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105 YORK ST., BROOKLYN, N. Y.

D. B. JUDD, VICE-CHAIRMAN
NATIONAL BUREAU OF STANDARDS
WASHINGTON, D. C.

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INTER-SOCIETY COLOR COUNCIL

R. G. MACDONALD, SECRETARY
122 EAST 42ND ST., NEW YORK, N. Y.

NEWS LETTER No. 15

October 1936

Note: The News Letter is issued from time to time by the Inter-Society Color Council to all members for the purpose of bringing to their attention the current activities of the Council and to serve in a clearing house capacity in keeping members informed concerning recent publications on color in the arts, sciences, industries and education.

The material for the News Letter is obtained from several sources, particularly from the representatives of member-bodies. It is hoped that each member-body representative will keep the News Letter in mind and furnish material that may be of interest. The basic color problems of all groups are alike and one industry can learn much from the others.

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All members are urged to send items of interest (similar to those in this News Letter) to R. G. Macdonald, Secretary of the Inter-Society Color Council, 122 East 42nd Street, New York, N. Y.

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COUNCIL ACTIVITIES

"WHO'S WHO IN COLOR"

The new Color Council Committee on "Who's Who in Color" has been organized with the following personnel: Dorothy Nickerson, Chairman, Walter M. Scott, Sidney M. Newhall, M. Rea Paul, Norman MacBeth, Deane B. Judd, John L. Parsons, Margaret H. Rorke, H. V. Arny, Elizabeth Burris-Meyer, Walter C. Granville, and R. C. Stillman.

Work has been started by the Committee on the preparation of a questionnaire to be sent to a number of sources of information with the intent of finding out who is actively interested in the study of color either from the technical, industrial, art educational or scientific standpoints. The first list can not be expected to cover the entire field of workers but will probably include those who are most prominent.

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NEW MEMBER OF COLOR COUNCIL

The Executive Committee of the Color Council has announced the election of George Welp, International Printing Ink Corporation, 75 Varick Street, New York. Mr. Welp was one of the lecturers at the February, 1936 meeting of the Inter-Society Color Council.

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NORMAN MACBETH DEAD

The Council has lost an enthusiastic and capable member through the death of Norman Macbeth, delegate of the Illuminating Engineering Society and President of the Macbeth Daylighting Company, New York, N.Y.

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CHICAGO COLORISTS MEET

Forty people were present at an informal meeting held in the Color Room of the International Printing Ink Corporation, on Thursday, July 16, 1936, at 7:25 P.M., at which Walter C. Granville presided. This meeting was held with the thought of organizing a permanent group for the purpose of disseminating and acquiring information on color and color problems.

Mr. Granville, after giving a short introductory talk, presented Mr. M. Rea Paul, Chairman of the Inter-Society Color Council. Mr. Paul spoke about the Inter-Society Color Council and its affiliate "The Colorists", telling in detail, about their membership, organization, purposes, and procedure of carrying on the meetings.

Mr. Granville read a letter received from Mr. Wm. A. Kittredge, of R. R. Donnelley & Company, concerning the use of color in plants and factories. This letter served to introduce the subject of the next speaker, who was E. D. Jacobson, Art Director of the Container Corporation of America. Mr. Jacobson spoke about a project recently completed in one of the paper mills of Container Corporation. Both interiors and equipment were painted in various colors, and Mr. Jacobson told of how he arrived at the color scheme and the many difficulties of putting it into effect. This was most interesting to the group, in that the use of color in this field is comparatively new.

Mr. Granville again took the floor and asked for volunteers to tell of their various experiences and interest in color. P. K. Baird, of the U. S. Forest Prod. Laboratory of Madison, Wisconsin, was then called upon.

Mr. Baird told of the experimental work they were doing in the utilization of various woods that could be made into satisfactory pulp for the manufacture of paper. Mr. Baird also mentioned his desire of obtaining an instrument that would satisfactorily measure the color of paper. An open discussion was held at the conclusion of Mr. Baird's talk, and several suggestions and thoughts were brought out.

DeForest Sackett, Art Director of Walgreen Company, told of the method he used to make up color swatches, using printing ink. Mr. Sackett had experienced considerable difficulty in having his airbrush color swatches matched by the printer, due to the difference in surface characteristics between the artist's swatch and the printed job. By matching the airbrush swatch with printing ink, he was able to get more satisfactory results, as the color tolerances were quite a bit smaller.

Following there was a general discussion of Mr. Sackett's problem.

J. A. Harrington, lighting engineer of the Commonwealth Edison Company, volunteered to tell of the various problems he encountered from his viewpoint.

Glenn Price, of the U. S. Gypsum Company, brought up the point of patenting the use of a particular color. Considerable discussion was held on this problem by various people at the meeting, and it is believed that a partial answer was given Mr. Price.

Walter Granville again took over the meeting, and discussed the continuance of this organization. Everybody was very much in favor of continuing. Mr. Granville then proposed to nominate Egbert G. Jacobson as temporary chairman of the meeting, until such time as the group wished to have a formal election. Also, Mr. Granville expressed his willingness to act as temporary secretary. Both of these proposals were approved by the people present. Mr. Paul suggested that the temporary chairman take the chair and vote to see how many would like to see this organization continue, and assured the group that in the event that they do desire to continue and form themselves into a group similar to "The Colorists" in Washington, the

Inter-Society Color Council will be very glad, indeed, to assist in every possible way, in order to promote such a group for the dissemination and acquisition of all information on the use of color. Mr. Granville, with the approval of Mr. Paul, suggested reading the various bulletins of the Inter-Society Color Council at the future meetings.

Mr. Jacobson, having taken the chair, asked every one present to introduce themselves, giving his or her name and the company. At the conclusion of this procedure, Mr. Jacobson asked for opinions as to the procedure of the future meetings.

Mr. Price made a motion that the first formal meeting be held in the middle of September. This was seconded and carried.

Mr. Harrington made a motion that a committee be appointed to organize the work of the group, so that by the time the first meeting is held, a definite program will be arranged. This was seconded and carried, and will be carried out by the chairman and secretary in the near future.

Mr. Jacobson commented about the fine work the International Printing Ink Corporation is doing in the line of Color Research, and made a motion that a vote of thanks be given Mr. Granville for his efforts in organizing this group.

A motion was then made by the chairman that the meeting be adjourned. This was seconded, and the chairman adjourned the meeting at 9:45 P.M.

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AMERICAN PSYCHOLOGICAL ASSOCIATION, INC. APPROVES OF COUNCIL

Following is a letter from Donald G. Paterson, Secretary of the A.P.A. Inc. to the Secretary of the Council. It is followed by the report of the official delegates to the Council and sums up in an excellent manner the activities of the Color Council.

September 12, 1936.

"Dear Mr. MacDonald:

This is to inform you that the American Psychological Association at its Hanover Meeting on September 3, 1936 voted to accept the report of its delegates to the Inter-Society Color Council, to order the report printed in the Proceedings, and to continue its affiliation with the Inter-Society Color Council for 1936-37.

The Association also voted to re-appoint our voting delegates and additional delegates to the Inter-Society Color Council for 1936-37.

For your information we are enclosing a copy of the report of our delegates. Permit me to state that the Council of Directors of the American Psychological Association are pleased with the progress being made by your organization and with the contributions apparently being made by our representatives to your Council. We trust that our affiliation will continue to be mutually advantageous."

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REPORT OF THE DELEGATES OF THE AMERICAN PSYCHOLOGICAL ASSOCIATION TO THE INTER-SOCIETY COLOR COUNCIL FOR 1935-1936

1. Activities of the Inter-Society Color Council.

Under its new articles of organization and by-laws, the I.S.C.C. has continued its activities with increasing vigor. A considerable number of commercial organizations who are not eligible to active membership have taken advantage of the opportunity to affiliate through individual associate memberships. This already is increasing the scope of the Council's activities by bringing to it new problems and wider recognition of its activities and influence.

The problem in regard to the accurate designation of colors which was presented by the U. S. Pharmacopea has been handled to the satisfaction of that group, and the recommendations of the Council have been accepted and acted upon.

Appeals for assistance with color problems have been so numerous that the Council has appointed Dr. Judd of the National Bureau of Standards to take charge of allocating problems for solution. One major activity now in progress is a compilation of color terms, color problems and color tests. It is obvious that every color problem must lead into physics, physiology, psychology, and practice; yet these fields have only the slightest common ground of terminology. Dr. Judd's committee is endeavoring to bring the various accredited usages together with the view of making the several fields intelligible to one another and perhaps unifying the terminology of color. Another project which is in the hands of a special committee is the compilation of a "Who's Who in Color". The value of such a directory can readily be understood.

We should like to call to the attention of the Association that the Council does not generate its own problems. Rather it attempts to assist its members who have problems in color and we wish to urge, therefore, that if any members of the American Psychological Association have such problems they should communicate them to one of the official delegates.

At its regular meeting in February, the I.S.C.C. sponsored a group of lectures on color, to which all members of Member Bodies were invited. The lectures were well received and similar ones are projected for the future. In order to increase the number of people directly involved in the activities of the Council, regional meetings of persons interested in color are now being sponsored.

The News Letter has been continued and improved in context and format.

2. Activities of the American Psychological Association delegates.

Your delegates have taken an appropriate part in the activities of the I.S.C.C. The chairman is serving as a director on the executive committee; five delegates are acting as a sub-committee in the compilation of color terms, problems and tests with special reference to psychology; another delegate represents psychology on the committee that is preparing the "Who's Who in Color".

Your delegates recommend to the Association that membership in the I.S.C.C. be continued.

Respectfully submitted,

Sidney M. Newhall, Michael J. Zigler, Forrest L. Dimmick, Chairman.

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DISCUSSION OF ITEMS APPEARING IN PREVIOUS NEWS LETTERS

CERTAIN COLORS IN MODERN PACKAGING PREVENT DETERIORATION IN OIL-BEARING FOODS.

The following comment was received from a research worker in this field; it refers to an article on this subject by Mayne R. Coe which appeared in our News Letter No. 14, July, 1936.

"The article by Mr. Coe entitled Certain Colors in Modern Packaging Prevent Deterioration in Oil-Bearing Foods has been brought to my attention, and while I believe Mr. Coe has in the main given a competent summary of our knowledge of this subject, in some respects our views do not agree. Since I have based my own views on nearly the same published data that are referred to in his bibliography, I have thought it worth while to show how this difference in interpretation might arise.

"I agree with Mr. Coe that the ultra violet portion of the spectrum affects rancidity the most, while the red of the visible spectrum appears to be next. This conclusion is consistent with McNicholas' data on absorption of radiant energy by vegetable oils considered in connection with the law of Grotthus which states that only absorbed radiant energy is photochemically effective. Further application of this law to the McNicholas data suggests that a filter transmitting only between 5800 to 6400A would offer considerably better protection than a filter such as described by Mr. Coe which transmits only between 4900 and 5800A.

"Do the actual data on deterioration contradict this suggestion? I believe that they do not. The experiments fail to be perfectly conclusive because of the small number of filters used and because equal amounts of radiant energy were not used, but they show some deterioration ascribable to radiant energy penetrating the usual orange and red filters. This deterioration I ascribe to the absorption band found in vegetable oils at about 6700A, a region within which both these filters transmit freely. High protection was found with a green filter (sextant green); this I ascribe not wholly to the wave-length limits of transmission of this filter (4900 to 5800A) but rather more to its generally low transmission.

"I, therefore, disagree with Mr. Coe's conclusion that green prevents rancidity better than any other color. It is true that a particular green filter worked better than any other tried, but it is my belief that if a filter transmitting only between 5800 to 6400 could be found, that color (orange) would probably be still better."

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UNITED STATES GOVERNMENT PUBLICATIONS

GLOSS AND GLOSSINESS

(A tentative outline of concepts, definitions and terminology)

This outline was prepared by Deane B. Judd following a conference between P. H. Walker, E. F. Hickson, K. S. Gibson, D. B. Judd, and R. S. Hunter. It has been agreed to by each.

Gloss is the power of a surface to reflect light regularly.

Glossiness is the appearance of a surface ascribable to its power to reflect light regularly.

Apparent Reflectance of a sample is the reflectance which a perfectly diffusing sample must have in order to yield the same brightness under the same conditions of illuminating and viewing. In this discussion we shall deal with unidirectional illumination; for such illumination apparent reflectance is a function of four variables, altitude and azimuth of the illuminating beam, altitude and azimuth of the direction of view.

The gloss of a surface is completely specified only when its quadruple infinity of apparent, unidirectional reflectances is known, and in these terms the gloss of a surface is the degree to which its apparent reflectances varies with angle. Thus it may be seen that there are many ways in which a surface can depart from the perfect gloss of an ideal mirror.

In dealing with actual samples in a practical way it has been found generally sufficient to make five kinds of determination, which are expressible as functions of apparent reflectance in the plane of the illuminating beam only; this permits us to use the symbol $A_{\theta,\theta'}$ for apparent reflectance

where the first subscript indicates the direction of the illuminating beam measured from the normal, and the second subscript similarly indicates the direction of view. The five functions of apparent reflectance, $A_{\theta,\theta'}$,

are given together with the names by which they are known and their definitions.

1. Regular gloss (G_r) is the ratio of apparent reflectance of the sample illuminated unidirectionally and viewed in the direction of regular reflection to the apparent reflectance of the standard, similarly illuminated and viewed; the standard is either a perfectly reflecting, perfectly polished surface or a perfectly polished specimen of the same material; the angle of illumination is 45° unless otherwise stated.

$$G_r = (A_{sample}/A_{standard})_{\theta,-\theta}$$

This concept has also been called objective gloss or polish.

2. Contrast gloss (G_c) is expressed as a fraction whose denominator is the apparent reflectance of the sample illuminated unidirectionally and viewed in the direction of regular reflection, and whose numerator is the same apparent reflectance diminished by the apparent reflectance of the sample similarly illuminated and viewed normally; the angle of illumination is 45° unless otherwise stated.

$$G_c = (A_{\theta,-\theta} - A_{\theta,0})/\frac{A}{x0,-\theta}$$

This concept has also been called simply gloss, or, since it correlates somewhat more perfectly than regular gloss with glossiness, subjective gloss.

3. Distinctness-of-image gloss (G_i) depends on the rate of change with angle of incidence of apparent reflectance for a direction of view deviating from the direction of regular reflectance by a small angle (perhaps about one minute to one degree). It may also be expressed as a function of the least angular separation $\delta\theta$, of two linear elements in the illuminant still permitting their resolution in the reflected image. Two possible quantitative definitions are:

$$G_i = (dA_{i,-\theta}/di)/(k + dA_{i,-\theta}/di), \text{ where } \theta = i + \delta i, \ \delta i$$

is a small angle of the order of one minute to one degree, and k is an arbitrary constant which should be adjusted once for all to give a convenient scale.

$$G_i = K/(k + \delta\theta)$$

This concept has also been called image reproduction.

4. Absence-of-bloom gloss (G_b) is exhibited only by samples for which distinctness-of-image gloss is high, and is defined as the degree of freedom from surface-scattered light near a high light. Bloom is the presence of surface-scattered light near a high light and is quantitatively defined as the difference between the apparent reflectance of the sample a few degrees (say 5) off from the direction of regular reflection and the apparent reflectance many degrees (say 45) off from it.

$$G_b = k/(k + A_{\theta,-\theta-\delta\theta} - A_{\theta,0}), \text{ where } G_i \text{ is greater than } 0.50.,$$

θ is 45°, $\delta\theta$ is 5° unless otherwise stated, and k is an arbitrary constant.

5. Absence-of-texture gloss (G_t) is possessed only by surfaces of relatively high gloss and is the degree of freedom of one of the preceding four types of gloss from variation depending on the size of the sample viewed. Texture probably affects judgments of sharpness-of-image gloss more than other types. Thus far texture has been treated by visual judgments of greater or less texture or by photographs which serve as a record of amount and kind of texture. A possible quantitative definition is;

$G_t = k/(k + dG/da)$, G greater than 0.50 where a is sample area, and as before k is an arbitrary constant which should be adjusted once for all to give a convenient scale.

This concept is also called surface smoothness.

All of the suggested definitions for these five types of gloss when applied to a perfectly diffusing surface yield a value zero except G_b and G_t which do not apply to matt surfaces; and all definitions when applied to the perfect surface of an ideal mirror yield a value of unity.

They each may therefore be taken as a direct measure of gloss of one particular type, and names for them have been selected on this basis. Taken together they form a fairly complete description of the gloss of actual surfaces which exhibit no structural regularities; that is, if a sample may be rotated in its own plane without changing in any of these five respects it has thus far been found that its gloss is specified with sufficient completeness for practical purposes. Other samples (fabrics, brushmarked paint films, machined metal surfaces) require further functions and concepts for a satisfactorily complete specification of gloss.

Regular gloss and contrast gloss may be evaluated by using suitable reflectometers, either visual or photoelectric. Distinctness-of-image gloss, absence-of-bloom gloss, and absence-of-texture gloss have not so far been evaluated in a quantitative way, but it is probable that this may be done in the near future. The quantitative definitions given for G_i, G_b and G_t may possibly prove to be suitable; a decision on this point must await attempts to evaluate them for actual samples.

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ABSTRACTS OF PAPER PRESENTED AT THE M.I.T. CONFERENCE IN COLOR

On the request of M. Rea Paul, Chairman of the Inter-Society Color Council a number of those who presented papers at the Conference on Color, submitted abstracts of their lectures. These are reproduced in this News Letter. It is hoped that others will be received so that they may be published in the next issue of the News Letter.

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COLOR PROBLEMS OF THE TEXTILE INDUSTRY

By Wm. D. Appel, Chief, Textile Section, National Bureau of Standards, Washington, D. C.

Applications of colorimetry and spectrophotometry in the textile industry are illustrated by a discussion of two specific problems which have been studied in the Textile Section of the National Bureau of Standards.

One, the grading of manila rope with respect to the color of the fiber in it, is shown to be practicable with simple equipment. This is because the range in colors to be graded is limited to a series having but one principal variable, lightness, and because the grading is for the control of the commercial qualities of fiber in the rope rather than in the appearance of the rope. The method has been adopted by the industry and is used in the federal specification for manila rope.

The other problem, the evaluation of color fastness to light, has not to date proved to be wholly feasible by means of the usual colorimetric or spectrophotometric methods, though these methods have been helpful in studying some phases of the problem. It does not appear that they will give an entirely satisfactory measure of color fastness to light because fastness is judged not only by the magnitude of the color change resulting from the action of light but also by the objectionableness of the change, which as yet cannot be evaluated. The fading of textiles is evaluated by visual comparison with the fading of dyeings of known fastness. This method is discussed and the efforts being made to provide standard dyeings for the general use of the industry are described briefly.

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THE INTER-RELATIONSHIP OF THE VARIOUS ASPECTS OF COLOR

By Loyd A. Jones, Physics Department, Research Laboratories, Eastman Kodak Company, Rochester, N. Y.

This paper was intended to serve as an orientation treatment in the general field of color and color measurement. After tracing through step by step the various events which occur from the time radiant energy is emitted by a radiator until, as a result of the arrival of sensory nerve currents in the sensory projection areas of the cerebral cortex, the sensation of color is produced, it is shown that the various events and relationships can be logically classified into three definite categories, designated as: (a) physical, (b) psychical, and (c) psychophysical.

It is shown that it is upon certain psychophysical relationships that the measurement of color depends. The sensory and perceptual aspects of the cerebral response are discussed briefly in an effort to establish the validity of limiting the attributes of color (a sensation) to three, namely, hue, saturation, and brilliance, and of classifying the various modes of appearance of color as perceptual aspects.

Note: This paper will be published in the Report of the Committee on Colorimetry of the Optical Society of America.

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COLORIMETRY IN THE DYESTUFFS INDUSTRY, WITH SPECIAL REFERENCE TO FASTNESS TESTING

By I. H. Godlove, E. I. du Pont de Nemours, Wilmington, Del.

This paper stressed first the difficulties involved in the application of the spectrophotometer and other precision instruments to the color determinations necessary in the testing of the fastness of dyeing toward various destructive agencies. Some of these are: (1) The enormous number, running into hundreds, of color determinations necessary for each dye; (2) lack of ready interpretation and understandability of instrument measurements, or computed variables, in terms of the mill man's concepts (especially of "strength," "shade," and "brilliance" or "dullness"); and (3) the factor expressed as straining at a gnat while swallowing a camel, i.e. attempting high precision in the determination of quantities inherently indefinite. By special reference to work on fastness to light and a review of the laws and facts of photochemistry and the destructive effects of light energies of varying wave length, it was shown how complicated are the effects involved, and how difficult it is to untangle the variables involved, in the present state of our knowledge. Important general questions not discussed, because so often treated elsewhere, were the lack of the personal equation in some instrumental determinations, and the effects, on the colors observed, of variability of the source of illumination, which effects are systematically diurnal, seasonal and geographic as well as sporadic with the weather; but the effects of great variations of intensity and ultra violet composition were discussed. As an important factor militating against the use of color-determining instruments, if not a difficulty, was mentioned the fact that dyeing problems are more often, or more importantly, problems of fastness or working properties of dyes, as well as of cost, than they are color problems. This unencouraging side is the one seen chiefly in a dye applications and development laboratory.

On the other hand, a number of applications of optical instruments, particularly of the spectrophotometer, in a dye manufacturing laboratory, were mentioned; and it was added that even the applications laboratory has many special problems which can be so treated, as well as the routine determination of the strength of dye lots for standardization. The manufacturing laboratory can use the spectrophotometer in the development of new dyes, in the study of the relation of chemical constitution and color, in following the course of purification of dyes (or of intermediates by converting them to colored compounds), in identifying competitive products or establishing the identity of two dyes, in the characterization of dyes for patent purposes, etc. Extension of measurements to infra-red and ultraviolet would enable the laboratory to handle further problems, which were mentioned. Certain general problems in the application of the "chrome," "vat" and "sulfur" classes of dyes, and the "after-treatment" of direct cotton dyes with copper and chromium salts, concerning which an immense mass of unrelated facts are known, could be correlated and scientifically developed. It was suggested how the use of such a body of data could be converted from an art into a new science. Finally, suggestions were made for laying the groundwork for the fundamental research ultimately necessary for correlating the dyer's concepts of "strength," "shade" and "brilliance" with instrument measurements and with the three attributes of colors commonly used by color scientists.

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COMPUTATIONS INVOLVING THE STANDARD OBSERVER

By David L. MacAdam, Massachusetts Institute of Technology, Cambridge, Mass.

The determination of the tristimulus values of colors is the fundamental problem of any method of color measurement. All of the direct methods for determining these quantities by the use of colorimeters involve some uncertainty as to the normality of the color vision of the observer. The indirect method of colorimetry, which determines tristimulus values from spectrophotometric data followed by computations utilizing data specifying the Standard Observer, avoids this uncertainty and provides color specifications which are reproducible in properly equipped laboratories all over the world and over indefinitely extended periods of time. Existing visual and photoelectric spectrophotometers which furnish data accurate to two or three tenths of one percent thruout the visible range of wavelengths from 400 millimicrons to 700 millimicrons make possible color specifications which are in error by considerably less than visually appreciable magnitudes. A consideration of several methods of computation leads to the conclusion that the selected ordinate method of color computation furnishes results of the necessary accuracy at the least expense of time and effort.

The selected ordinate method of computation has been described in full, and the necessary tables of data are supplied in the Handbook of Colorimetry, published by the Technology Press, Massachusetts Institute of Technology. Computation of the tristimulus values of seven very selective filters by the indicated methods of computation led to the mean deviations from the results of integration of one hundred selected ordinates as shown below:

10 selected ordinate integration	±.0025
20 selected ordinate integration	±.0008
30 selected ordinate integration	±.0005
10 millimicron weighted ordinate integration	±.0008

These are the largest probable computational errors to be expected in tristimulus values determined by the methods shown, because the great selectivity exhibited by the spectrophotometric curves of the filters imposed as severe a test on the methods as is likely to be encountered in practice. Computations for less selective substances will be subject to somewhat less error, provided that the spectrophotometric data is carried to the third decimal place thruout the computations. It is evident from the table that integration by the use of at least thirty selected ordinates should be recommended for all except quite unselective materials.

Thirty ordinates should prove quite sufficient for all except rare cases of filters transmitting in very narrow bands of the visible spectrum. It is believed that thirty ordinates will be sufficient for accurate colorimetric specification of all opaque substances.

Labor saving devices and procedures have been designed to facilitate integration by the thirty selected ordinates methods. When such aids are used, the computation of the three tristimulus values from the spectrophotometric curve of a sample requires less than ten minutes.

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THE SPECIFICATION OF WHITENESS

By David L. MacAdam, M.I.T. Cambridge, Mass.

The term whiteness is commonly used to express degree of satisfaction with the color of a substance as an approximation to some idealized color called white. The most generally accepted standard white is the color of a diffusing, perfectly reflecting surface. Until recently there was no recognized basis on which colors differing from this standard could be called white. So long as only the standard color was defined, but no standard method of measuring degree of approach of other colors toward the standard white, no other description of the whiteness of a substance could be given legitimately except to say that it was white or not white.

All substances which are ordinarily called white differ from the standard white in at least one of two ways. All are darker, grayer than the perfect white. Some may show no other difference, and these are legitimately regarded as grays of differing degrees of lightness. The lighter members of this series of grays are commonly called whites, the brighter substances being regarded as whiter than the others. The method of measurement of the brightness or daylight reflectivity of grays is well established, and a scale of whiteness for neutral (non-colored) materials can be established on the basis of such measurement. One such scale could be defined as identical with the reflectivity. For some purposes a scale of whiteness equal to the square root of the reflectivity is considered preferable.

Most substances are not only grayer than the perfect white but are also actually colored to a slight degree. Frequently this color is yellow, although it can be practically any color. The evaluation of the effect of these slight colorations on the commercial whiteness gradings as compared with the measured grayness constitutes the most difficult problem in the establishment of a useful whiteness scale. This problem was solved for yellowish white textiles by measuring the daylight reflectance (lightness) and color purity (yellowness) of a large group of samples. This group of samples was then arranged in the order of whiteness by each of a large group of graders. The orders of arrangement by the various graders agreed fairly well and an average order was taken and compared with the measured discoloration and grayness of the samples. It was found that the order of whiteness could be predicted by the formula

$$\text{Reflectance} - 50(\text{excitation purity})^2.$$

This formula applies only to samples similar to the white cloths investigated, which were yellowish (dominant wavelength 575 millimicrons). The constant, 50, will be different for other colorations, and the formula gives the correct whiteness grading for yellowish white samples only when the daylight reflectance and excitation purities are expressed as decimals. As mentioned previously in the case of the whiteness grading of neutrals, grays, the use of the square root of the above quantity may be preferable to the expression as given. Samples having excitation purities greater than .05 should not be regarded as white, and the formula for whiteness should not be applied to such samples.

It is believed that this type of investigation when extended to other classes of samples will provide a basis for accurate and truthful commercial use of the previously qualitative term, whiteness. Investigations of this nature can most profitably be undertaken by the industries to which such problems are important. It seems doubtful if any extensive programs of this nature will be undertaken by academic laboratories, which regard such investigations as obvious applications of general principles which are well established. The formulation of new general principles is the most imperative responsibility of workers in university laboratories. The limitation of time available for research discourages extensive elaboration of such principles. This is especially true when the only demand for such elaboration is from industries which possess material and technical resources quite adequate for such detailed applications of established principles and methods of measurement. It is confidently hoped that the majority of the future contributions to the study of whiteness and of color tolerance in general will emanate from industrial laboratories.

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THE SOLUTION OF GRADING PROBLEMS BY THE USE OF A DISK COLORIMETER

By Dorothy Nickerson, Bureau of Agricultural Economics, Washington, D.C.

It has been said that the study of color may be divided into three general fields:

1: Physical elements and relationships (illustrated by spectrophotometry),

2: Psychological elements and relationships (illustrated by the Munsell system) and

3: Psychophysical elements and relationships (evidenced by many methods of colorimetric analysis, the I.C.I. system, for example).

The strictly physical method of measuring the light reflected, absorbed, or transmitted by a material, is well standardized, and, due to the development and increasing availability of photo-cell spectrophotometers, is coming into wider use in fundamental industrial and commercial problems. The I.C.I. method, under item 3, is now well established. But the strictly psychological method, of finding out what the color "looks like", although of major importance in many fields of color work, has not been so much used or so well standardized.

Many methods have been described at this conference for measuring or specifying "color", but in none have results been indicated in terms of what the color looks like -- in terms of "color", as defined by the O.S.A. Colorimetry Committee. The Munsell system, described in the preceding paper, provides a basis for doing just that. It is not perfect, but it does provide an adequate and convenient method for psychological specification of color.

The disk method of colorimetry was designed to make use of the Munsell system of notation by providing a convenient means for making a colorimetric match so that results might be expressed in terms of scales approximating those of hue, brilliance, and saturation. In the not too distant future instruments may give the whole story -- a spectrophotometric curve, with hue, brilliance, and saturation for specified conditions of illumination, the data for the curve being converted within the instrument on the basis of an internationally adopted system. Meanwhile different instruments must be used for different purposes, and the disk instrument finds its greatest usefulness in grading problems, particularly those in which the color range of the product is narrow, as in the grading of agricultural products.

The initial instrument development was a simple motor and disk apparatus. Later, the cooperation of the Keuffel and Esser Company, then of the Bausch and Lomb Optical Company, led to the development and marketing of disk colorimeters in which a spinning optical part obviates the necessity of spinning the disks to match the samples, thus making disk matches quick and easy to make. A color match is made by changing areas of selected disks until there is a match in the contrast field of the comparator unit.

Formulas for working out disk mixtures have been developed and published for providing a practical means of arriving at the approximate hue/brilliance/chroma notation. Spectral reflectance measurements of the entire series of Munsell colors are a great boom to the disk method, since they will provide a way to substitute for approximate formulas, accurate ones based on the I.C.I. data for the disk colors, with resultant mixture values read from charts in terms of H/B/C.

Most everyone wishes to avoid the labor of visual observation, but for many problems a method of measurement that employs a visual instrument that is quick and easy to use, that does not require a technically trained staff, one whose results can be checked in terms of a calibrated spectrophotometer, will be successfully used - if only because of its cost - for a long time to come. In fact, instead of supplanting other methods of colorimetry, the increasing amount of spectrophotometric data being made available will undoubtedly serve as a complement, or supplement, to increasing amounts of work by all other methods which may be related to, or standardized upon, its basic data. The disk method is presented as one of these -- its chief objective being to provide a specification in terms of "color" as defined in the opening paper of the conference.

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ARTIFICIAL DAYLIGHT AND ITS APPLICATION IN COLORIMETRY

By H.P. Gage, Corning Glass Works, Corning, N.Y.

What do we mean by the colors of objects? According to the extreme scientific view color is a sensation; objects have no color only the property of selective reflection or transmission in different portions of the spectrum.

As commonly used there is no chance of misunderstanding the meaning of the statement that "the apple is red". The meaning is that as ordinarily observed, it excites the sensation of red. This involves a series of events which are commonly met with and whose occurrence it is assumed, are strictly adhered to. Otherwise the description of the color of the object is meaningless. These occurrences are:

1. The object is illuminated by a continuous spectrum of the "black body" type of energy distribution and preferably by natural daylight.

2. The object is viewed by a normal, not a color blind, observer. Under these conditions, and these only, may the sensation experienced by the observer be used to express the property of the object known as its color. Under unusual types of illumination objects appear of different color than when viewed in daylight. Some colors such as purple are changed enormously under different types of illumination.

With the importance of viewing objects whose color is to be described, under a standard illumination it becomes imperative to produce a standard artificial daylight which will be constant and available at all times of night or day and under all outside weather conditions and in any part of a building. This can be done and for a long time has been available by using a high efficiency tungsten lamp modified by a glass color filter.

As both the light source and natural daylight can be expressed by equations for the spectral energy distribution (Wien's equation), it is possible to determine a simple straight line equation in logarithmic form for the spectral transmission of the filter required. This equation shows among other things that a given glass will increase the color temperature of the source in such a way that the difference of the reciprocal of the temperature of source and transmitted light is constant irrespective of the temperature of the source and that with the glass filter this change in reciprocal temperature is proportional to the thickness of the glass.

The unit used for expressing reciprocal temperature is the "microreciprocal degree". This has been contracted to "mired" pronounced "my red".

With the discovery of these relations the formulae developed reduce the computations of the daylight correcting filters to a simplicity which can be shown on an 8 x 10 chart accurately enough for all engineering purposes.

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THE MUNSELL SYSTEM OF COLOR SPECIFICATION

By Water M. Scott, Gustavus J. Esselen, Inc., Boston, Mass.

This subject should be of particular interest to the residents of Boston and vicinity because the originator of the Munsell Color System, Albert H. Munsell, was a native of Boston and taught color composition and artistic anatomy at the Normal Art School in this city for many years.

Stated concisely, the Munsell System is a three-dimensional system for classifying and notating colors according to the qualities which are distinguished by the eye. Helmholtz, the noted German scientist, discovered about the middle of the last century that the quality of every color impression depends on three variable factors which he called "hue", "luminosity", and "saturation". Unfortunately many different names have been used to describe these factors.

Mr. Munsell called these color qualities, Hue, Value and Chroma and he defined them as follows:

Hue: Hue is the quality by which we distinguish a red from a yellow, a green, a blue or a purple.

Value: Value is the quality by which we distinguish a light color from a dark one, i.e., a pink from a maroon or a white from a black.

Chroma: Chroma is the quality by which we distinguish a strong color from a weak one, i.e., a vermillion red from a reddish gray or a "canary yellow" from an "old ivory".

Mr. Munsell conceived the idea that these three color dimensions could be most easily specified by a color sphere.

Hue is measured on the equator of the sphere, the entire circumference being divided into ten equidistant "major" hues arranged in the order of the spectrum. Each of the ten major hues can be divided into ten subdivisions, making one hundred hues in all. For purposes of notation each major hue is considered the center of its hue group and is given the designation 5 (5R in the case of red, 5Y in the case of yellow, etc.).

Value is measured on the axis of the sphere, progressing in a series of equal steps from black at the lower or south pole, to white at the upper or north pole. For purposes of notation, ten steps are provided between black at 0 and white at 10. At the level of each step of value is a plan including all colors of the same value as the Neutral Gray.

Chroma is measured outward on the horizontal radii extending from the axis of the sphere toward the circumference. The equal steps of chroma are numbered outward on these radial lines, starting from zero at the center.

The complete Munsell color notation is written HV/C. Thus, a typical "pink" would have the notation 5R8/2, indicating that it is 5R in hue, 8 in value, and 2 in chroma.

Mr. Munsell spent the years from 1901 to 1914 in developing color charts to illustrate the measured scales of hue, value and chroma. Since that time, the work which he started has been carried on by the Munsell Color Company under the direction of his son, A. E. O. Munsell. The original color scales have been revised and improved and are now shown on charts in the Munsell Book of Color.

The Munsell color system is as fundamental from the psychological standpoint as the measurements of color on the photoelectric spectrophotometer is fundamental from the physical standpoint. Fortunately, the two systems of color specification have lately been correlated so that it is possible to convert color measurements from one system to the other. It is quite difficult for the average person to visualize the differences between two colors by a comparison of their spectral reflection curves, but to anyone who is familiar with the charts of the Munsell color system it is very easy to visualize the differences between two colors in terms of their relative hues, values, and chromas.

The Munsell color system has many practical applications at the present time. A commercial color printing concern is using this system to transmit color information from the designer to the printer. Instead of delaying to send a sample, the designer can simply designate to the printer by telephone the Munsell notations of the colors which he desires.

Just this summer the Munsell color notations are being used to identify the new fashion colors shown in Paris. The color notations are transmitted to this country by cable or radio, thus making it possible for the designer here to have advance notice of the latest developments in color.

If greater accuracy in color specification is desirable, it can be obtained by the method of matching the unknown color by blending measured areas of the standard Munsell Color discs. This method has been used by the United States Department of Agriculture to grade the colors of raw cotton, of hay, and of meat. It has also been used as the basis for certain principles of color harmony dealing with harmonies in one hue, in adjacent hues, or in complimentary hues.

Finally, the Munsell color system is decidedly the most satisfactory from the standpoint of promoting a better understanding and appreciation of color, as well as forming a basis for teaching the fundamentals of color to children and to adults as well.

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THE ACCURACY OF SPECTROPHOTOMETRIC MEASUREMENTS

By K. S. Gibson, National Bureau of Standards, Washington, D. C.

Various factors affecting the reliability of spectrophotometric data have previously been discussed by the author ( ).

( ) See, for example, Visual Spectrophotometry, J.Opt.Soc.Am.24, 245 (1934).

Such are the type of illumination and the reference standards, the accuracy and maintenance of the wave-length calibration, the presence of stray light, the slit-widths used, and the over-all reliability of the photometric scale. Errors due to inadequate attention to these factors may be present in data obtained by both visual and photoelectric instruments.

It is of interest to note the magnitude of errors or discrepancies from such causes when expressed in terms of the trichromatic coefficients, x and y, computed on the basis of the 1931 I.C.I. standard observer and coordinate system:

(1) It was found that very careful measurements on a glass sample of moderate spectral selectivity made at three different times over a period of seven years, gave a maximum spread of 0.0002 in either x or y.

(2) Slit-widths of 10mμ are not apt to cause errors in x or y greater than 0.001.

(3) A constant wave-length error of 1mμ may produce rather important errors for highly selective samples. Such an error was computed for each of seven railway signal glasses; the maximum error in x or y from this cause was found to be 0.0045, the average maximum error being 0.0023.

(4) Miss Nickerson has published data ( ) illustrating for various Munsell samples the differences in x and y resulting from differences in spectral reflectance curves as shown. The maximum x or y difference shown is 0.0244, the average maximum difference in x or y being 0.0074.

( ) Disk Colorimetry; Including a Comparison of Methods for Computing Tristimulus Values for Certain Disks, J. Opt. Soc. Am., 25, 253 (1935).

(5) Data are on file illustrating for certain glass samples errors of the same order of magnitude as (4), produced apparently by a combination of wave-length and stray-light errors.

Miss Nickerson also showed that differences in methods of computation -- whether by the weighted-ordinate method at 5 or 10mμ intervals or by the selected-ordinate method at 30 points -- produced differences in x or y up to 0.0018. While the method of computation thus affects the absolute accuracy of such computations, it does not affect the values of the differences illustrated above, which result in each case from values of x or y computed by the same method.

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SPECIFICATION OF THE COLORS OF RAILWAY SIGNAL GLASSES

By K. S. Gibson, Washington, D. C.

As a result of a cooperative program of the Signal Section of the Association of American Railroads, Corning Glass Works and the Colorimetry Section of the National Bureau of Standards, a three-part specification of railway signal colors and glasses have been prepared and issued. This is known as A.A.R. Signal Section Specification 69-35 and was officially approved in December, 1935; it is now recommended practice for American railroads.

The purpose of Part A of this specification is "to define the minimum values of luminous transmission for signal glasses and the limits of chromaticity for signal colors produced by illuminant-glass combinations". Values are specified on the basis of the 1931 I.C.I. standard observer and coordinate system, and a chart illustrating the permissible areas on the (x,y) mixture diagram accompanies the specification Part A of the specification enables the bureau or other standardizing laboratories to test signal colors and glasses for conformity thereto, but is of little practical use to the glass manufacturer or railway inspector.

Parts B and C of the specification define the procedure for certifying duplicates of the standard limit glasses and prescribes the method of use of these duplicates in practical testing. The standard limit glasses are those which were selected by the signal engineers, and on which the spectrophotometric measurements were made leading to the fundamental colorimetric definitions given in Part A. The purpose of Part B is "to define the maximum deviations from the standard limit glasses, both in transmission and chromaticity, to be permitted in glasses certified as duplicates of the standard limit glasses". The range in the values of x and y so specified varies from 0.0008 or ± 0.0004 for the red glasses to 0.0020 or ± 0.0015 for certain of the green, blue, and lunar white glasses. The specification requires these duplicates to be certified by the National Bureau of Standards.

The purpose of Part C of the specification is "to provide for approved colored roundels, lenses, discs and slides for railroad signaling, to describe the materials, and specify the appliances and appurtenances necessary to make the required tests and inspection". It requires that the one making the test have at hand the proper certified duplicate glasses, in terms of which he is to test the luminous transmission and the chromaticity of the sample.

AAR Signal Section Specification 69-35 may be obtained from the secretary of the AAR Signal Section, 30 Vesey Street, New York, N.Y. Most of the bureau's work leading up to this specification is described in a series of five reports by Gibson and Walker, published in Signal Section Proceedings, AAR, vol. 30, p. 384, 1933. Application for this issue of the proceedings should be made to the address above.

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THE STANDARD OBSERVER IN COLORIMETRY

By Deane B. Judd, National Bureau of Standards, Washington, D. C.

Human vision depends on a mechanism that is both complicated and incompletely understood. This mechanism, considered as a detector of radiant energy, is capable of responding to and distinguishing between many different wave-length distributions of energy, and it is adaptable to a wide range of energies. The visual mechanism adapts itself by variations in sensitivity, and on this account quantitatively accurate visual judgments are ordinarily not possible; that is, it is impossible to say reliably which of two yellow lights is the greener unless they are seen at the same or nearly the same time and brightness. The mechanism, however, for fields of small angular extent and within the range of energies yielding daylight vision, is a satisfactory null instrument. Thus, if two lights are stimuli of different wave-length distribution of energy be found which are once responded to alike by the eye, they will still be seen alike after exposure to another light even if this pre-exposure stimulus is such as to change considerably the appearance of the two equivalent lights. For example, if a portion of the spectrum near 640mμ (red) be superposed on a portion near 550mμ (yellow green), it will be found possible to obtain the color of this combination from an intermediate portion of the spectrum, say 600mμ (orange). If the eye is then exposed to a bright light of wave-length near 640mμ and its sensitivity to radiant energy of this wave-length region considerably reduced in this way, it is found that although neither of the equivalent stimuli appears orange, they still give identical colors, for example, they may yield identical yellows or identical greenish yellows. Hence, stimuli once found to be equivalent are always equivalent, and it is possible to specify any light by giving another light or combination of lights to which it is equivalent. This is the basis of the colorimetry of lights.

Color, however, appears as an attribute of non-self-luminous objects as well as lights. Thus far the discussion has been restricted to the illuminant mode of appearance; colorimetry of objects is probably more important than the colorimetry of lights and refers to color seen as the attribute of the surface of an object or as the attribute of a transparent or semi-transparent volume. Object color is judged, however, by a comparison of the light leaving the object with that which is incident upon it; it may thus be handled by the method of equivalent stimuli just as is the colorimetry of lights.

There are many systems of stimuli from which equivalents may be found. Some of these are surface-color systems (color charts of Ridgway, Munsell, Maerz and Paul), some are volume-color systems (Jones subtractive colorimeter, Lovibond glasses, Arny solutions) and some are illuminant-color systems or combinations of lights (tristimulus system, "monochromatic-plus-white" system). The specifications to be obtained from these various systems are more or less convenient according to the greater or lesser simplicity and regularity with which the various members of the system are related. The various members of the tristimulus system are related by simple addition; this accounts for the greater interest and importance of the tristimulus system of color specification to which attention will hereinafter be confined.

In the tristimulus system a light to be specified is compared to the additive combination of three other lights called primaries, the specification being merely the amounts of the primaries required to produce a stimulus equivalent to the original. A stimulus made up of the sum of two or more lights can be specified in the tristimulus system by merely adding together the respective specifications of the components. Since any light may be considered as the sum of a number of parts of the spectrum, the tristimulus specification of any light may be found from the tristimulus specifications of the various parts of the spectrum provided the strengths of the various spectral components be known by spectrophotometry. This supplies a convenient method of specifying the characteristics of a colorimetric observer; it is only necessary to determine his tristimulus specifications of the various parts of the spectrum; then his tristimulus specification of any composite light may be computed. In this sense the tristimulus system is the fundamental system.

There are significant and important differences in the tristimulus specifications of the various parts of the spectrum depending upon the observer even when color blind and partially color blind observers are excluded. But it is expedient for everyone to use the same observer in colorimetric calculations based on spectrophotometric data, and the one commonly used is the standard observer adopted in 1931 by the International Commission on Illumination. The characteristics of this observer were derived from a smoothed mean of 17 normal observers studied in Great Britain.

With minor restrictions any three lights may serve as primaries in a tristimulus system. But it is also expedient for everyone to use the same primaries. The primaries adopted by the International Commission on Illumination are unreal, that is, it is not possible to build a tristimulus colorimeter reading directly in the ICI colorimetric coordinate system although conversion factors may readily be applied. The use of real primaries has been avoided chiefly because they bring negative numbers into the calculation of spectrophotometric results, for there are no three real primaries which will yield by additive combination all spectrum colors. An additional advantage obtained through the particular primaries chosen is simplicity in the computation of photometric quantities; two of the primaries have been chosen so as to refer to no luminosity whatever, the amount of the remaining primary indicating, therefore, the whole luminosity of the stimulus to be specified.

The tristimulus system of color specification has in past years often been linked unnecessarily with the Young-Helmholtz theory of color. The 1931 ICI colorimetric coordinate system if so linked with theory would suggest that there exist in the human eye three independent receptor mechanisms, one of which is responsible both for the green sensation and for the sensation of luminosity, the other two of which are responsible respectively for red and blue. Since this hypothesis has very little to recommend it, there is little chance that anyone will continue in the mistaken belief that the validity of color specification by the tristimulus method depends on corroboration of one or another of the many hypotheses advanced in a speculative way to account for various visual phenomena. Tristimulus specification requires for validity only that equivalent stimuli remain immutable; this has been amply established for usual daylight vision. The 1931 ICI standard observer and coordinate system for colorimetry has been successfully used for several years and while improvements in methods of specification will, no doubt, be discovered and perfected eventually, there is every reason to believe that international accord on an improved coordinate system is many years in the future.

(For further details consult, D. B. Judd, The 1931 I.C.I. Standard Observer and Coordinate System for Colorimetry, J. Opt. Soc. Am. 23, 359; 1933.)

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COLOR TOLERANCES IN TERMS OF MATERIAL STANDARDS

By Deane B. Judd, Washington, D. C.

In the manufacture, for example, of pistons for automobile engines, it is important that the size and shape of the pistons be controlled so that they will fit into the cylinders. In the finishing, for example, of the various parts of the automobile body, it is important that the color be controlled so that when the parts are assembled objectionable color differences will not appear. In the control of piston size and shape it has been found practical and economical not to attempt the construction of pistons which duplicate as closely as possible some master piston; instead of this the diameter is controlled to some small amount which practice has shown is not objectionable and may be tolerated. The success of these tolerances depends upon the existence of a length scale which may be applied according to a standard method to obtain reproducible results. But in the control of the color of, for example, automobile finishes, little explicit recognition is accorded the fact that there exist color differences which are not objectionable. The attempt is made to duplicate exactly the color of some master sample, and the fact that this wasteful and primitive method of color specification is used in the great majority of transactions involving colored materials is ascribable to the failure of industry to use color scales which may be applied according to standard methods to obtain reproducible results.

What recognition of color tolerances exists is largely embodied in the phrase "a good commercial match" and it is recognized that what is a good match for some materials is a poor match for others. Probably the idea of a tolerance of this sort is implied in most of the contracts which state that the goods shall match the standard; but the wastefulness of the system arises because no actual tolerance is included in the contract; this permits a customer to reject goods because of color differences which are of purely imaginary importance. The inevitable effect of this system is that the exchange of goods is carried on according to variable tolerances which have no relation whatever to consumer usefulness. In the end, the manufacturer, retailer, and consumer all lose out; they all have to share the burden of added cost from unreasonably close color control and senseless rejection of deliveries.

A step toward remedying this situation is to supply not only a standard sample whose color the goods are supposed to approximate but also a limit sample whose color deviates from the standard color by an amount which is just tolerable. This partial remedy does not involve the purchase of colorimetric apparatus, nor the setting up and maintenance of color scales, and it does not constitute a final, completely satisfactory solution to the problem of color tolerance; but it does ensure that the buyer and seller come to an approximate agreement as to closeness of color match, and that they do it before delivery of the goods to fill the order.

For this simple system of color tolerances to be completely successful, it is necessary that the expert color matcher be able to estimate relative sizes of color difference and to do it even when the sample deviates from the standard in a different sense than the deviation represented by the limit sample; that is, the inspector has to be able to estimate with satisfactory accuracy whether, for example, a given departure from a yellow standard toward a reddish yellow sample is greater than or less than the departure represented by the limit sample which might be a departure toward darker yellow or toward stronger yellow and not a hue departure at all. A trial at this sort of estimation has been made by ten unpractised observers; the results differ from one such observer to another only by a factor of three. This rather large uncertainty is still small enough to promise definite savings by the inclusion of a limit sample, and practised observers make such judgments with considerably less uncertainty than this.

The fastness-to-washing test of the American Association of Textile Chemists and Colorists depends on direct visual estimates of color differences; and there are other useful and successful specifications administered on the same basis.

An investigation is under way whose object is to discover a method of deriving from fundamental color specifications (such as by the 1931 ICI colorimetric coordinate system) numbers referring to differences between samples which will correlate well with direct visual estimates of the color difference. If this investigation is successful, it will be possible to appeal to the spectrophotometer in disputed cases, or, if desired, to deal rigorously with all color tolerances by means of the spectrophotometer. But even then there will be many color specifications in which color tolerances by material standards will be preferred because of simplicity, directness, and low cost.

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THE SPECIFICATION OF THE WHITENESS OF PAPER

By - Deane B. Judd, Washington, D. C.

Whiteness of paper is of interest because in addition to being for many uses a desirable characteristic in paper, it is often taken as an indication of the quality of the pulp from which the paper is made. Whiteness has been a subject of controversy because it is possible to some extent to cover up at small expense the appearance characteristic of low-grade pulp by the addition of a small amount of dye (blue or blue and red). Sometimes the whiteness of paper made from high-grade pulp is also increased by the addition of such dye to give it a more pleasing appearance.

The method of defining whiteness discussed here is based on work done by D. L. MacAdam on whiteness of yellowish-white textiles. Dr. MacAdam determined experimentally the relative importance of achromatic departures from white (departures toward gray) and chromatic departures (those toward yellow), and he expressed this experimental result in a formula. The present paper extends MacAdam's formula to chromatic departures of all hues (red, green, and blue as well as yellow) by making use of a color triangle (called the uniform-chromaticity-scale or UCS triangle) because equal distances in any direction refer to equally perceptible color differences. This paper also describes tests designed to show how closely this extended formula agrees with whiteness grading by paper experts.

Whiteness if qualitatively defined as degree of approach to the appearance of a perfectly reflecting, perfectly diffusing surface; and a surface of magnesium oxide prepared by deposition of smoke from magnesium burning in air was taken as the working standard white. When the formula with this working standard white was applied to 30 papers collected through the color committee of the Technical Association of the Pulp and Paper Industry and compared to visual whiteness gradings by 15 observers obtained through cooperation of the same committee it was discovered that the general principle of the definition had been corroborated, but only about one-third of the observers found magnesium oxide an acceptable standard white. About the same number based their judgments on a standard which is slightly greenish yellow compared to magnesium oxide. This color is called by some of the observers "natural paper white" by which is meant the color of paper made from good grade, well-bleached pulp to which no dye has been added. The remaining third of the observers showed some agreement with both working standards.

It is suggested that it might be well to define "natural paper whiteness" as the degree of approach to the appearance of "natural paper white"; this would satisfy those who use this type of visual grading as an indication of the quality of the pulp from which the paper is made. Whiteness defined with reference to magnesium oxide refers more particularly to appearance of the paper for appearance's sake alone.

(For further details consult, D. B. Judd, A Method for Determining the Whiteness of Paper, Paper Trade Journal, 100, No. 21, TS 40; 1935; also a Method for Determining the Whiteness of Paper, II, Paper Trade Journal, 103, No. 8, TS 38; 1936.)

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THE OPTICS OF PIGMENTED FILMS

By G.F.A. Stutz, New Jersey Zinc Company, Palmerton, Pa.

This paper discusses films pigmented with white pigments; that is, those whose absorption is negligible in the visible range of the spectrum. The properties necessary in such white pigments to give maximum efficiency are first considered.

The efficiency of white pigments is in part dependent upon their having a high index of refraction, such that the difference in index of refraction of the pigment and of the medium in which it is dispersed, is large. For a fixed index of refraction, to have optimum optical efficiency, pigment particle size and uniformity should be such that the maximum surface is presented at the particle size which still reflects light, and the particles should be perfectly dispersed throughout the medium. Use of particles of larger size results in decreased efficiency. Use of particles of smaller size also results in lower efficiency, though this may be desirable in order to obtain other properties.

The optical properties of the films formed from white pigments; namely, color, brightness, opacity, and gloss are also discussed. It is pointed out that the definition of the color of white films is open to considerable controversy. It is suggested that color of whites may be defined on a physical basis, for example, defining a white as a film having nonselective spectral reflection. However, a demonstration is needed of the value of such a physical definition of color since it is related to the ability of the modern spectrophotometer to determine the same minute differences that are detectable to the eye. It is considered that the measurement of brightness by means of a modern reflectometer is entirely satisfactory. While opacity measurements are reasonably satisfactory, they are complicated and time-consuming. The relationship established by Kubelka and Monk between film thickness and opacity should be applied to such films and should be further extended to include the variable of pigment concentration. The measurement of gloss is quite complicated and it is suggested that only measurements peculiar to certain conditions can be satisfactorily made at the present time. No general determination of gloss appears possible.

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THE INDUSTRIAL SIGNIFICANCE OF COLOR MEASUREMENTS

By A. W. Kenney, E. I. du Pont de Nemours, Wilmington, Del.

The use of color measurements by industry has, in the past, been negligibly small due probably both to instrumental difficulties and to difficulties in interpreting physical measurements in terms relating to visual experience. In recent years, there has been striking progress towards overcoming both these difficulties, and industry must naturally be interested in the significance of this development. It is difficult, if not inaccurate, to form generalizations for industry as a whole. It may be convenient to discuss separately those industries which provide the customer with a finished colored product and those industries which provide a coloring material which the customer uses to impart color to other objects.

As to the value of the subjective and objective viewpoints in discussing color, it appears that the manufacturer of a colored product must be interested in the subjective viewpoint since his customer is concerned with the visual effect produced by the material in question. In controlling the color of products, therefore, physical measurements are of value insofar as and to the extent that they can be correlated with the appearance of objects as experienced visually. In this connection, it is to be noted that the eye is much more sensitive to small color differences which it can perceive simultaneously than it is to absolute color. This suggests that the manufacturer in many cases is more concerned about the closeness of color match to some previous lot or standard than to the precise maintenance of an absolute color. The common industrial practice of passing against a material standard is in accord with this idea. It is noted, in agreement with other speakers, that it is difficult to judge closeness of match (that is, relative color differences) from data expressed in the C. I. E. co-ordinate system.

The manufacturer of coloring materials is concerned with the considerations mentioned above because they indicate the practical use of his product by his customer, but he is less concerned with the appearance of his product for its own sake. Its important property is its ability to absorb, transmit, or reflect light selectively, and the maximum information on these points is provided by spectrophotometry. The adequate objective specification of a pigment, therefore, will not be in the form of tristimulus specifications but in its absorption as a function of wave length, particle size, and so on. Particularly in research work is the spectrophotometric approach helpful, for it gives nearly a complete answer to any question in physical terms concerning the interaction of material and light.

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TOLERANCE IN COLOR SPECIFICATION

By M. Rea Paul, Research Laboratories, National Lead Company, Brooklyn, N.Y.

The approach to this subject of Tolerance has been confined to the practical point of view of the manufacturer of paints, in an attempt to indicate the needs of the industry as concerns color.

The demand in paint specifications for extreme precision in the matching of "an agreed upon color standard" should, in most instances, be discouraged, rather than encouraged. This statement may sound somewhat revolutionary, but, as a matter of fact, precision in color matching in the paint industry today appears to be far in excess of the average commercial requirement.

Specification of color may take one of several forms. The most elementary is to specify color by name. It may be described as red, and then the character of the red made more clear by terming it light or dark, saturated or unsaturated. While this is extremely loose, as specifications go, it is quite generally used in describing the degree of departure of any color from an agreed upon standard.

Words are, at best, a poor substitute for a sample in specifying color, and yet they are, of necessity, employed. As an example, an instance might be cited in a recent consumer specification, where an attempt was made to designate the type of surface effect desired, as a "lively, velvet-like finish." While reasonably descriptive, it does not tend toward insuring that all surfaces under the specification would be similar by appearance. In the same way, specification of a color, if merely described by its general effect upon the eye, will not always conform to the desired requirements unless more precisely designated.

A second form of specification, infinitely more precise than the use of words, is to supply a sample of the color required. Some people would imagine this the most satisfactory and fool-proof specification possible to employ. For general purposes, this is true, but where high precision is necessary, standards of this type are only of use where the finished paint work is to be viewed under the same conditions of illumination as were employed at the time the match was carried out.

While precision, as such, should be conscientiously maintained in the preparation and retention of standards, the commercial specification should be founded upon tolerance and not precision. There are only a few actual instances where conditions are so carefully controlled in the painting work that high precision becomes an absolute requisite. Even though a paint has, with considerable care, been brought to a precise match against the agreed upon standard, the factors beyond the control of the manufacturer, which may influence, or appear to influence, the final appearance of a paint, are, needless to say, quite numerous. For instance, the extent to which a paint is stirred in the container prior to application; the varying degree of absorption of the ground over which it is applied; the character of the surface, whether it be rough or smooth; the character of illumination under which the paint is to be observed; the large area which the color occupies, as compared with the small standard chip, multiple reflection and the colors in the immediate vicinity; are all factors that play an important part in influencing the subsequent impression the color conveys.

In general, a specification should clearly state in some detail, the use to which a paint is to be put, in order that the manufacturer may be permitted a certain leeway or tolerance in the preparation of the color, and, on the other hand, incline toward greater precision where the need is evident. For general purposes, then, industrial users of large amounts of material should strive, wherever possible, to avoid the use of a single sample, save as a central or average point, and instead, should indicate the limits within which a color should fall in order to meet satisfactorily the requirements of the work in hand. This would save time needlessly spent in painstakingly matching standards that, in themselves, have often changed to a considerable extent. It would be successful in avoiding many disputes over rejected paints, where a small color difference that is apparent prevented the material from meeting the requirement in the specification that calls for a satisfactory match with the agreed upon standard.

Small color differences permissible under the tolerance type specification, would be equally satisfactory in probably ninety per cent of the instances where a careful match is now required. To follow this method of agreed upon tolerance limits with a prospective buyer, requires plus or minus notations established in terms of some instrument that will indicate extent or permissible departure from standard, in hue, in strength, and in degree of lightness or darkess, when viewed under illumination of a designated character. Instruments of use in this connection are readily available, and would serve a valuable purpose in specifications of this type.

Another, and more satisfactory method from the buyer's point of view, is to provide a group of color samples with which to establish the tolerance limits. To follow this method entails the use perhaps of more color samples than are available to the average consumer. Several large industrial groups have, however, already adopted this method as a basis for color specification involving tolerance limits.

It should be kept in mind that the above applies only to general specification work, and should not be confused with the precision necessary in the matter of retaining standards for use in the plant.

In communicating recently with a hundred manufacturers of paints and related materials, a very live interest was encountered in the matter of maintaining color standards. It appears that 20% of the manufacturers consider the method which they employ for the maintenance of standards to be quite satisfactory, 60% as only reasonably satisfactory, and 20% as unsatisfactory. From this, it would appear evident that there is opportunity for considerable improvement.

One of the points of interest reported by the manufacturers was the fact that approximately 25% provide for a further check on the standards they maintain, by measuring and checking by spectrophotometric means at regular intervals.

From the above, it would appear that all the manufacturer had to do would be to purchase some color measuring apparatus and his troubles would be over. This is far from true since maintenance of standards represents such a small percentage of the effort that is spent by the industry on color problems. While it is true that means are available for the measurement and description of color as such, there does not exist an appearance specification that covers the various characteristics by which dissimilarities between colors are readily appreciated visually. The need on the part of Industry for a means of describing and specifying appearance, is very great. Attention, therefore, to this aspect of color would prove decidedly worth while.

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