc. of Am., May, 1921, 5, No. 3, pp. 213–217.

whose diffuse and specular reflecting powers are in the ratio of 1 to 1 will not appear as bright under the Pfund colorimeter as a sample of the same color whose diffuse and specular reflecting powers are in the ratio of 2 to 1.

While a limited amount of thought and experimentation have been given to the relation existing between relative brightness as determined by the Pfund colorimeter and finish as determined by the Ingersoll glarimeter, this problem will require more time than can be given to it in this paper and must be deferred to some future time.

It was thought advisable during this investigation to have several persons at this bureau who have had experience in color matching to grade the 21 samples for color, the best white, in the estimation of each person, being placed at the head of the list, the second best white next, etc., through the 21 samples. The samples were graded for color by 17 individuals, with the results as shown in Table 1. A glance at this table will convince one that there is need for some method of grading which will eliminate, in large measure at least, the personal factor in such work. Two columns of this table have the samples graded as to nonselective reflection and as to relative brightness as determined by the Pfund colorimeter.

**TABLE 1.—Papers Arranged as Graded by Unaided Eye Observation.**

| | Order in which the 21 samples were graded by the 17 individuals. | | | | | | | | | | | | | | | | | Nonselective reflection. | Brightness. | Finish (per cent gloss). |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | | | |
| | SAMPLE NUMBERS. | | | | | | | | | | | | | | | | | | | |
| 1 | 81 | 81 | 81 | 81 | 75 | 84 | 76 | 75 | 72 | 72 | 70 | 71 | 70 | 70 | 70 | 70 | 74 | 81 | 69 | 70 |
| 2 | 82 | 82 | 82 | 82 | 74 | 81 | 75 | 82 | 69 | 73 | 69 | 70 | 83 | 69 | 75 | 71 | 72 | 82 | 72 | 71 |
| 3 | 76 | 84 | 76 | 75 | 81 | 75 | 74 | 81 | 83 | 69 | 73 | 69 | 84 | 72 | 71 | 75 | 69 | 75 | 70 | 62 |
| 4 | 75 | 76 | 75 | 76 | 82 | 82 | 72 | 74 | 73 | 83 | 74 | 81 | 74 | 71 | 74 | 73 | 81 | 84 | 73 | 78 |
| 5 | 84 | 74 | 84 | 74 | 76 | 74 | 73 | 76 | 71 | 75 | 72 | 73 | 71 | 73 | 72 | 72 | 70 | 74 | 83 | 75 |
| 6 | 70 | 75 | 73 | 70 | 72 | 83 | 70 | 72 | 74 | 71 | 83 | 72 | 75 | 74 | 69 | 69 | 82 | 76 | 71 | 61 |
| 7 | 73 | 70 | 70 | 84 | 70 | 72 | 81 | 73 | 70 | 70 | 71 | 75 | 85 | 75 | 73 | 85 | 75 | 69 | 84 | 79 |
| 8 | 72 | 72 | 72 | 78 | 69 | 76 | 84 | 69 | 75 | 74 | 84 | 82 | 72 | 81 | 81 | 74 | 71 | 70 | 74 | 77 |
| 9 | 74 | 85 | 74 | 71 | 73 | 73 | 69 | 70 | 84 | 85 | 75 | 84 | 73 | 84 | 84 | 81 | 73 | 85 | 81 | 85 |
| 10 | 69 | 83 | 83 | 69 | 71 | 71 | 71 | 84 | 85 | 84 | 76 | 74 | 69 | 83 | 82 | 82 | 76 | 71 | 75 | 63 |
| 11 | 83 | 71 | 85 | 72 | 83 | 70 | 82 | 71 | 82 | 81 | 85 | 83 | 81 | 82 | 76 | 83 | 83 | 72 | 76 | 76 |
| 12 | 85 | 69 | 69 | 85 | 84 | 69 | 83 | 83 | 81 | 82 | 82 | 85 | 76 | 77 | 83 | 84 | 84 | 73 | 77 | 64 |
| 13 | 71 | 73 | 71 | 83 | 85 | 85 | 85 | 85 | 76 | 76 | 81 | 76 | 82 | 85 | 77 | 77 | 85 | 83 | 82 | 84 |
| 14 | 77 | 80 | 77 | 73 | 77 | 77 | 77 | 77 | 79 | 78 | 80 | 77 | 77 | 76 | 85 | 76 | 77 | 77 | 85 | 82 |
| 15 | 78 | 77 | 78 | 79 | 78 | 80 | 78 | 79 | 78 | 79 | 77 | 78 | 78 | 79 | 78 | 79 | 78 | 80 | 79 | 69 |
| 16 | 79 | 78 | 79 | 77 | 79 | 78 | 79 | 78 | 77 | 77 | 78 | 79 | 79 | 78 | 79 | 78 | 79 | 78 | 78 | 81 |
| 17 | 80 | 79 | 80 | 80 | 80 | 79 | 80 | 80 | 80 | 80 | 79 | 80 | 80 | 80 | 80 | 80 | 80 | 79 | 80 | 74 |
| 18 | 63 | 63 | 64 | 63 | 64 | 61 | 61 | 61 | 62 | 63 | 61 | 63 | 61 | 61 | 61 | 64 | 61 | 63 | 62 | 73 |
| 19 | 61 | 64 | 62 | 62 | 63 | 63 | 63 | 63 | 61 | 62 | 63 | 61 | 62 | 64 | 64 | 63 | 64 | 61 | 63 | 72 |
| 20 | 64 | 61 | 61 | 61 | 61 | 64 | 64 | 64 | 64 | 61 | 62 | 62 | 64 | 63 | 63 | 61 | 63 | 64 | 64 | 83 |
| 21 | 62 | 62 | 63 | 64 | 62 | 62 | 62 | 62 | 63 | 64 | 64 | 64 | 63 | 62 | 62 | 62 | 62 | 62 | 61 | 80 |

In grading papers for whiteness by unaided eye observation the individual necessarily combines the relative brightness with the selectivity. In grading by means of the Pfund colorimeter, however, these two factors must be determined separately. It seems probable that these two factors as determined by the Pfund colorimeter and specular reflection or finish of the paper as determined by some reliable method could be combined in such manner as to approximate the unaided eye grading; but until the relation between relative brightness as determined by the Pfund colorimeter and finish is determined it is useless to attempt to determine the relation between grading by the Pfund colorimeter and grading by the unaided eye.

## III. CONCLUSION.

It may be stated in conclusion that practically all, and perhaps absolutely all, commercial white papers are not really white, in that they do not reflect all the components of white light in the same ratio, reflecting less blue light than green and red light.

The Pfund colorimeter offers a simple, rapid, and relatively accurate method for determining the color characteristics of white papers, and much closer grading of white papers for color may be done with it than with the unaided eye.

WASHINGTON, August 28, 1923.