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ORDINARY MEETING.*

PROFESSOR E. HULL, F.R.S., IN THE CHAIR.

The Minutes of the last Meeting were read and confirmed. The following paper was then read :—

THE HUMAN COLOUR SENSE, AND ITS ACCORDANCE WITH THAT OF SOUND, AS BEARING ON THE "ANALOGY OF SOUND AND COLOUR." By Dr. JOHN D. MACDONALD, I.H.R.N., F.R.S.

IN dealing with the sense of colour it is usual for writers to affirm that "colour is in fact an internal (subjective) sensation," and has no external and objective existence, but surely this can only be true in part. Now that we are able to obtain colour as well as outline light and shade in photography, objective conditions must be present in all. The word subjective is only applicable where colour vibrations are induced in the nerve terminals independently of any corresponding objective vibrations impinging on the retina. We are still confronted by the "*ultimate fact*" that a certain wave length will induce in us the sensation of *Red* and not *Blue*, and *vice versâ*, while the intermediate wave length will induce *Yellow* and nothing else. We may use the word subjective in this connection, but it gives us no further insight into the true cause of a specific colour sense.

* Monday, 1st February, 1897.

Nor does the following gratuitous supposition do anything more than send the inquirer farther, which is the usual effect of all attempts to clear up ultimate facts. *A Trichromic Colour Sense* seems to have sprung out of the doctrine of three primary or fundamental colours, though a tripartite constitution of light is untenable on scientific grounds. As set forth by Professor Church, "Young's theory of colour perception amounts essentially to this, that in each minute elementary part of the retina of the eye there is at least one set of three different nerve fibrils (whether 'cones' or 'rods'), each of the three fibrils of a set being especially adapted for the production of its specific colour sensation, yet in a less degree of the two others. Thus, the receptive structure of the retina as a whole may be said to consist of an immense number of nerve fibrils of three orders, what we may call red fibrils being particularly acted upon by such long light waves as those in the red, but being also stimulated in a minor degree by the shorter waves in the green, and still less by those in the blue. The green fibrils will respond most actively to green waves and in some measure also to red and to blue waves; while the blue fibrils will be most excited by blue waves, though not uninfluenced by green and even by red waves. It follows that when all three kinds of nerve fibrils are equally and simultaneously affected, the complex sensation of white is alone produced." In the above statement as far as Young was concerned Violet should be substituted for Blue. In his selection he obviously laid stress on the question of refrangibility, which is least in Red, most in Violet, and intermediate in Green; but if the octave Red (760) were visible, Blue (570) would undoubtedly be in the mean of refrangibility, and this would be in keeping with the musical analogy, the 5th G, holding an intermediate position between the 1st C (380) and its 8th or octave C (760). But to return to the argument. If the nerve terminals are accredited to be the recipients of the three so-called primary colours, though in different degrees, one having the predominance to aid the trichromatic theory, it would be just as reasonable to suppose that each of those nerve terminals were equally susceptible of the impact, not even of all the three primary colour waves, but also those of the intervening hues. This would do away with the necessity for the co-operation of two or more nerve elements in the perception of every ordinary mixture of colours, a complex physiological condition which would infallibly give rise to minute interruption in any simple wash of colour, in which nothing of the kind is perceptible to the normal eye, no matter what the hue or tint may be.

Helmholtz's independent theory is practically the same as that of Young, but he has simply carried inventive histology one step further, and thus given additional force to the foregoing argument and the legitimate deduction drawn from it. As to the support which certain forms of colour blindness are supposed to yield to this theory, the matter will not bear close investigation, and certain other considerations may be adduced to meet any apparent difficulty in the case. We are thus brought back to the simple but sound exposition of the physiology of the colour sense given by Newton himself, and have gained nothing by setting it aside. He held that all the nerve filaments of the retina were equally sensitive to the different prismatic hues whose specific vibrations were thus in effect conveyed to the centre of perception. Dr. Rutherford, F.R.S., in his excellent address delivered before the British Association in Edinburgh, 1892, contends very naturally that "we should refer our different colour sensations to differences in the nerve vibrations transmitted from the optic terminals rather than to specifically different activities of cells in the vision centre."

In reference to the pseudo-anatomical refinement of the Young-Helmholtz theory, Dr. Rutherford or any other anatomist must fail to see a tripartite constitution in the retina which such a view would necessitate. "There are indeed," he remarks, "two anatomical elements, namely, the rods and the cones so called, that would require special notice. The rods are very much more numerous than the cones, and though both are found in the general field of the retina, the cones alone occur in the yellow centre where the visual sensitiveness is most perfect. Here then we perceive that the colour sense is not impaired by the absence of the rods." But to return to a subject already referred to, though the cones are necessarily very small they would appear to be a sufficient distance apart, with numerous intervening rods in surrounding zones to render it improbable, if all the colour sense be attributed to them, that a continuous wash of any colour could be perceived without minute speckling or a finely broken ground, but as we know that no such obstruction occurs normally, we can scarcely withhold colour perception from the rods. Further, as Professor Rutherford remarks, "the image of a coloured star, small enough to fall on only one cone, can be seen of a fixed and definite colour that does not alter when the position of the eye is changed and the image shifted from one to another on the yellow spot." That fact alone seems to him sufficient to show the necessity for supposing that each cone is capable of stimulation by all visible undulations of light, and transmitting such nerve vibrations as are capable of inducing all the colour sensations. Moreover, when the image of a coloured star is made to fall on parts of the retina peripheral to the yellow spot, its colour does not disappear and reappear when the eye is moved as would inevitably be the case if the rods were not terminals concerned as well as the cones in colour sense. It is indeed obvious that if the colour of the star were made to pass through all the hues of the iris, the facts would be practically the same. There is, therefore, no standing room here for the Young-Helmholtz theory, while the Newtonian view is in touch with every part of the argument.

Though we are not at all prepared to say that the number seven does not reign in the vibrations of taste and smell in keeping with the properties of their appropriate stimuli,* no one has ever thought it necessary to invent special nerve terminals for the perception of the leading notes of the musical scale, or for particular tastes and odours, which are far more diverse and indescribable than colours and sounds.

Further, as to the perception of white and grey in the absence of all objective colour, it is hard to accept the gratuitous and complex doctrine that it requires the balanced stimulation of all three coloured terminals for red, green, and violet, to effect this. Of course the principle would be the same if red, yellow, and blue, or any other colours were selected as primitives. It is rather curious to notice how scientists differ in their choice of such colours, while each suggestion is supposed to be satisfactorily set forth by its propounder. Thus 1.—Newton and Brewster adopted *red*, *yellow*, and *blue*; 2. Young and Helmholtz, *red*, *green*, and *violet*; 3. Maxwell, *red*, *green*, and *blue*; 4. Hering, *red*, *yellow*, *green*, and *blue*; 5. Rosenstiehl, *orange*, *yellow*, *green*, and *blue*; and 6. Roechlin takes *yellow* and *blue*, while a *third principle* is supposed to be present, but always

* Messrs. Piesse and Lubin distinguish their perfumes by musical notes, and the former gentleman informed the writer that he is quite satisfied that all the senses are allied, by analogy.

associated with yellow or blue to form the reds and the violets (probably a kind of red?). From this also it will be seen that every colour in the scale has been made to take its part as a primitive by special authority, thus:—

1. Red	is taken by	Newton and Brewster.
2. Orange	„	Rosenstiehl.
3. Yellow	„	Newton and Brewster.
Yellow Green	„	Rosenstiehl.
4. Green	„	Young and Helmholtz.
5. Blue	„	Newton and Brewster.
6. Indigo	„	Often confounded with blue and violet.
7. Violet	„	Young and Helmholtz.

Physically speaking, there would appear to be ground enough for any unbiased person to form the conclusion that no one colour in the rainbow can be more primitive than another, or a bit more than any one sound can be, taken in the abstract. Independently of relative refrangibility, and taking the analogy of sound into consideration, the relative position of the colours in the scale would naturally determine their relative importance. This will be apparent in the following tables, corresponding ratios in the vibrations producing definite pitch in sound and definite hue in light.

TABLE I.

THE SYMMETRICAL SCALE OF COLOUR.

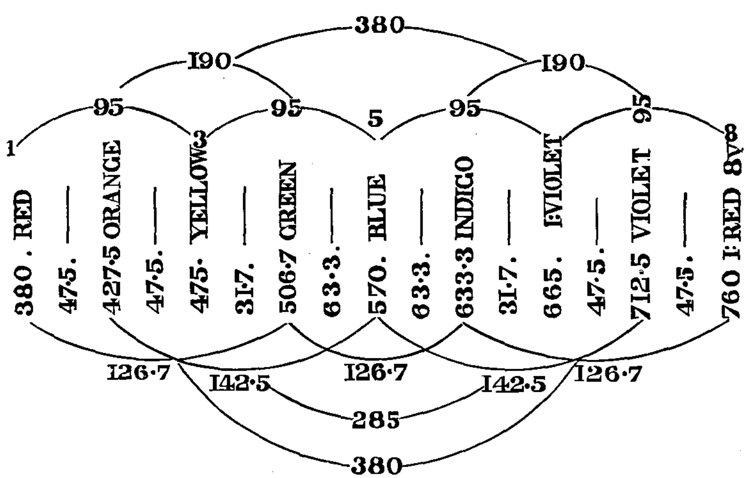
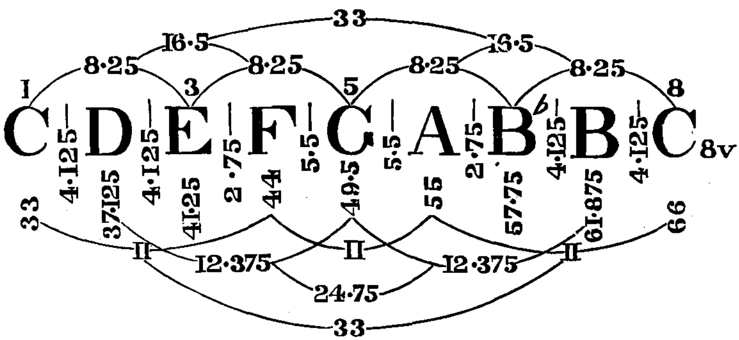


TABLE II.—THE SYMMETRICAL SCALE OF SOUND.
(*The Contra Octave.*)



N.B.—The note numbers here express the frequency per second, but in both tables the intervening and arc numbers are *increments*, which demonstrate the symmetry more palpably than if the frequency numbers alone were supplied.

On comparing the two foregoing tables it will be seen that the 1st, 3rd, and 5th C, E, and G in the musical gamut correspond with red, yellow, and blue in the scale of colour, and that the colour (blue) and the note G hold the central position in their respective scales. Moreover, it is all-important to notice that the "*intervening increments*" are disposed in the most perfect symmetry on either side of the centre in both cases.

It is rather a good thing that the musician and the painter have not so much to deal with thunder and lightning or acoustic and optical experiment as with the well-tempered musical and colorific scales. Two important laws or tenets have been brought to bear in the construction of the foregoing tables, namely, 1st, *that the undulatory theory is applicable to both light and sound*, and 2ndly, *that the musical ratios appertain also to colour*, though comparatively low numbers in one case have to be compared with billions in the other.

Angström's tables of the wave lengths and frequencies of the undulations of colour, which are now taken as the standard, were consulted and applied in Table I with no difficulty whatever. Herschel's calculations gave some little hope of success, but they were found to be a little too narrow. Thus, the chief difficulty in founding the analogy of sound and colour on a truly scientific basis would appear to be swept away; so that we have now only to apply the laws of musical harmony to painting, with no reservation whatever, only observing that juxtaposition is to colour what synchronous co-operation is to sound. The visual faculty deals with space and the auditory with time; but this simple physiological fact can scarcely be taken into account by those experimentalists who mix rays of colour in the hope of obtaining a harmonious combination, and further, if they don't succeed good names may go to swell the list of the opponents of the "*analogy of sound and colour.*" Moreover, they don't appear to be aware that they are only dealing with "*overhues,*" as physical mixture would seem to be impossible, except in the case of pigments. Thus great stress is laid on the fact that green cannot be produced by the mixture of yellow and blue light, but the cause of this is not far to seek. In the first place the mean of the two sets of vibrations would be a blue green (F♯) and not pure spectral green (F♮), and 2ndly, the sum of the two would be theoretically the octave of the same green, and consequently overreach the limit of colour vision. In the prism itself the formation of green is always coincident with the overlapping of the yellow and blue bands, though it is assumed that the fact admits of some other explanation.

In all the experimental mixtures of coloured light hitherto carried out, no reference has been made to the analogy of "*overhues*" in colour to "*overtones*" in sound, and the result has been the reception of green and violet as primitives so called to the exclusion of yellow and blue, and so lend support to the "*Young-Helmholtz theory.*"

Whatever progress had been made in the study of music up to the days of Pythagoras it is clear that he made good use of the monochord, and handed it down to us as the only test of musical perfection, so that the validity of the deductions drawn from any other means must still be submitted to the same test, which is satisfactorily applied in Table II. We talk familiarly of the scale of colour as being composed of red, orange, yellow, green, blue, indigo and violet, but as in the iris there are numerous grades of hue in all the colours, and the human colour sense is not always to be depended upon, without the application of the musical ratios it would be quite impossible to furnish so perfect a scale of colour as that given in Table I.

As might be expected whenever the analogy of sound and colour is ignored, all reference to tones and semitones of colour must be indefinite and uncertain. Thus red spoken of might have a mixture of orange in it, and yellow the same, or it may be too much on the green side, while blue, indigo, and violet with their intermediate *semitones* or *semihues* are often so indefinitely alluded to as to preclude that precision which is a *sine quâ non* in the statement of experimental results. The annexed table is intended to supply a reliable scale and nomenclature of the semitones of colour in relation to the chromatic scale of music.

TABLE III.

Chromatic scale of colour.	—	Chromatic scale of sound.	
	Billions.	Vibrations per second.	
1 Red	380	1 C	33
— Orange Red	403·75	— C♯	35·0625
2 Orange	427·50	2 D	37·1250
— Orange Yellow ...	451·25	— D♯	39·1875
3 Yellow	475·00	3 E	41·2500
4 Green	506·70	4 F	44·0000
— Blue Green	522·50	— F♯	45·3750
5 Blue	570·00	5 G	49·5000
— Indigo Blue	617·50	— G♯	53·6250
6 Indigo	633·30	6 A	55·0000
— Indigo Violet	665·00	— A♯	57·7500
7 Violet	712·50	7 B	61·8750
8 Red 8ve.	760·00	8 C 8ve.	66·0000

N.B.—The numbers to the left of each column indicate the Diatonic Scale of sound and colour respectively.

Unless some intrinsic defect can be shown to exist in the frequencies of the notes and colours given in the foregoing table as well as the inapplicability of the undulatory theory to the case, it would be difficult for any opponent to evade the truth of the analogy of sound and colour. On the other hand if these matters are admitted to be intrinsically correct, notwithstanding the temporary opposition which is sure to present itself, the well-founded laws of musical harmony will be applied to painting, the art will be converted into a science, and the principles of the analogy will be taught at the Royal Academy in time to come.

DISCUSSION.

At the request of the Chairman, the author added some verbal explanations of his diagrams, and a hearty vote of thanks was accorded to him.

Mr. D. HOWARD, D.L., etc.—I do not know whether the learned author of this paper has considered the relation of this theory (which I confess is extremely interesting, and one which commends itself very much to my mind) to the question of colour-blindness, which is one of the oddest phenomena that we have experience of. Of course, the limitation of one's ear to sound is pretty familiar to many people. I do not know whether you have noticed how many people are stone-deaf to a bat. I am, for instance, but I think, on the other hand, I can hear a 50-foot organ-pipe better than most people. A colour-blind person may be utterly unable to see *these* two colours, and may be able to see *these* two colours [*pointing on the diagram*]. What condition of the nerves one can imagine to explain that is certainly difficult to make out. Even with the idea of three nerves in each of the cones, or filaments, whichever it may be, according to one's imagination, it is very difficult to see how you get two out of four colours missing, and the other two perfect. It so happens that I have known a good deal about colour-blindness since I was a small boy. A school-fellow of mine, now my brother-in-law, was absolutely colour-blind in red and green; therefore my boyish mind was taken up a good deal with it. A colour-blind woman is one of the rarest things possible, but here you have, undoubtedly, relations of vibrations with colour, though the cause is difficult to discover.

Mr. HULME, F.R.C.S.—Has Dr. Macdonald, in his experience, found out what is the deficiency in colour in colour-blindness?

Dr. MACDONALD.—A normal deficiency occurs in the retina, beyond a certain cone, that limit being confined to blue and yellow. Outside a certain cone there are certain properties in the retina itself which vary in perceptive power.

Mr. HULME.—It has fallen to my experience, as a surgeon to the Marine Society, to examine boys, and I have never found (out of the three colours on a table, red, violet, and green) a boy refuse violet, and very rarely red. It is invariably the green.

So in matching colours I will say, "What are those three colours?" (red, violet, and green). Perhaps ninety-nine out of one hundred will distinguish them, and the hundredth will go up and see the red and violet, and will go up to the green and not know what to make of it. Then I will give him my skeins of silk, and say, "Match those," and probably he will put the red on the green.

Dr. MACDONALD.—I remember in the case of my brother, when, as boys, we used to make paper soldiers and paint them, he would paint a soldier's coat with emerald green with the same satisfaction that he would vermilion.

Mr. HULME.—What is the percentage of colour-blind boys or men?

Dr. MACDONALD.—It is seriously stated, but it is remarkable, that ladies are more highly gifted than men in this respect. There is a matter of great importance connected with this, and that is the subject of signals. As to violet, if you extend it to blue, the blue is more constantly present than green—consequently, if signals were red and blue instead of red and green, there would be much less likelihood of confounding them.

[Dr. MACDONALD here further explained his diagrams.]

Mr. WALTER H. THELWALL, M.Inst.C.E.—I think it may be as well to mention, though no doubt it is known to many, that these vibrations are, of course, only theoretical. The actual vibrations of the sounds we hear are not *these* vibrations, because all music is planned on what is called a tempered scale, and it is these sounds we hear in listening to music. The notes of the diatonic scale, C, D, E, F, are almost always used by mathematicians in dealing with matters of music, and they form, to a great extent, the basis of the theoretical laws of harmony; but those intermediate notes, D sharp and F sharp, and so on, have no existence at all. They are neither tempered sounds, nor are they the sounds required by theoretical harmony. I do not know whether this has relation to the question of sound and colour, but that really is the case, and the ratio of one musical note does not continue below—it is always a twelfth, or 1·05946. I am not quite certain of the figure, and I do not know whether that fact has a bearing at all upon it; but if this table is going out as a table of sound used in music, I think it well that the correction should be made, particularly as the author speaks of the improper tuning of the organ. That is just one of the points that theoretical, mathematical, and practical musicians cannot agree upon. If we were to go by what mathematicians tell us we should have, in organs, about fifty notes to every octave, which would be practically impossible, and which no musician requires, and the fact whether music would be possible under such conditions is an open question, but the tempered scale throughout music is, as I have said.

One point in regard to discord. Musicians have got a way of talking of concord and discord, the idea, apparently, being that discord is something unpleasant to the ear; but that is not so at all. The most disagreeable sound you can have in music is a perfect fifth by itself, and that is what all technical musicians call a concord; but I think when there is a discordant sound the ear requires some particular note to follow, or one of a particular series of notes.

Dr. MACDONALD.—No doubt the question of temperament you have taken up is very important and one of some difficulty, so as to admit of modulation. A scale such as I have given here is limited to C, and you cannot apply it in any other key with the vibrations this way [*explaining on the diagram*], but you may take an equal temperament, or some principle which enables you to give a semi-tone at equal distances apart. It is rather difficult in some instances, for you would require an infinite number of key-boards, or pipes, or notes, as the case may be.

Mr. THELWALL.—I only thought it important to distinguish between the theoretical scale and the sounds that we hear.

The Rev. A. K. CHERRILL, M.A.—I should like to ask one or two questions about this table. If you divide two scales proportionally they would be proportional when you divide them; but I do not quite understand how you select this so-called scale. I suppose the musician selects the notes by ear. You cannot draw a fine line and say, "This is red and this is orange."

Dr. MACDONALD.—Yes; you take the musical ratio and you do it at once.

The Rev. A. K. CHERRILL.—Exactly; if you take the musical ratio. But if you take the musical ratio of course that corresponds. I do not quite see where the point comes in there. I do not see where the visual point, with regard to the light, comes in.

Dr. MACDONALD.—In regard to the monochord, whatever scale is adopted that will be found to be the test of the monochord. The division of the string is found in this diagram, and the number is determined exactly by the string of the monochord—for instance if the whole string sounds C, you get off $\frac{1}{9}$th, and $\frac{8}{9}$ths go on D, and you divide their parts according to the ratio given in this first series, $\frac{8}{9}$, $\frac{4}{5}$, $\frac{2}{3}$, and so on, and divided into three parts you get three G's, one part G, and two parts G, and the whole three sounded together give you the note of the string itself. The same law applies to these colours. If you have a certain number of pigments *here* you would have double the number of vibrations [*explaining the diagram.*]

Professor ORCHARD.—One of the most important parts of the paper is at the commencement, viz., that colour is, in fact, not merely subjective but also objective.

The phenomenon of colour-blindness, to which allusion has been so interestingly made, and also those other phenomena, colour sensations, when the eyes are closed to external objects, abundantly prove that there is a subjective aspect of colour, and we should, indeed, on other grounds, be led to that conclusion. It is very important, to my mind, to remember the two sides of the shield—that it is not merely objective on this colour (though it is objective), but that it is also subjective; but it is only when those two are on this colour that you call it unison and we get the sensation of colour.

It is rather surprising that Dr. Rutherford, on page 3 of the paper, should have reasoned in the fashion he did in regard to the cones and rods: "The cones alone occur in the yellow centre, where the visual sensitiveness is most perfect. Here, then, we perceive that the colour sense is not impaired by the absence of the rods." That is, indeed, a very curious conclusion to adduce from that premiss. I think it is clearly shown that the rods also play their part in connection with colour sensations.

We have to thank Dr. Macdonald for a most concise presentation of a most fascinating subject, and as one reads the concluding sentence one may endorse the hope and expectation that the art may become a science and be taught at the Royal Academy in the future.

Dr. BIDDLE.—One does not like appearing as a critic of such an admirable paper as this, but I feel that exception ought to be taken to one or two passages at the beginning of it. The author objects to our affirming that "colour is in fact an internal (subjective) sensation," and says that "the word subjective is only applicable where colour vibrations are induced in the nerve terminals independently of any corresponding objective vibrations impinging on the retina." But in conceding that colour sensations can arise without the presence of an external object to produce them, he, in fact, confirms the view of those whom he opposes. The colour is not in the object, but in the subject, being simply excited by the object, or, more correctly, by the peculiar vibrations of the light which the object reflects to the eye of the observer, and the impression of which is conveyed through the optic tract, a specially organised instrumentality, to the sentient power, in which alone the sensation arises.

The fact that colour can be obtained on a photograph simply indicates that the peculiar conditions in any object, which give rise to colour sensations, can be transferred to the chemicals on the sensitive plate; and it is only by bearing this in mind that progress in colour-photography will be made.

In the Appendix to Vol. xlii (1885) of reprints from *The Educational Times*, on page 127, is a part of my paper, *Ratio Rationis*, which may be considered worth repeating in the present connection:—"The most intimate faculty of the human mind (next to that of bare *feeling*) consists in the detection (however imperfect and undefined) of similarities and dissimilarities in the various objects of which it takes cognisance. This in its simplest form is a matter of impression or perception, which defies further analysis. For, though we can perceive the difference between the impressions produced, for instance, by two colours such as red and blue, we cannot adequately describe the difference, much less the impressions themselves; and for aught we know, our impression of red may be totally unlike that produced on another person, and this without any colour-blindness, either on our part or his. It matters little, provided we can distinguish red from other colours, as well as our fellows. But it is more than probable that the impression produced by red is compound. If, therefore, it is difficult to describe the compound impression, how impossible must it be to describe the simpler impressions which compose it! It is the same with all elementary impressions: we cannot describe them to other persons. But we can distinguish between them and we can select and classify objects which produce various combinations of them."