CROONIAN LECTURE.—"Studies in Visual Sensation." By C. LLOYD MORGAN, F.R.S., Principal of University College, Bristol. Lecture delivered March 21, 1901,—MS. received March 25, 1901.

Peculiar difficulties are encountered when any attempt is made to express the relative values of sensations in quantitative terms which shall make some approach to exactness. No doubt we commonly deal with the less and the more of sensation; we say that a surface appears duller or brighter; but on what scale shall we determine with any precision how much the less, or by what amount the more? What is to be our unit of sensation in terms of which we can reckon our gains and our losses? At first sight it may seem reasonable to assume that the unit of sensation is that which corresponds to some definite and constant amount of physical stimulus or physiological excitation. And unquestionably we seem justified in asserting that under constant conditions, physical and physiological, a given amount of stimulus produces an amount of sensation which is constant in quantity. If it be not so the relation of stimulus to sensation is not a subject that is open to scientific investigation. But apart from the fact that there is some variation of sensitiveness among different individuals, and even in the same observer at different times, there are many familiar facts which show that the physical measurement of luminosity does not accord with the estimates we make of the brightness of the illuminated surface. If a sheet of white paper be illuminated by a standard candle at a given distance it appears of a given brightness; if now the distance of the candle be doubled, the physical luminosity is reduced to one-fourth. But it looks a good deal more than one-quarter as bright. Its brightness may not be even halved. Again, the physical luminosity of coloured paper, as measured by Sir Wm. Abney's methods, does not give values which satisfy sensation. A blue with luminosity 9, as compared with white paper reckoned as 100, appears to have a brightness nearly half-way between black and white; a red with luminosity 18 does not certainly appear twice as bright as the blue. Furthermore, it is well known that a series of equal increments of stimulus does not produce a similar series of equal increments in sensation.

This may readily be illustrated by means of a rotating disc. If a disc be prepared with equal sectors of black and white, the effect on the eye, when rotation is sufficiently rapid completely to extinguish flicker, is that of a uniform grey. But it is a grey so light as to be not far removed from white. We may assume that the physical luminosity of the surface is, since the sectors are equal, the arithmetical mean between that of the white and that of the black employed.

But the brightness or sensation-luminosity is certainly far removed from the arithmetical mean between that due to white and that produced by black. The fact is, perhaps, even more clearly brought out if we divide a disc into eleven concentric areas of equal width, of which the inner is all white and the outer all black, while the intervening areas have sectors giving a series of 10 per cent. increments of white. On setting such a disc in rotation a series of concentric grey rings is obtained. Now if the equal increments of stimulus produced equal increments of sensation, the ten steps leading from black to white should appear to be of equal value. But they appear to be of very unequal values. While the step from black to the darkest grey involves a large stride in sensation, seemingly almost half-way towards the white, that from white to the lightest grey is of no great amount. Nor is this difference materially altered by reversing the order of the rings. With steps proceeding from inner black to outer white their inequality for sensation is just as obvious.

No doubt in reaching this conclusion we are dependent on the exercise of comparison and judgment. We must compare the value of the steps from ring to ring in order that we may perceive their inequality. But the inequality is not a property of the perception but of the visual sensations which are perceived to be separated by unequal intervals. We cannot investigate sensations at all without passing judgment upon them. It is fatal, however, to clear thinking to confuse the act of judgment with the sensory data on which such judgment is passed.

It is noteworthy that the rings afforded by such a disc when in rapid rotation are not uniform in shade. Apart from the differences of luminosity for sensation between ring and ring, the shade of grey within any selected ring is not the same throughout its width. There is the same percentage of white stimulus throughout its breadth; but there is not the same brightness for the eye between its limiting boundaries. When the ring adjoins its lighter neighbour it appears distinctly darker than it does on that side which is in juxtaposition to its darker neighbour. This is unquestionably due to the effects of contrast, through the subjective influence of which each ring is differentiated in sensation, though there is no corresponding differentiation in the exciting stimulus. It is noteworthy, too, that this contrast effect is more marked in the darker rings than it is in the lighter rings. We have here a disturbing element, for which we must be prepared to make the necessary allowance. For the present, however, we may assume that, though introducing a factor which somewhat distracts the judgment, the disturbance is not sufficient to invalidate the conclusion that equal, or approximately equal, increments of stimulus produce increments of brightness which differ widely in value.

We may next endeavour to ascertain whether we cannot by experi-

mental work obtain a series of rings which do afford approximately equal steps from black to white—of which any intervening ring appears to be of an intensity or shade which is the arithmetical mean between its neighbours on either side. This may be done by means of slit discs on Maxwell's method, giving sectors which slide over each other so as to alter the relative proportions of the white and black. First a mid-grey may be found, which appears to give a half-way sensation between black and white; then other greys, which appear to be arithmetical means between the mid-grey and black on the one hand, and on the other hand between the mid-grey and white. Thus by a series of careful adjustments rings may be obtained which enable the eye to pass from black to white by steps which are of approximately equal value for sensation.

It is not, however, easy to judge of the exact equality of the sensation increments. It is not easy, for example, to say what shade of grey stands just midway between black and white; and with four steps, even when one judges them to be approximately equal, one feels that there is equality with a subtle difference. The step from black to dark grey may be substantially similar in value to that from light grey to white; but it is not the same; and there is the disturbing element of contrast causing the rings to lack uniformity of shade. One feels that the method of rings giving equal sensation increments can only give a first approximation to a scale of sensation. For what they are worth, however, let us consider the results.

Admitting that we have reached a first approximation towards an evenly graded series of sensations, we have at least advanced a stage towards the establishment of an arbitrary unit of sensation. We have obtained a scale or ladder from black to white. How shall we deal with it? Let us term our black the zero of an arbitrary scale, and our white 100 per cent. We must realise, however, that our zero, which we term black, is simply a datum level from which to reckon. That which I employ is a dull black surface paper coated with black enamel. This gives a bright reflecting surface; but it is not difficult so to arrange matters that the scanty light reflected to the eye from its surface is derived from black velvet or cloth hung in a dark corner. Still it is not, and it makes no pretence to be, absolute black. Let us assume that it is a very dark grey, and let that be our zero of stimulus and also our zero of sensation. So too at the other end of the scale. Our white paper affords an arbitrarily selected luminosity under given conditions of illumination, and we call it 100 per cent. of stimulus, corresponding to 100 per cent. of sensation. We have thus a percentage scale—I repeat again a purely arbitrary percentage scale—for both stimulus and sensation, by means of which we can bring them into relation to each other within the assigned limits.

Let us now compare the results we have so far obtained, stating

them in the terms afforded by the arbitrary scales. The percentages are as follows:—

Sensation	0	25	50	75	100
Stimulus............	0	6·5	20	47	100

Stated in this form, while the sensations are in arithmetical progression there is at first sight no very definite series in the stimuli. But if we express the results in a somewhat different form the stimuli fall into an orderly sequence. The following figures give the *increments* of sensation and of stimulus:—

Sensation	0	+ 25	+ 25	+ 25	+ 25	= 100
Stimulus	0	+ 6·5	+ 13·5	+ 27	+ 53	= 100

It is clear that the stimulus increments are here nearly in geometrical progression. And if we may base a purely provisional and empirical generalisation on so slender an experimental foundation, we may say that equal increments of sensation require increments of stimulus in geometrical progression.

Such being the preliminary results obtained from a series of approximately equal sensation steps, we may now, on the basis of our provisional generalisation, interpolate other points between those obtained by observation, and through them sweep a smoothed curve. And having done so, we can translate the curve on to a disc which shall give a continuous geometrical increase of stimulus from our zero black to our 100 per cent. of white. And this on rapid rotation should afford a smooth passage from black to white in sensation. There ought to be a perfectly even and uniform ascending slope of sensation from our zero black through progressively lightening shades of grey to our limit of 100 per cent. of white. Our mid-grey should lie just in the middle between the extremes. When the disc so prepared is set in rapid rotation, however, though there is a gentle shading from white into black, this shading is not uniform. There is a lack of balance. The mid-grey does not appear to be just half-way between black on the one hand and white on the other hand. It lies too near the black, and the shading is therefore too rapid from this mid-grey into black, not rapid enough in the opposite direction towards white. The appearance is not that of a uniform slope of sensation, but rather that of a gentle convex curve, the surface appearing slightly spherical.

It may here be noted in passing that we have to be on our guard against the misleading effects of a so-called optical illusion. In our rotating disc we have to judge the position of the mid-grey, which should lie equidistant from the black and the white. But in a disc or a sector thereof there is a tendency to misjudge the distance, from the centre, of a circle which bisects the radii. The inequality of the areas tends to confuse the judgment as to distance, and the position where

the mid-grey should fall is apt to be placed too far from the centre. The position of the mid-grey is also apt to be misjudged according as we are shading from inner white to outer black or *vice versâ*. In practice I endeavour to avoid these disturbing effects, first by constructing discs to shade both ways and taking the mean results, and, secondly, by dealing with a reflected image of a portion of the disc, from centre to circumference, in a slip mirror, 140 mm. long by 25 mm. wide, the edges of which may be graduated. It is easier to judge of the accuracy of shading in such a band than in a complete disc. Making all allowances, however, for misjudgment of position in the mid-point, the smoothed curve drawn through the points experimentally determined by the method of graded rings does not shade satisfactorily.

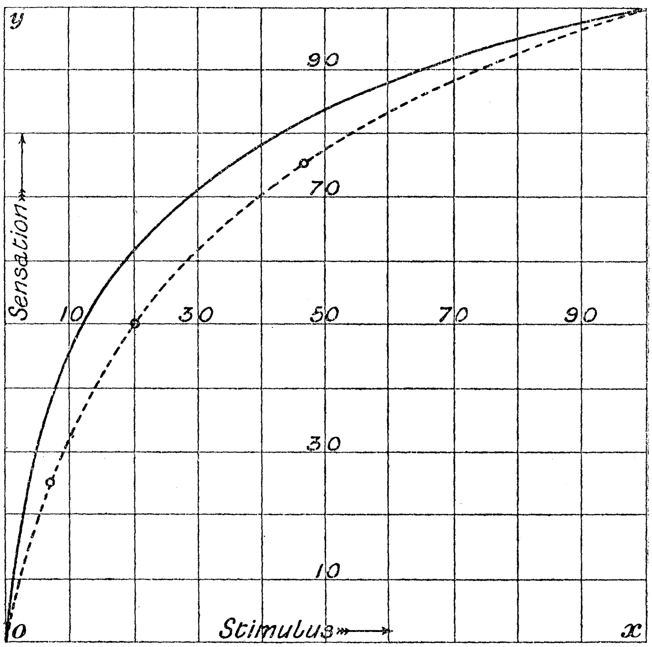
Before attempting to indicate the probable cause of this discrepancy, it will be convenient to draw attention to the further experimental work which it suggests. If the smoothed curve we have so far obtained does not afford to the eye satisfactory shading, it obviously remains to determine what curve does give results in sensation which appeal to the judgment as approximately accurate. The shading of the disc which expresses the curve passing through 20 per cent. of white stimulus as the mid-point is so far satisfactory as to suggest that the curve is right in principle but faulty in its application. And a great number of experiments, which need not here be described, convinced me that the introduction of + and − variations at different parts of such a curve, so as to alter its character, only serve to make matters worse and not better. It seems, therefore, that what requires alteration is the position of the mid-point of the curve, or in other words the value of the first of the series of smoothed steps, and that of the factor required to give a geometrical progression of stimulus increments.

It is easy to construct a curve on the same principle which shall pass through any desired mid-point, and to translate it into the answering curve on a disc. It being obvious that the required mid-point is less than 20 per cent., a series of discs were constructed in which the value of the mid-point ranged from 20 per cent. down to 10 per cent. By using these, I found that the mid-point for continuous shading of white into black lies between 10 per cent. and 15 per cent.; and by further experimental work, I found that 12 per cent. gives the best result for my eye under the conditions of daylight illumination which I employ. The accompanying figure shows the curve representing the relation of stimulus to sensation which is deduced from it. The firm line shows the curve passing through 12 per cent. as mid-point, the dotted line that passing through the points determined by means of the graded disc with grey rings.

It here naturally suggests itself that the data obtained for the graded ring disc were erroneous, and that the discrepancy is due to

faulty observation. This can now be readily put to the test of further experiment. A ring disc can be constructed on the basis of the new curve. But this on rotation affords steps which are of very distinctly unequal value to the eye.

Fig. 1.



There is therefore a real discrepancy for sensation between the results obtained by the method of continuous shading, and those obtained by the method of graded steps. May it not be due to those effects of contrast to which attention has already been drawn? To test the validity of this suggestion attempts were made to get rid of the effects of contrast within each ring, and in doing so, to obtain a rough quantitative measure of these effects. We have seen that each ring appears too light on that side which adjoins a darker neighbour, too dark on the other border where it is in contact with a lighter neighbour. Either by increasing the amount of white stimulus on its darker side, or by decreasing that amount on its lighter side, the ring may be made to appear of uniform shade throughout. It was found that approximately the same proportional amount of white must be added at one border or subtracted at the other border to produce this result.

Taking the step disc, which gives fairly equal sensation increments,

it was found that the three grey rings required very unequal amounts of proportional reduction in order to render them of uniform shade to the eye. As the mean of three sets of observations, the dark grey ring required 50 per cent. reduction of the white at its outer border; the mid-grey ring 40 per cent.; the light-grey ring 25 per cent. These figures give only a rough and preliminary approximation to a quantitative estimate in terms of physical stimulation of the effects of contrast under certain conditions of illumination and for speeds of rotation sufficiently rapid completely to get rid of any flicker effect. If the illumination be materially reduced or if flicker occur, the contrast effects within the rings reappear. In other words, with reduced illumination or with that flicker effect which has recently been studied by Professor Sherrington,* a large proportional amount of reduction is required.

The quantitative estimate of contrast and its physiological bearing, cannot here be further discussed. The markedly different effects in the several rings is sufficient to suggest that we have here a sufficient cause for the discrepancy between results obtained by the method of ring grading and those reached through continuous shading. For the present, however, I am not prepared to do more than suggest that the curve for continuous shading affords a more trustworthy scale for comparing the relative values of stimulus and sensation than is afforded by graded rings which do not appear of uniform shades of grey throughout their width. I provisionally accept therefore the curve through 12 per cent. mid-point as a basis for further experimental work.

I must here confess that in a previous paper† I gave far too high a percentage for the mid-point. But the black I then used was not nearly so deep, the white was not quite so brilliant; I failed to make due allowance for the so-called optical illusions before mentioned; and, the worst error as I now see, I used ring grading as a check on continuous shading, not realising that the effects of contrast vitiated the results in the manner in which I have just attempted to indicate.

I may now pass on to consider another fact which shows the importance of conducting observations in visual sensation under approximately uniform conditions of illumination. Suppose that with a given illumination we have obtained even shading or fairly equal steps on a ring disc, and suppose that the illumination be then materially diminished. The one disc no longer gives even shading; the other no longer gives rings with equal sensation steps. Delbœuf‡ drew attention to this fact for discs with grey rings, and accounted for it by a somewhat far-fetched hypothesis of physiological tension. No such

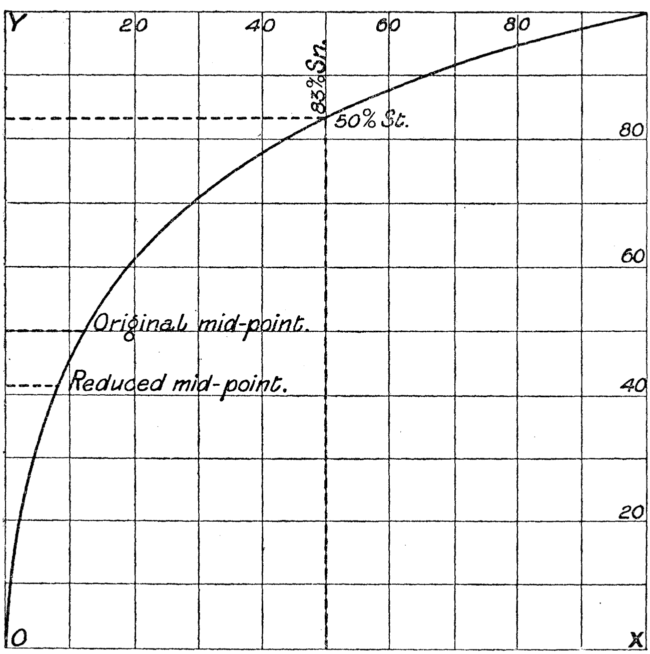
* 'Journal of Physiology,' vol. 21, p. 33 (1897).

† 'Psychological Review,' May 1900, p. 217 (vol. 7).

‡ 'Examen Critique de la Loi Psychophysique,' 1883, pp. 147–48.

hypothesis is, however, needed. The fact is a necessary corollary from the nature of the curve which brings stimulus and sensation into relation with each other. This may best be illustrated by taking a somewhat extreme case, and dealing only with the value of mid-grey. Let us suppose that 12 per cent. of white stimulus gives, under a given illumination, a sensation of approximately 50 per cent. on the arbitrary scale—that is to say, a sensation half-way between black and white. And let us further suppose that the illumination is reduced to one-half. What will be the effects in sensation? It might at first sight be supposed that since the full-white was reduced by half, and the 12 per cent. for mid-grey also reduced by half, the sensations underwent a similar reduction. But further consideration shows that the two scales (that for stimulus and that for sensation) being unequally reduced, the position of the mid-point for sensation is necessarily shifted.

FIG. 2.



Reference to fig. 2 shows that 50 per cent. stimulus affords 83 per cent. sensation, and that 6 per cent. stimulus affords 36 per cent. sensation. But 36 per cent. sensation is not the mid-point between 0 per cent. and 83 per cent. The mid-sensation will be 41·5 per cent., and this requires 8 per cent. of stimulus. Hence, for the given reduction of illumination an additional 2 per cent. of stimulus is required to

afford a mid-sensation between the black and the reduced value of the white. It is here assumed that the reduced illumination makes so small a difference in the black as to be inappreciable and practically negligible.

Fortunately for experimental work a *slight* reduction of the illumination makes but little difference in the mid-point for sensation. A reduction of the physical luminosity of the white paper by 15 per cent. only reduces the sensation it affords by 4 per cent., and the additional stimulus to be added to give the new mid-point is only 0·74 per cent.

It may be pointed out that the general fact of the alteration of sensation values by changes in the illumination is quite familiar. An ill-lit engraving not only looks duller, but the relative intensities of the shading are not preserved. And the fact would probably be more noticeable were it not that we are daily accustomed to changes of illumination of the same scene as the sun declines and sinks below the horizon.

I shall return presently to the question of illumination so as to bring these facts into relation with the results of the further experimental work to be ere long described.

If the provisional scale represented by the graphic curve gives an approximation to the relative values of stimulus and sensation, that is to say, of physical luminosity and apparent brightness to the eye, we may use it to interpret the facts which I mentioned at the outset with regard to the physical illumination of a surface of white paper and its apparent brightness. Let us suppose that with standard illumination the luminosity of the surface is 64, the corresponding value for sensation in terms of brightness is 89. If now the physical luminosity is reduced to one-fourth, it will have the value $64 \div 4 = 16$, the corresponding value of which is, for sensation, 56. One-quarter the illumination thus affords about two-thirds the brightness, which is pretty well in accordance with the testimony of sensation. The 9 per cent. luminosity of blue gives a sensation-luminosity or brightness of 44 per cent., and the 18 per cent. luminosity of red a brightness of 59 per cent. These again accord very fairly with the verdict of the eye.

Having now obtained a fairly even shading from white into black, colours were next dealt with. Coloured papers were employed, and no attempt was made to obtain colours with any approach to spectral purity. Continuous shading will alone be considered for comparison with that of black into white. The curves for five colours on black were experimentally determined and plotted. The early work was purely empirical. Plus and minus alterations at different parts of the extent of each curve were introduced until the eye was satisfied that there was an approximately even shading from black into the colour under investigation. But when it was found that in each case for

equal increments of sensation increments of colour stimulus in geometrical progression were required, further work was based on the assumption that this empirical generalisation is trustworthy. For convenience of plotting an arbitrary percentage scale was used in each case, so that the curves merely represent the percentages of red, blue, or other stimulus which give equal increments of colour sensation between black and the unmodified colour reckoned as 100. The curves being constructed on similar principles, they are sufficiently indicated by reference to their mid-points, that is, to the stimulus which affords 50 per cent. of colour sensation. The following table gives the results for five colours :—

	Mid-point.		
Light yellow on black.........	13·5	per cent.	of yellow stimulus.
Orange on black	18·0	,,	of orange ,,
Light blue on black............	19·0	,,	of light blue stimulus.
Red on black	23·0	,,	of red stimulus.
Full blue on black	28·0	,,	of blue stimulus.

Two cases were also taken so as to afford the even sensational shading of white into colour. The results obtained were as follows :—

	Mid-point.		
White on full blue	25	per cent.	of white.
,, red	30	,,	of red.

And three cases were taken so as to obtain even shading from one colour into another—for example, red into blue through intervening tints of purple—with the following results :—

	Mid-point.		
Orange on full blue	36	per cent.	of orange.
Yellow on light blue	40	,,	of yellow.
Red on full blue	44	,,	of red.

The fact that in all these ten sets of experimental results, a curve is obtained based on the principle that equal increments of sensation require increments of stimulus in geometrical progression, materially broadens the empirical generalisation based on the observation work for the shading of white into black.

Can we not, however, bring the results yet further into line and express them all as portions of a single curve exhibiting the relation of visual stimulus to visual sensation ?

It is well known—largely through the valuable work of Sir Wm. Abney—that the luminosity of any colour may be measured by matching it with a grey.* I have thus determined the luminosity of my coloured papers in terms of greys produced by sectors of the black

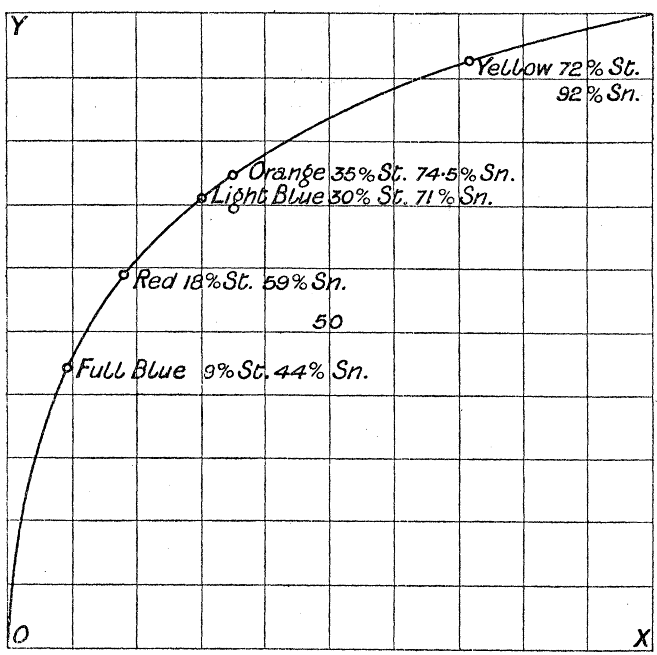
* See Abney, 'Roy. Soc. Proc.,' vol. 67, No. 436, p. 118.

and white employed for continuous shading. In other words, their physical luminosity was assigned in terms of the arbitrary scale. The approximate means of forty observations are given in each case, the variations from the mean ranging from + − 1 per cent. for full blue to + − 3 per cent. for yellow. The following table gives these approximate means—the brightness or sensation luminosity being taken from the black-white curve through 12 per cent. mid-point, which affords our scale of sensation.

	Physical luminosity.	Sensation luminosity.
Full blue	9 per cent. white	44·0 per cent.
Red	18 ,, ,,	59·0 ,,
Light blue	30 ,, ,,	71·0 ,,
Orange	35 ,, ,,	74·5 ,,
Yellow	72 ,, ,,	92·0 ,,

The values so determined are indicated on the accompanying graphic representation of the black-white curve.

Fig. 3.



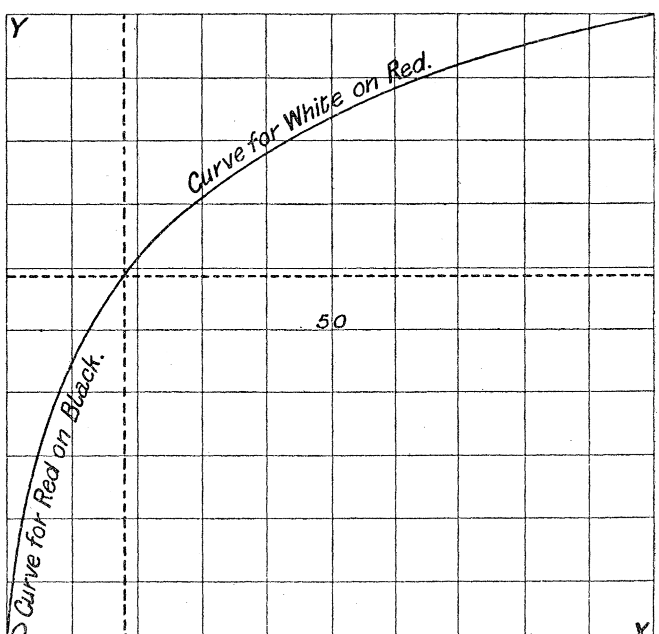
It is now an easy matter to compare the portions of the curve limited by any determined luminosities, with the whole curves

obtained by directly experimental methods. That portion of the curve, for example, which lies between black and the luminosity point for red may be compared with the curve for red on black, and similarly the remaining portion of the curve with that for white on red. We have to deal with the parts of the graph blocked off by dotted lines in fig. 4. For convenience of comparison these are in the following table converted into mid-point percentages.

Mid-point Percentages.

	Luminosity method.	Method of shading.
Yellow on black	13·8	13·5
Orange on black	18·6	18·0
Light blue on black.........	19·7	19·0
Red on black	23·6	23·0
Full blue on black	29·5	28·0
White on full blue	24·7	25·0
White on red	30·6	30·0
Orange on full blue.........	35·4	36·0
Yellow on light blue	39·1	40·0
Red on full blue	43·0	44·0

FIG. 4.



If these results be accepted as giving a sufficiently close agreement it follows, first, that for colour shading the percentages of stimulus required are dependent on the physical luminosity of the colours employed, and secondly that all the data obtained by the method of shading can be plotted on a single curve which exhibits the relation of stimulus to sensation in visual impressions. It also follows that if the intensity of illumination of a disc for white-black shading be so reduced as to lower its luminosity to that, say, of orange under full illumination, the mid-point value will be the same as that for orange on black. I am instituting experiments to test the accuracy of this result; but they are at present incomplete.

Incomplete too are experiments on the method of least perceivable difference.

I find that under certain conditions of illumination and at a given distance from the eye, the amount of white necessary to give a just observable grey ring on a black disc is approximately 0·1 per cent., while under the same conditions the amount of black necessary to give a just observable grey ring on a white disc is approximately 1·1 per cent. I believe, though I cannot assert with confidence, that the least perceivable amounts of white on an intervening series of greys are such as to give a geometrical series. But I find this method of least perceivable increments of sensation—lying though it does at the very basis of so much psychophysical work in the past—far from easy of application, since the required increments are small, and since it is difficult to say what is just perceivable. The extremes I have quoted indicate a geometrical series of 240 stages, with a mid-point of nearly 23 per cent. of white—which is nearer the results with the ring discs than those obtained by continuous shading.

I have also attempted to check the foregoing luminosity determinations by finding the least perceivable amount of coloured paper on a black disc. On the assumption that the amount required is inversely proportional to the luminosity, the results obtained are not very different from those above given. But since I do not regard these results as comparable in accuracy to those obtained on Sir Wm. Abney's method, I do not think it necessary to quote them here.

I have now described the experimental work on which a purely arbitrary scale of visual sensation in relation to the exciting stimuli is based. It is mainly founded on an appeal to my own eye, which is fairly normal with regard to colour sensation. Unquestionably it depends on the personal equation. But I have now only to determine the luminosities of any coloured surfaces, and I can by reference to the scale construct a disc which shall give without further experimental work an even shading of the one into the other. For example, I had not experimentally determined the mid-point for the shading of light blue and orange. By calculation the mid-point should be 48·9 per

cent. A disc with 49 per cent. was constructed and shaded quite satisfactorily. At the same time all I venture to claim is that the general principle is correct. For other eyes the mid-point of the black-white scale may differ somewhat from the 12 per cent. which for me gives the best results. For them the luminosities of the colours may be slightly or even markedly different. But I believe that if the luminosities be determined on their scale it will be found that for them, too, equal increments of sensation are due to increments of stimulus in geometrical progression.

I have not so far adequately correlated my own results with those obtained by previous observers. I regard the investigation as still incomplete, and think that this important part of the work should be reserved as an appendix to follow the presentation of independent observations. A few words may be added in conclusion, however, on the relation which the empirical scale of sensation may hold to an absolute scale based on certain assumptions.

It will be remembered that for purposes of comparison with the black-white curve colour luminosities were determined and recorded in terms of the arbitrary scales. Sir Wm. Abney's determinations are in reference to an absolute zero, his black having a value of about 3·3. Let us assume that the absolute zero of stimulation lies a little less than 2 per cent., or more exactly 1·87474, below the arbitrary zero of my curve, and let this amount be added to the stimuli throughout the scale, so that the white becomes 101·87474, the mid-point 13·87474, and so on. On this assumption the arbitrary scale becomes, so far as stimulus is concerned, an absolute scale. And on this absolute scale of stimulus, the sensations, + some undetermined constant, form an arithmetical series, while the stimuli which are in relation to them form a geometrical series. In other words, the addition of this constant to the summed increments of stimulus at any stage of the scale causes these summed increments to fall into line as the terms of a geometrical progression. The stimulus value of our mid-point on the absolute scale is the geometrical mean between the values of our extremes on the same scale. *On this assumption*, therefore, and *between these limits*, Weber's Law and Fechner's expression of it hold good.

Fechner's logarithmic law, however, involves other assumptions. It involves the assumption that some unit of stimulus 1, gives sensation 0, and that below this threshold of sensation there range an indefinite series of sensations or quasi-sensations of negative sign. And, pushed to its logical conclusion, it further assumes that the logarithmic law holds good throughout this negative series.

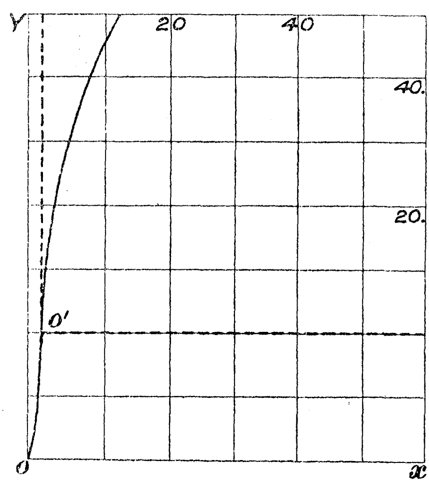
Now it is clear that no studies in sensation can throw light on what lies below the threshold of sensation. But physiological research may afford data for the continuation of the curve into the subliminal region.

The valuable and important researches of Dr. Augustus Waller,* on retinal stimulation and electrical response, seem to indicate that near its lower limit the curve becomes sigmoidal. The stimulus has to overcome a certain amount of physiological inertia before the normal sweep of the curve is established.

For a time I believed that I had obtained evidence of such a sigmoidal flexure near the origin of the curve in my experimental work on shading. But further observation led me to the conclusion that if it exist within the limits of my curve, the method of investigation is not sufficiently delicate to establish its influence.

Apart, however, from the experimental evidence which Dr. Waller adduces in support of the sigmoidal curve, and apart from the general considerations which he suggests in favour of such a change of sign, some such assumption seems to be well-nigh necessary if we are to attempt to give a complete curve, which near the threshold of sensation does not land us in the maze of difficulties arising from the asymptotic character of a wholly logarithmic curve. There is nothing therefore extravagant in the assumption that the origin of the completed sigmoidal curve should be placed in round numbers 20 per cent. below the arbitrary zero of sensation, and that this amount should be added to the terms of the sensation series on the arbitrary scale in order to convert it into an absolute scale of physiological response. This is indicated in fig. 5, which represents the hypothetical continuation of

Fig. 5.



the curve, on the assumption of sigmoidal curvature, beyond the limits of sensory observation. The part of the graph blocked off by dotted lines shows the lower part of the empirical curve, the absolute zero

* See 'Brain,' vol. 23, Part 1, p. 30 (1900).

of stimulus being placed in round numbers 2 per cent. below the arbitrary zero, that of physiological response in round numbers 20 per cent. below the arbitrary point of origin (0′) of the empirical curve.

At the same time this 20 per cent. estimate is little better than a guess. I am of opinion that the time for an absolute scale is not yet, and that an empirical generalisation in close touch with observation and experiment, such as that on which my own curve is based, is more likely to be helpful as a guide to further investigation than a wider law involving assumptions the validity of which is doubtful.

"The Yellow Colouring Matters accompanying Chlorophyll and their Spectroscopic Relations. Part II." By C. A. Schunck. Communicated by Dr. E. Schunck, F.R.S. Received June 5,—Read June 20, 1901.

[Plates 5, 6.]

In the former investigation* the yellow colouring matters, generally known as the xanthophyll group, which accompany chlorophyll in the healthy green leaves, and which are extracted along with it by means of alcohol, were separated from the chlorophyll by treating the alcoholic extracts with an excess of animal charcoal in the cold, by which means the chlorophyll is absorbed by the charcoal, leaving the yellow colouring matters in the alcohol. On investigating this crude yellow solution it became evident that more than one colouring matter was present, and I now give the results of the experiments I have made in the endeavour to further isolate the constituents of this group by means of carbon bisulphide, which method was adopted by Sorby† in his investigation of the different colouring matters present in plants. The crude alcoholic extracts of the accompanying yellow colouring matters, which I will for the future term the xanthophylls, can be obtained either by the above method or by boiling the chlorophyll extracts for three or four hours with caustic potash or soda (10 grammes to 1 litre of solution), allowing to stand, and shaking up with ether, which takes up the xanthophylls unaltered, whereas the chlorophyll is changed to an alkali compound of alka-chlorophyll, which is insoluble in ether, but soluble in water; the ethereal solution is then evaporated, and the residue dissolved in alcohol. From either method of preparation the same results are obtained.

These crude yellow alcoholic solutions of the xanthophylls show, as a general rule, four distinctive absorption bands in the violet and ultra-violet situated between the lines F and L (Plate 5, C, 2), any indication of

* 'Roy. Soc. Proc.,' vol. 65, p. 177.

† 'Roy. Soc. Proc.,' vol. 21, p. 456.