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Colour Group

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Twenty-five Years

The Colour Group emerged twenty-five years ago as a vigorous. healthy side-shoot of the Physical Society. There, however, a strict botanical analogy must stop, for the shoot immediately bore blossoms of many kinds and colours, usually showing no apparent relation to the parent plant. Twenty-five years takes us back to the dark, frustrated days of the second world war and there is some strangeness in the association thus of the destructive blindness of war and the creative urge to found a new scientific group. But such association is not uncommon in history, perhaps it is the expression of the age-long balance of the two conflicting sides of our human nature. However this may be, our Colour Group has gone from strength to strength, has thrust its own roots into the soil, has become an independent plant.

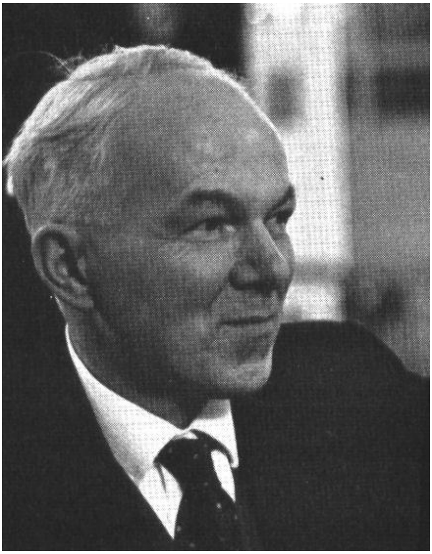
I have referred to our group as scientific, but I should like this to be taken in what I believe to be its true connotation of knowledge, all knowledge, of whatever kind, not the closed hierarchy of specialisations which is too often its popular image. This explains the essential unity of our meetings which draw within the one net the vast variety of our speakers; whether we are addressed by an artist, a craftsman, a technologist, a politician, a "scientist" of the more abstruse kind, there is but the one basically important character which our subsequent discussion should have—the probing of what the speaker knows, its dissection from what he supposes. I believe we have, indeed, pursued this path with considerable faithfulness, which may be at the root of our continued success and perennial interest. Let us only hope for a limitless series of speakers of infinite variety of outlook, who instruct us with ascertained facts and stimulate us with bold suppositions. B. H. CRAWFORD.

Twenty-five Years

The first Science Meeting of the Physical Society Colour Group was held at the Polytechnic, Regent Street, London, on the 12th February, 1941. The Chairman was W. D. Wright. The speakers were W. D. Wright, H. W. Ellis, R. F. Wilson and J. W. Perry, and the subject was Colour Tolerance.

The lecture theatre of the Strand Electric Company was packed for the Group's 25th Anniversary meeting on the 2nd February, 1966. The Chairman, Dr. Crawford, opened the meeting, and reviewed the early history of the group, as revealed by the minutes of the firstmeetings. These minutes, like those written today, concerned the administrative and scientific affairs of the Group, and there were only occasional fluctuations in the numbers attending meetings to indicate the difficulties that must have faced the organisers of the new Group at this time. The subjects discussed in these early meetings are still of interest to the Group, but the more recent activities have widened the field covered by the Group considerably.

The speakers at the Anniversary meeting, all past chairmen of the Group, described the advances in four aspects of colour over 25 years. Superficially the continuance of interest in these aspects might indicate lack of progress, and that the same old problems—particularly that of colour tolerance with which the Group started—are still with us. The problem of colour tolerance is certainly still with us, although Professor Wright's talk emphasised the progress that has been made. In other fields progress has been spectacular. Numerical methods of predicting colourant formulations are now in large-scale commercial use, and in the field of colour vision the completeness of our knowledge and the sophistication of the techniques available are much greater than in 1941. All the speakers, however, emphasised that much remained to be done and looked forward to further developments that promised to keep the Group interested in the future.



Dr. B. H. Crawford,
Chairman of the Colour Group

This part of the meeting concluded with a demonstration by Mr. Bentham of Strand Electric Ltd. Using only a row of spotlights and a screen, and his experience as a specialist in theatre lighting, he showed only too clearly how our visual process can be fooled. His rows of projected colour patches, changing their apparent colours as other patches were added, provided a lighthearted emphasis of the complexity of our subject.

Dr. R. W. G. Hunt was the official host at the cocktail party following the science meeting and given by the Directors of Kodak Limited to mark the occasion. Two of Kodak's Directors, Dr. A. Batley and Mr. I. D. Wratten were also present to welcome the Group to Kodak House. Discussion quickly became informal as members relaxed and enjoyed the magnificent selection of viands provided. This gathering emphasised again the friendly character of the Colour Group, and we look forward to continuing progress through the next twenty-five years.

Mr. A. G. Tull (left) speaking to Mr. M. H. Wilson at the cocktail party at Kodak house following the Colour Group's Twenty-fifth Anniversary meeting.

Colour Tolerances
Yesterday and Today
W. D. Wright

The theme of the first meeting of the Colour Group on February 12th, 1941, was Colour Tolerances. I was warned that at that time industry might not take too kindly to the idea of quantitative limits being set on the accuracy to which customers' samples should be matched, but we thought it would set the Group on an interesting course to choose a controversial theme for its first meeting.

Four speakers presented papers and, in a report of the meeting, H. W. Ellis is quoted as saying that in his experience the trained eye was superior to any instrument for the detection of small colour differences. I imagine a good many people would still subscribe to that view. He also stressed the need for a standard illuminant for industrial colour matching. Today our need is for an illuminant which is an adequate representation of daylight both in the ; visible and near ultra-violet spectrum, but at least we now possess reliable data on the energy distribution of different phases of daylight.

In another paper, J. W. Perry described how a tolerance area could be defined on the C.I.E. chromaticity chart and that, while this area was approximately elliptical in shape in the normal form of chart, it could be made approximately circular if projected obliquely. On this projected diagram, the tolerance could be specified by the radius of the circular area. This anticipation of a uniform chromaticity chart has now been realised to the extent that transformation equations from the normal X, Y, Z co-ordinate system have been recommended by the C.I.E. to provide a reasonable approximation to a uniform colour solid.

But do these advances mean that colour tolerances have now come into widespread commercial use? The answer must surely be "No", although it isbecoming increasingly common to discuss the accuracy of colour matching in terms of the colour matching error ΔE, as calculated by one or another of the various colour difference formulae that have been proposed from time to time, and which can now be calculated on the new uniform scale of the C.I.E. There are, of course, certain instances where tolerances are specified colorimetrically, notably in the specification of signal glasses, while combinations of Tinto-meter glasses are often used to control the quality of a product by defining acceptance limits to its colour.

In industries such as the car body industry, however, it would seem that the paint manufacturer is not yet required to supply his paint to within a certain limiting value of AE, although this does not mean that the requirements for the reproducibility and stability of the colour are not very strict indeed. The point is that the stage has not yet been reached when these requirements are specified in colorimetric terms.

Professor W. D Wright

There may well be commercial reasons for this, but there still remains a very real instrumental problem. A colorimeter is required that combines robustness with sensitivity and reliability, so that very small colour differences can be measured with sufficient accuracy to form the basis of a commercial agreement under which goods are either accepted or rejected according to their colour specification.

The development in recent years of instrumental and computational methods of colorant formulation in the dyeing and pigment industries, as, for instance, the Instrumental Match Prediction (IMP) service provided by Imperial Chemical Industries, seems certain to hasten the more widespread use of colour tolerance specification in industry, always assuming, of course, that instruments can be produced to meet the demand.

A rather different aspect of this tolerance question is now, however,beginning to emerge, namely to what precision does a tristimulus colorimeter have to conform to the standard C.I.E. functions, $\bar{x}_\lambda$, $\bar{y}_\lambda$ and $\bar{z}_\lambda$, if it is to be used in colorant formulation? This question was raised, for example, by Berger and Brockes at the 1965 Colour Conference in Lucerne, and it would seem that the introduction of both 2/ and 10/ Standard Observer Data has suggested to industrialists that there are tolerances here of which they might well take advantage. It is true that any significant metamerism between a customer's sample and a dye recipe means that the match may be correct for one observer and not for another, may be correct for one condition of viewing and not for another, and may be correct for one phase of daylight and not for another. The susceptibility of a match to these variables must surely lead the colorist to ask how hard he needs to strive to produce what seems to him to be a perfect match, and how precisely he needs to measure the colour of the sample in the first instance. If there are significant tolerances on both these questions, he may as well know what they are so that he can feed them into his computer.

Significant Advances in The Field of Colour Vision

W. S. Stiles

The Colour Group's twenty-five years have seen considerable progress in our knowledge of colour defects particularly of the rarer types, a continued attack on problems of subjective colour and colour adaptation in normal vision, and the successful application of objective methods giving information on the electron-microscopic structure of rod and cone end-organs, the properties of visual pigments, and the electrical responses to light of the retina, all potentiallyrelevant to colour vision. This talk can touch on only a few salient points.

The beginning of the period was marked by the discovery by E. N. Willmer that, for the colour-normal observer, colour discrimination in very small fields is reduced in a special way to a form of dichromatic vision, corresponding to the failure of the "blue" response mechanism. This was called foveal tritanopia, as it was first observed in the small central area of the fovea, although similar colour confusions occur outside the fovea if the stimuli are sufficiently small (Hartridge). The tritanopic defect was already known as a rare congenital type, in which there is a complete failure of the "blue" response mechanism in fields of any size But because of its rarity, data on congenital tritanopia were fragmentary, and a big step forward was made by W. D. Wright (1952) when he located 17 full tritanopes and determined the complete colour-matching properties of 7 of them. Exact knowledge of tritanopia is now comparable with that of the much commoner red-green defects, protanopia and deuteranopia. More has also been found out (R. A. Weale, 1953) about the even rarer colour defect of cone-monochromatism — complete lack of colour discrimination —even though, unlike the more familiar rod-monochromatism, a cone-response system is present. The most striking discovery in the field of colour anomalies was made by H. R. and 0. M. Blackwell (1961) who found three brothers, all cone monochromats, possessing the "blue" response mechanism as their unique cone system, a type previously unknown. On the whole the various studies of rare colour defects bear out trichromatic conceptions.

An unexpected observation by G. S. Brindley (1955) shows that such a basic property of colour vision as the order of the hues in the spectrum can still provide something new. Brindley found (for colour normals) that, as wavelength is increased towards the long-wave extremity, the hue changes through yellow and orange to red and then beyond about 700 nm. reverses to become again slightly yellowish. This result — independently confirmed — has negligible consequences in ordinary colour questions but is theoretically interesting.

The many quantitative psychophysical studies of colour adaptation, while employing diverse methods, are directed, broadly, to determining pairs of test stimuli, defined by their tristimulus values, that, applied to two similar retinal areas (usually foveal) in different states of adaptation, have the same subjective brightness and colour. Experimenters have always had hopefully inmind that the von Kries principle would hold and that if the tristimulus values were expressed in terms of three suitably chosen fundamentals different adaptations of the retinal area would correspond to raising or lowering the response in each fundamental by a constant factor independent of the test stimulus. The development of the subject has turned on the failure of this simplification and on the proper modification of the von Kries model. The key investigations of R. W. Hunt and D. L. MacAdam, respectively, illustrate the ways in which the von Kries model breaks down, and two principles on which a more adequate theory may be constructed. Hunt's work by the binocular matching method was concerned, in the main, with adaptation to widely different luminance levels by white adapting stimuli. The domain of all possible subjective colours was shown to expand and contract as the adaptation level rose and fell, the domain remaining roughly centred on the white point. This is quite irreconcilable with von Kries and suggested to Hunt that the matches being made were not between responses in the individual fundamentals but between complexes comprising mainly one fundamental but with admixtures of the other two, the amount of this admixture depending on the adaptation level. This scheme goes far to explain Hunt's data and is susceptible of generalisation to more general adaptation conditions. MacAdam, on the other hand, who used a special monocular method and concentrated on adaptations of widely different colour but of similar luminance, developed a different idea in explaining with considerable success the deviations from von Kries of his own and similar data. He retains the privacy of matching in each fundamental but postulates that at the matching site the response is non-linearly related to the corresponding tristimulus value, the non-linear relation (of a generalised power law or logarithmic type) being modified progressively as the adaptation is varied. These two ideas of adaptation-dependent complexes and adaptation dependent non-linearity have been shown to be effective respectively in two different types of adaptation situation; they have perhaps to be combined for a more comprehensive theory.

Mr. H. M. Cartwright (left) and Mr. I. D. Wratten

Outstanding in the objective measurements bearing on colour vision, has been the observation of cone pigments in the living human eye by the fundus reflection method, and the objective demonstration of the existence of two light-sensitive pigments with maxima respectively at about 540 nm. and at a longer wavelength. This has largely removed a nagging difficulty. Much of this work was presented to the Colour Group only last year in Dr. Rushton's Newton Lecture. After the first successful push there still remains some mopping-up, but the breakthrough has been made.

Meanwhile improved micro -spectrophotometry has enabled three American teams—Marks, Dobelle and MacNichol, Brown and Wald, and Liebman and Entine—to measure the spectral absorption or difference spectra in individual rods and cones including those from the retinae of man and other primates. A tentative conclusion on an important point is that human cones may each contain one only of the three pigments so far revealed by the measurements. Most satisfying is the fact that one of the pigments found is blue-sensitive with a maximum around 450 nm. which appears to be, very probably, the pigment of the "blue" response process inferred from much psycho-physical work but not put in evidence by the fundus reflection studies.

Temperature Variables in Coloured Light Signals

J. G. Holmes

In the early 1930s, colours for signal lights were a simple matter—there were only red and green Board of Trade limit glasses first chosen for marine signals and then adopted, with the addition of orange glasses, for railways and for road traffic. Aviation signals started to introduce complications because they included yellow and they called for high transmission factors, leading to the use of relatively new glasses with selenium, cadmium and sulphur as the colouring agents. These justified a full reexamination of the whole problem.

The 1935 C.I.E. meeting in Karlsruhe made a great contribution by specifying the practical tolerances for each colour in trichromatic co-ordinates; for red, yellow and green signals as used in aviation (ground lights and airborne lights), in railway and in road traffic signals. These determined the objective colours as then used and provided a basis for research and development.

There were few temperature problems at that time and very few people, if any, even realised that there might be serious problems. It was of course known that a red glass had a lower total transmission factor for an electric lamp of high colour temperature than for an oil flame and that a green glass had to be of a bluish-green colour if it was to give a green light from an oil flame. Nobody worried about the operating temperatures of the filter itself; the 1935 colour limits had been chosen on the basis of practical experience and the effects, if there were any, had been automatically allowed for in the specifications.

The great surge of colorimetric research which led to the birth of the Colour Group in 1941 carried with it a world-wide series of enquiries into thecolours of glasses and other filter materials for light signals; Gibson, McNicholas, Judd and Farnsworth in American, van der Werfhorst in Holland, Hill and the author in this country, all collected a very wide range of data which enabled the colour specifications to be greatly refined and improved. At about the same time, the range of colour temperature of the light source was considerably extended, from the old 1900/K used in railway and lighthouse signals to 3000/K used in high-efficiency airborne signals. The effect of the colour-quality of the light source made itself felt as a major variable and it was realised that different coloured filter glasses had to be used with different lamps. Perhaps the first specification to include these explicitly was the American Railroad Specification AAR-69-40 of 1940 or 1941, although the effect had been appreciated and partly controlled in the British Standards for Railway Signals B.S.623 issued in 1934 and in 1937. When the first rationalised colour signal specification was issued in this country in 1947, different sets of limits were stated for three colour. temperatures of light source, 2000/K, 2360/K and 2848/K.

It was not until the late 1940s that the effect of the operating temperature of the filter was investigated and even now there is little information available. Gibson in 1916 and Holland and Turner in 1941 had done some of the fundamental research, but almost the only paper on the practical implications is a supplement to a C.I.E. Report in 1955. As an example of this temperature effect in the author's experience, a red aerodrome approach light designed in 1952 was required to have a red glass filter of at least 20% transmittance and was found to transmit only about 5% of the available light; the operating temperature of the filter was known to be about 230/C but the extent of the effect was quite unexpected. It was found necessary to use a filter which was orange at room temperature in order to provide the required red colour under service conditions. This problem became more acute as lamp wattages were increased and as signalling equipment became smaller.

Thus this historical background indicates that there are two main factors, the colour temperature of the light source and the operating temperature of the filter. These effects may lead to variation in the colour or intensity of the light from a given filter glass greater than the tolerances permitted in the specification. As those tolerances were in general chosen to provide only for the unavoidable manufacturing variations in coloured glass, the task of the glass maker becomes difficult.

The Development of Physical Methods of Colour Matching in the Textile Industry

T. Vickerstaff

If there is one industry which should have an outstanding interest in colour measurement then it is the colour making and colour using industry, since colour is its sole raison d'etre. Twenty-five years ago, although interest may have been present, the practical use of colour measurement in these trades was trivial. This was primarily because the instruments available at the time were not sufficiently robust, reliable and foolproof and were too time consuming to be of practical value. During the past twenty-five years the situation has changed completely due to instrument development and the availability of computers, and the uses of physical methods of colour measurement are now growing at a widening and accelerating rate.

The development of this interest has occurred in two stages. First chronologically came the production of reliable photoelectric photometers which made it possible to estimate dye concentrations in solution accurately, and such instruments are now widely usedby most dyestuff manufacturers to control the dye content of their commercial products. Their use has led to tighter quality control and economies in the standardising operation. The use of such instruments is universal in research on dyeing processes and it is doubtful whether dyeing theory could have advanced so rapidly without them. The second stage of development has been in the colour using trades and this has only occurred more recently with the availability of computers. In textile dyeing significant development is confined to the last five years.

Dr. T. Vickerstaff

The dyer's problem is concerned primarily with colour matching and is much more complex than the mere estimation of the concentration of a single dye in a solvent in which Beer's Law is obeyed. In the traditional form of colour matching, the dyer is presented with a physical sample of a colour—"the standard"—and is required to dye a large quantity of textile material to a "colour match" or in other words to a colour which is visually the same as the standard. The established method is empirical. From experience and samples of previous dyeing the dyer selects two or more suitable dyes, and guesses the relative quantities needed to match the standard. He then carries out a trial dyeing, compares the colour with the standard, makes adjustments to the recipe, carries out a second trial dyeing and so proceeds step by step until a match is obtained. The colour physics of this process were known 25 years ago and a similar process could be followed to obtain a match from physical data; in fact such recipe predictions were made for academic interest. However, no-one has yet discovered how to derive a matching recipe directly from a spectrophotometric reflectance curve of the standard so the procedure was, and still is, iterative in the same way as the practical dyer's process.

Even with modern computers this type of calculation is lengthy, and the economics of colour matching by calculation from physical data may determine the approach used by any particular dyeing concern. The cheapest approach is to rely upon the dyestuff manufacturer to provide the information, assuming that the latter has installed a computer and can provide the service. The first service of this kind in the world was introduced by the Dyestuffs Division of I.C.I. in September, 1963, under the name I.M.P. (Instrumental Match Prediction). Later developments of a similar type are the C.C.M. Service of American Cyanamide (late 1963) and the SARFO service of Sandoz (Jan., 1966). The dyer measures the colour of the required standard shade, transmits the data to the dye maker and receives back one or more computed recipes, together with correction factors.

If the dyeing firm has access to a computer, possibly used within the firm for other calculations, then it may be possible to use this for the colour computations. The dyeing firm must have a suitable colour measuring instrument and also must provide its own basic data in terms of the reflectance spectra of the dyes to be used at various concentrations applied to various materials in various machines. The firm must also develop suitable programmes. The acquisition of data and programme development is an expensive and time-consuming process and usually costs much more than the charge for computer time.

The purchase of a computer designed solely for colour matching is generally more expensive than using an existing computer because the computer is an additional item to the spectrophotometer and the basic data must still be acquired. However, programme development is not involved. Computers of this type are the COMIC (Davidson and Hemmendinger), the Pretema FR-1 and the Redifon Colour Computer. Methods dependent on pre-calculation by the dye makers are also available in the "Colorthek" system of B.A.S.F. (a colour atlas containing 1320 shades) and the Ciba Q Method.

The mere listing of these methods is perhaps sufficient to show how interest has developed in this subject in the last five years. There can be little doubt that computation of colour matching recipes from physical data will have a very important effect on the dyeing industry in the next quarter century.

Scottish Meetings

In view of the increasing interest in the study of colour in these parts, stimulated by the use of instrumental colour measurement in industry, it is hoped to hold three or four meetings each session in Scotland.

LINKING THE ART AND SCIENCE OF COLOUR

The first meeting was held in the College of Printing, Glasgow, on 14th October, 1965, at which there was a very good turnout from a variety of professions. The staff of the college arranged an interesting exhibition of various aspects of the colour printing process. The meeting took the form of a discussion led by Mr. J. Rae, an artist doing research work on colour vision and colour measurement in the Psychology Department, Edinburgh University. He discussed the wide range of professions which had an interest in some aspect of colour, but complained that each group specialised in their own field and made little attempt to understand the problems of any other group. Mr. E. Odling (Glasgow School of Art) was questioned closely about the artist's method of communicating his ideas and concepts of colour. The artist was trained to make critical observations, but the imprecise nature of colour terminology meant that he could not communicate with scientists who had to express everything in numbers. Other subjects discussed included the requirements of an ideal pigment, the poor colour naming system used for artist's paint tubes, the effect of surface structure on colour appearance and colour measurement and the influence of size, shape and environment on colour appearance. It wasgenerally agreed that the Munsell terminology offered the best hope of bridging the gap between appearance and measurements or between the art and science of colour.

ILLUMINATION FOR COLOUR MATCHING

The second meeting was held on 6th December 1965, in the Electricity Showrooms, Sauchiehall Street, Glasgow. The speaker was K. McLaren, of I.C.I., Dyestuffs Division.

Mr. McLaren surveyed the work of the National Illumination Committee which led to the recent draft specification for artificial daylight tubes to be used for colour matching. Recent studies of the properties of various phases of daylight in both this country and the U.S.A. had indicated a mean correlated colour temperature of about 6,500/K, the actual chromaticity coordinates lying mainly on the green side of the colour temperature locus in the C.I.E. diagram. The C.I.E. standard Illuminants B and C however lie on the pink side. These investigations have led to the new C.I.E. Illuminant D (5,500. 6,500 and 7,500/K). The B.S.I. draft specification now includes an ultraviolet content and specifies spectral distribution and chromaticity co-ordinates. The specification includes tolerances which are small in the green region but are larger in the red and violet bands. Fuorescent tubes which conform to the above specification are now available commercially and have been shown to compare favourably with daylight even when metameric samples are being matched.

A lively discussion followed during which the following points emerged:

1 The level of illumination should be greater than the recommended mini 4. mum of 45 lumen/sq. ft., particularly for blues and blacks and a value of about 150 1/sq. ft. is usual.

2 It was suggested that tube manufacturers should specify tube life.

3 The tubes should be used in an open fitting since a diffuser would cause selective absorption.

4 In C.I.E. computations the effect of using Illuminant D (6,500) rather than Illuminant C would be smaller than the difference due to use of 2 / data rather than 10/ data.

R. S. SINCLAIR.

New Book

SUBJECTIVE LIMITATIONS ON PHYSICAL MEASUREMENTS
by C. A. Padgham.
77 pages, 38 figs., 44 references. Chap-man and Hall, London. 12/6.

This is one of the series "Monographs for Students" issued by the Institute of Physics and the Physical Society. With the exception of a few references to hearing, the subjective limitations that are considered are entirely those of vision. This bias in content reflects the author's own interests, as well as the paramount importance of the visual act in many measurements.

A description of the gross anatomy of the eye and retina introduces the concept of visual acuity. Other modes of perception are banished in the time-honoured fashion to the "obscure" workings of the visual cortex. Repeated mention is made of the wide range of response to a given stimulus by a population of normal individuals, and the consequent uncertainty in defining various visual standards is rightly emphasised. The author lapses into occational biological heresy when he refers to the eye as an optical instrument (pp. 5-6) or implies that the macular boundaries are circular (Fig. 2.4).

The main chapters deal with the use of verniers, microscopes, telescopes, theodolites and rangefinders in relationto visual acuity (Chapter 2) and of photometers, polarimeters and optical pyrometers in relation to contrast discrimination (Chapter 3).

Facts and figures are instructive and well presented. In the event of this monograph being reprinted, one irritating typographical error should be cordected. In the description of the action of the Lummer-Brodhun contrast photometer head (p. 39) the equations $L_B = 0.92, L_C = 0.92(0.92), L_A = 0.85$ L_A read correctly without the two commas.

Other, shorter chapters deal with absolute visual thresholds, colour discrimination and visual transients. The dependence of visual characteristics on a variety of adaptation conditions is also discussed.

More and more measurements are being made without recourse to the eye, some merely with a higher precision, others with a real gain in accuracy. The author mentions photo-electric polarimetry and optical pyrometry but overlooks important developments in length measurement using moire fringes or angular measurement using coded scales.

These criticisms do not seriously detract from the value of the monograph. for students will no doubt continue to follow the historical pattern in laboratory work and will still need to use their eyes.

J. D. MORELAND.

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