ON INTERMITTENT STIMULATION OF THE RETINA. PART II. By O. F. F. GRÜNBAUM. (Five Figures in Text.)

SECTION I.

TOWARDS the end of Part I.[1] a somewhat unexpected result of observations with intense stimuli was stated; in Section I. of this paper the experiments upon which that result was based will be given.

The method of experiment was exactly similar to that adopted for observations with moderate stimuli, except that an arc lamp of the Brockie-Pell type replaced the incandescent lamp. That lamp when properly adjusted and burning carbons of good quality, maintains the difference of potential between its terminals within 2 °/₀, and gives a light the intensity of which varies but slightly more.

To prevent direct vision of the light, which would have caused positive after-images of considerable duration, the lamp was placed in a box in one side of which a circular hole had been cut.

When making a series of observations, it is essential that the eye shall be in as nearly as possible a similar condition throughout that series, otherwise fatigue may become a factor which will modify the nature of the resulting curve. To eliminate this, an attempt was made to fatigue the eye slightly and to approximately the same extent, before each observation: this was accomplished by gazing at a bright surface for ten seconds and then at the field under observation. If a discontinuous sensation did not result during the first three seconds, fusion was said to have occurred.

A limit of time of observation is required, for if an intensely but intermittently illuminated field be gazed at for some time, until fatigue

[1] This *Journal*, XXI. p. 396. 1897.

is induced, a discontinuous sensation may result, while to a less fatigued eye fusion would have occurred.

The bearing of this observation upon the theories of fusion will be considered later.

The eye was rested for at least two minutes between each observation, in a room lighted by diffuse daylight.

TABLE I.

Exp. IV. Source of light, Brockie Pell arc. Zero of Nicol's, 0° 00′. Distance from aperture to disc, 6 cm. Distance from disc to screen, 6 cm. Breadth of sectors removed, 6 cm. Breadth of sectors remaining, 6 cm. Aperture, 5 mm. Ratio 12 : 1.

Frequency	Flicker appears	$\frac{\sin^2}{4}$	Fusion occurs	$\frac{\sin^2}{4}$
25	0° 8′	·00000132		
29	0° 16′	·00000529		
32	0° 52′	·0000570		
35	1° 16′	·0001155		
37	1° 36′	·000513		
46	3° 36′	·001604		
51	4° 36′	·002376	82°	·2455
53	5° 30′	·003300	60°	·1836
54	7° 40′	·005556	56°	·1676
56	8° 32′	·006972	50°	·1421

TABLE II.

Exp. V. Ratio of sector-breadth to diameter of aperture 4 : 1. Other conditions same as in Exp. IV.

Frequency of alternation	Angle at which Flicker appears	$\frac{\sin^2}{4}$	Angle at which Flicker disappears	$\frac{\sin^2}{4}$
40	2° 28′	·000462		
44	3° 36′	·000986		
48	4° 36′	·001608	65°	·2016
52	7° 8′	·00384	62°	·1910
56	8° 28′	·00540	55°	·1636
60	10° 36′	·00846	49°	·1380
64	11° 36′	·0101	44°	·1160
68	12° 40′	·0120	38°	·0740
72	14° 52′	·0164	25°	·0412

Tables I. and II. are but samples of the results obtained; the intermediate numbers however cannot be supplied from other series of observations for two reasons, (1) the observer's[1] variation from day to day is not inconsiderable, (2) the current supplied to the lamp was not the same on every day.

I attach but little importance to the values of the very low intensities, since the amount of light passing two Nicol's prisms which are very nearly at right angles to one another does not vary directly as the square of the sine of the angle between them.

The main facts to which I wish to draw attention are however well illustrated.

On increasing the intensity of intermittent stimuli a rapid increase in frequency is necessary at first to produce fusion; after a certain frequency has been attained a further increase in intensity does not necessitate a further increase in frequency, this has been shown by Bellarminow[2] and surmised by Haycraft[3]: but on still further increasing the intensity of the stimuli fusion occurs with a decreased frequency.

Taking the actual numbers of Exp. IV.; at a frequency of 51 alternations per second an intensity of slightly more than ·002376 is required to produce a sensation of an intermittent nature, and this results with that frequency until an intensity of ·2455 is reached, an intensity, more

[1] It will be advisable to point out that the rate of repetition of retinal stimulation necessary to produce sensory fusion varies in different individuals, indeed individual variation is great in this respect. In my own case practice has considerably increased this frequency.

To illustrate individual variation, I record observations by W. M. S., who was experienced in observations in physics, but fresh to work of this nature.

Rothe's coloured papers illuminated by two 16 c.p. lamps at one foot distance, were observed through a tube at the end of which a black semicircle was rotating: observations by W. M. S. and myself were alternated.

Observer:	W.M.S.	O.F.F.G.	
Colour	Frequency	Frequency	Difference
Red	35	40	12 %
Orange	38	48	20 ,,
Yellow	40	50	20 ,,
Green	36	46	21 ,,
Light Blue	33	39	13 %
Dark Blue	29	34	14 ,,
Violet	31	36	14 ,,

There is a tendency for the percentage difference to be greater with colours of high luminosity than with those which fuse at a low frequency.

My object in drawing attention to individual variation lies in the fact that if the observations recorded be repeated by other experimenters the resultant curves will be similar but the actual numbers may vary considerably.

[2] *Archiv f. Ophthalmolgie*, xxv. p. 25. 1889.

[3] This *Journal*, xxi. p. 139. 1897.

than a hundred times as great as that necessary, just to produce a discontinuous sensation.

On increasing the frequency of alternation, the range through which an intermittent sensation results is diminished, but in all cases where the ratio of sector breadth to the diameter of the aperture is great, this range is considerable; with a frequency above 60 per second and the above ratio, no discontinuous sensation was obtained, while at 56 fusion does not occur between intensities ·006972 and ·1421.

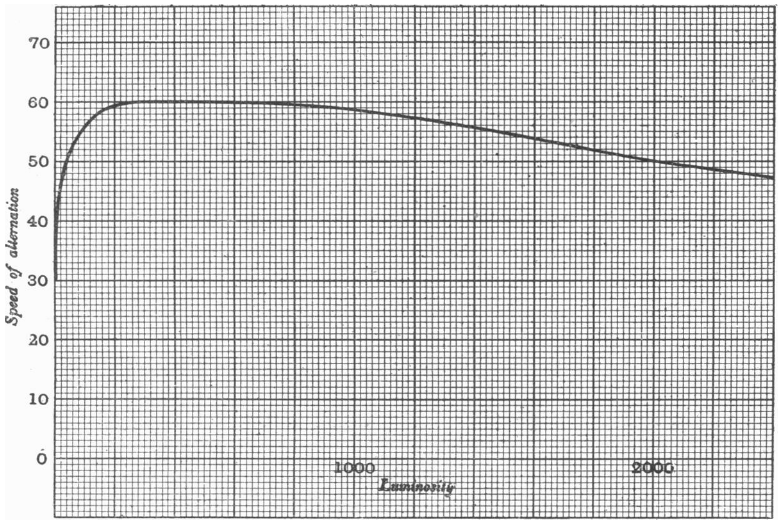

Fig. 4.

On representing the results in the form of a curve we note a rapid rise which becomes less steep, followed by a plateau and then a slow descent.

We know that if the eye be subjected to an extremely intense stimulus a positive after image of great brilliancy and duration is produced, which being in many respects similar to the result of more moderate stimuli in certain pathological cases, we may consider to be of a pathological nature; in what part of the curve the transition from normal to pathological takes place cannot easily be determined, but the intensities recorded never produced positive after-images of long duration.

Dr Rivers was good enough to make some number of observations for me, but as the experiments seemed to tire his eyes rapidly, only parts of series are recorded, and those happen to be with different units of intensity of light.

TABLE III.

Observer, Dr Rivers. Ratio of sector breadth to aperture 2 : 1. Other conditions the same as in Exp. IV.

Frequency	Flicker appears	$\frac{\sin^2}{4}$	Fusion occurs	$\frac{\sin^2}{4}$
187	48′	·000049		
225	2° 36′	·000513	41°	·107
263	3°	·000638	32°	·0702
300	3° 8′	·000745	15° 12′	·0171
375	4°	001214	14°	·0146
Ratio equal				
61	2°	·000302	64°	·2016
80	2° 20′	·000414	56°	·1718
118	2° 50′	·000610	39	·0989
150	4° 20′	·001425	35°	·0821
171	5°	·001896	34°	·0781

The observations show that the length of the plateau decreases as the ratio of sector breadth to the diameter of the aperture approaches unity. On altering this ratio results similar to those described in Pt. I. are obtained. The most satisfactory way of diagrammatically representing this, is by keeping the intensity of stimulus constant and varying the ratio.

TABLE IV.

Exp. VI.

Intensity	Frequency of alternation	Ratio of sector-breadth to diameter of aperture
Moderate	43	11
	44	6·1
	49	4·6
	53	3·8
	112	1·8
	225	1
Greater	58	10
	60	6
	68	4·5
	98	3
	200	2
Very great	50	7·5
	52	4·5
	56	2·8
	62	2
	76	1

The curves obtained by taking the frequency of alternation as ordinates, and the sector-breadth divided by diameter of aperture

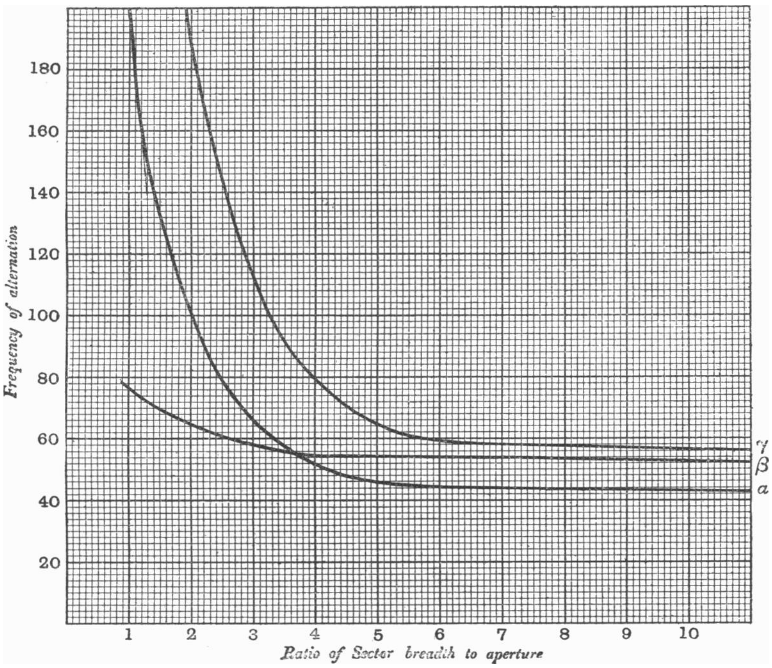

Fig. 5.

as abscissæ, show that the greatest effect of this ratio is when the stimulus is of that intensity at which fusion does not occur until a very high frequency is attained when the ratio is unity.

Curve α results from observations with moderate stimuli, γ with somewhat greater, and β with very intense stimuli.

Section II.

The Talbot-Plateau law.

The absolute accuracy of the Talbot-Plateau law was questioned by Fick[1] in 1863, who adopted the same method of investigation as Plateau[2] had devised some years earlier.

[1] *Reichert's Archiv*, p. 739. 1863.

[2] *Pogg. Annalen*, xxxv. p. 457. 1835.

White discs with different angular sectors of black were rotated in a dark room some distance in front of a white screen of the same surface as the white discs: a lamp was placed behind the observer and adjusted until the screen and disc matched, the relative physical luminosities of the screen and disc would be represented by the reciprocal of the square of their distances from the lamp.

Fick[1] found that the luminosities of the rotating disc measured in this manner did not agree absolutely with that determined by the angle of black upon the disc.

	Photometric	Angular	Discrepancy
I	·664	·650	2·7 °/₀
II	·305	·286	5·7 „
III	·123	·109	13 „
IV	·086	·074	17 „
V	·030	·032	− 6 „

All except the last disc were found to produce a sensation of greater luminosity than would have been expected from calculation of their angular brightness.

The observer draws attention to the fact that if the error were due to reflection from the black surface on increasing the source of error the error would increase, but in V. there is the greatest amount of black and yet far from the greatest discrepancy.

More recently Marbe[2] has stated several theoretical reasons for considering the Talbot-Plateau law inaccurate but has not made any direct observations.

The observations given in the earlier part of this paper led me to believe that the law would prove inaccurate when dealing with intense stimuli, and seemed to me worth investigation.

The method I adopted consisted in equalising the apparent luminosity of the two halves of a field, one of which was illuminated intermittently and the other continuously.

The luminosity of each half was easily adjusted, and the average physical value determinable by an apparatus, an explanation of which is most easily accomplished by reference to a diagram.

The source of light was an arc lamp (*A*), two mirrors (*B*) and (*C*) reflect pencils converging towards (*H*), these pencils pass through lenses (*E*) and (*D*) to converge the rays, and then through polarisers (*F*) and (*G*) in order that their intensities can be regulated by analyser

[1] *loc. cit.*

[2] *Wundt Philosoph. Stud.* XII. p. 279. 1896 and IX. p. 384. 1893.

(K), after they have been deflected into parallelism by prisms (I), between the lamp and mirrors, sheets of ground-glass were intercepted.

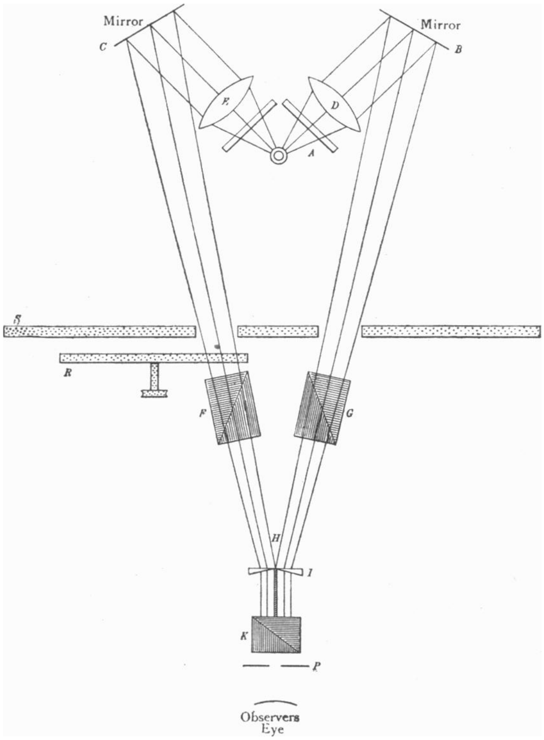

Fig. 6.

The size of the field was regulated by an iris diaphragm; an artificial pupil (P) insured the correct position of the observer's eye. The faces of the analyser (K) were parallel and normal to its axis of rotation: this prevented unequal reflection on its rotation.

The experiments were conducted as follows:

The analyser was placed in a definite position $\phi°$, and one polariser F was turned into a position of total extinction, the analyser was then turned to $\phi + 90'$ and a black disc (R) from which a definite number of sectors of known angles had been removed was rotated between C and F.

Polariser G was turned until the halves of the field were approximately equal. After removal of the disc, the axis of G was determined by rotating the analyser to $\theta°$ where extinction occurred.

Now on turning the analyser to $\frac{\phi^\circ + \theta^\circ}{2}$ the two halves of the field were found to be equally illuminated when the apparatus was set up symmetrically: if this were not the case, the necessary alteration in position of lenses or mirrors was made.

The rotating disc (R) was then replaced, and the analyser turned until equality of the two halves was attained. Practice was found necessary to distinguish small differences in luminosity.

By careful arrangement of screens (S) and unstinted use of black paint, the half of the field which was intermittently illuminated appeared quite black when a sector of the disc was cutting off direct light from it: by contrast with the lighted half naturally the depth of the black appeared great, but even if a certain amount were reflected from the disc, it is fair to suppose that a certain definite fraction would be reflected, in which case, comparative results would not be vitiated in the slightest.

The usual methods of eliminating experimental errors were adopted, such as changing the polarisers, working at various parts of the scale, etc.

The most striking results were obtained by the substitution of an incandescent lamp for the arc, care being taken that the position was identical and that the plane of the filament of the lamp was perpendicular to the face of the analyser.

Few observations are recorded here since I intend adopting the method for investigation of the nature of the waning of sensation after intense stimulation, by utilising discs with varying proportions removed.

Exp. A. Position of extinction of right half, 107°. Position of extinction of left half, 72°. Disc has six sectors each of 10° removed.

Speed of rotation just sufficient to cause complete fusion.

Source of light:	Arc lamp	Arc lamp	Positions of apparent equality of luminosity of the two halves
Observer:	W.H.R.R.	O.F.F.G.	O.F.F.G.
	51° 20′	51° 20′	82°
	47°	50° 50′	82° 10′
	47°	50°	81° 50′
	53°	51° 10′	82°
	52° 30′	52°	82°
	51° 40′	51°	82°
	53°	50°	81° 30′
	53°	51°	82°
	52°	50°	81° 20′
Mean	51° 3′	50° 42′	81° 54′

From these observations the following results are obtained.

When the source of light was an arc lamp but the position of the prisms such that the amount of light passing was but small, the average physical value of the intermittently illuminated field was $\frac{1}{6}$ [$\sin^2(107° - 81° 54')$] = ·0300 while that of the continuously illuminated was $\sin^2(72° - 81° 54')$ = ·0296 a difference of 1·3 °/₀ which is within the limits of experimental error.

On making observations with more intense stimuli we obtain the value $\frac{1}{6}$ [$\sin^2(107° - 51° 3')$] = ·1144 for the intermittently illuminated part and $\sin^2(72° - 51° 3')$ = ·1278 for the other, a difference of 12 °/₀, while from the other series of observations $\frac{1}{6}$ [$\sin^2(107° - 50° 42')$] = ·1157 and $\sin^2(72° - 50° 42')$ = ·1307, a discrepancy of 13 °/₀, these are distinctly beyond the error due to observation.

The position of the analyser in most cases was such that any movement of it did not decrease the intensity of illumination of one half of the field and increase that of the other, but decreased or increased both halves, but not in the same ratio; this accounts for the comparatively large variation in the observations.

Exp. B.	Source of Light:	Incandescent	Arc	Incandescent
	Points of Extinction:	107° & 72°	59° & 96°	59° & 96°
		52° 32′	37°	39°
		52° 10′	37°	39° 20′
		52° 8′	36°	38°
		51° 50′	36°	39°
		52° 10′	37°	38° 40′
		52°	38°	39°
		51° 50′	38°	38° 30′
		52° 20′	37°	39°
		52°	38°	39°
		53°	37°	38°
	Mean	52° 18′	37° 6′	38° 42′

The numbers resulting from Exp. B, are for the incandescent lamp $\frac{1}{6}$ [$\sin^2(107° - 52° 18')$] = ·111 and $\sin^2(72° - 52° 18')$ = ·114, giving a difference of a little less than 3 °/₀.

With the arc lamp $\frac{1}{6}$ [$\sin^2 96° - 37° 6')$] = ·1222 and $\sin^2(59° - 37° 6')$ = ·1390, a difference of 14 °/₀, while if an incandescent lamp replace the arc we obtained $\frac{1}{6}$ [$\sin^2(96° - 38° 42')$] = ·118 and $\sin^2(59° - 38° 42')$ = ·119, a difference of little less than 1 °/₀.

In tabulating the results the absolute values of the light would increase the value of the observations, but as above mentioned the intensity of the lamp varied from day to day and hence the numbers are given with an indication of the luminosity.

Luminosity	Average intermittent luminosity measured physically	Average continuous luminosity measured physically	Discrepancy
Weak	300	296	1·3 %
	118	119	1 „
	278	283	1·5 „
	111	114	3 „
Strong	1144	1278	12 „
	1156	1307	13 „
	1222	1390	14 „

It seems that the Talbot-Plateau law is correct for low intensities, but with intense stimuli the intermittently illuminated field appears to be considerably lighter than its physical value. I am inclined to think that this shows that the positive after-image plays an active part in increasing the apparent luminosity of an intermittently illuminated surface, but when the intensity is small, the effect it produces is very slight.

The apparatus used for the above work lent itself excellently for repetition of the experiments published in Pt. I., for if the fine flicker seen were due to any other cause than intermittent illumination of the field, such as vibration etc., or was a purely subjective phenomenon[1] the half of the field illuminated continuously should have presented a similar appearance when its intensity was equal to the other half. This was not found to be the case and the results confirmed those already published.

SECTION III.

Two main theories have been suggested to explain the fact that intermittent retinal stimuli repeated above a certain frequency give rise to a steady sensation.

The older, which I shall in future style the "persistence theory," seems to have been suggested by d'Arcy[2] in 1765 and maintains that a steady sensation results from intermittent stimuli, when the intervening periods do not exceed the time of duration of the positive after-image of undiminished brightness: in fact, attempts were made by this observer to determine this quantity by noting the minimum

[1] Burch. *Proc. Physiol. Soc.* p. xxvii. 1897. (This *Journal*, xxi.)
[2] *Mem. Akd. Sci.* p. 439. 1765.

frequency with which a burning coal must be rotated in order to produce a sensation of a ring of fire: 0·133 secs. was his estimation.

All subsequent writers, Plateau, Talbot, Helmholtz, etc. adopt d'Arcy's view, Fick[1] being the first to suggest an alternative. This author accepted Exner's[2] conclusion, that if the eye be exposed to black after having been stimulated by light, there is at first a rapid fall in the brightness of the positive after-image, which then more gradually disappears; the curve representing the decrease and disappearance being of exactly a similar nature to that representing the growth of sensation produced by a white stimulus.

Fick diagrammatically represented the sensation resulting from intermittent stimulus by a serrated line, the abscissa being the time-relation and the ordinates the strength of sensation, and pointed out that if the frequency become great, the amplitude of oscillation of sensation diminishes until a frequency is reached at which a continuous smooth sensation results.

It is surprising that writers after Fick's explanation did not adopt his view, since even if Exner's statement that under normal conditions the duration of the after-image of undiminished brightness is infinitely short, be disallowed, nevertheless the persistence-theory seems unsatisfactory; to illustrate this I cannot do better than quote a passage from Rood's[3] *Modern Chromatics.*

"The duration of the sensation of light or the duration of the impression of the retina, as it is called, varies with the intensity of the light producing it, and in the case of white paper is not by any means so great as with the coal of fire. According to an experiment of Helmholtz the impression on the retina lasts in this case with undiminished strength about $\frac{1}{48}$ of a second; hence it is necessary for the disc to revolve 48 times per second in order to produce the appearance of a steady uniform ring of light. While as just stated the impression lasts for $\frac{1}{48}$ sec., its total duration with decreasing strength is greater, being perhaps as high as $\frac{1}{3}$ sec., though the interval varies with the circumstances and is a little difficult of determination.

"It is not however to be supposed that in the experiment the ring of white light will have the same luminosity as its source, viz.: the slip of white paper on the black disc; on the contrary the luminosity of the ring will be much feebler than that of the source. The reason

[1] *Hermann's Handbuch,* III. p. 215. 1879.

[2] *Sitzungsberichte Akad. Wein.* LVIII. p. 601. 1868, and *Pflüger's Archiv,* III. p. 240. 1870.

[3] p. 207. 1879.

is quite evident: we have virtually spread out the light of the spot over a much larger surface and it will be proportionately weaker, if the surface of the ring is one hundred times as great as that of the spot, then the luminosity of the ring will be exactly one hundredth that of the spot."

Assuming that the statements are correct the reason seems to me far from obvious. Remembering that the "duration of the impression with undiminished strength lasts $\frac{1}{48}$ sec." and the disc rotates 48 times per sec., if the duration of exposure of the stimulus be sufficient for it to produce its maximum sensation, we should be led to suppose that the resultant ring would be as bright as its source, while if the duration of exposure be too short for the maximum sensation to be developed, then protracted observation would produce a gradual increase in the brightness of the ring owing to a summation of stimuli.

Again, it was on the above theory that Charpentier[1] in 1887 drew the conclusion from observation on intermittent retinal stimulation that "the persistence of the impressions of luminosity decreases when the light increases and *vice versa*."

Contrast the statement with that of Helmholtz[2], "the greater intensity of the primary light the greater is the brightness of the positive after-image and the longer does it last."

If curves were plotted to represent the relation of intensity of primary light to the duration of after-image, the intensity being the abscissa and duration the ordinates, upon Helmholtz's view the curve would start from the zero point and gradually rise, the exact nature is not known as direct determination of length of after-image offers insuperable difficulties: according to Charpentier with very small luminosity we should have an after-image of long duration which would gradually decrease as the luminosity increased, in fact the one curve would be the mirror image of the other.

Fick's theory at first sight seems to be subject to grave objections.

A serrated line the ordinates of which are proportional to the intensity of sensation, while the abscissæ to time represents diagrammatically a smooth steady sensation, *i.e.* alterations in sensation occur of which we are not conscious: of this we are well aware, for if we can determine the value of stimulus x to $\frac{x}{y}$, then stimulus $x+\frac{x}{y}$ will not be distinguishable from x, therefore the range of the serrated line may

[1] *Compt. Rendus Soc. Biolog.* Series VIII. Tom. IV. 1887. (Several papers.)

[2] *Phys. Optik.* p. 503. 1896.

be a certain fraction of the ordinate: without stipulating here whether the zero be represented by the sensation of black or a gray of certain luminosity.

Another and more serious objection lies in the fact that red and green or blue and yellow, if of the same luminosity, fuse at a very low frequency of alternation: on the assumption that red light is a stimulus for katabolism and green for anabolism one would expect their alternation to behave in a way similar to that of white and black.

Since coloured light may be considered to be composed of

(1) Wave length (vibration frequency)—affects tone.
(2) Amplitude —affects brightness.
(3) Dilution with light of many vibration frequency —affects brightness.

Tone and brightness have no inherent connection. We may represent recorded observations diagrammatically by a modification of Lambert's suggestion; alterations of sensation of luminosity being drawn in a vertical plane and those of tone in a horizontal one.

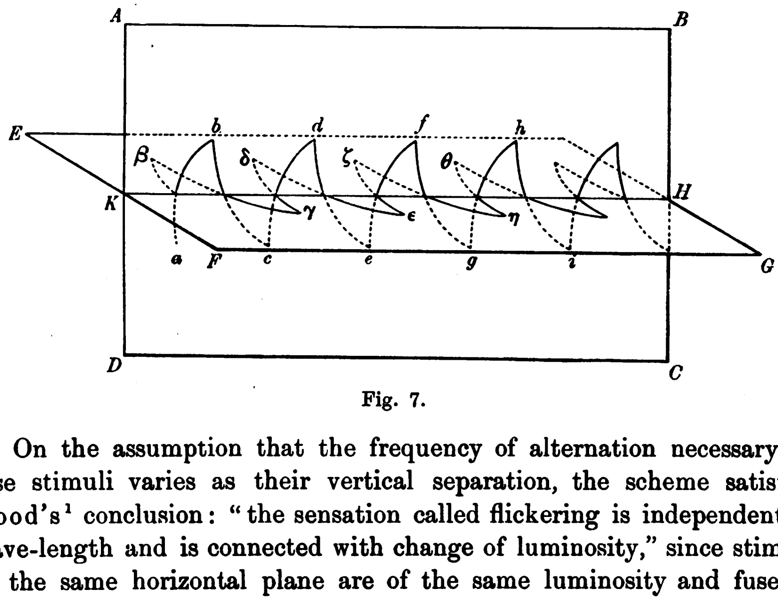

Fig. 7.

On the assumption that the frequency of alternation necessary to fuse stimuli varies as their vertical separation, the scheme satisfies Rood's[1] conclusion: "the sensation called flickering is independent of wave-length and is connected with change of luminosity," since stimuli in the same horizontal plane are of the same luminosity and fuse at a low frequency. Fig. 7 represents the alterations of sensation produced by alternating dull red with bright green, *KH* is the resultant

[1] *American Journ. of Science*, XLVI. p. 173. 1893.

gray, while curves *abcdef* in plane *ABCD* record the variations in sensation of luminosity and curves $\alpha\beta\gamma\delta\epsilon$ in plane *EFGH* alterations in tone.

Now let us consider what light Fick's representation throws upon the observations recorded above.

Fig. 8 A, represents the alterations in sensation at a frequency of alternation of moderate stimuli at which fusion just occurs, *eg* being the time of exposure of the stimulus, and *cd* the range of apparent constancy, which will vary in magnitude with the intensity of the resulting sensation *ba*, since from Weber's[1] law it will be a definite fraction of that sensation. On slightly decreasing the frequency, that

[1] It is interesting to note that some alteration in magnitude of range of apparent constancy with moderate intensities seems well borne out by the observations of Marbe, (*Wundt. Philos. Studien*, IX. p. 398) who found that if discs consisting of various ratios of black and white be rotated, fusion occurred at a slightly lower frequency on the preponderance of white, and draws the conclusion that "Fusion occurs at a lower frequency of alternation if the time of exposure of the more intense stimulus predominate, than if that of the lesser predominate."

This increase in range of apparent constancy would be easily calculable if black were the absence of stimulus. Hering considers black to be a sensory stimulus in virtue of simultaneous or temporal contrast: Marbe states that it is a stimulus of reconstitution of that material which is decomposed by white light; while Sherrington (This *Journal*, XXI. p. 50, 1897) believes and has indirectly shown that black may not be considered the absence of stimulus which the "persistence-theory" assumes.

There is a considerable amount of evidence for considering black as a stimulus, but great difficulty is met on attempting to determine the gray which most nearly approaches the absence of stimulus, since its luminosity differs under varying condition of the surroundings of the observer's eye.

Some of the evidence may be briefly stated.

We know that as the intensity of a visual stimulus increases in geometrical progression, the time taken for its maximum sensation to be produced decreases arithmetically (through a short range). If a curve be drawn with the times as ordinates and intensities as abscissæ and compared with that which may be deduced from Haycraft's (This *Journal*, XXI. p. 139, 1897) curve, they are found to coincide for some distance, proving that the increase in range of apparent constancy must be minute when the intensities vary considerably but are feeble.

On noting the mean variation when gray discs are matched, we find that the variation divided by the luminosity of the disc does not result in a constant which would be expected if Weber's law held true and black were the absence of stimulus.

Angle of white	Mean variation of 40 obs.	$100 \times \frac{\text{variation}}{\text{angle of white}}$
24°	·225	·92
60°	·413	·69
157°	·622	·40
324°	·670	·209

is increasing *eg*, the sensation would pass beyond *cd* and a discontinuous sensation result. On increasing the strength of stimulus the up curve would assume a greater average steepness, as shown by Exner, and the sensation would become discontinuous if it passed beyond the range of apparent constancy, which would also be slightly increased.

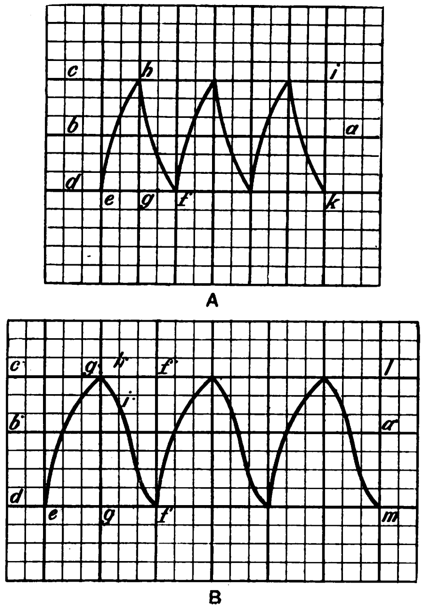

Fig. 8.

Now it has been seen that by a sufficient increase in the intensity of the stimulus a decrease in frequency may occur without destroying fusion, this may be explained in one of two ways.

(1) That at first the increase in the average steepness of the up curve is greater than the increase in magnitude of the range of apparent constancy; gradually the rate of increase of both becomes equal and then the latter increases more rapidly than the former.

(2) The explanation of the rise is the same as above, but the plateau and descent are due to the positive after-image which so modifies the decrease in sensation of light on exposure to black that the sensation wanes more slowly, and does not pass beyond the range of apparent constancy, while the stimuli become so intense that the maximum sensation is produced while they are still exposed and hence the average steepness of the curve is not increased.

Fig. 8 B represents the alteration of sensation, based upon the latter explanation, which to my mind seems the more probable from the following considerations. To a fatigued eye a discontinuous sensation resulted when intense stimuli were used, at a frequency at which to a fresh eye fusion had occurred. We know that the positive after-image is of a less pronounced character to a fatigued eye than to a fresh eye, while it is scarcely probable that the range of apparent constancy would be greater for the latter than the former. Again, we have seen that the Talbot-Plateau law does not hold for intense stimuli. Fig. 8 B represents a resultant sensation $b'a'$ of a greater brightness than its physical value, which agrees with the recorded observations on that question.

SECTION IV. APPENDIX.

Some months[1] ago the effect of simultaneous contrast upon the frequency of alternation necessary to fuse moderate stimuli was investigated by me, the method adopted consisted in altering the ratio of the time that the eye was exposed completely to light or darkness and the transition period.

In that paper two kinds of flicker were distinguished, which more recently Schenk[2] has recognised and termed "Flackern" and "Flimmern," corresponding to ordinary or "coarse flicker" and "fine flicker" or molecular movement respectively. This experimenter has made observations on discs similar to those designed by Sherrington[3] to show areal induction, and concludes that if the ring-bands be observed separately and closely, disappearance of fine flicker occurs in both at the same speed of rotation. Bearing this in mind I have repeated observations upon the original discs and can but confirm Sherrington's results: that if the physiological difference of two visual stimuli be increased by simultaneous contrast, a greater frequency of alternation is required to produce their fusion, that if the physiological difference of the same too physical stimuli be decreased by the same method. By fusion I mean disappearance not only of coarse flicker but fine flicker as well.

It must be noted that if the ring-bands be examined separately and

[1] This *Journal*, XXI. p. 396. 1897.
[2] *Pflüger's Archiv*, LXVIII. p. 32. 1897.
[3] This *Journal*, XXI. p. 37. 1897.

the eye be placed very close, little if any of the background will be seen, and thus the effect of simultaneous contrast may be greatly diminished or even absolutely eliminated.

SUMMARY OF PARTS I. AND II.

1. The ratio of sector-breadth to the diameter of the aperture through which observations are made is an important factor in determining the frequency at which fusion occurs.

2. On increasing the intensity of an intermittent stimulus beyond a certain point, a further increase in intensity allows a decrease in frequency without destroying the sensation of fusion.

3. The Talbot-Plateau law does not hold for intense stimuli.

4. Fick's view of fusion of alternating stimuli throws more light on the nature of the phenomenon than the "persistence-theory."

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Erratum. Part I. Vol. XXI. p. 401, 9 lines from bottom, for "the ratio becomes unity" read "the second term of the ratio etc."