

Inter-Society Color Council *Newsletter*



NUMBER 222

January-February 1973

42ND ANNUAL MEETING

The 42nd Annual Meeting of the Inter-Society Color Council will be held at the Statler-Hilton Hotel, New York, New York, on Monday and Tuesday, April 30 and May 1, 1973.

On Monday, April 30, open meetings of the ISCC Problems Subcommittees will be held, in both morning and afternoon sessions. As in the past, members and friends of the Council are urged to attend. In addition to meetings of the established active Subcommittees, two new Subcommittees will meet for the first time. They are No. 33, Human Response to Color, and No. 34, Color Difference Problems.

The annual business meeting of the Council will be held on Tuesday morning, May 1, and will include the presentation of reports by Chairmen of Member-body Delegations as well as by Officers and Standing Committee Chairmen.

Mr. Richard S. Hunter, President of the Council, has arranged a symposium on "1973 Professional Education in Color for Art and Technology." Nine short papers will be presented in late morning and afternoon sessions, on topics describing the breadth of educational aspects of color, and education in color science, color in applied art, and applied color science. Printed abstracts of these papers, and the text of others to be read by title only, will be available at the meeting.

The reception and banquet of the Council will be held on Tuesday evening, May 1, as has been traditional except for last year's experiment. During the banquet, the Godlove Award will be presented to the 1973 recipients. The banquet speaker will be Mr. Ray Kicklighter, Head of the Learning Systems Laboratory of Eastman Kodak Company's Research Laboratories. He will speak on the subject of the use of color in education.

A final program, abstracts of symposium papers, and registration form will be sent to the membership in late March. Preregistration and the advance purchase of banquet tickets is urged.

DOROTHEA JAMESON HURVICH AND LEO M. HURVICH TO RECEIVE GODLOVE AWARD

Dorothea Jameson Hurvich, lecturer in psychology and senior research investigator and Leo M. Hurvich, Professor of Psychology, University of Pennsylvania have been nominated as the co-recipients of the Godlove Award for their work in the quantification of the opponent color theory of color vision.

The award is given in memory of I. H. Godlove by the Inter-Society Color Council for outstanding contributions to the subject of color. Presentation will be made on May 1, 1973 in New York City by Council President Richard S. Hunter at the annual banquet. The citation will be given by Ralph M. Evans, the second recipient of the award.

1974 MACBETH AWARD

The Macbeth Award Committee hereby solicits nominations for the 1974 Macbeth Award of the Inter-Society Color Council. Note that two sections of the Recommended Practice for the Macbeth Award pertain specifically to the selection of a nominee.

Award Qualifications

The Macbeth Award shall be given in recognition of recent important contributions in the field of color, preferably within the 5 to 10 years preceeding the Award. The work may concern a specific project, application, service or use of color, or other accomplishment related to color in science, art, industry, education, merchandising, etc.

The candidate need not be a member of the ISCC, nor be a citizen of the United States. The Award Qualifications and nomination letter shall be the basis for the selection of the nominees.

Macbeth Award Nomination

Nomination shall be made by letter from the Nominator to the Chairman of the Macbeth Award Committee, containing the name, address, and the affiliation of the Nominee, and discussion (with exhibits if appropriate) of his particular achievements or activities on which the nomination is based.

Nominations should be sent to the Chairman of the Macbeth Award Committee no later than June 30, 1973.

For the Macbeth Award Committee

W. J. Kiernan, Chairman
38 Beechwood Road
Florham Park, New Jersey 07932

Committee Members

Walter C. Granville
Melvin R. Johnston
Randall M. Hanes
John A. C. Yule

INTER-SOCIETY COLOR COUNCIL BOARD OF DIRECTORS MEETING, JANUARY 15, 1973

Approved Applicants for Individual Membership

Applicant

Member-Bodies and Interests

Miss Sue Bartfield
2035 North Lake Dr.
Milwaukee, Wisc.
53202

Professional artist -- working color engineer on development of new media for artists, emphasis on clean color. Writing book

on color correlating industrial developments in color for the artist.

Mr. Jack Hansen
School of Forestry
Univ. of Missouri
Columbia, Mo. 65201

ASP. Techniques in the analysis of color differences and their use on aerial photographs to identify plant communities.

Mr. John P. Horsey
Operations Manager
Darworth, Inc.
P.O. Drawer K
Avon, Conn. 06001

ACHS, FSPT, NPCA. Management, firm producing exterior stains. Formulation, color matching.

Miss Becky L. Love
156 SE-Aylesworth
Colorado State Univ.
Ft. Collins, Colo. 80521

Research Assistant in Department of Consumer Sciences and Housing, doing work in color and lighting as related to consumer

applications, educating consumers to use lighting efficiently and aesthetically in the home, and the effects of lighting and color in the environment.

Dr. János D. Schanda
1011 Budapest
I. Szonyeg u.1.
Hungary

Research in the field of measurement techniques, development of the MOM-COLOR colorimeter, spectrophotometry, color

rendering of light sources, lecturer on colorimetry and photometry. (Dr. Schanda is a renowned international expert and is active on several CIE committees.)

Mr. John M. Smith
Dye Quality Control
-- GAL

Spectrophotometric analysis and correlation to end use.

Du Pont Chambers Works
Deepwater, N.J. 08023

Mr. Peter Tytell
116 Fulton St.
New York, N.Y. 10038

Age of fountain pen inks, differentiation of carbon typewriter ribbons, differentiation of ball pen inks

by use of monochromatic light and photographic filters. Measurement and differentiation of colors on documents in situ, often involving small differences in blacks or whites.

Mr. Asao Komachiya
Niigata University
Faculty of Education
2 Asahimachi-dori
Niigata City, 951
Japan

Naming colors of dyed rayons, expressional values in pictures (for example "valeur"), and color schemes in convention varying with climates and nations.

The following information was received from new member-body delegates. These are not applicants for individual membership.

Mr. Brian John Addenbrook FSPT. Maintenance of Thornley & Knight, Ltd. colour standards, industrial colour matching.
Bordesley Green Rd.
Byrmingham B9 4 TE
England

Mr. Miles F. Southworth TAGA, GTA. Problems of photomechanical reproduction of color. Control of that reproduction. Color
Associate Professor
School of Printing
Rochester Institute of Technology
1 Lomb Dr.
Rochester, N.Y. 14623
Densitometry.

ERRATUM:

In the Addenda and Corrections to the Membership List published in the Fall of 1972, a very active member of our Publications Committee was listed as a "deleted member" of the Council. This inadvertent deletion was, indeed, regrettable. He has, indeed, been the right hand of your editor. This issue, in particular, was largely his doing -- for which I am very grateful.

R. W. Burnham, Editor



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REPORT ON THE AIC

The preparation of the 2nd AIC Congress in York is perfectly progressing under the direction of Prof. Wright. The response to the first circular was very promising with approximately 400 tentative registrations and 120 papers offered. The second circular will be distributed early in 1973.

Preceding Colour 73 a Congress on Photometry and Colorimetry will be organized by the Bulgarian Committee on Illumination in Varna (June 27-30, 1973). After the AIC meeting the following CIE Committees will meet in London:

TC-2.3 -- Photometric Characteristics of Materials (July 7-8, 1973) and

TC-1.3 -- Colorimetry (July 9-10, 1973)

The Austrian Colour Group (Arbeitskreis Farbe der OVE-OIAV Fachgruppe Messtechnik) has applied for AIC membership. The Canadian Society for Color in Art, Industry and Science has been founded in 1972 and it is hoped that it will also become a member organization of AIC.

The Secretary was corresponding with representatives from Bulgarian, Mexico, Poland, Czechoslovakia and USSR concerning membership of AIC.

The Dutch Group having organized the Helmholtz-Memorial Symposium on Color-Metrics in Driebergen in 1971 has edited the transactions of the symposium and presented copies to all participants. This book gives an excellent survey on the present state of color metrics and the Dutch Group is to be highly commended for the perfect publication.

E. Ganz, Secretary-Treasurer
International Colour Association

ISCC PROBLEMS SUBCOMMITTEE ON COLOR DIFFERENCE PROBLEMS TO BE LAUNCHED

The Board of Directors of the Inter-Society Color Council at its meeting in Newburgh, N.Y., on January 15 approved the formation of ISCC Problems Subcommittee No. 34, "Color Difference Problems." The inaugural meeting of this committee will take place during the coming ISCC Annual Meeting on April 30 in New York City. The purpose of this committee, chaired by Rolf Kuehni, is to define industrial color difference problems, to investigate the relationship of perceptibility and acceptability in small color differences, as well as to produce observational data suitable for the evaluation of color difference formulas as called for by the CIE Technical Committee TC-1.3 (Colorimetry).

A questionnaire is enclosed with this issue of the Newsletter, which will help the new Committee in determining its priorities. We urge you to cooperate in this most important subject.

OPTICAL RADIATION MEASUREMENT

The Council for Optical Radiation Measurement (CORM) has arranged its next meeting to follow the ISCC Annual Meeting. The CORM meeting will take place on Wednesday, May 2, 1973 at the United Engineering Building, 345 East 47th Street, New York. The meeting will start at 9:00 a.m. in the auditorium with the following program:

Morning:

Talks on documentary standards given by representatives of standard organizations.

Afternoon:

Technical program on detectors; two formal talks followed by discussion on measurement problems.

CORM is a body of American industrial, governmental and university scientists and engineers organized to facilitate the development of reliable procedures for the measurement of optical radiation. It is an activity of the U.S. CIE TC-1.2 Technical Committee. For further information call Mr. Ed Steeb, General Electric Company, Nela Park, Cleveland, Ohio 44112. His telephone number is (216) 266-2366.

SOCIETY OF PLASTICS ENGINEERS

The 31st Annual Technical Conference of the Society of Plastics Engineers will be held May 7-10, 1973, at the Queen Elizabeth Hotel, Montreal. The Color and Appearance Division will sponsor three sessions at the conference:

Tuesday Morning, May 8:

Moderator: Ralph Stanziola, Applied Color Systems

"Fluorescence and Colorimetry of Fluorescent Materials," Eugene Allen, Lehigh University

"Coloring of Plastic Materials with Fluorescent Dyes and Pigments," Joachim Richter, Farbwerke Hoechst AG

"Optical Whiteners for Plastics, Coatings and Adhesives," Geoffrey W. Broadhurst, Ciba-Geigy Corp.

"New Pearlescent and Interference Pigments -- Chameleons that Change with Package Content," Jules Pinsky, The Mearl Corp.

Tuesday Afternoon, May 8:

Moderator: Al Chapel, Michigan Plastic Products Inc.

"Advanced Production Spray Mask Painting," Harry Szczepanski, Thierica/Sepanski Inc.

"Finishing of Plastics," Roger F. Hruby, Bee Chemical Co.

"Assembling Large Parts Ultrasonically," Jeff Sherry, Banson Sonic Power Co.

"Washing Paint Masks Without Solvents," Charles G. Fossati, Service Tectonics Inc.

"Vacuum Metalizing," Charles D. Storms, Red Spot Paint & Varnish Co.

"Meeting Contemporary and Future Finishing Processor's Spray Application Needs," Howard P. Miskill, Finish Engineering Co.

4:30 PM -- Annual Business Meeting of the Color and Appearance Division.

Wednesday Morning, May 9:

Moderator: Richard Chenowith, Marbon Div., Borg-Warner Corp.

"Sears Coordinated Color System," Robert A. Hillman, Sears Roebuck & Co.

"Application of Contact Microradiography to the Study of Dispersion of Titanium Dioxide Pigment in Solids," C. G. Waterfield and J. Peacock, Tioxide International Ltd.

"High-Temperature Synthetic Inorganic Pigments," Norman Napier, Shepherd Chemical Co.

"Pigment Coloring of Melt Spun Synthetic Filament and Fiber Products," S. Leonard Handen, Hercules Inc.

For further information about the ANTEC, contact Ken Galione, SPE, 656 West Putnam Ave., Greenwich, Conn. 06830.

HUMAN FACTORS

Members of the ISCC are cordially invited to attend and participate in the 17th Annual Human Factors Society Convention to be held at the Marriott Twin Bridges Motor Hotel, Washington, D.C., October 16-18, 1973. Due to unavoidable planning delays, the due date for submission of material from interested participants has been postponed from March 1 to May 1.

For information write to:

A. Carl von Sternberg
Essex Corporation
303 Cameron St.
Alexandria, Virginia 22314

BRITISH COLOUR GROUP

Report on the 89th Meeting in November, 1972. Colour Systems and Colour Scaling -- R. J. Hawkes

(This paper has already been published elsewhere: Art, 2/1, Nov. 1971, pp 16-22.)

Dr. Hawkes prefaced his talk by saying that the results of some of his experiments suggested that, unlike the three dimensional definition of colour by the Munsell system, colour could, in fact, be perceived in a two dimensional manner and that differences between colours are not necessarily seen in terms of hue, value and chroma. He said that the specific objectives for a successful colour system stated by Judd (Colour in business, science and industry) were too demanding and (as stated in his paper) "may be mutually exclusive." In an earlier paper (*J. of Architectural Research & Teaching*, 1, (2) 1970, pp 34-45) the author used the method of multi-dimensional scaling to examine the way in which people judged the acoustics of concert halls and a number of authors had seen the applicability of the technique to colour scaling and colour systems.

Using conventional techniques, when a naive observer is asked to give a subjective rating of a series of coloured chips, he would use such words as, say, "dim" at one extreme to, say, "bright" at the other. For an objective rating, again using conventional techniques, the observer would seek to find objective criteria where the same rating is obtained as in the subjective rating.

Agreement between the results from the subjective and objective ratings would be a measure of the success of such a correlation technique.

Multi-dimensional scaling was used on the results from two experiments with different subjects, "all naive, with respect to colour experiments." In the method of diads subjects were presented with all possible pairs of colour chips and asked to make a numerical judgment -- using their own set of numbers -- of the magnitude of the difference between the members of each pair. In the method of triads the same data was derived statistically from two judgments on each of all possible trios of colour chips. The judgments were: which two colour chips are most different, and which two are most similar? The ten coloured samples (150 mm x 100 mm) were chosen by an independent judge to be "as varied as possible" and ranged in Munsell Value (3 - 8.5) Chroma (3 - 12) and Hue. The resulting matrix from the method of diads was formed from "judgments of difference" in which greater differences are indicated by larger values. The matrix from the method of triads was formed from "judgments of similarities" in which case the larger values indicate smaller differences. When the results are plotted using % stress/dimensions axes, where the stress value is defined as the degree to which the computer is able to obtain a pattern of points to agree with the empirical data, then the resulting curves (for diads and triads) are seen to be in close accord and the maximum inflection is at two dimensions in each case.

When the configurations of points in psychological space are plotted, there is a close correspondence between the configurations from diads and triads experiments, and colours occur in general accordance with the Munsell circle -- with only one small inversion from one of the experiments. The actual geometric shape of the plot approximates to an ellipse, where the displacement from the centre is NOT related to Munsell value or chroma.

It is suggested then, that only two dimensions are necessary to enable an observer to judge differences in the colour of the ten samples which varied on all three Munsell co-ordinates. It may be, that with naive observers, some differences may be totally ignored or differences in two dimensions combined into differences on a single dimension, and therefore such a two dimensional system for colour perception may not be adequate for colour specification.

Further, the radial positioning of colours as subjectively determined by these experiments shows some difference to the positioning by the Munsell system. Apart from the one inversion mentioned above, those hues which are accepted as complementaries are no longer diagonally opposite. If the colours are listed in order of radial displacement, there is seen to be no association between their positions in the configurations and their Munsell chroma. However, when the colours are arranged in a series of increasing distance from the centre, subjects perceive the series as one of increasing "saturation" of "strength of colour" -- giving the second dimension to hue.

During discussion, the author was referred to the procedure by Judd whereby an observer starting at one dimension moves to two dimensions and finds difficulty in moving to three dimensions and that perhaps just two more appropriate colours added to the author's selection of chips might increase the number of dimensions. In reply, the author expressed his interest in analysing such a new range.

The analogous example of objects having the same area but different shapes was brought to the author's attention and that such a situation would not be identified by his analysis. The author said that area if per se was important it would be perceived as a single dimension, but if individual length and breadth, was important they would be perceived as two independent dimensions.

It was suggested that two dimensions cover most of the information and an extra dimension does not necessarily contribute extra information pro rata.

M.B.L.

A Revised Neutral Axis for the Assessment of the Colour of Papers -- D. J. McConnell

The author described his further work in which his "line of best whites" has been examined for coloured papers at lower reflectance levels.

Two assumptions were made. Firstly, the L, a, b colour space used is based on the Glasser Cube Root system but with the "L" scale proportional to blue rather than green reflectance; this results from the paper industry's preference for brightness measured as a function of blue reflectance. Secondly, changing from Illuminant C to D65, and from 2° to 10° observer, did not significantly effect his results described below.

Previous work by the author had shown that for tinted papers, the line of best whites, or observer preferred neutrals, did not agree with the traditional achromatic axis, since the position of the line appeared to be dependent upon the blue reflectance of the sample. This Preferred White Line has been used by the author's company to describe whites and tints having blue reflectance levels above 50%. The line works well for papers containing fluorescent whitening agents. Extending the Preferred White Line gives the anomalous situation where best neutral greys are yellow which the author overcomes by the arbitrary "bending" of the neutral axis from yellow to neutral black.

One anomaly of L, a, b systems is that the "a" axis measures redness/greenness, but true red and green are off this axis in the yellow-red and yellow-green sectors of the colour space. Using the "bent" neutral axis seems to overcome this phenomenon and makes the description of colour in this modified L, a, b space even more acceptable to the layman's understanding of colour.

When a set of paper dyeings were judged by observers in hue terms, the pattern obtained, plotted in Glasser Cube Root space, fitted the normal pattern for L, a, b space, with respect to the anomalous "a" axis. Use of the arbitrary neutral axis corrected this.

A further experiment was described in which observers were used to compare the strength of a range of blue dyed samples with yellow dyed samples. The locus of points plotted for the normal Glasser Cube Root space gave an ellipsoidal shape which converted to a circle when using the revised neutral axis.

Hence both visual colour description and visual strength assessments appear to be more meaningful when expressed in a colour space using this new axis.

It would appear that use of the axis expands the red/yellow/green regions of Glasser Cube Root space and contracts the green/blue/purple/red regions, which,

the author suggested, agrees with Dr. Hawkes' contention that the Munsell spacing should be corrected. During discussion, the Preferred White Line was defined by the author as:

$A = 0, b = 0.36 (80 - B)$, where B is percentage blue reflectance. The minimum blue reflectance for this expression was given as 50%. Below that level the arbitrary "kinked" line was defined as: $a = 0, b = 10.8 L/75$ where L is dependent upon the blue reflectance. Further, it was agreed that, despite the "kinking" of the axis, the a/b planes remained parallel.

M.B.L.

Report on the 90th Meeting in December, 1972. Colour as an Aid in Primary Schools -- M. Hollyfield

Mr. Hollyfield introduced WORDS IN COLOUR, a system for learning to read using a battery of techniques, film, chart, question and answer, and so on. The system consisted of colour coding the different letters of the alphabet and groups of letters that stood for phonetic sounds in English and in certain other European languages. It had been designed by Dr. Caleb Gattegno to overcome the special difficulties in coping with the many phonetic anomalies of English, and was presented in such a way that the learner might progress independently of the teacher. Colour systems had not only been used extensively in learning to read, write and speak foreign languages, especially French and Spanish, but also in learning mathematics with the Cuisenaire system. These systems had been widely adopted in the reorganisation of the ghetto schools of New York.

In spite of the colourfulness of WORDS IN COLOUR the lecturer insisted that he was not concerned with aesthetics. He compared the ease with which one learned to speak with the difficulty in learning to read, which he argued, might well have been expected to have been easier. A chart demonstrated how different colours were assigned to phonetic sounds in such a way that no matter what letters were used to stand for particular sounds, they always had the same colour. The reasons for the attribution of the specific colours used for each sound were not explained, and seemed arbitrary, but the lecturer did demonstrate the unique properties of the system, and dealt with the vowel correspondences at length.

Colour Theory for Very Young Children -- Eileen Graham

Miss Graham showed how a child looked at the outside world and interpreted it from within; how colour and light, for example, affected a child's inner eye. However, the aesthetic faculty is soon broken down by the

conditioning of bad teaching. More play with colour might help to redress the balance, and lead to discoveries that posed questions. The world of colour might be explored through toys or books, so that a child might play with the parameters of colour and discover what is possible; afterwards beginning to relate things together. Eventually a child might play with a full range of colours, very dark, very light, neutrals, and so on, helping him to become more able to cope with the objective world. Kits could present rainbows, prisms, white light, the spectrum, and even go so far as to deal with pigments, the extraction of dyes, or yet again, encourage children to discover how colours are applied in, say, works of art, or how they relate to biology, photosynthesis, etc. In fact this could be for parents as well as children. The primary stage might be covered with modular toys, and the secondary with, for example, domestic furnishings. Many materials might be brought into this, perspex, opaque and translucent, additive and subtractive filters, weaving and ceramics.

Phase 1 was represented by toys, and it was Miss Graham's contention that as children played with the coloured objects they would ask questions which would lead to learning more about light and the basic essentials of colour, something, too, of the complexities and contradictions in colour-learning. It was thought that this would generate an enthusiasm for the whole subject of colour.

Phase 2 was more secondary, and at this level, specialish lessons in physics and chemistry, for example, as well as art, would make available apparatus so that experimentation might be developed in depth.

Miss Graham was not able to demonstrate any of the kits as they had not been cleared for publicity by the prospective manufacturers.

Colour Dimensions and Systems and Visual Apprehension -- Enid Verity

The reasons for learning about colour are diverse. Classification can be quantitative or qualitative, scientific or perceptual. The drive to give order to visual perception from random to structured was part of human experience. Mrs. Verity's talk was structured around 20 charts she has designed for teaching colour theory in secondary schools, art schools and teacher trainer colleges. The charts illustrated the development and theory of colour systems and their applications, and colour theory relating to light mixtures. The talk took the form of brief answers to prepared questions about the information contained in the charts and concluded with a quotation from Professor Wright's "The Rays are not coloured."

Structuring Colour in Paintings -- Alan Cuthbert

Mr. Cuthbert, a well-known painter who is also an educationalist, described his own paintings, and his attitudes towards colour usage, though he only incidentally referred to the teaching of colour in schools of art. He aimed at clarifying the stages in the process of controlling the colours of an artist's palette and arriving at the final colour structure in a painting. This was what, in his own paintings, he wished to be a visually satisfying and coherent arrangement of colours.

After a brief historical build-up from Neo-Impressionism to Constructivism and to Op Art, Mr. Cuthbert gave a fascinating evaluation of the inter-related networks of numerical proportioning, especially of the desaturation scales in the colour-structuring of his own paintings. These involved areas of colour organised in non-representational shapes and lines, mainly geometrical and rectilinear. Power of shape was complemented by rigorous selection of colours according to thoughtfully contrived progressions through the colour solid, giving each painting its own peculiar emotive restraint and a strangely compelling unfamiliarity. The audience became absorbed in following the painter's attempts to rationalise a process where judgments are ultimately subjective.

Donald Pavey

Report of the 91st Meeting of the Colour Group in January, 1973

The first paper entitled "Tests of the C.I.E. Colour Rendering System" by D. A. Palmer, M. B. Halstead, D. I. Morley and A. G. Stainsby was presented by Dr. Palmer. He began by outlining the work of the C.I.E. Colour Rendering Committee on their system for assessing colour rendering and explained that he and his colleagues had felt it necessary to carry out tests on the system even though these should have been done before the system was established.

The C.I.E. system uses a single number index based on eight samples to express the general colour rendering properties of a lamp compared with those of a reference standard but a special index can be determined if only one sample is assessed. A series of eight Munsell samples of medium value and chroma are used for determining the general index and their spectral luminance factors are specified so that the indices can be obtained solely by calculation.

A reference standard having a correlated colour temperature close to that of the test lamp is chosen and this enables a simple correction for chromatic adaptation to be included in the calculation of the index. The average chromaticity shift for the eight

specified samples, when the test lamp is replaced by the standard, is multiplied by a weighting factor and subtracted from 100 to give the general index. The values for most fluorescent lamps lie between 50 and 95.

The original aim of the authors was to determine by visual experiment the smallest difference between the general indices for two lamps which could just be detected. However, Dr. Palmer admitted that they had failed in this aim although they had been successful with the special indices.

The experiments used a viewing room which was divided into three parts by means of venetian blinds. The centre section (or booth) was used for displaying the number scale in which the observers were asked to assess the differences of similar samples placed in the outer booths illuminated by various lamps. The samples selected were the C.I.E. Munsell samples so that the visual observations could easily be correlated with the physical measurements. A series of fluorescent lamps of the same correlated colour temperature viz 4000K, but different colour rendering properties was used. Each observer sat in the centre booth and was asked to judge the difference of the samples in terms of the scale, where 0 = no difference, 1 = just noticeable difference, 2 = noticeable difference and 3 = clearly noticeable difference. A large number of the observers took part each of whom judged four lamp pairs, and all possible lamp pairs were presented to them in random order. The results from different observers for each sample under each lamp pair were averaged.

The analysis of the results presented some difficulties and Dr. Palmer explained that it was not possible or desirable to describe all the methods which had been tried. The physical measure, for instance, was complicated because the C.I.E. method involved a reference standard which was not physically realisable. The authors had found that it was better to use a measure, β , based on the colour shifts of the samples illuminated by the pairs of lamps, a correction for adaptation being included.

The average visual scores when plotted against β showed correlations which were not straight lines. Also, comparison of similar lamps showed that a number of observers recorded a difference even when there was physically no difference. Dr. Palmer described a method of analysis for dealing with this problem. The main point was that since the scale used by the observers did not allow the direction of the difference to be recorded, the results did not form a normal distribution, that is, the tail of the curve to the left or negative side of the origin was folded over onto the positive side. The effect of this could be allowed for by determining the width of the expected normal distribution for each sample from the results of comparisons of similar lamps. Statistical tables then enabled theoretical curves to

be drawn which showed the relation between the observed score and the value that would have been obtained if the distribution had been normal. The observed scores were converted into mean scores by means of these curves and the mean scores showed straight line correlations when plotted against β . A mean score of 1 denoted a just noticeable difference and values of β corresponding to this were read back from the curves.

Dr. Palmer concluded by saying that he had previously been somewhat suspicious of statistics but he admitted that it was essential to use these techniques when dealing with psychophysical threshold experiments which by definition involve small differences between stimuli.

The second part of the meeting was devoted to a paper by Dr. A. M. Marsden on "New concepts in visual performance." Dr. Marsden said that the brief given to him was to describe and explain C.I.E. Publication 19, "A Unified framework of methods for evaluating visual performance aspects of lighting." This was virtually an impossible task considering the size of the document, which he showed to members, and so he had decided to restrict his talk to the general philosophy and terminology of the document and leave details for the discussion.

The scope of the responsible C.I.E. Committee was "to study visual performance as a function of the lighting conditions and to provide guidance in use of such information for lighting recommendations." In other words, it was to provide a bridge between the visual scientists and the lighting code makers by digesting and relaying all relevant information.

Two alternative ways of dealing with its brief occurred to the Committee. One was to gather a collection of information on the performance of real and simulated tasks with notes on the special requirements of young and old people. The alternative was to try to devise a comprehensive method from first principles of evaluating the performance that would be expected from a normal population under different lighting conditions. The committee under Professor Blackwell chose the second way but hoped to deal with abnormal conditions later.

Performance may be measured at four different levels:

- (a) productivity -- this includes mechanical effort;
- (b) visual productivity -- this removes the mechanical component;
- (c) visual performance capability -- this deletes effects such as training, fatigue and motivation; and
- (d) visual performance potential -- this removes the oculomotor and visual information processing effects. The C.I.E. framework commences with (d), works up to (c) and goes some way towards (b).

A question that must be asked is whether or not there is a fundamental characteristic of vision that relates visual performance potential to lighting and the C.I.E. report says that there is. The simplest visual task is detection of a circular blob, and the most obvious seeing measure is threshold. Blackwell has carried out a number of experiments using a four minute diameter disc in a uniform field exposed for 1/5 second and shown that the plot of log (contrast) against log (luminance of background) for 50% probability of detection produces an exponential type curve. If the size or shape of the object, the exposure time, or the probability of detection are altered, the shape of the curve remains the same. (Thus relative contrast sensitivity (RCS) as a function of luminance is a fundamental characteristic.) A point which lies above the threshold curve represents a suprathreshold condition and the degree of suprathreshold is usually stated in terms of contrast.

A family of curves parallel to the threshold curve can be produced and these are called visibility levels. The VL value for any curve is the contrast multiplier which is needed to obtain the curve from the reference threshold level.

However, Dr. Marsden pointed out that lighting recommendations are made for actual situations, e.g. office tasks, not for four minute discs. Such real tasks can be assigned a value of equivalent contrast by using a visibility meter. In such a device, the task is illuminated under standard conditions and the amount of a veiling luminance which has to be added to reduce the fine detail to threshold is determined. The task is then replaced by a standard four minute disc of variable contrast and the contrast is found for which the same veiling luminance reduces the disc to invisibility. Task analyses of this sort enable different luminance values to be prescribed for a variety of tasks so that they all have the same visibility level.

Visibility level is a new concept to code makers who are used to terms such as visual performance which equals accuracy x speed and which evaluates visual performance capability. The relationship between visibility level and relative visual performance (the fraction of the maximum performance that could be obtained with unlimited light) has been determined for experiments carried out by a number of workers and approximate to a single curve, from which it is possible to determine the visibility level for a required value of relative performance.

However, this relates to "integrating sphere lighting." Real lighting is different, e.g. there are directional effects, and visual performance is modified. In the real environment, three factors have to be considered.

1. The geometry of the light on the task affects the equivalent contrast and is quantified by the contrast rendering factor. A visibility meter is used to

determine the ratio of the contrast of the detail of the task and its background under the particular lighting system to that under a reference lighting situation. A slight reduction in contrast is equivalent to a large change in luminance and this is the most important of the three factors which have to be considered.

2. The surrounding field of the task can cause disability glare when the sources of light are badly placed. The effect is analysed in terms of veiling luminance compared with a reference system to give the disability glare factor.

3. Again the surround to the task can cause transient adaptation effects when the eye looks away from the task and these effects are quantified by a factor which expresses the ratio of the relative contrast sensitivity for the practical situation to that for the uniform reference field.

The resultant of these effects is that performance in real installations only corresponds to that under a much smaller value of diffuse lighting.

Finally, Dr. Marsden said that the C.I.E. framework still has a lot of holes in it. Work is needed on the requirements for different age groups -- most of the studies are based on 20-30 year old subjects and it is known that at 50 years, there is a dramatic change in the shape of the relative contrast sensitivity curve. Also, most of the tasks used to date have been black and white and research on coloured tasks is needed. The requirements for three dimensional tasks need exploring as the effects of shadow and specularly are important in real situations. More data on actual tasks and interior lighting situations is required so that eventually the C.I.E. framework will provide a comprehensive guide to all lighting situations.

M. B. Halstead

2nd Symposium of the International Research Group on Colour Vision Deficiencies

28-30 June, 1973, Edinburgh, Scotland. Symposium fee £ 20, accompanying persons £ 9, symposium dinner £ 4. Accommodation: Daily rate per person, University Halls of Residence, Dinner, Bed and Breakfast £ 3; Hotels, Bed and Breakfast only £ 3-15.

There are trains between Edinburgh and York on Sunday, 1st July, to connect with the A.I.C. meeting.

The papers are too numerous to list but the following will chair the various sessions:

Methods of Examination

Generalities and macular vision, I. Schmidt
Generalities and macular vision, L. M. Hurvich
Peripheral vision, L. Rositani-Ronchi

Congenital Defects

Functional aspects, M. Richter
Spectral luminosity and colour mixture functions,
mechanism, R. A. Weale
Psychological approach, R. W. Pickford
Genetics, H. Kalmus

Acquired Defects

Effects of illumination, R. Fletcher
Pathology, W. Jaeger
Pathology, W. S. Foulds

Practical Aspects, H. Schober

Two full day outings to the Scottish countryside have
also been arranged for the accompanying persons.

Full details from:

R. S. Sinclair
Department of Chemistry
Paisley College of Technology
High Street
Paisley, Renfrewshire

TEXTILES IN AN AGE OF TECHNOLOGY

NEW BERN, N.C. -- The newest of textile fiber
installations in this old Dutch town points to the
direction in which the textile industry is headed.

After a 10-year period in which capital investment in
the industry was concentrated mostly on older methods
of output, an era is emerging in which an unbelievable
amount of brainpower is being focused on new methods.

The Texfi fiber plant here, a 300,000-square-foot
installation producing textured yarn, is a prime ex-
ample of what the combination of energy, ingenuity
and solid planning can do.

Texfi's scientific approach includes the financing and
development of electronic scanning and computeriza-
tion of pattern designs on doubleknit machines as a
tremendous step forward in providing new fabrics for
fashion apparel.

After operating less than a year, the plant has already
justified its \$24-million investment, turning out 20
million pounds of yarn, most of which is texturized.
In this process the extruded filament is drawn out and
twisted into a product that has stretch characteristics
so necessary to the modern need for long-wearing
men's slacks, jackets and women's and children's
sportswear, dresses and other outerwear.

Texfi's work in the field of pattern design has brought
another new dimension to knitting and knitted
apparel. Louis Cramer, executive vice president,
supplied a demonstration of the company's "Response"
system of high-speed scanner-computer design
sampling.

Similar optical scanner systems are in various
stages of development by knitting-machine manu-
facturers, including Sulzer Brothers, Inc.; Mayer &
Cie; Wildt Mellor Bromley; Bentley Group, Cie;
Dubied & Cie.; Lebocey & Cie.; Spiesman Industries;
Inc.; Stibbe International and the North American
Rockwell Corporation.

The Response system has advanced further than the
others in transferring creative designs from paper to
fabrics in a matter of minutes or hours, eliminating
tedious design steps that took weeks.

The Response is a spinoff of advanced technology
perfected in aerospace optics for the Israeli Air
Force. The textile application was developed by a
task force headed by Dr. Efraim Arazi in Rehovat,
Israel, under an 18-month research project funded by
Texfi.

At present the system can produce a new design every
10 minutes. A design blocked out on mylar graph
paper is picked up by the scanner through a projected
light ray that reads or senses up to six colors. Then
the design is transferred to a computer, which in turn
puts it on tape.

The tape acts as a sampling medium and its punched-
out design can be picked up by a mini-computer
attached to a doubleknit machine, which knits a sample
length of several yards.

The design can also be scanned by a black and white
television camera that soon will be replaced by a color
camera. The camera, it was said, will free the design
staff from the laborious hand-painting of mylar graphs,
each of which now takes an average of 16 hours to
prepare.

The color camera will allow designers an instantaneous
view of the fabric in various colors, and make possible
32 gradations of color for each of the six basic tones
now available.

The company's lines can now be turned around 10 to 12
times a year, in contrast with the old concept of a
four-season turnaround.

As opposed to weaving, the technology of knitting has
burst forth as a significant source of fabric for the
apparel trades. Knitting's growth is reflected in the
output figures. In doubleknits alone, there has been a
ten-fold increase since 1965 (from 62 million pounds
to more than 600 million).

This rise has been spurred by the greater availability of textured yarn, the consumption of which has jumped from 110 million pounds to about 900 million.

Herbert Koshetz

Reprinted from The New York Times, 1/7/73
(Italics added)

BOOK REVIEWS

NOTE FROM THE EDITOR

DEANE JUDD'S full review of MacADAM's SOURCES OF COLOR SCIENCE is enclosed as a separate with this issue of the Newsletter, No. 222.

In the March-April 1972 Newsletter, No. 217, appeared a review by Dr. Judd of the MacAdam selection and editing of a recent MIT publication, SOURCES OF COLOR SCIENCE. This was a fairly long and thoughtful review of material basic to color science.

Since Dr. Judd's death, in sorting and cataloguing his papers, Dorothy Nickerson has found the original draft for this review. It was a long one -- 37 typed pages -- but one that she found so interesting that she forwarded it to Dr. MacAdam who, in turn, found it interesting enough to copy and show to your editor. Both of us, and Miss Nickerson, think that Judd's comments on the papers included in the book contain valuable insights that were lost when the report was cut down to the seven pages he submitted for publication.

Therefore, believing that the uncut report should be made available to Newsletter readers, your editor has decided to publish the complete draft as a separate to be enclosed with this Newsletter.

This is one among the several last color projects to which Dr. Judd turned his attention during his final illness, and serves to illustrate how very keen and observant his color interests remained to the very end.

R. W. Burnham, Editor

Anni Berger and Andreas Brockes, "Color Measurement in the Textile Industry."
Farben Revue, Special Edition 3/1 by Dr. Anni Berger and Dr. Andreas Brockes,
Farbenfabriken Bayer A. G. Leverkusen,

Germany, 60 p., August 1971 (available in the United States from Verona Division of Baychem, P.O. Box 385, Union, New Jersey 07083)

This extensively revised reprinting and updating of the superb introduction to color measurement by the well known German pair of experts is, like its predecessor, an outstanding publication. While addressed to the textile industry its basic information is useful in all industries dealing with the measurement of colored materials.

In the brief space of some 60 pages it attempts with a high degree of success to provide a sound introduction to the principles of colorimetry, a review of existing instruments for color measurement, an outline of principles of computer color formulation and color difference equations, and the measurement of fluorescence and whiteness.

As compared with the earlier version printed in 1964, the new edition places more emphasis on the requirements for computer color matching. This is discussed briefly but with sufficient detail to permit one to judge whether such techniques are applicable to the problems in one's own laboratory. The discussion of practical experience and limitations while brief are also sufficiently detailed to be useful.

The literature references have been brought up to date through 1971. References to new instrumentation include a discussion of some European instruments not yet available in the United States, but all the well known instruments are included; not only spectrophotometers, but also colorimeters. Photographs (in color) of some of the newer instruments are a feature of this edition.

The reviewer considers this revised version not as a replacement for the earlier edition but more as a supplement. It is impossible in the small amount of space (60 pages) utilized in this brochure to give ample consideration to all of the subjects and in this newer edition some extremely useful discussion has had to be omitted, for example the discussion of the Derby method of color matching.

This edition is beautifully illustrated in full color of remarkable quality. It is highly recommended that anyone with an active interest in color measurement obtain this new edition to add to the earlier version. The authors, Dr. Berger and Brockes are to be congratulated.

Max Saltzman
Manager, Color-Technology
Allied Chemical Corporation
P.O. Box 98
El Segundo, Calif.

MEMBER GROUP CHANGES ADDRESS

The new address of the Industrial Designers Society of America will be:

1750 Old Meadow Road
McLean, Virginia 22101

Tel. (703) 893-6995

The Industrial Designers Society of America is the national professional organization of industrial designers and is composed of consultants, industrial designers employed by major corporations, educators and students.

PRODUCTS AND SERVICES

R.I.T.'s Photography Summer Session Program

Twenty-one college credit photography courses that cover a broad spectrum of areas in the photographic arts and sciences, will be offered by Rochester Institute of Technology's 1973 Photography Summer Session program which starts June 25. The majority of the courses will be offered during two five-week sessions from June 25 to July 27, and from July 30 to August 31.

Further information on the 1973 Photography Summer Session program is available by writing: Dr. David E. Hooten, Director, Summer Session program, Rochester Institute of Technology, One Lomb Memorial Drive, Rochester, N.Y. 14623, or by calling (716) 464-2205.

Hunterlab Appoints Representative in Canada

Hunterlab, of Fairfax, Virginia, a manufacturer of instruments for the measurement of color, gloss and other attributes of appearance, announces the appointment of J. B. Atlas Company of Rexdale, Ontario as its exclusive representative in Canada effective February 1. The J. B. Atlas Company is prepared to furnish literature, technical information, demonstrations and maintenance on the Hunterlab colorimeters, glossmeters and other equipment. It can also arrange to use the services of the Hunterlab Appearance Measurement Laboratory in Fairfax. The J. B. Atlas Company is located at 44 Fasken Drive, Rexdale, Ontario (Phone: (416) 677-5156).

Kollmorgen Corporation

Norman Macbeth, Chairman of the Board of Directors, and Richard Rachals, President of Kollmorgen Corporation, 60 Washington Street,

Hartford, Connecticut, have announced the company's expansion of its organization, investment and color production control in science, business and industry.

Recently, Kollmorgen through its Munsell Color Division, concluded a license agreement with the Graphic Arts Technical Foundation in Pittsburgh to produce and provide its members, on or about January 1, 1973, with a Kollmorgen-Munsell newly developed color order system designated as the "Foss Color System." This new and patent applied for system will enable a printer to print sets of color charts in such a way as to calibrate his total printing system from photographic separation to ink on paper. These charts in fact characterize in an orderly manner the particular printing house's color gamut and are useful for selection of colors, exposure control and means for the prediction of the color fidelity of the reproduction compared to the original. Such a printing calibration procedure which provides process variable control information is believed to be the route to semi-automatic off-line color control followed by on-line color control. Statistical studies are being conducted on normal color variations in printing as related to buyer or customer color acceptability. Such a study when completed is expected to provide the means for buyers and suppliers to specify practical color tolerances of printing quantitatively with measuring equipment under development by Kollmorgen.

The recent color technology research and development progress, together with the growing market opportunities, have advanced to a point where the company's expansion and reorganization plans are being implemented and announced as follows:

A new division of Kollmorgen Corporation has been formed as of September 1, 1972 wherein the expertise of the people in marketing, production, engineering, research and development from four former divisions, specifically, Macbeth Division, Color Systems Division, Macbeth Research Laboratories and the Munsell Color Division can be maximized to accelerate color technology conversion through accelerated product development, improve customer services, coordinate and expand marketing and gear up to meet the real challenge of the aforementioned growth opportunities.

The new division's name is "Macbeth Color & Photometry Division," with Mr. Lewis A. Curtis as its President, who reports to Mr. W. B. Reese, Vice President of Kollmorgen Corporation. The key people of the four former divisions have developed the reorganization plans and are jointly and fully responsible for the operation of the new division which will be housed in two buildings consisting of 87,000 sq. ft. located in Newburgh, New York with about 225 employees. Among the members of the new division are: C. James Bartleson, Vice President for Research; C. S. McCamy, Director of the Research Labora-

tories; A. J. Blanc, Vice President -- Sales; Boris Momiroff, Vice President -- Engineering; Miss Ruth Johnston, Manager of Applications and Hugh R. Davidson, Software and Applications Development. In addition, Dr. George P. Bentley is Group Vice President for Science and Technology, and Carl E. Foss is Group Vice President for Color Cartography and will be associated with the new division as well as the other divisions of the Macbeth Color and Photography Group.

Diano Acquires Martin Sweets Instrument Division

Announcements have been made that Diano has purchased the Instrument Division of the Martin Sweets Company for an undisclosed amount of money.

The Instrument Division of Martin Sweets Company manufactures electro-optical instrumentation with primary applications in the paper and graphic arts industries. In addition, it imports Rheological equipment for measuring viscosity and flow properties of fluids and semi-solids used in paint, plastic and medical applications. As part of Diano, the business will be retained in Louisville and will become the Midwest Technical Center of Diano's Optical Systems Division.

In addition to this new acquisition, Diano is further expanding its service capabilities for its optical products by the recent addition of factory trained company service engineers in Raleigh, North Carolina; Dallas, Texas; Des Plaines, Illinois; and Bedminster, New Jersey.

Diano operates two divisions: the Optical Systems Division based in Mansfield, Massachusetts, and the Industry X-Ray Division based in Winchester, Massachusetts. In addition, it has sales and service offices in fifteen other cities throughout the United States and one in Bovingdon, England.

For further information write:

Diano Corporation
75 Forbes Boulevard
P.O. Box 346
Mansfield, Mass. 02048

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NOTE:

The Council promotes color education by its association with the Cooper-Hewitt Museum. It recommends that intended gifts of historical significance, past or present, related to the artistic or scientific usage of color be brought to the attention of Christian Rohlfsing, Cooper-Hewitt Museum, 9 East 90th Street, New York, New York 10028.

Sources of Color Science

by David L. MacAdam

(The MIT Press, Cambridge Massachusetts, and London, England, pp. x, 282, 1970)

Reviewed by Deane B. Judd

When I was asked in October 1970 to review this book, I was glad to agree to undertake it, but because of illness I was prevented from fulfilling this commitment. When Dr. Burnham renewed his request more than a year later, I was doubly glad, first because I have recovered enough to complete this assignment, and second because I welcome the chance to support Dr. MacAdam in his unique tutorial project. I think he has done color science a great service by selecting excerpts from the writings of those who have shown the greatest insight into the mysteries of color, editing them by incorporation of modern (1970) terminology, and arranging for publication of this compilation in a most legible and attractive format by the MIT Press. Dr. MacAdam has done his best to resolve the contradictions among these basic views, and has left them in a form that encourages the reader to attempt his own resolution of them.

The excerpts were taken from 26 different publications by 15 authors. The importance attributed by Dr. MacAdam to each author may be judged by the number of pages devoted to excerpts from his writings. Schrödinger was granted 60 pages, followed by Guild (47), v. Kries (26), Newton (24), Polyak (23), Maxwell (22) and v. Helmholtz (17). The remaining eight authors in chronological order are Plato, Aristotle, Palmer, Young, Grassman, F. E. Ives, L. F. Richardson, and Le Gros Clark.

In my ignorance of the old literature I was prepared to quibble about devoting any space to writers, except Isaac Newton, before 1800. From our comparatively advanced state of present-day knowledge about color, much of what these writers had to say we now recognize as wrong, but it is probably good for us to learn that some of our fundamental color concepts are far from modern. For example, Aristotle said that it is only in light that the color of a thing is seen, that color sets in movement, not the sense organ, but what is transparent, e.g. the air, extending continuously from object to eye, and that in

turn sets the sense organ causing color to appear at the external boundary of the transparent medium. He also knew that color signals go from sense organ to the brain and said that the eye is an offshoot from the brain. But Aristotle sought the explanation of chromatic color as a mystical juxtaposition, or perhaps a superposition, or perhaps an interpenetration, of black and white, that produces agreeable colors if the ratio of black to white can be expressed by simple-integer ratios, like 3 to 2 or 3 to 4.

Palmer (1777) stated that the surface of the retina is compounded by particles of three different kinds, one kind moved by yellow rays of light, another by blue, and the third by red. Complete uniform motion of these particles produces the sensation of white; the absolute want of motion, the sensation of darkness. But he entertained the paradoxical thought that colored objects absorb the rays analogous to the colors of which they seem painted and are perceived only by the reflection of the other rays.

Grassmann (1853), formulator of the laws generally recognized as the basis of modern colorimetry, cannot be faulted on mathematical theory, but he was sufficiently unfamiliar with the facts of color mixture that he supposed homogeneous red light to form the transition color between the violet and red of the ordinary (impure) spectrum. This supposition led him to state wrongly that to every color belongs another homogeneous color, which, when mixed with it, gives colorless light.

In the preface Dr. MacAdam emphasizes that he is not a linguist and has not examined the original Greek texts. The selections have been ruthlessly pruned, he says, and all selections, whether based on published translations, literal translations especially prepared for this book, or works originally published in English, have been freely edited, by substitution of modern (1970) terminology and by elimination

of circumlocations made unnecessary by such terminology. The advantages of this plan are particularly evident in the more extensively excerpted and more modern works to which we now turn attention.

Often the most confusing bar to comprehension of these works is uncertainty about what the author intended his words to mean. No such uncertainty handicaps these edited excerpts. They have a clarity achievable only by a master scholar of color science such as Dr. MacAdam, and this is far beyond what any purely linguistic scholar could hope to do.

These excerpts from the writings of the foremost thinkers about color also pack a punch greater than the writing of any one color scientist because of the greater diversity of the views and concepts developed by any one author, and because the concepts are defended, not by someone-else's rehash of the arguments, but by the most pithy statements that their originators have managed to put together. The clash of these views is most dramatic, and the reader is forced to some hard thinking to decide whether the different views are compatible, and, if not, to decide which view is correct. This compilation is thus in a sense an intellectual mystery. By juxtaposition of conflicting views the reader is almost forced to decide for himself where the complicated truth lies. The likelihood that no two readers will come precisely to the same decision is merely an evidence that our modern views of color measurement are by no means cut and dried, though their underlying unity becomes ever clearer with additional study of their sources. The greater the knowledge of the reader, the more valuable he is likely to find this book; but even the beginning student, by skipping some of the passages from Schrödinger and Guild, will find that this compilation provides a quick and very readable introduction to the outstanding physiological problems of color science.

The enormous literature on the psychology of color, and the dependence of the color perceived to belong to a central field on the characteristics of the surrounding field have been purposely omitted as outside the competence of the editor.

The 24 pages excerpted from the writings of Newton include the complete descriptions of the experiments by means of which Newton concluded:

(1) The light of the sun consists of rays differently refrangible.

(2) The heterogeneous rays of compound light may be separated from one another by means of

a prism.

(3) All homogeneous light has its proper color corresponding to its degree of refrangibility; that color cannot be changed by reflections and refractions.

(4) Colors may be produced by composition which shall be like the colors of homogeneous light as to the appearance of color, white or gray may be produced by too much composition, and colors (purples) may also be produced by composition which are not like any of the colors of homogeneous light.

(5) The whiteness of the sun's light is compounded of all the homogeneous colors mixed in a due proportion.

(6) In a mixture of homogeneous colors, the quantity and quality of each being given, the color of the compound may be found by the center of gravity principle.

It is obvious from the description of his experiments that Newton referred to the appearance of colors only when viewed with dark surround, but he does not state this necessary condition. His law of color mixtures is correct, but Newton supposed that to make it work the homogeneous colors had to be represented by points placed around the arc of a circle with a space on that arc, to represent the purple colors. Nearly 200 years later, Maxwell carried out the experiments required to corroborate Newton's laws of color mixture, but these same experiments showed that the locus of points representing homogeneous colors is much more nearly along two straight lines intersecting at the point representing the green color corresponding to 510 nm.

The single page devoted to Young includes almost all that this famous scientist ever wrote about color. We see that he first (1802) adopted the then current view that red, yellow, and blue are the principal colors; but later (1845) adopted the choice, red, green, and violet, still held by most modern adherents of the three-components theory. Palmer, however, enunciated the three-components theory in 1777, thus antedating Young's statement by 25 years.

Maxwell wrote as clearly about color and color measurement as anyone, before or since. He was the first to state the connection between partial color blindness (dichromatic vision), and normal (trichromatic) vision. He said that the mathematical expression of the difference between color-blind observers and ordinary vision is that color to the former is a function of two independent variables, but to an ordinary eye, color is a function of three independent

variables, and that the relation of the two kinds of vision is not arbitrary but indicates the absence of a determinate sensation, depending perhaps upon some undiscovered structure or organic arrangement that forms one third of the apparatus by which we receive the sensations of color. Maxwell's determination of the tristimulus values of the spectrum agree remarkably well with the 1931 CIE standard observer. He was the first to show how to construct a chromaticity diagram, still often called the Maxwell color triangle, and his description of the spectrum locus, though he overemphasizes its resemblance to two straight lines intersecting in the green, is not seriously wrong. He said that the chart of the spectrum may be described as consisting of two straight lines meeting in a point representing the color of the spectrum (about 510 nm). Proceeding from this green toward the red end of the spectrum we find the different colors lying *almost* exactly in a straight line. On the blue side of primary green the color equations are seldom so accurate. The colors, however, lie in a line which is *nearly* straight. Instead of the red, green, and violet mentioned by Young as the principal colors, Maxwell speaks of red, green, and *blue*; but he also states that primary blue is a sensation differing little from that excited by the parts of the spectrum near 434 nm. The difference is thus a matter of name only, because most modern authorities use the hue name, violet, for this part of the spectrum.

Forty years later (1900), F. E. Ives made use of a simplified version of the tristimulus values of the spectrum determined by Maxwell to develop the theory of the trichromatic process of color photography. This simplified version made the spectrum locus plot precisely along two straight lines intersecting at the point corresponding to 527 nm. By adjusting the spectral sensitivities of the photographic plates by dyes and by auxiliary filters to conform to these simplified tristimulus-value curves, and by projecting the positives so procured by means of the purest possible red, green, and blue lights, Ives was able to produce a much more accurate reproduction to the eye of the colors of the objects photographed than he had been able to do by trial and error, and was convinced that this success would never have been accomplished without the aid of this theory.

In the brief excerpt given from the first edition (1866) of the Helmholtz Physiological Optics, there is a clarifying discussion of Aristotle's view that the various colors are

produced by a mixture of black and white, and of Goethe's then recent attempt to push ahead in researches based on this idea. Of course, Goethe could not believe that the purest of all colors, white, could be analyzed into homogeneous components, as shown by Newton, and he was so sure of this that he seems never to have tried to verify Newton's experimental results, but contented himself with deriding them and with abusing Newton himself. Even Maxwell's early writings (1856) spoke of white as the purest of all colors, but by 1857 he reversed himself, and thereafter spoke of the spectrum colors as maximally pure. Helmholtz recognized the fundamental importance of Newton's experiments and pointed out that Huygens' hypothesis that light consists of undulations of an elastic medium is not inconsistent with them. One must only substitute different frequencies of vibration for Newton's different degrees of refrangibility. Huygens' hypothesis had the advantage of explaining the colors of thin plates by interference. Helmholtz also discussed the puzzling effects of color perception based on learning by experience. He pointed out that anybody who has had experience with the effect of mixing colored light may occasionally fancy that he really does see the simple colors (e.g. red and green) in a compound color (yellow). The most curious illusion is when two simple colors are seen in the same place at the same time, the surface being illuminated simultaneously by two different colors, one of which predominates at certain places and the other at other places. In a case of this kind we often imagine we see the two colors simultaneously at the same place, one through the other as it were. The effect is very much as if objects were seen through a colored veil or mirrored in a colored surface. We have learned by experience, even under such circumstances, to form a correct judgment of the true color of the object, and this distinction between the color of the background and that of the light that is irregularly distributed over it is taken into consideration in all similar cases. This is an example of the psychological color phenomena that are only briefly touched upon by the MacAdam excerpts.

Helmholtz discussed clearly the dissimilar results of light mixture and pigment mixture, as Maxwell had done before him, and he points out that the quality of every color impression depends on three variables, luminosity, hue, and saturation, as Grassmann had done previously. He made a rather trivial improvement in Newton's circular locus of the purest colors

by introducing a chord of the circle to represent the mixtures of homogeneous red and violet light that form purple colors, but from Young's brief statement of the three-components hypothesis, he sketched the distribution of the three fundamental sensations, red, green, and violet, throughout the spectrum in truly remarkable agreement with the results of measurements Maxwell had not yet undertaken. It was Helmholtz' view that the essential thing in Young's hypothesis is the idea that all color sensations are composed of three processes in the nervous substance that are perfectly independent of one another.

In the excerpts from the writings of Johannes v. Kries (1878-1905) the method used by him to study adaptation phenomena is described in these terms. A part of the retina whose border passes through the center of the retina is exposed for some time to what is called the adapting light. At the end of the adapting time, on the same spot, the reacting light falls; on the neighboring spot, not exposed previously, the comparison light falls. The comparison light and the reacting light meet, therefore, in the stared-at point. One of the two is varied in successive experiments until they appear equal at the beginning of the comparison. In this way there is found a light required to produce in a rested portion of the retina, the same color as the reacting light for the part of the retina previously exposed to the adapting light.

There is an assumption involved in this procedure. It is assumed that the sensitivity of the rested portion of the retina is not changed by exposure of the contiguous portion to the adapting light. If the comparison light is weak or absent, the after-image of the adapting light is seen to have a halo that extends into the area intended to be in a rested, or dark-adapted, state. Von Kries regarded the halo as due to a spread of the stimulation and not from a changed excitability. Now, since the study of adaptation has to do with the determination of excitabilities, he maintains that it is permissible to regard the immediate neighborhood of the after-image as unchanged if rather strong reacting and comparison lights are always used. This precondition of the v. Kries experiments should not be disregarded.

The great importance of adaptation phenomena is that they permit experimental variations of visual sensations and the determination of whether such variations are attributable to three individual components, as demanded by the

Young-Helmholtz theory, and what those components are. A basic assumption is that the more the excitability of each component is reduced, the greater activation that component receives from the adapting light.

From his adaptation experiments v. Kries first established the persistence of optical matches; that is, if two objectively different lights are found to match (form a metameric pair) after adaptation to any one adapting light, then they will also be found to match after adaptation to any other light. This is a prerequisite for modern colorimetry. Von Kries gives the argument by which he concludes from the persistence of optical matches that there are only three components in play. Note that if experimental conditions are such that the degree of freedom introduced by rod vision is added to the three degrees of freedom available from cone vision, optical matches no longer persist for all adaptations.

Also described are the experiments in adaptation that enabled v. Kries to conclude that the primary nervous processes of the Young-Helmholtz theory correspond to a red, slightly more saturated and less yellowish than any spectrum red, to a green of a hue close to that of the spectrum at 517 nm but much more saturated, and to a blue or violet color somewhat more saturated than the spectrum color whose wavelength remained open to question. These are the colors that, if they could be produced, would be found to be invariant in quality regardless of adaptation, and v. Kries said they seem to be quite different from the primary colors computed from dichromatic color systems (by Maxwell's method).

Finally there is excerpted a statement of the famous v. Kries coefficient law by means of which, given the color points invariable to chromatic adaptation, and given the matching color (optimally near neutral) for any one combination of adapting and reacting lights, the matching color for any other reacting light may be computed for that same adapting light. The coefficients give the fractions of the rested-eye excitabilities of the three components, and serve to characterize the adaptive state produced by that adapting light. Like the law of the persistence of optical matches, the coefficient law breaks down under experimental conditions permitting intrusion of rod vision.

For this reviewer the English translation of the monumental Outline of a Theory of Color Measurement for Daylight Vision by Erwin Schrödinger, edited and brought up to date by

insertion of modern colorimetric terminology is Dr. MacAdam's most valuable achievement in this compilation. I spent many weeks in 1928 studying this 1920 work with very limited comprehension of the original German and my first reading of the MacAdam version was like a revelation. With the exception of a few passages in Part II, Advanced Color Measurement, all statements appeared to me marvelously clarified. It is true that these exceptions are more or less basic to the whole treatment. These passages refer to equations 2 to 6 dealing with the differential equation of the area element that, in the sense of Riemann geometry, is perpendicular to the direction of the vector corresponding to constant chromaticity. Equations 23a to 26 were intended to prove that in the space generated by the square-root transform of tristimulus values, these vectors are plane logarithmic spirals. The difficult passages also include the entire section 8 on the course of the geodesic curves in tristimulus-value space. I suspect that the mathematical treatment is sound, but is too brief to be followed by anyone with only the limited mathematical insights possessed by the reviewer. Many readers, like myself, may have to take these derivations on faith. The MacAdam version has made clear to me for the first time what Schrödinger was trying to do.

Schrödinger treats as elementary color measurement the derivation and use of what we now know as color-matching functions, first determined by Maxwell. This kind of color measurement is elementary because it includes only information derivable from settings of equality between two fields. The treatment is based upon the König and Dieterici determination of color-matching functions and is elegant both from the algebraic and geometric standpoints. He uses two types of equations, as many British writers do: ordinary equations and color equations. Color equations take the form of: $F = a_1 F_1 + a_2 F_2 + a_3 F_3$, in which F stands for any color, F_1 , F_2 and F_3 stand for three primary or calibration colors, and a_1 , a_2 , a_3 , for their amounts or tristimulus values. Note that in a color equation the equal sign does not mean numerical equality but rather "color matches," the plus signs do not mean scalar addition of two numbers but rather "addition of color components in a colorimeter," and the expression $a_1 F_1$ does not mean the product of two scalars

but rather should be read " a_1 units of primary color F_1 ." The transformation of tristimulus values (a_1 , a_2 , a_3) of a color expressed in terms of one set of primaries to those expressed in terms of another set is given in determinant form with the scales of both sets of primaries defined in terms of the color of the undispersed light (sunlight) whose normal spectrum was used by König and Dieterici to obtain the color-matching functions.

The manifold of colors, or color space, is a tridimensional system of affine structure based only on the equality judgment. Transformation to another set of calibration colors is linear and homogeneous. Only such properties of shapes in color space that remain unchanged by such transformation are affine and significant for this color space. By such transformations straight lines are converted into straight lines, plane surfaces into plane surfaces. Angles have no meaning because they may, by affine transformation, be completely deformed; nor do ratios of lengths.

In affine color space every color is represented by a vector extending from the origin $X_1 = X_2 = X_3 = 0$ to a length that for that one direction is proportional to the radiance of the stimulus; but the ratio of lengths of two vectors having different directions has no meaning. Therefore we cannot conclude from such ratios what the luminance ratios are. The colors corresponding to vectors of different directions have different chromaticities, but from the ratio of angles no conclusions as to the ratio of chromaticity differences can be drawn, unless the three directions are coplanar, in which case the larger angle from some central direction (say, the white direction) must correspond to a greater chromaticity (or saturation) difference. For departures from the white direction not all coplanar, we do not know whether a larger angle from the white direction means a greater or a less saturation of the corresponding color. The colors of the spectrum are represented by vectors forming a cone that encloses the bag or bundle of vectors for colors producible by all possible combinations of lights from the spectrum. The vectors corresponding to colors produced by combining extreme spectrum red with extreme spectrum violet lie in one plane and complete the boundary of the vector bundle corresponding to all real colors.

To transform color specifications relative to a set of real calibration colors to a form cor-

responding to the Young-Helmholtz theory requires the use of unreal calibration colors; that is, colors outside the gamut of real colors. For such calibration colors none of the tristimulus values of the spectrum will be less than zero, so they may be interpreted as excitabilities of the three components of color vision postulated by that theory.

In Part II, Advanced Color Measurement, methods of determining brightness, hue, and saturation are suggested together with a geometry appropriate to them. It is assumed that a measure of the dissimilarity of two colors can be set up in this geometry in a manner originated by Helmholtz to accord with the Fechner law such that for all just distinguishable color pairs this measure has a constant value. The Helmholtz line element:

$$ds^2 = \frac{1}{3} \left[\frac{dx_1^2}{x_1^2} + \frac{dx_2^2}{x_2^2} + \frac{dx_3^2}{x_3^2} \right] \quad (1)$$

is rejected because it implies a luminosity function equal to the cube root of the product, $x_1 x_2 x_3$, which is grossly different from the experimental facts. Schrödinger proposed a modified line element as probably approximating the experimental facts most closely:

$$ds^2 = \frac{1}{ax_1 + bx_2 + cx_3} \left[\frac{adx_1^2}{x_1} + \frac{bdx_2^2}{x_2} + \frac{cdx_3^2}{x_3} \right] \quad (2)$$

where x_1, x_2, x_3 are tristimulus values of the color, and a, b, c , are the luminosity coefficients.

This differential formula suffices to express the dissimilarity of two colors that differ by not much more than the threshold, but this is not sufficient to deal with brightness measurement in general that requires an assessment of the brightness of two colors of quite dissimilar chromaticities. The further assumption is therefore made that the dissimilarity of any colors is judged according to the magnitude of $\int ds$ for the shortest connecting path (geodesic path) between the two color points in the manifold. The shortest connecting path has to be followed, not the straight line in the vector space, but that curve for which that integral assumes the smallest value.

If we have one particular color A required

to find the color B of not too different chromaticity that is seen as equally bright, the radiance of the stimulus producing this color is adjusted until the dissimilarity of the two colors is a minimum. In the affine color space discussed under elementary color measurement, we might think of locating this second color B by choosing the length of the vector so that the perpendicular to that vector passes through the end of the vector representing the color A. Then we can ask which length of the vector having the first direction (that of the vector representing color A) has the same brightness as the color represented by the second vector, and by the same method this length is found to be less than that of the vector originally chosen. By endowing this affine geometry with metrical properties that seem intuitively reasonable we have managed to achieve a definition of brightness such that if color A has the same brightness as color B, and color C has the same brightness as color B and the same chromaticity as color A, nevertheless color C is producible by a radiance less than that required to produce A, and is therefore of brightness less than A. This contradictory property of brightness equalities proves that the affine color space built up simply from judgments of the equality of two fields is not appropriate to represent the results of judgments of settings for minimum dissimilarity.

For colors of not too different chromaticities, colors of constant luminance are seen as of constant brightness. If the tristimulus values of a color x_1, x_2, x_3 are referred to calibration colors of the same luminance, then the luminance of the color is simply $x_1 + x_2 + x_3$, and in x_1 space constant luminance corresponds to a plane. By introducing the square-root transform, thus:

$$XI_1 = x_1^{\frac{1}{2}}, XI_2 = x_2^{\frac{1}{2}}, \text{ and } XI_3 = x_3^{\frac{1}{2}} \quad (3)$$

we find that this plane in x_1 -space transforms into a sphere centered on the origin ($XI_1 = XI_2 = XI_3 = 0$) provided the values of XI_1 are plotted orthogonally. The line element (Eq. 2) based on the Fechner law becomes:

$$ds^2 = 4(dXI_1^2 + dXI_2^2 + dXI_3^2)/(XI_1^2 + XI_2^2 + XI_3^2) \quad (4)$$

and if we wish to set up separate measures of luminance and chromaticity difference, the variables are the length of the radius vector, r , and the angle ϕ subtended at the origin $x_1 = x_2 = x_3 = 0$. Expressed in these variables the line element becomes:

$$ds^2 = 4(dr^2 r^2 + d\phi^2) = 4 \left[(d \ln r)^2 + d\phi^2 \right] \quad (5)$$

By this line element, the lines of constant chromaticity are geodesics, and the geodesics between colors of the same brightness are great circles on the sphere centered on the origin, or ellipses in x_1 -space. The brightness difference between two colors of the same chromaticity but having vectors of length r and r' is measured by $\ln(r/r')$. Thus, the geodesics expressed by the variables, $\ln r$ and ϕ are straight lines. It is assumed that the geodesics between the neutral color $x_1 = x_2 = x_3$, and all other colors of the same brightness correspond to loci of constant hue. The measure of saturation is simply the angle ϕ in x_1 -space. In x_1 -space this measure becomes:

$$2 \arccos \frac{a(x_1)^{\frac{1}{2}} + b(x_2)^{\frac{1}{2}} + c(x_3)^{\frac{1}{2}}}{(a + b + c)(ax_1 + bx_2 + cx_3)^{\frac{1}{2}}}$$

which is, of course, equal to zero for the neutral condition: $x_1 = x_2 = x_3$, and with a, b, c , being the luminosity coefficients as before.

The line element proposed by Schrödinger based on the Fechner law was subjected by him to a few checks with experiment. He showed that the just noticeable wavelength difference found by Uhthoff among equally bright spectrum colors from 490 to 640 nm agreed in a general way with the implications of the proposed line element, though the agreement was no better than that achieved by the otherwise unacceptable line element proposed by Helmholtz 50 years previously. He noted that the lines of equal-brightness geodesics deviated from the lines of constant dominant wavelength in almost precisely the way opposite to that found by Abney for the lines of constant hue on dilution with white light. Schrödinger's own repetition of Abney's experiment seemed, however, to support

the line element and contradict Abney's experimental result.

Finally Schrödinger pointed out that the line element proposed is such as to imply that luminance variations at constant chromaticity correspond to geodesics, and so implies that such changes correspond to constant hue. He admitted that this implication of the line element is contradicted by the well-established Bezold-Brücke phenomenon, but pointed out that Brücke ascribed the hue change to the fact that the primary least represented in the color being judged drops near or below the threshold, and so becomes ineffective. This corresponds to a failure of the Fechner law for stimulation approaching zero, and we should expect a line element based precisely on the Fechner law as an approximation not to predict a phenomenon corresponding to a failure of that law. This line element thus has had only limited support from experiment, and Schrödinger did not indeed claim very much for it. Schrödinger was, however, the first to inquire carefully into the kind of geometry appropriate to represent color phenomena. His method of approach has great and permanent value and should not be considered as marred by the indifferent success of the first line element proposed by him.

The excerpts of the writings of J. Guild consist of reprints of two papers, *Some Problems of Visual Perception*, and *Interpretation of Quantitative Data in Visual Perception*, both presented at the 1932 *Discussion on Vision* organized in London by the Physical Society. The trichromatic theory, whatever form it takes, is an attempt to explain one fundamental empirical fact. This fact cannot be stated by saying, as many carelessly do, that any stimulus, whatever its spectral distribution, can be matched, as regards the color it evokes, by a mixture of three other stimuli. This statement is simply wrong. No matter what three stimuli are chosen it is easy to find other stimuli not matchable by a mixture of these three. Even the statement by v. Kries who says: "the resultant of all the various light stimuli, so far as sensations are concerned, can be completely represented as a function of three variables," will not serve. The principle here stated is the basis of modern colorimetric practice, but like that practice it applies only to a restricted range of experimental conditions, avoidance of rod intrusion, for example, in the sense that within this restricted range the most precise measurements fail to disprove it. For Guild the basic empirical fact is that to set a color match

between two fields the observer need never operate more than three independent controls. This statement is true regardless of the adaptation of the eye to darkness or to excessively bright fields, and for Guild any explanation of it is a trichromatic theory.

A reception system for radiation consists of (1) a receptor, (2) a coupling, (3) an indicator, and (4) a cognizer. It frequently happens in experiments with radiation that simultaneously several reception systems are exposed to the same radiation. The individual reception systems may have receptors of different types and indicators of different modalities, but they usually have one cognizer in common. If any two or more of the reception systems contribute to the value of the same one (and only one) of the response parameters, or if they contribute to various parameters in the same proportion, it is evident that these systems are simply acting as a single composite reception system. Such reception systems may be said to form a cumulative group. The fundamental fact that in visual experiments three independently operated controls are in general necessary and always sufficient to effect a complete visual match between two samples of radiation means simply that there are three, and only three, independent cumulative groups of reception systems in simultaneous operation.

For the human visual system the rods and cones are the receptors, the nerve or nerve chain leading from the receptors to the visual center constitute the coupling, and the central connections form the location of the indicator. The indicator supplies an effective presentation of the stimulus to the cognizer, the psychological element of the system. The sensation is the reaction of the cognizer to the effective presentation. The relative sensitivity of the reception system depends entirely on the properties of the receptors.

Normal color discrimination requires an appreciable area; so it must be described in terms of the operation of cumulative groups of reception systems. Schrödinger never considers this basic aspect of vision.

There are three and only three independent systems in operation simultaneously in the normal human visual system. Whatever may be the actual number of elementary systems, the allocation of such types of receptor as may exist to central connections of such modalities as may exist must be of such character that the systems form three cumulative groups. The resultant peripheral properties (spectral sensi-

tivity) and the resultant central modality of each group must differ from those of the other two groups.

Vision is characterized by an essential triplicity of function involving at least a threefold differentiation of the retinal receptors, and at least a threefold differentiation in central behavior. This is all that should be meant by the name trichromatic theory. There are four possibilities:

(1) Only three dissimilar types of receptor and only three dissimilar central modalities, all receptors of one type being coupled to central connections of one modality. This possibility seems to be what Young and Helmholtz had in mind, and it can apply only to experimental conditions ruling out rod vision.

(2) Only three dissimilar types of receptor, but any greater number of dissimilar modalities in the central connections. This possibility would indeed account for the existence of three, and only three, independent cumulative groups of reception systems in simultaneous operation, but do we not know that there are at least four dissimilar types of receptors — three types of cones plus one type of rod.

(3) Only three dissimilar modalities in the various central connections, but any greater number of dissimilar types of receptor. To the reviewer it seems that this possibility is the correct one, with the greater number of receptor types set at four.

(4) Any number, not less than three, of receptor types, and central connections of any number of different modalities, not less than three. The essential triplicity of visual function may be achieved without any special distribution of properties of the individual receptors alone or of the central connections alone, although it does not rule out such special distributions. The variations of the spectral properties of the individual receptors, for example, might be variation from three mean types, but it might also be a normal variation from one mean type; and the same thing for variations in central-connection modalities. Three independent reception systems might be obtained provided that the allocation of receptor types and central modalities were not also a random selection.

Guild's definition of trichromatic theory permits any of these possibilities to form a trichromatic theory, and since one of them must be valid, he has defined trichromatic theory in a way that prevents it from ever being proved wrong. By this definition, most forms of Hering

opponent-colors theory are trichromatic theories.

The "persistence of optical equations" so carefully studied by v. Kries is not, by this view, a necessary consequence of the trichromatic theory; nor does it follow from this theory that selective adaptation should necessarily be explicable as a mere change of the relative sensitivities of the three reception systems, without alteration of their individual spectral sensitivities as implied by the v. Kries coefficient law.

In his paper, Interpretation of Quantitative Data in Visual Problems, Guild adopts the narrow view of measurement that its basis must be analogous in principle to the process of measuring a distance by finding the number of measuring rods, each of equal length, which have to be laid end to end to occupy the distance in question. The criterion of equality of magnitude of two quantities of the same kind, simultaneously observed under identical conditions, is the fundamental criterion in the construction of all scales of measurement. In establishing photometric relations, the most precise work requires that an appreciable area of the retina shall be used, and that the property of the viewed surface by virtue of which it is visible shall be uniformly distributed over its area. This property is the *rate of emission of radiant energy per unit area of surface (projected normally to the line of sight) per unit solid angle in the direction of the line of sight*. The modern name for this property is *radiance*.

The complete specification of the stimulus is given by the distribution of its radiance throughout the spectrum. In photometry the criterion of equality in magnitude is that two juxtaposed fields appear equally bright. Guild says that a photometrist can make valid judgments of brightness equality even though the chromaticities of the two fields are quite different, and that the uncertainty of the settings becomes smaller as the chromaticity difference is reduced. The radiances E_A and E_B of the two half-fields are

under the control of the photometrist, and when he has adjusted them to appear equally bright, the result of the experiment is simply that under the actual conditions prevailing as regards the size, shape, and position with respect to the observer of the half-fields, and at the actual time when the observation was made, the radiance E_A of field A evoked the same sensation of brightness in this observer as the radiance of the field B. In symbolic form this result may

be written: $E_A K_A = E_B K_B$, where K is a quantity proportional to luminous efficacy. If similar experiments comparing fields C, D, and so on with field A are carried out, we are immediately tempted to write:

$$E_B K_B = E_C K_C = E_D K_D \text{ and so on}$$

and to regard these as equal quantities of the entity that has been measured in the photometric process since each has been separately found as having the same brightness as $E_A K_A$, but this is not correct, says Guild. It assumes that the quantity $E_A K_A$ can be regarded as a standard of constant magnitude, but the only thing known to be constant in all of the settings is the radiance E_A . Nothing in the nature of the photometric process either proves or disproves the constancy of K_A under the conditions of the various comparisons, which, though identical in all other aspects, necessarily differ with respect to time.

In order to obtain from the photometric process something that is really measurable we must write the observation equations in the form:

$$E_A = E_B (K_B/K_A), E_A = E_C (K_C/K_A)$$

and so on. The quantities (K_B/K_A) , (K_C/K_A) , and so on are simply dimensionless ratios. From this series of equal quantities a scale of measurement may perhaps be built up that gives a quantitative measure of magnitude for the entity, brightness, of which these quantities are samples.

The quantitative measure is called luminance; its dimensions are the same as those of radiance. In the case of luminance the photometric process provides a practical means of obtaining a series of equal quantities. To construct a quantitative scale from this series, we must assume them to be additive without alteration of their individual significance. That is to say, the ratio K_B/K_A associated with radiance E_B must be assumed to remain constant for all values of the total luminance and for all qualities of the total radiance that may result from adding $E_B K_B/K_A$ to other members of the series $E_C K_C/K_A$, $E_D K_D/K_A$, and so on, and a similar constancy must be assumed for K_C/K_A , K_D/K_A ,

and so on. From this assumption it follows that the luminance associated with a radiance of any one given quality (spectral distribution) is proportional to the radiance. If we select the luminance associated with E_B as a standard unit, the luminance of a surface emitting nE_B will numerically equal n units of luminance.

The fact that this luminance scale involves the quite arbitrary assumption of the constancy of the various ratios K_B/K_A , K_C/K_A , and so on, does not imply that we could have obtained a scale with other properties by making some other assumption. No scale with other properties would be a quantitative measure of brightness. Insofar as there can be a measure of brightness, that measure must be luminance, and we have to find by suitable tests within what range of stimulus values the luminance scale has any practical significance. The series of comparisons having the most direct significance is that in which the radiances E_B , E_C , E_D , and so on, are concentrated in narrow wave bands throughout the visible spectrum. In this case the ratios K_B/K_A , K_C/K_A , and so on are known as values of spectral luminous efficiency. It will be seen that the assumption of constancy of the various ratios under all conditions is equivalent to the assumption of a constant shape for the curve of spectral luminous efficiency. Only within the luminance range in which this curve is in fact constant, to within the errors of experiment, is it true that luminance has any meaning as a quantitative measure of brightness. Intrusion of rod vision destroys this meaning; so the applicable luminance ranges depend upon the size and location of the retinal region involved. At the upper end of the luminance scale, the shape of the spectral luminous efficiency curve also becomes seriously disturbed. For these conditions also use of photometric quantities is illegitimate.

Guild likewise sternly insists that photometry has meaning only with regard to luminance of an extended area. The idea that a particular luminous efficacy may be regarded as associated with radiant energy of a particular quality without reference to its spatial distribution is rather prevalent. This idea underlies the technical photometrist's definitions of luminous flux, luminous intensity, and allied entities. We are not entitled to form any such general conceptions. Guild's views in this respect have found few adherents, but nobody seems to have

pointed out in what respects they are wrong. The established techniques of photometry are, in general, convenient and appear to be useful. Can it be that this usefulness is illusory?

In his analysis of color measurement, Guild covers much the same ground as Schrödinger in his elementary color measurement. Guild, however, insists that the tristimulus values by which a color are specified must be expressed in luminance terms to provide a true measurement on quantitative scales. The implication is that color matches hold only for experimental conditions yielding a substantially unchanged shape of the curve of spectral luminous efficiency, but it would seem that only the shapes of the individual color-matching functions are significant. Note that Schrödinger treats color measurement as elementary, and does not deal with brightness measures until he comes to advanced color measurement. The Schrödinger hue and saturation measures are regarded by Guild as no measures at all.

L. F. Richardson in his paper, *Measurability of Sensations of Hue, Brightness, or Saturation*, mentions three ways to measure these sensations as distinct from stimuli: (E) by counting small equal-appearing intervals, (J) by counting just-perceptible intervals, and (R) by directly estimating the ratio of unequal intervals, both much larger than the least perceptible. As individuals differ in color vision and in aesthetic opinions, the standardizing institutions, he says, are led to measure stimuli, not sensations — to do physics, as being easier than psychology. Guild in discussion said that sensation does indeed have a quantitative aspect, but we cannot measure the magnitude of a sensation. We can make subjective estimates of this magnitude, but these estimates do not constitute measurement. Richardson in reply said that it is a mistake to attempt, as Guild does, to forbid the study of the functional relationship between magnitudes of sensations and those of stimuli. He does so for the reason that they are philosophically noncomparable phenomena. Nevertheless some of these functional relationships have been discovered and many others will no doubt be discovered later.

In his paper, *Retinal Structure and Color Vision*, Polyak gives a clear description of the anatomy of the central fovea including macular pigment, cones of the rod-free area, rods and cones in the surrounding regions, but particularly the various types of nerve cells of the retina, and how they are interlocked to form a complex retinal tissue. He describes bipolar

cells, ganglion cells, and interrelations of the retinal neurons, and he presents an analysis of the synaptical relationships of retinal neurons. He points out that the mop bipolar cells are capable of being stimulated both by the rods and by the cones, either at the same time or alternately. The midget ganglion cells in the rod-bearing regions may also serve as a common rod and cone pathway. Only the midget bipolar cells (besides the cones) preserve the character of a strictly cone mechanism. Since in the rod-free foveal center there is complete hue distinguishability, we may conclude that cones by themselves may act as color receptors. Again, since there is no concrete evidence of any further differentiation of the foveal cones into several varieties, the central cones must be declared pretty much alike in their function, and all central cones seem to be able to react in exactly the same way to every hue to which the eye responds at all. If there is a triplex factor basically responsible for selective spectral responsiveness on the cone level this factor is not of the kind demonstrable by ordinary microscopical methods.

If there is no differentiation of the cones into three types, they would then merely furnish a dynamical "material" for other structures of the visual system to work with. In such a case the bipolars and ganglion cells must in some way be the carriers of the process by which the global cone excitation is transformed and directed into one or the other channel according to the spectral position of the stimulus, its magnitude, and other qualities. Note, however, that this suggestion is contrary to Guild's contention that the receptors, and receptors alone, determine the spectral sensitivity of each reception system. We can certainly agree with Polyak's later statement that "what arrive in the center are the impulses that originate in the cones but that are in many ways modified by the intervening neurons." The modification cannot, however, be such as to produce two different impulses in the center for two stimuli yielding identical cone impulses.

The final paper of the MacAdam collection, Laminar Pattern of the Lateral Geniculate Nucleus Considered in Relation to Color Vision, by Wilfried E. Le Gros Clark provides evidence of a segregation of red, green and violet reporting fibers in the visual systems of men and macaques. The evidence is provided by an analysis of the main primary optic center, the lateral geniculate nucleus through which retinal

impulses are relayed to the cerebral cortex. The geniculate nucleus is made up of six well-defined cell laminae which are quite separate in the area for central vision, but are partly fused in the area for peripheral vision. If one eye is removed, three layers undergo rapid degeneration, the first, fourth, and sixth of the geniculate nucleus on the side opposite to the eye, and the second, third and fifth of the nucleus on the same side. Thus each nucleus consists fundamentally of two sets of three layers, each set related to one eye.

If a very small and localized lesion in the central part of the retina is made experimentally, a circumscribed patch of transneuronal-cell atrophy appears in all three of the corresponding laminae. It has been inferred from this observation that from each local spot in the central area of the retina three types of fiber pass back in the optic tract, one to each lamina. If the laminae are labeled a (for outermost), b and c (for innermost), layer a is composed of much fewer and larger cells. At a fixation point the a fibers are relatively very few or may be absent altogether, but the relative number of a fibers increases progressively towards the periphery of the retina.

It has been suggested that if the a fibers correspond to the violet factor of trichomasy, and the b and c fibers to red and green, this would explain the smaller extent of the red- and green-perceiving retinal fields. The paucity (or possible absence) of the a fibers from the foveal center accords well with the evidence that here the retina is relatively insensitive to violet. More direct evidence is supplied by experiments with monkeys kept for several weeks in light from which the short-wave end of the spectrum is completely excluded. The cells in the central retinal zone of cell lamina a may undergo marked atrophic changes, though those of cell laminae b and c also show some degree of cell atrophy.

Furthermore two cases of diabetic amblyopia reported by Rönne showed central scotomas for red and green, and in both cases there was a corresponding degeneration in the central retinal areas of layers b and c, while the whole of layer a appeared to be intact. All this evidence is presumptive, according to Le Gros Clark, and needs further corroboration before the existence of a three-fiber connection between retina and geniculate, one fiber for red, another for green, and a third for violet, can be regarded as proved.

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