Journal of the

Colour Group

Number 4 September, 1965

"Teaching those things which tend to the perfection of vision"

The Newton Lecture is to be on a subject of wide interest to the Group and its friends, and is to be delivered by a person distinguished in the field of colour.

The Chemical Basis of Colour Vision and Colour Blindness

W. A. H. Rushton, F.R.S.
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Just three hundred years ago, Newton, then twenty-two years old, was building a telescope that was to be very much more powerful than Galileo's. He had, of course, to grind his own lenses and he was having trouble with the objective glass for he could not get the image of a star to focus really sharply. I think he must have seen, when he stopped down the objective glass and allowed rays only to pass near the centre, that the star image was a sharp point, but when the stop was moved to the periphery of the objective then, instead of being a point, the image was a streak running in the direction of the excentric stop. It was not just that the curvature of the lens here was not quite right, for the streak could not be brought to a point of focus no matter where the eye-piece was placed. It really looked as though Snell's Law could not be exact and that parallel rays that were deviated were not all deviated to the same extent. It was difficult with an objective glass and starlight to see what was happening. It would be much clearer to use sunlight and deviate the light through a large prism where the result should be much more definitely visible. He bought a prism at the fair on Midsummer Common, but before he had time to perform experiments with it the Great Plague spread from London to Cambridge, and in the autumn of 1665 the University disbanded, and Newton went to his home farm in Lincolnshire. He did not do experiments there nor did he do farming, but his time was not altogether wasted, for he saw the apple fall, extended his concept to the moon, and invented the calculus to solve the problems of celestial mechanics that resulted. But in the summer of '66 the plague abated from Cambridge and Newton came back to his rooms in Trinity College and cut "a hole in the shut of his window" and placed there his prism, and produced the solar spectrum on the far wall. We know how he discovered chromatic aberration and found that rays of light with different refrangibilities produce images usually of different colours, though from respect to the title of our first Newton Lecture I must remind you that "the rays were not coloured." Newton also performed experiments in colour mixture and enunciated his Centre of Gravity Law for the way in which different colours were produced. Now the Centre of Gravity Law implies the trichromacy of colour vision, and no one could have seen this more plainly than Newton. Nevertheless he did not draw that conclusion. He preferred to reject his experiments, (which were somewhat rough), and to stress the similarity between sight and hearing. He divided the spectrum into seven regions corresponding to the tones and semitones of a diatonic scale, and concluded that each point on the retina has resonators to respond to every frequency of light. I must pass over much work that followed : Lomonosov, still tied to the concepts of alchemy but the first to state the principle of trichromacy ; the brilliant physical conjectures of Thomas Young, and the massive experimentation of Helmholtz already well under way at the time that the Centre of Gravity Law was proved by another student of twenty-three, James Clerk Maxwell, whose rooms faced those of Newton across the Great Court of Trinity. Since Newton's rooms faced south, Maxwell's faced north, and he could not get the sunlight into them ; and, as is well-known, he performed his experiments with coloured papers spun upon a top of his own construction. With this simple appliance he was able to plot the tristimulus values for a range of colours and to show that the red-blind type of colour defective lacked the red primary sensation ; so that, plotted upon the colour triangle, their confusion loci were straight lines converging upon the red corner of the triangle.

In the century that has elapsed since Maxwell's early experiments the technique of colour matching has enormously improved. Maxwell himself later used spectral lights mixed by an ingenious device, and with the classical work of Professor Wright, our first Newton Lecturer, the problem of trichromatic colour mixtures was virtually completed, so that it was possible to say for a light of any known spectral composition what mixture of the three primary colours would match it exactly. But though this result, which was confirmed by Guild and by Stiles, allows us to specify the colour mixture in every circumstance, it tells us nothing uniquely about the colour mechanisms in the eye. It is here that the investigation of the actual visual pigments in the retina proves of some help.

PHOTOSENSITIVE PIGMENTS

Light imprints its image on the retina in very much the same way as it does upon a photographic plate. The lens system of the eye forms a pretty sharp image and the retina, like a plate, contains a photosensitive pigment that will break down when light is absorbed. Ninety years ago Kuhne worked out the properties of the visual purple, or rhodopsin, that can be seen in the eyes of frogs and mammals, and he showed how this purple pigment was bleached to whiteness on exposure to light and how, in the living eye, it was regenerated again by the biochemical processes in the retina and pigment epithelium. Dr. Dartnall, who is well-known to the Group, is one of the world authorities on these visual pigments, particularly when extracted and brought into solution where the most accurate measurements are made. He has, in fact, (with Dr. Crescitelli), been able to extract rhodopsin from fresh human eyes and correlate the absorption spectrum with Dr. Crawford's measurements of the twilight sensitivity spectrum, and shown that the two coincide very closely indeed. This adds great strength to the belief that rhodopsin is the pigment underlying twilight vision ; but, as we all know, twilight vision is colourless vision, and therefore rhodopsin is not the pigment to be studied if we are interested in the chemical basis of colour. Rhodopsin is the pigment of the rods in the retina. We need the pigments in the cones.

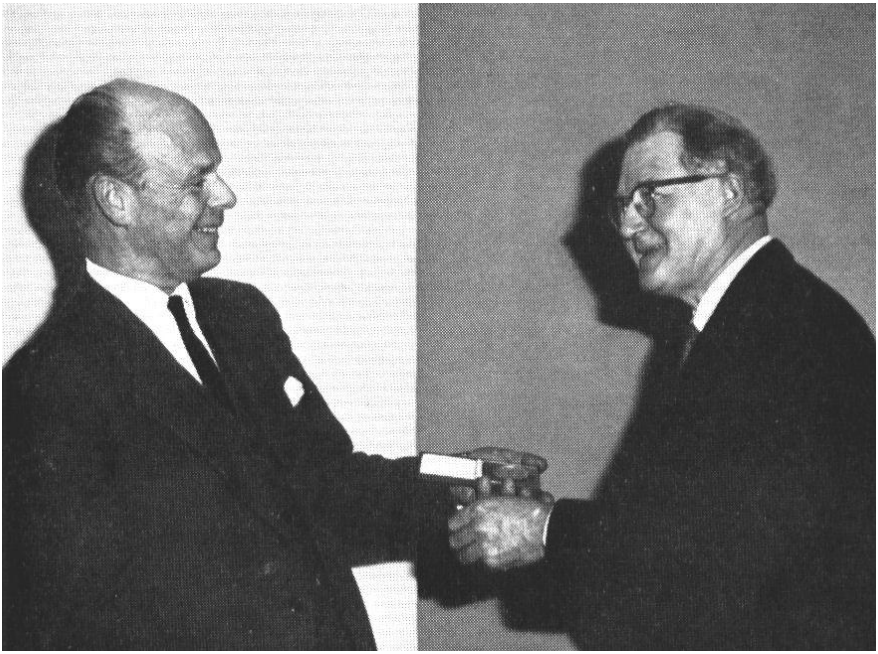
Unfortunately there is so little pigment in cones that no one has ever satisfactorily obtained an extract of cone pigment from any mammal. Such extracts are so contaminated by rhodopsin that the small cone contribution cannot well be measured. But we can get round this difficulty by a trick. If, instead of taking out the whole retina and mixing together all the ingredients, as happens when pigments are extracted ;if, instead of this, we can make measurements in the living human retina, then we may take advantage of its well-known structural peculiarity, namely that at the centre in the fovea centralis there are no rods, there is no rhodopsin; measurements made here cannot be contaminated by rhodopsin, and if we can make the measurements at all it must give us nothing but cone pigments. But how are we to make measurements in the living eye?

The principle that we use is that of the ophthalmoscope, or of the eye shine that comes back from a cat's eye when it is caught in the head lamps of a car. That light has been twice through the retina and must bear upon its spectral composition the imprints of the pigments through which it has passed and which have absorbed part of the light. This is not the place to discuss the techniques of measurement. As the Group well knows, both Dr. Weale and I have devised and built equipment that is capable of analysing the light returning from the eye and deducing from it some properties of the visual pigments through which the light has passed. My densitometer was designed to make measurements as accurately as possible even though it took some time to make them. So, by means of a phase-sensitive rectifier, we obtained a rather good signal-to-noise discrimination, and using one wave length at a time and taking between five to ten seconds for a measurement, we got reliable estimates of the pigment. When Dr. Weale built his equipment he did not follow our pattern but designed an instrument to do quite a different kind of thing ; namely, to make measurements throughout the whole spectrum extremely rapidly so that he was able to record the reflectivity at over a score of spectral wave lengths within a second. It is clear that my equipment is better designed for equilibrium or slowly changing conditions whereas Dr. Weale's is ideal for the rapid record of transient changes throughout the whole spectrum. In the experiments that I wish to speak of now we are concerned with measurements as accurate as possible in steady states, and therefore the Cambridge densitometer is probably the instrument of choice, and it is to our results that I shall refer.

The first definite results were published just ten years ago, and we were able to show that the protanope, (the red-blind kind of colour defective) lacked the red-sensitive pigment that is present in the normal ; so exactly a nundred years after Clerk Maxwell (1855) showed that protanopes lacked the red primary sensation, we were able to demonstrate (1955) that the physiological entity that they lacked was the red-sensitive pigment, erythrolabe. In the subsequent ten years we have improved the technique a good deal and made measurements on a very large number of normal and colour-defective subjects, and the results seem to come out as Konig suggested long ago. In the red-green range protanopes lack the normal red pigment, erythrolabe, and contain the green-sensitive pigment, chlorolabe, only. Deuteranopes, on the other hand, lack chlorolabe and contain erythrolabe only ; but normal eyes contain both erythrolabe and chlorolabe and everyone, (except tritanopes) contains the blue-sensitive pigment, cyanolabe. The evidence for this will take me most of the rest of this lecture.

THE EVIDENCE

In order to see whether a protanope contains one pigment or two in the red-green range we use the most powerful of all the scientific tools, that of substitution. In the first experiment we bleach the fovea by a red light ; in a second experiment we bleach with a blue-green light. Everything else in the experiment is the same and the intensities of the two bleaching lights are chosen so that the protanope himself thinks that they are equally bright. Now if the protanope, in fact, had a red-sensitive and a green-sensitive pigment, but lacked the power to discriminate between their outputs, it would be the red pigment that was chiefly bleached with the red light, and the green pigment chiefly with the blue-green light. If then we measure the change after bleaching in the two cases, they ought not to be at allidentical ; for the change after red should be greatest in the red, and the change after green should be greatest in the green. But when this experiment was done it was found that the change was very nearly identical in the two cases and where there was a small change it was not systematic but just the sort of change that occurred when the experiment was repeated with apparently identical conditions. We may therefore conclude that the protanope has only one photosensitive pigment in the red-green range, or at least if he has another it is in such small quantity that it cannot be detected by our technique.



Dr Rushton receiing the Newton Medal from Chairman, Mr Michael Wilson.

Photo: A Khopkar

Now when in any spectral range there appears to be only one photosensitive pigment present, we can tell whether or not it is the visual pigment of that range by the tests, mentioned earlier, that Dartnall & Crescitelli and Crawford applied to human rhodopsin, namely, to see whether the action spectrum of the pigment corresponds to the spectral sensitivity of vision. This test we applied to the pigment chlorolabe in the protanope and we found that lights of different wave lengths, adjusted in intensity to bleach chlorolabe equally fast, were judged by the protanope to be equally bright using flicker photometry. We may therefore conclude that the pigment that we can measure in the protanope is that which generates the signal that he sees.

These experiments on the protanope were repeated on the deuteranope with exactly the same results. The deuteranope was proved to have only one pigment in the red-green range since bleaching with a deep red light, or with a blue-green light that the deuteranope found of the same intensity, produced the same change in pigment. Thus he has only one pigment present and this was found to correspond with his spectral sensitivity curve. Consequently the pigment that we measure on the deuteranope is not the same as the pigment we measure on the protanope : there is a difference that corresponds to the well-known difference in the spectral sensitivity curves of these two types of dichromate.

Turning now to the more difficult case of the normal eye where two different pigments have to be measured at the same time, we can gain a great deal of strength from the results with protanopes and deuteranopes. If we bleach the normal eye with a deep red light that has no bleaching effect upon the protanope, the pigment affected appears to be the same as the erythrolabe of the deuteranope, for the two pigments have the same difference spectrum, the same action spectrum, the same photosensitivity, and the same regeneration rate; and the spectral sensitivity corresponds very closely to that of the Stiles' red mechanism π_5

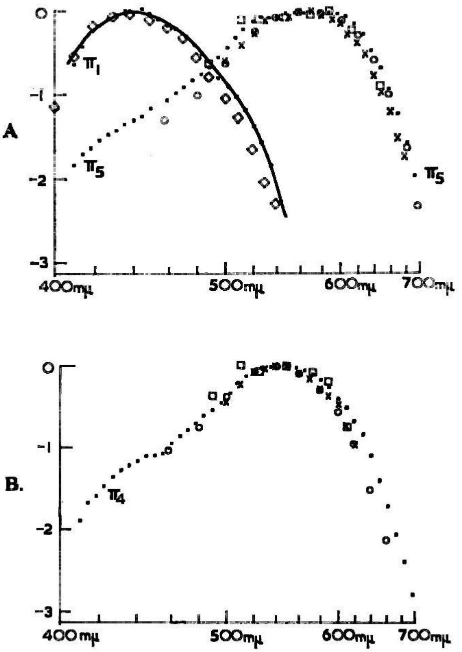


Fig. 1. ***A,*** *red mechanism on the right, blue mechanism left.*

B, *green mechanism. Dots, Stiles' 2-colour increment threshold sensitivity ; circles, foveal sensitivities in deuteranopes (A) and protanopes (B). Crosses, Brindley's artificial monochromacies after adapting to very bright green or red lights. Squares, the action spectra of erythrolabe and chlorolabe in deuteranopes and protanopes measured by retinal densitometry. Diamonds, Blackwells' blue cone monochrotnat. Curve, expectation of blue mechanism from Wright's spectra tristimulus values.*

Rather similar considerations lead us to the conclusion that chlorolabe in the protanope is the green pigment of the normal eye whose action spectrum corresponds closely to Stiles' green colour mechanism π_4. There are four very different kinds of approach that lead to similar spectral sensitivity curves for the red and the green mechanisms in the eye (Fig. 1 A and B). Stiles, by his two colour increment threshold, has shown that there is a red mechanism and a green mechanism whose spectral sensitivity is the same whether determined by varying the colour of the flash or varying the colour of the background. The dots in Fig. 1 plot his π_1 (blue), π_4 (green) and π_5 (red) mechanisms. Willmer has shown that these curves are very similar to the spectral sensitivities of protanopes and deuteranopes measured upon the fovea (Fig. 1 circles). Crosses show the spectral sensitivity in Brindley's artificial monochromacies produced by adapting the eye to very bright red or green lights together with violet. Finally the squares show the action spectrum of erythrolabe and chlorolabe determined objectively upon the fovea by retinal densitometry.

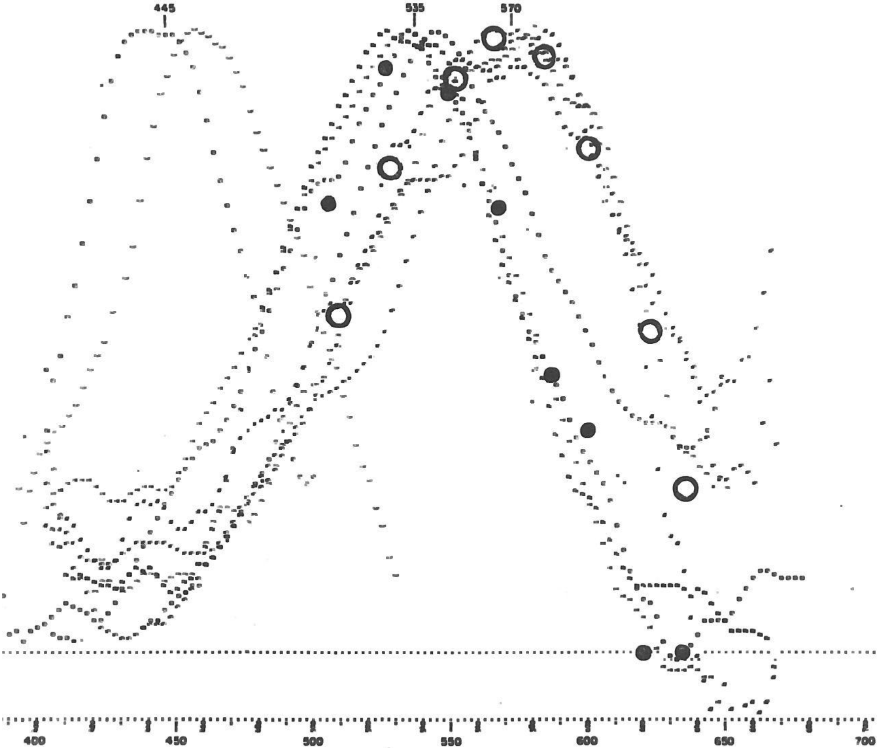


Fig. 2. Pigment density in single cones of monkey and man (Marx, Dobell & MacNichol). Each point represents a compensated density measurement plotted by their computer. Each set of points represents the difference spectrum of a different cone. They fall nearly upon 3 curves. Heavy circles plot the difference spectrum of erythrolabe ; heavy dots, chlorolabe. Clearly the red cones contain erythrolabe, green cones chlorolabe, and blue cones show the missing cyanolabe that corresponds to the 7, curve of Fig. 1A.

These congruent results are supported by the fine work of Marx, Dobell & MacNichol recently reported from U.S.A. They have succeeded in measuring the visual pigments in single cones from the eyes of monkeys and man. This is a remarkable achievement because there is so little pigment in a cone that it is bound to be bleached away by the light used to measure it. They used a computer instructed to take into account the inevitable bleaching as measurements went on, and give the adjusted answer. Fig. 2 shows their results, each point being a computed measurement, and each curve so formed being obtained from a separate cone. It is seen that all the points lie approximately on one of three curves ; that means that each cone contains one of three kinds of pigment. The heavy circles and dots are plotted from our (previously determined) difference spectrum of erythrolabe and chlorolabe. So this new work with single cones confirms and extends our conclusions. Erythrolabe lies in one kind of cone, chlorolabe in another, and yet a third class of cones contains the blue pigment, cyanolabe, which we have not been able to measure reliably. I think we may say that the chemical basis of colour vision is virtually settled.

To this statement there may be several in the Group who will feel inclined to answer "Well, the chemistry of something may be settled, but why do you say it's the chemistry of colour vision ? In all the lecture I don't remember that you mentioned colour at all, and if you did, it certainly wasn'tthe colour of colour that you were speaking about. Where does colour come in ?" This I think is the view of Dr. Edwin Land.

COLOUR APPEARANCE

I was talking to Dr. Land at a meeting on Colour Vision last summer and he said to me "Have you noticed that at meetings on Colour Vision people never talk about Colour. They discuss the structure of the eye, the pigments involved and the electrical signals. When it comes to appearances they are concerned with whether fields look identical, or what is the threshold for detecting a difference. But no one is indiscreet enough to say "What colour did it seem to be ?"

I am sure that for very many of the Colour Group Dr. Land's complaint is a very pertinent one. Perhaps the majority of you are concerned mainly with what the colour seems to be in a range of conditions of viewing, and I think some of you may feel that there is quite a perverseness- particularly in physiologists - in blandly treating this central aspect of colour as though it did not exist or was so trivial that it deserved no mention. If in this Lecture I have never touched on colour-appearance it is certainly not because the subject is too obvious or too unimportant. For my part I think it is fascinating, but it is very hard to investigate.

There are two stages in the encoding of colour. The first we know now is the catching of quanta by three visual pigments each situated in its own kind of cone. The output of each cone, like the output of a photocell, is univariant ; it depends upon the total quantum catch but not independently upon the wave length of the quanta caught. The second stage is nerve interaction as a result of the various cone signals. It is an organization of the utmost complexityand its stages occur at many different levels of retina and brain.

Now the only colour relations that are exact and rather general are those that depend upon the pigment stage—the stability of metameric matches and of Stiles' π mechanisms. It is their stability and simplicity that have encouraged most of the great investigators to study them, and, as we have seen, an attack from all sides has now at last captured this citadel—or is it only the first pill box on the long advance ? At any rate this is about as far as a physiologist can go at present in his contribution towards colour vision. Those vital factors in appearance, aperture colour or surface colour, colour memory, colour association—even colour prejudice—these and many more, have at present no clear correlation with neurology nor electrophysiology.

If then I do not mention the Appearance of Colours it is not that I undervalue it, but simply because it is still too difficult a question, as it was 300 years ago when in his first paper Newton wrote : "But to determine more absolutely what Light is . . . and by what modes or actions it produceth in our minds the Phantasms of Colours, is not so easie. And I shall not mingle conjectures with certainties."

The Swedish Colour Group

From GUNNAR TONNQUIST

With the co-operation of about forty Swedish Industries and some official institutions we have succeeded in establishing a foundation called "Svenskt Fargcentrum" (Swedish Color Center).

You will find the name very similar to the old Color Center, which in fact is operated by the same staff and in mainly the same way as before but now under the auspices of the new foundation.

Report of Meeting

At intervals the Colour Group has an "Imperial College Meeting" at which work carried out in the Technical Optics Department is described. This year the meeting was held on 14th April, and Miss J. A. Spencer and Mr. W. R. Willcox presented results they had obtained.

MAXWELL'S SPOT

Miss J. A. Spencer

The various static and dynamic patterns of Maxwell's Spot were described, with a brief account of the theories which had been proposed to explain its existence.

The theory most widely held attributes the Maxwell Spot to the absorption of blue light by the yellow macular pigment. The present investigation was an attempt to correlate Maxwell's Spot with macular pigmentation for some 20 observers. W.D.W. chromaticity coordinates of a white light stimulus were measured for each observer and these were compared with the threshold obtained for visibility of Maxwell's Spot. This threshold was found by reducing the retinal illumination level until the Spot was no longer distinguishable against the background. A high degree of correlation was found between the two variables. As differences in the white point chromaticities are thought to be due to varying amounts of macular pigment absorption, this appears to relate Maxwell's Spot and the pigment.

The effect of pre-adaptation to five different spectral bands upon the visibility of Maxwell's Spot was also investigated and described.

TROXLER'S EFFECT AND THE STABILIZED RETINAL IMAGE

W. R. Willcox

Changes in the appearance of a peripheral test object which occur within a few seconds of commencing voluntary fixation are generally thought to be due to stabilization of the retinal image. Results of experiments on this Troxler's effect may therefore be considered in the light of hypotheses drawn from the behaviour of the visual system in conditions of foveal stabilized stimulation.

Using angles of eccentricity between 10/ and 50/, a 1/ circular light stimulus was viewed with careful fixation for a period of 80 secs. Periods of visibility and disappearance were signalled by the observer and recorded. The results have been examined in three ways. Firstly the visibility factor has been calculated ; secondly the frequency distributions of the lengths of the periods of visibility and invisibility have been plotted ; thirdly the method of Ekman and Lindman has been used to examine regularities in the phases of visibility.

The results seem to provide evidence for the "Two Channel" hypothesis of of Barlow and suggest that this hypothesis can be related to the "Process Intensity" of Ekman and Lindman.

K.H.R.

Correction

The third author of the paper "Who Needs to Know What About Colour" on page 14 (January, 1965 issue) should have been given as Mr. D. A. Pavey.

Book Reviews

The December, 1964, meeting of the Colour Group was held at the National Book League, Albermarle Street, London, and consisted of reviews of six "Classic Books on Colour." These reviews were given by members of Group, and it is hoped to print them in the Journal as space allows.

"DE LA LOI DU CONTRASTE SIMULTANE DES COULEURS"

M. E. Chevreul (Paris 1838)

Reviewed by P. Kowaliski

Being in charge of the "Manufactures Royales des Gobelins" in Paris, M. E. Chevreul, artist and scientist, attempted to find a rational classification for the many thousand delicate colours of the threads employed in making the Gobelin tapestries. His friend Andre-Marie Ampere encouraged him in this task and in fact obliged Chevreul to find a solution by expressing doubt in the validity of any classification not satisfactory to the physicist's mind. After several years of search, Chevreul, while attending in 1827 a lecture in the Academie des Inscriptions et Belles Lettres by Mongez on the crossing of the Alps by Hannibal, suddenly found the solution : the hues laid out on a circle, in a horizontal plane, with the "white" in the centre, the radial lines representing the saturation scales for each of the hues, and the whole covered by a hemisphere, the highest point of which was the "black," its surfacecarrying on the vertically placed quarter circles the brightness scales. Chevreul took care to introduce in his system the intrinsic lightness of each colour by placing the "optimal" colours on different radial distances. An important part of his book is not only devoted to applications of his system to the manufacture of the Gobelins, but also to garden architecture.

"SIX LECTURES ON LIGHT"

J. Tyndall (London 1873)

Reviewed by R. A. Weale

I have always been puzzled by the nature of Helmholtz' celebrated remark about Thomas Young wherein he observed that the physician of Wimpole Street had been a man far in advance of his age. Why did Young need this prop, why was his renown less than it is today, why less at a time when he had been dead almost 30 years ? In the second of the six lectures that Tyndall delivered in America 90 years ago, we obtain a partial answer. "For twenty years," he writes, "this man of genius was quenched—hidden from the appreciative intellect of his countrymen—deemed in fact a dreamer, through the vigorous sarcasm of a writer who had then possession of the public ear, and who in the Edinburgh Review poured ridicule upon Young and his speculations." The assailant turned out to be a Mr. Henry Brougham and the story —partly told in an appendix to Tyndall's lectures—is not devoid of interest. Brougham was born in Edinburgh in 1778. He records in his autobiography that just after his father had taught him to read, he was attacked by "a putrid fever which produced an extraordinary effect in destroying my memory almost entirely ... " a significant observation in view of later events. At the age of 18 he wrote a paper entitled "Experiments and Observations on the Inflection, Reflection and Colours of Light" which the Royal Society saw fit to publish.

Now Thomas Young criticized Brougham's early work without being severe. He states that those "optical speculations, partly confuted before, and already forgotten, appeared to their fond parent, to be in danger of a still more complete rejection from the establishment of my opinions" (as regards the undulatory nature of light). This would seem to have been the immediate cause, if not the reason, for Brougham's attacks.

About the famous Bakerian lecture Brougham wrote "As this paper contains nothing which deserves the name, either of experiment or discovery, and as it is in fact destitute of every species of merit, we should have allowed it to pass among the multitude of those articles which must always find admittance into the collections of a Society which is pledged to publish two or three volumes every year. The dignities of the author, and the title of Bakerian lecture, which is prefixed to these lucubrations, should not have saved them from a place in the ignoble crowd." He upbraids Young for a change in opinion, ridicules his notion of the ether, condemns him for departing from Newtonian dogma, questions his honesty and integrity, accuses him of eclecticism, and generally deals with him as behoves the Advocate of the Scottish Bar that he was.

Young's Bakerian lecture thus met more obloquy lacking in substance, more derision without cause other than that Newton's writings shone with the infallibility of an Aristotelian star.

At last Thomas Young was roused. He was prepared to ignore the evanescent effects of uniformed invective. "But," he writes, "it is possible that art and malice may be so insidiously combined, as to give the grossest misrepresentations the semblance of justice and candour . . " That he may have changed his opinion he does not deny: on the contrary, he quotes with approbation one Dr. Olbers of Gottingen who remarked in connection with his own erroneous views on ocular accommodation that his object is to discover truth and not to support his opinion. He then moves to the defence of the undulatory theory of light with some appeal to the authority of Hooke and Huygens, a passing reference to Laplace and Benjamin Franklin, and the unequivocal non credo that "much as I venerate the name of Newton, I am not, therefore, obliged to believe that he was infallible." In the end, however, Young flays his assailant without mercy. He writes "The whole purpose of the paper inserted in the ninth number of the "Review" might be supposed to have been, not to confute the principles which the writer attacks, but to show that he is incapable of understanding even the simplest of them . . "

The rest was silence. Thomas Young died and became famous, Mr. Brougham became famous and died. You know him from the conveyance that he invented—the "travelling garden-chair." Those versed in Education recognize in him the founder of Birkbeck College and of London University, the Whigs amongst us recall that he abolished Slavery and the Tories curse him for his efforts in connection with the Reform Act. His temper explains the ferocity of the attacks which Thomas Young had been subjected to, but not their rationale. It may be that the "putrid fever" of Brougham's youth had partly affected his mind. The cause is hard to establish now, but the fact remains that Lord Brougham's body outlived his mind.

What is there to say of Thomas Young ? He acquitted himself well in a matter that must have gnawed at him for a long time. Yet while he must be admired in his distress he is also to be envied ; for though the attacks on him had been mordant, and made with the cowardice of anonymity, he enjoyed a boon beyond measure for they had been launched in public.

"PRINCIPLES OF LIGHT AND COLOUR"

E. D. Babbitt (East Orange, 1878)

Reviewed by J. M. Adams

This book is of interest to the Colour Group for two main reasons. It is uncommon ; it was published privately in 1878 and a second edition was issued in 1896. Secondly, it is a classic in its field. Babbitt was a doctor—he held a medical degree—and much of the book is concerned with colour psychology and colour therapy. Many of the current ideas on these subjects can be found in Babbitt's book in some form.

The book is comprehensive. There are over 550 pages, and the Author's philosophising extends over many subjects. The sub-title of the book includes "among other things, the Harmonic Laws of the Universe, The Etherio-atomic Philosophy of Force, Chromo Chemistry, Chromo Therapeutics together with Numerous Discoveries and Practical Applications."

The first chapter "Harmonic Laws of the Universe" is concerned mainly with aesthetic appreciation, and pictures, architecture and simple designs are considered from an artistic point of view.

A long chapter is concerned with basic theories of a variety of subjects including chemistry, atomic structure (visualised as an array of spirals and Descartian vortices), electricity and magnetism. The chapter on light sources opens with a discussion on astronomy and is followed by one on "Chromochemistry" dealing mainly with spectroscopy. These chapters are a mixture of experimental results from contemporary scientific work and semi-mystical derivations and theories.

All this leads up to the chapter on colour therapy and is claimed to allow the author to "construct a more exquisite and exact Materia Medica, and erect a standard of medical practice based on principles of almost mathematical precision." This includes the usual concept of red as a warm colour and blue as cold, but the effects of each colour are discussed in great detail, and the medicinal properties of substances are explained in terms of their colours. Thus senna is described as having golden yellow flowers, a calyx composed of five oval and yellow leaves and stamens with yellow filaments and brown anthers. It is, therefore, "an efficient and safe cathartic." Sulphuric acid has "blue, indigo and violet very strong. Diluted, it is tonic, refrigerant and astringent."

Much of the treatment proposed is by exposure to coloured light, the colour being provided by liquid filters. But the colour is the important factor, and drinking appropriately coloured liquid or wearing coloured cloth next to the skin is also recommended. One could imagine therapy on this basis having somewhat variable results, but the chapter is illustrated by many case histories, so patients must have beep treated in this way, and some at least apparently cured.

The later chapters extend the author's philosophy, stressing the psychological effects of colour.

There is much in this book that is true—one might even say that there is so much in it that some is bound to be true—but facts are so hedged around with theory, and there is such a superstructure of ethers and spirals, that it is difficult to take the work seriously.

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