"R E F L E X   V I S U A L   S E N S A T I O N S
A N D   C O L O R   C O N T R A S T."

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S Y N O P S I S O F T H E S I S .

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This research undertaken with the intention of studying the effect, of light stimulation on increasing areas of the retina of one eye, upon the principle of Visual Sensory Reflex Sensations recently propounded by Dr. Frank Allen.

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INTRODUCTION.

Recent investigations by Dr. Frank Allen in the field of Colour Vision have established a new principle named by him "Reflex Visual Sensations."

Quantitative measurements have been obtained on the effects of stimuli on the retina of one eye upon the sensitivity of corresponding receptors in the retina of the other eye.

Measurements have also been obtained in the field of Touch and Taste, showing that a stimulus applied to one portion of a receptor affected the sensitivity, not only of the stimulated portion of that receptor, but also of surrounding areas in all similar sense receptors.

The purpose of this research is to study the effect of stimulating definite portions of the retina of one eye upon the sensitivity of the receptors of the same eye. This was accomplished by selecting tubes of increasing diameter, thereby stimulating increasing areas of the retina when the eye was fixated upon white and coloured backgrounds through the various tubes.

SECTION II.

APPARATUS.

The apparatus used, and the method adopted, for the purpose of measurement in this research was essentially the same as that employed by Allen and others in recent investigations of the visual sensory reflexes. The source of light was an acetylene flame completely enclosed, with the exception of the top, by a black wooden box. To secure constant luminosity the gas was supplied to the burner at a constant pressure of 7 cms. as measured by a water manometer.

A small glass window in the side of the box allowed the light of the acetylene jet to fall on the collimator slit of a four prism Hilger spectrometer. Between the slit and the window an aluminum disc of two opposite open sectors of 90 degrees each was rotated by an electric motor whose speed of rotation, controlled by a brake, was recorded by an electric chronograph.

The spectrum obtained was of considerable dispersion, and narrow strips of this spectrum were observed by means of fixed slits in the eye-piece. The mean wave-lengths of these coloured bands were known to correspond with definite angles of the Vernier Scale of the Telescope in accordance with a calibration by Dr. Allen.

The Spectrometer itself was shielded from all extraneous light by a black velvet cover, and about the eye-piece was a tight-fitting cardboard collar resting against the observer's eye, so that all measurements were made under identical conditions. The observations were taken under conditions of daylight which were regarded as approximately the same. The research was performed in a room well illuminated with daylight. No measurements were taken on cloudy days, nor on dull days, and never with artificial lighting, since the sensory reflexes of the visual organs vary with the nature of the illumination.

SECTION III.

METHOD OF MEASUREMENT.

The fundamental point of view is that of determining the critical frequency of pulsating stimulation, or, in other words, to find the duration in seconds of the hang-over effect of a preceding stimulation. The rotating sectored disc produced alternate flashes of colour and darkness which caused a sensation of "flicker" in the isolated patch of the spectrum viewed. The speed of the motor was adjusted by means of a friction brake until the flicker phenomenon was just imperceptible. While the record was being made the brake was oscillated slightly so as to cause the flicker to remain just on the point of appearing and disappearing.

The chronograph record gave the time in half-seconds for 200 revolutions of the disc in the violet portions of the spectrum and increased to 400 revolutions in the brightest portions. The average of the time for as many revolutions as possible was taken as the accepted reading, and the time of duration of one flash, or that produced by one-fourth of a revolution of the disc, was calculated.

Readings at the dim ends of the spectrum were very difficult to perceive with accuracy, and so several independent readings had to be taken for these regions. This is especially the case for the last three readings in the violet section where the coloured slit showed a decided tendency to migrate, sometimes moving to the right as to be apparently situated on the telescope arm. By holding the hand over the left eye for a few deconds during the reading the slit could be held stationary while these three measurements were taken.

As the luminosity of the slit increased or decreased the eye-piece was focused accordingly so as to give a sharp image.

The reading itself occupied about half a minute. Between readings the eyes were kept in daylight adaptation for approximately four minutes.

The experiments described in this paper occupied approximately four months of the first year and one and one-half months of the second year devoted to the research.

On the average one curve a day was attempted until a uniform and satisfactory set of data was obtained for the eight tubes used.

The interval between the two years' work appeared to have no effect on the constancy of the Normal Curve. This was ascertained by repeated checking at short intervals to detect any variations.

THE NORMAL CURVE.

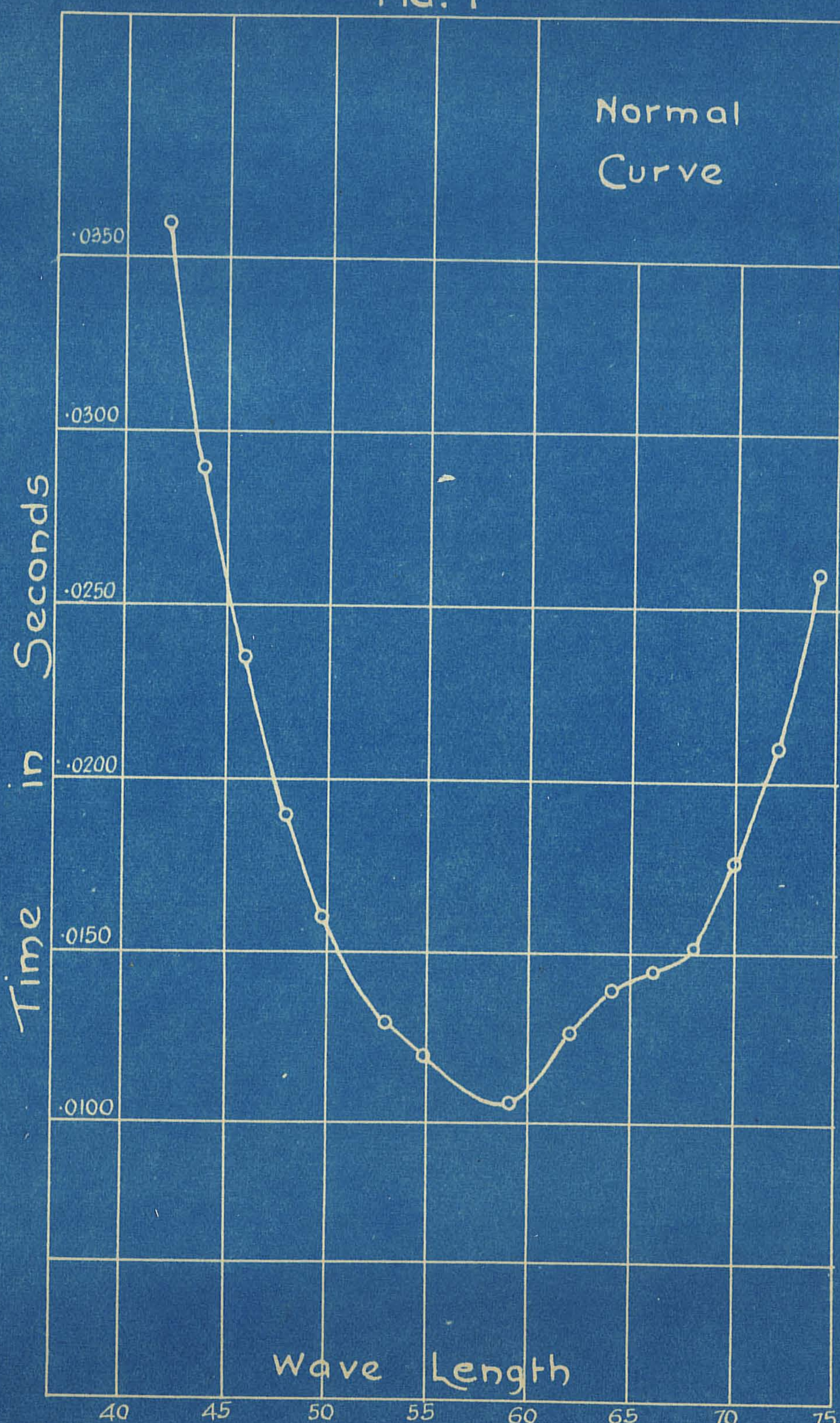
The normal curve is the curve obtained when the two eyes are in constant daylight adaptation. It gives a qualitative relationship between the mean wave-length of the colour viewed and the duration in seconds of the hang-over effect of that colour.

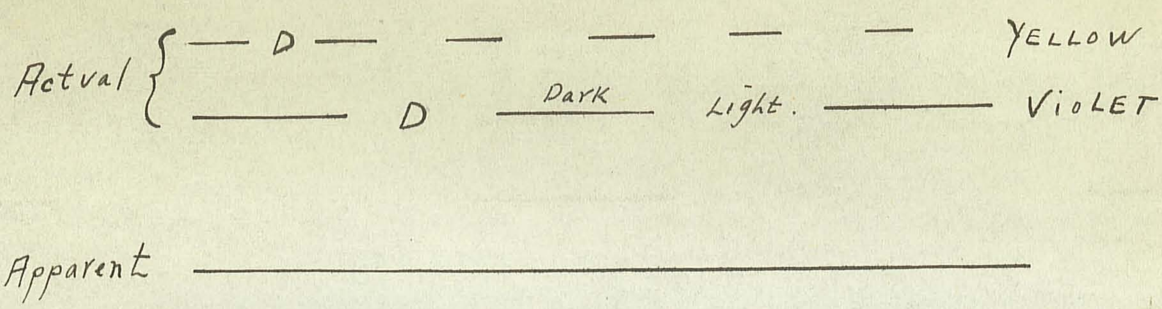
In all fifteen separate colours were isolated by means of the slit, each of these colours being viewed by the right eye, the left eye remaining at all times in diffuse daylight adaptation. The critical frequency of flicker was then found and recorded for each colour. The curve itself was obtained by plotting the duration in seconds as the ordinates, and the wave-lengths in Angstrom units as abscissae.

The curve may be interpreted as giving measure of the brightness or luminosity of the various spectral colours, since the duration D of the hang-over effect was found by Ferry and later by Porter to depend only on the brightness or luminosity of the colour and in no sense on the wave-length under a constant source of illumination.

Therefore a lowering of the curve at any point indicates increased luminosity of that particular colour, because the disc had to rotate faster to produce continuity of sensation. An elevation in the curve denotes a decrease in the brightness of the observed colour. For example the value of D for the central or brightest portions of the spectrum is considerably smaller than the values for the ends of the same spectrum. That is, the hang-over is considerably diminished in the brightest portions of the spectrum. This can be illustrated in the following diagram.

FIG. 1


Normal
Curve
·0350
·0300
·0250
·0200
·0150
·0100
Time in Seconds
Wave Length
40
45
50
55
60
65
70
75



The gap measures the duration in seconds which the effects of the light impulse actually lasts on the retina when the sensation apparently seems to be continuous.

These observations show that the bright colours of the spectrum require rapid disc rotation and the duller colours require a slower rate of rotation. The conclusion is that the time of exposure for the bright colours requires to be considerably less than that for less bright colours so as to give continuity of sensation.

The writer's normal curve shows that an anomaly exists for him between λ .69μ and λ.66μ in the orange portion of the spectrum.

The rise above a smooth curve in this region indicates that the writer's eye is not so sensitive to the brightness of spectral orange, or in other words the sensitivity of the writer's eye is less for that portion of the spectrum, than Allen's or any normal eye.

TUBE DATA AND REFLEX PHENOMENON.

The tubes used in this series were manufactured from a fairly thin cardboard of a neutral grey colour, the inside surface being blackened with a dull finish to absorb as completely as possible all stray light. The physical measurements of the tubes are given in Table III.

The method of measurement consisted in fatiguing the right eye by gazing fixedly through the tube at a very small pencil mark on a white cardboard background. The left eye was also focussed on this same mark, but under the normal conditions of vision, which permitted the entire sensitive area of its retina to be undergoing diffuse daylight stimulation.

The distance between the end of the tube and the cardboard background was kept constant at approximately 80 centimetres. The mark on an otherwise uniform background served equally as a focusing spot for both eyes, which counteracted a tendency of the eyes to relax, with a consequent loss of distinct retinal vision of the background, and at the same time provided a method of insuring regularity and conformity of the readings as far as the position of the tube and the head of the observer were concerned.

The position of the background screen was so arranged that at all times it was under approximately uniform illumination from the outside, excluding, at the same time, any possibility of direct reflection of the light from the windows, through the tube into the eye.

Care was taken to exclude external light from the right eye during fatigue, by cupping the hand about the forehead and right cheek, and keeping the nasal side of the eye pressing lightly against the edge of the tube. Thus the only light reaching the retina was that directed through the tube from a circle of definite area on the white background, the area depending entirely on the size of the diameter of the tûbe, all other conditions being constant.

After fatiguing the right eye in this manner for at least from four to five minutes, the same eye was immediately placed before the eye-piece of the spectrometer, which was never more than five inches distant from the end of the tube, and a chronograph record was made for a particular wave-length. After the record had been made, approximately two minutes were consumed in the preparation of the apparatus for the next reading, during which time, both eyes were under conditions of normal daylight adaptation.

Then the fatiguing process was repeated, a complete record requiring from seven to ten minutes. The record for a single tube was usually completed at one time, a night always separating different tube records, although the records were taken as conveniently close together as was consistent, for fear of a change in the normal curve of the eye. In all, fifteen separate records were made for each of the eight tubes provided.

THE REFLEX EFFECT.

The first startling effect noticed when the right eye was directed through the tube, was the appearance of the circular area on the white background as seen outlined by the end of the tube. This area was distinctly more luminous than the same surface and background as seen by the left eye. It resembled a brilliant white circular patch pasted on a duller white background.

The luminosity of this area was seen to visibly decrease and more closely resemble the remainder of the sheet as the diameter of the opening of the tubes increased. The greatest variation in luminosity between the circular portion and the background, occurred with the smallest tube, No. I.

This apparent increase in luminosity can be quite satisfactorily explained if certain facts are taken into consideration as recently expostulated by

Allen in a New Principle of Colour Vision.

Formerly it was known that nerve impulses travelled from the stimulated receptor to the nerve centre in the brain. The essentially new principle of Allen, states that the returning impulse is dual in its nature. The stimulating impulse releases two returning impulses, one travelling via the medium of the afferent nerves, whose function is one of depression or fatigue. The othér travelling via the efferent nerves, and of reflex origin, whose principle function is one of enhancement.

The afferent impulses produce a depression in the sensitivity of the receptors reached, while the reflex or efferent nerve impulses produce a counteracting effect by tending toward enhancement of the receptors affected.

These returning impulses affect not only those portions of the receptors under stimulus, but, depending on the relative proximity of the nerve centres in the brain, they return to all the corresponding portions of the same organ.

For example, if the left eye is under stimulation, the sensitivity of the retinal receptors of the right eye is noticeably affected by refles impulses and fatigue impulses. Also if the middle finger of the right hand is bound tightly, the receptors of touch in the other fingers are depressed or enhanced in sensitivity under the action of the reflex and direct or fatiguing impulses released from the brain by the ascending nerve stimulus.

It has also been found, that if the equation relating the duration D of the stimulus to the intensity L of the same stimulus be of the nature, $\frac{1}{D} = k \log L + k_1$, then the effect of a weak stimulus is predominantly one of depression.

On the other hand, if the equation is of the order $D = k \log L + k_1$, a feeble stimulus produces an enhancement of the receptors affected.

In the case of light the equation is of the order $\frac{1}{D} = k \log L + k_1$, where k_1 and k are two constants. Therefore the result of a feeble stimulus on the peripheral or outer portion of the retina of one eye produces an effect on the central portion of the same retina that is predominantly one of depression.

Under normal conditions of vision, the whole of the retina of the eye is under the influence of light stimulation. It is known that the peripheral region of the retina has a more feeble stimulus than the central portion. The effect of this feeble stimulus is one of depression, which spreads over the whole of the retina of each eye. This is due to the fact that the returning impulses of direct origin predominate those of reflex origin, therefore there are not enough enhancing impulses returning from the nerve centre in the brain to keep the receptors under stimulation in a supersensitive condition. The returning impulses, then, both of enhancement and depression, reacting over the whole of the retina of each eye, produce a decrease or depression in the sensitivity of the central portion of the retina, which is due to the weak stimulus acting on the peripheral portions of each retina.

Therefore under normal conditions of vision the sensitivity of the central portion of the retina of the eye is being continually depressed, resulting in a diminution of the physiological luminosity of any object or surface fixated by the eyes.

The primary function of the tube is to remove as far as possible all light stimulus from the periphery, thereby removing the source of the depressing influence which is acting on the central portions of each retina. The sensitivity of the receptors in this area is consequently enhanced, the stimulating objects then appear in the correct condition of luminosity, which is brighter than that perceived by the left eye as the depressing influence still predominates under the normal condition of daylight adaptation.

When the right eye is directed at an object through a tube of suitable diameter, the central area of the retina of that eye functions with its fundamental sensitivity, whereas the left eye directed at the same object functions at a lower sensitivity than its fundamental.

The area of the retina under light stimulation depends solely on the inner diameter of the tube, since the length of the tube and the distance from the end of the tube to the screen is constant. Therefore for the right eye, with increasing diameter of the tube we have increasing area of retinal stimulation and decreasing area of peripheral retina which is tending toward enhancement of the sensitivity of the receptors in the central portion. Decrease of periphery therefore causes an <u>increase</u> in returning impulses whose function is one of depression, and a consequent <u>decrease</u> in the returning impulses functioning toward an enhancement of the receptors. This is the explanation of the decrease in variation of the luminosity between the surface seen by the right eye and the same surface as seen by the left eye.

The effect is very noticeable in the first four tubes, becomes less marked in the last four, and is almost negligible in the last tube, No. VIII.

TABLE I TUBE DATA

λ	Tube I	Tube II	Tube III	Tube IV	Tube V	Tube VI	Tube VII	Tube VIII
	Sec.	Sec.	Sec.	Sec.	Sec.	Sec.	Sec.	Sec.
74	.0265	.0262	.0267	.0265	.0260	.0264	.0267	.0254
72	.0217	.0215	.0222	.0205	.0203	.0202	.0210	.0212
70	.0190	.0184	.0188	.0180	.0161	.0179	.0165	.0187
68	.0172	.0162	.0161	.0157	.0144	.0150	.0153	.0165
66	.0164	.0158	.0160	.0154	.0151	.0155	.0156	.0140
64	.0154	.0152	.0148	.0144	.0148	.0148	.0147	.0147
62	.0136	.0130	.0132	.0125	.0137	.0125	.0124	.0138
59	.0105	.0105	.0115	.0105	.0110	.0109	.0101	.0110
55	.0117	.0125	.0126	.0122	.0117	.0124	.0118	.0117
53	.0126	.0133	.0138	.0124	.0125	.0126	.0129	.0132
50	.0158	.0160	.0162	.0158	.0158	.0154	.0155	.0160
48	.0190	.0172	.0195	.0187	.0187	.0178	.0190	.0187
46	.0237	.0240	.0244	.0245	.0230	.0231	.0229	.0242
44	.0292	.0295	.0305	.0298	.0292	.0286	.0282	.0285
42	.0365	.0378	.0369	.0376	.0372	.0374	.0362	.0325

TUBE DATA

FIG. II

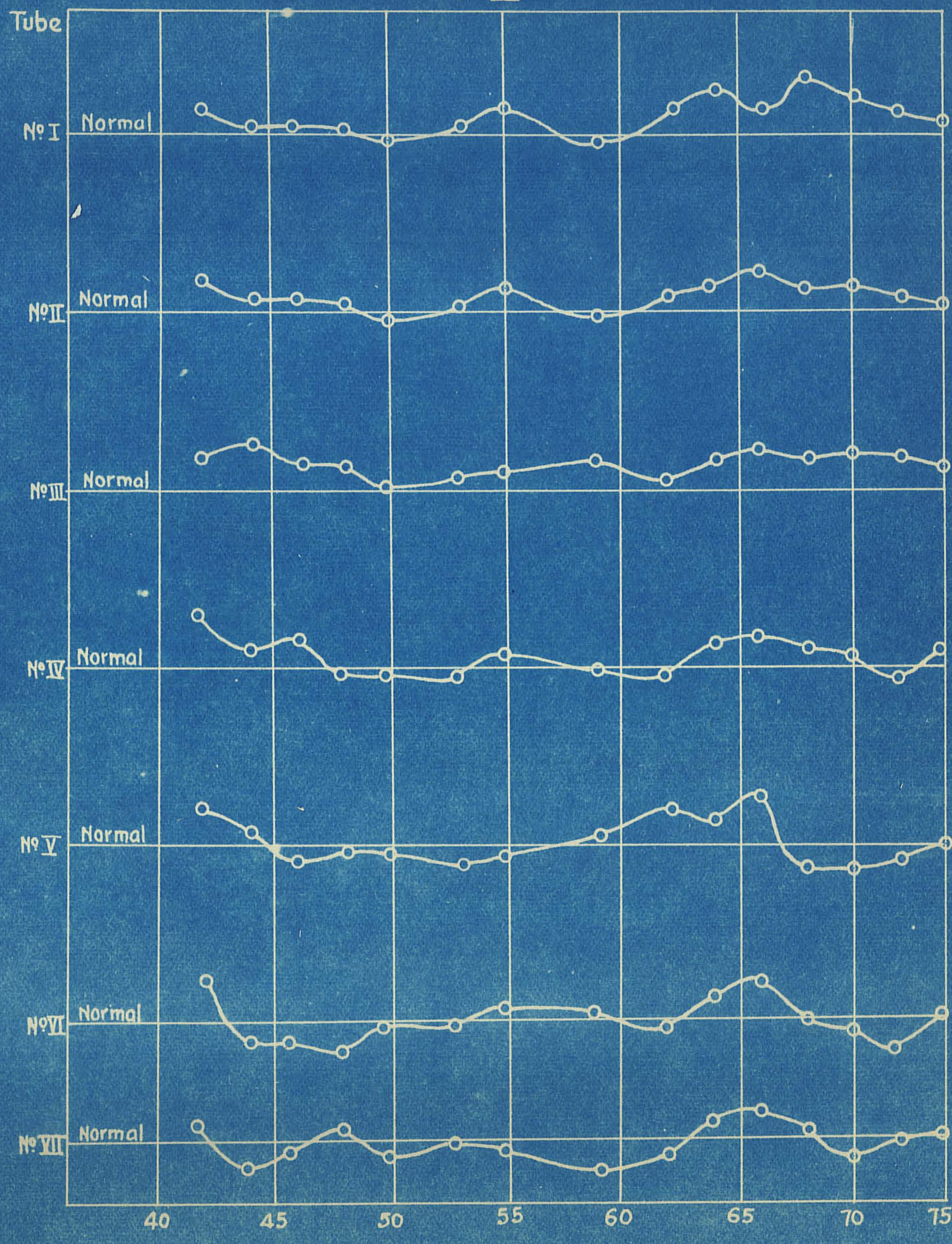
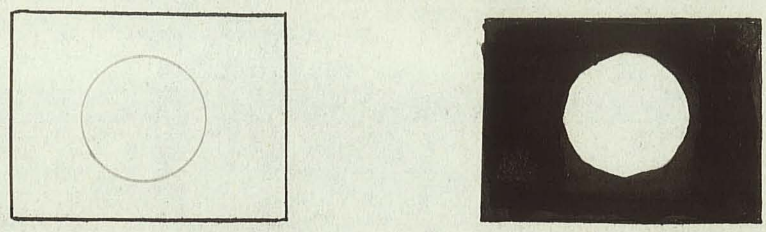


TABLE III TUBE DATA

TUBE No.	INNER DIAM.	LENGTH	DIAM. of CIRCLE
	CMS.	CMS.	CMS.
1	2.0	40.4	5.7
2	2.7	40.5	8.0
3	3.6	40.5	11.1
4	5.0	40.7	14.8
5	6.5	40.0	20.5
6	7.3	40.5	23.0
7	9.0	40.0	27.0
8	10.3	40.2	30.2

Vision through a tube in the manner described, is a form of simultaneous light contrast. The effect obtained by looking through a tube at a white surface is very much the same, as when two areas of the same luminosity are observed on two different backgrounds, one black and one white. The area surrounded by a black background is observed to be of greater luminosity than the area surrounded by a white background.



When the right eye observes a bright surface on a darker ground, the image formed on the retina is that of the far end of the tube, which appears to be a white circle deriving its luminosity from the area it encloses on the white cardboard background. This fact is strikingly demonstrated by the tendency of this white patch to migrate over the surface of the cardboard, unless there is some mark on the surface to serve as a focussing spot to which the vision is directed. Surrounding this circle is the black border provided by the interior of the tube.

The existence of the tube itself seems to be entirely unnoticed. When this circular surface is viewed, it stimulates a portion of the retina. But as in the Black-White contrast system, it is not seen by itself, but it is a part of a larger surface which is the background. In this case the background as seen by the right eye is black, and very little light is reflected from this background to the retina. The background, as seen by the left eye, however, is the same surface as the circular area fixated by the right eye. Therefore when the backgrounds of two identical surfaces are altered the values of the luminosity of the surfaces are also changed. This is the phenomenon of simultaneous light contrast. If reflex principles can satisfactorily explain colour-contrast, as published by Allen in several J.O.S.A. papers, then reflex principles should be properly applicable to Tube Effects.

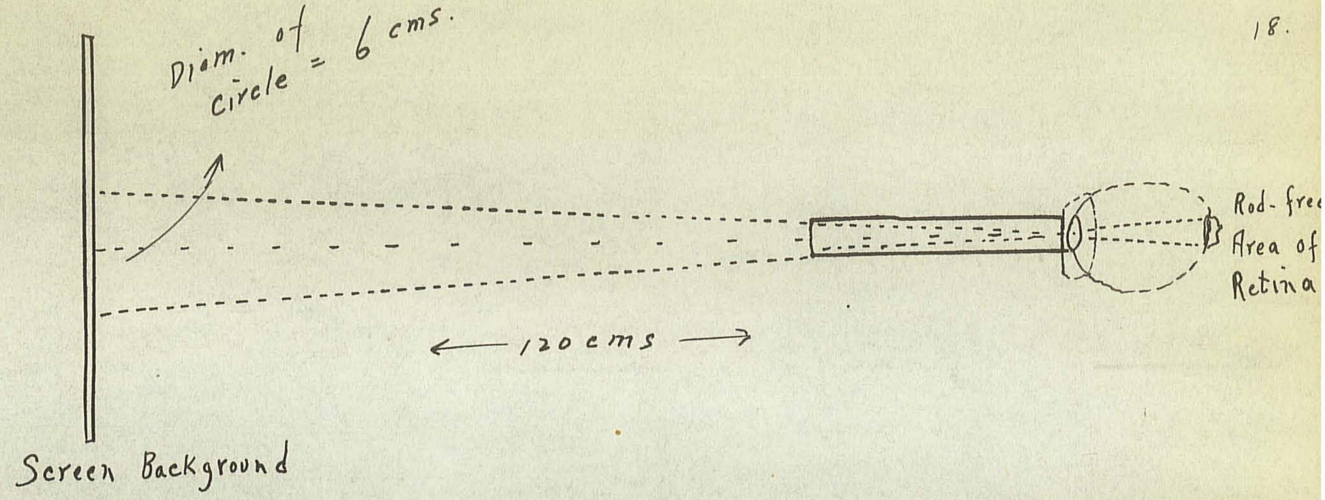
Some anatomical data will present clearly the various portions of the retina of the eye stimulated by the set of tubes. From Vierordt's Anatomical Tables is derived the following data.

Depth of the eye = 47 millimetres. Height = 38 millimetres.

Region of the Eye.	Diameter.	Subtending Angle.	Approximate No. of Rods	Approximate No. of Cones.
Fovea Centralis	.2 mms.	55' 70''	----	4,000
Rod-free area	.8 mms.	3° 3'	----	9,000
Macula Lutea	1-3 mms.	4°--12°	Very Few	13,000
Periphery	20 mms.?	12°-150° Horizontal 12°-120° Vertical	13,000,000	6,900,000

When fatiguing the right eye by looking through the first tube the image of the centre of the circle, which was marked on the background, will be formed on the Fovea Centralis of the right eye since this is the point of most distinct vision. If the attention is concentrated on the small mark on the background, it is natural for the eye to focus itself so as to project the image of the mark on that portion of the retina where vision is most accurate.

Then if the angle subtended by the rod-free area of the retina is 3° 3' we can calculate the diameter of the circle of cardboard at a distance of 120 centimetres from the eye, which will stimulate this rod-free area and no other.



The diameter of the circle on the background was found to be approximately 5.9 to 6 centimetres, using the centre of the crystalline lens as the apex of an equilateral triangle. From this we find that the area of the retina stimulated by vision through Tube No. I, must have been entirely within the rod-free zone, which includes the Fovea Centralis and extreme inner portion of the Macula Lutea.

Similarly if the angle subtended by the Macula Lutea of the retina is given as that between the angles 4° and 12°, we can find the diameter of the circle on the background which will stimulate only this portion of the retina. Using the centre of the crystalline lens as the apex of the triangle, we find that subtending an apical angle of 12°, the height being 120 centimetres, the base has a diameter of 23 to 24 centimetres.

Also we find that the diameter of the circle seen on the background, when the eye was directed through the largest tube #VIII, was approximately 30 to 31 centimetres. Using this diameter as the base of an equilateral triangle, of height 120 centimetres, the apical angle would require to be about 18°.

Therefore the largest tubes #VII and VIII must have stimulated an area of the retina that would include, Foveal, Macular and Peripheral regions, so

we incl

we conclude that all tubes larger than No. VI will include a portion of the true periphery in their effective retinal light stimulating properties. Tubes between No. II and No. V will accordingly stimulate only Foveal and Macular portions of the retina. Tube No. I will stimulate only Foveal and the Rod-free area of the Macular regions. This tube therefore confinés the action of the direct light stimulus to the retinal portions of the eye which are composed entirely of cones. Foveal stimulation occurs only when the subtending visual angle is less than 1°, therefore at no time during this research was the action of the direct stimulus confined to the Fovea Centralis. In order to do this, the circle seen through the tube on the background, would have to be only 5 to 6 millimetres in diameter at 120 centimetres distance.

When a beam of light is allowed to fall on the central portion of the retina, and the surrounding portion is unstimulated from the outside, then the central portion becomes fatigued, as is evidenced by the fact that after allowing the white light to fall on the retina for about four minutes, and then to take, with the same eye, a spectral reading of a colour formerly seen by that eye under normal conditions, the spectral colour is observed to be of less brightness than it was before.

Assuming that fatigue consists in the diminution, however extensive, of the energy-response of a cell or nerve, we can examine the effect of fixating the image of a white circular area of constant illumination on the sensitivity of the receptors of the retina of the eye.

The data, given in Table I, were obtained from the stimulation of the right eye by means of the eight tubes. The data of seven of these tubes have been plotted in the conventional condensed form in Figure II. The straight line called the Normal represents a nominal value of 100, while variations of the fatigue curve above or below the normal are represented to scale. Where the fatigue curve is above the Normal curve, the conclusion is drawn that the sensitivity of the receptors for the luminosity or brightness of that particular spectral colour has been decreased. This shows that the direct effect of fatiguing the eye with white light has a depressing effect on the sensitivity of the receptors that were stimulated by that light. On the other hand, where the fatigue curve is placed below the Normal we have an indication that the sensitivity of the receptors has been enhanced for that particular spectral colour. The resultant effect of the action of white light on the sensitivity of these receptors is, therefore, one of enhancement.

Where the fatigue curve is coincident with the Normal, it appears that the sensitivity of the receptors, for spectral colours indicated by these coincident points, has apparently remained unchanged. The stimulating action of the white light has no effect on the sensitivity of the receptors for the particular wave-lengths designated by the coincident points.

Since in order to procure continuity of sensation we must decrease the speed of the disc when the luminosity of the colour is decreased, and since we can increase the speed of the disc when the luminosity of the colour is increased, we have here a quantitative method of measurement of the enhancement or depression of the sensitivity of the receptors of the retina to stimulation. Therefore we can study quantitatively the direct effect of fatiguing these receptors by means of focussing a white circular patch of definite area on a portion of the retina whose dimensions can be calculated.

The curve obtained for the first tube shows primarily that the sensitivity for the luminosity of all the spectral colours has been diminished, with the exception of two points where the sensitivity has apparently remained unchanged. These points can be approximately assigned to wave-lengths .50 μ and .58 μ. There are four prominent indications of diminished sensitivity. The first is a general depression for luminosity over the whole of the band of wave-lengths from .74 μ to .60 μ. Two points are elevated in this general depression, one at .67 μ and one at .64 μ. These two wave-lengths would correspond to a dark red colour. The next prominent elevation of the curve, or in other words a depression in sensitivity, occurs at wave-length .55 μ which would correspond to a bright green colour. Following this there is a gradual elevation of the curve in the violet or lower end of the spectrum, between wave-lengths .48 μ and .42 μ. The depression of the sensitivity of the Red sensation is greater than that of the Green or Violet sensation, while the Green is slightly more depressed than the Violet.

Here we find that fatiguing the right eye with white light in the manner of the experiment produces a depression in the sensitivity for luminosities for areas corresponding to Red, Green and Violet, with Blue and Yellow areas approximately remaining unchanged.

In the data derived from Tube # II we have further evidence that there are three prominent elevations in the curve which agree very closely with those obtained by Tube No. I. The curve, as before, shows a general depression of the receptors over the whole band of wave-lengths with the exception of the two points at .50 μ and .58 μ which remain unchanged.

The difference occurs only in the Red wave-lengths where the two prominent depressions have been fused and form a common one situated mid-way. The depression of the Green is of equal magnitude with that of the Violet.

This tube allows more light to enter the eye, thereby stimulating a larger area of the Macular region of the retina. Nevertheless there is produced a depression in those areas corresponding to Red, Green and Violet while the Yellow and Blue have remained unchanged.

In tube No. III the result obtained agrees fairly well with the first two. The exception being the elevation of the curve at wave-length .58μ which indicates a shift toward the yellow of the maximum depression of that portion of the curve corresponding to Green. This reading however seems to be in disagreement with every other reading for the wave-length .58μ Coincidence with the Normal curve is the rule for five of the seven curves. The depressions for the Red, Green, and Violet have all approximated the same magnitude, the maximum depression for the Red, however, still remaining at wave-length .66μ. This tube allows still more light to enter the eye, stimulating an increased area of the Macula Lutea. The sensation for the Blue wave-length is still coincident with the Normal at .50μ indicating no change in its sensitivity.

The curve obtained by plotting the data for Tube No. IV has approximately the identical form of the first three, with the radical change occurring as one of enhancement in certain portions of the curve which are placed below the Normal. The three depression maxima are still located in portions of the Curve corresponding to the Red, Green and Violet. The coincident points are approximately located at wave-lengths .50μ and .58μ. Five of the readings however are below the Normal curve which is either an indication of enhancement of these sensations or a discrepancy in the measurement of these critical frequency of flicker by amounts varying from .0004 seconds to .0002 seconds.

With tube No. IV we have the area of the circular patch on the background stimulating completely the Foveal and Macular areas of the retina of the right eye.

With Tube No. V true peripheral portions of the retina are stimulated directly for the first time. The curve is seen to lose its characteristic position and form, the readings varying both above and below the Normal, indicating both depression and enhancement for the various sensations. The Red, Green and Blue show enhancement, the Orange and Violet show depression. The coincident points however are still approximately at wave-lengths .50μ and .58μ.

The data plotted for the last two tubes No. VI and No. VII, show that the curves have lost all the former characteristics. The readings vary considerably with the developement of enhancements in the wave-lengths corresponding to Dark Red, Green, Blue and Violet. The data for Tube No. VIII agree very closely throughout the entire spectral band with that of the Normal Curve.

These results may be due to the effect of stimulating, not only Foveal and Macular retinal areas, but also including increasing portions of the periphery as the diameter of the tubes following No. IV increases beyond a certain limit. The use of tubes larger than No. IV brings the conditions of vision to approximate those of constant daylight adaptation, or the normal condition of the eye. Consequently in this condition there is no special fatigue produced by stimulating the retinal receptors, therefore the curves obtained closely resemble that which was obtained when the eye was in its normal state of adaptation. The slight variations between the readings of Tubes VI, VII and VIII and the Normal readings, may be due to, either, discrepancies in measurement, or to a slight action still produced by that small area of the sensitive portion of the periphery not yet under direct stimulation by white light. The latter may be the more logical explanation, since if the records of the last three tubes are examined closely, it will be noticed that the general trend of enhancement and depression occurs throughout approximately identical bands of wave-lengths. The depressions occur regularly in the Violet and Orange regions, while general proximity with the Normal is the outstanding feature of the Green and Blue portions of the spectrum.

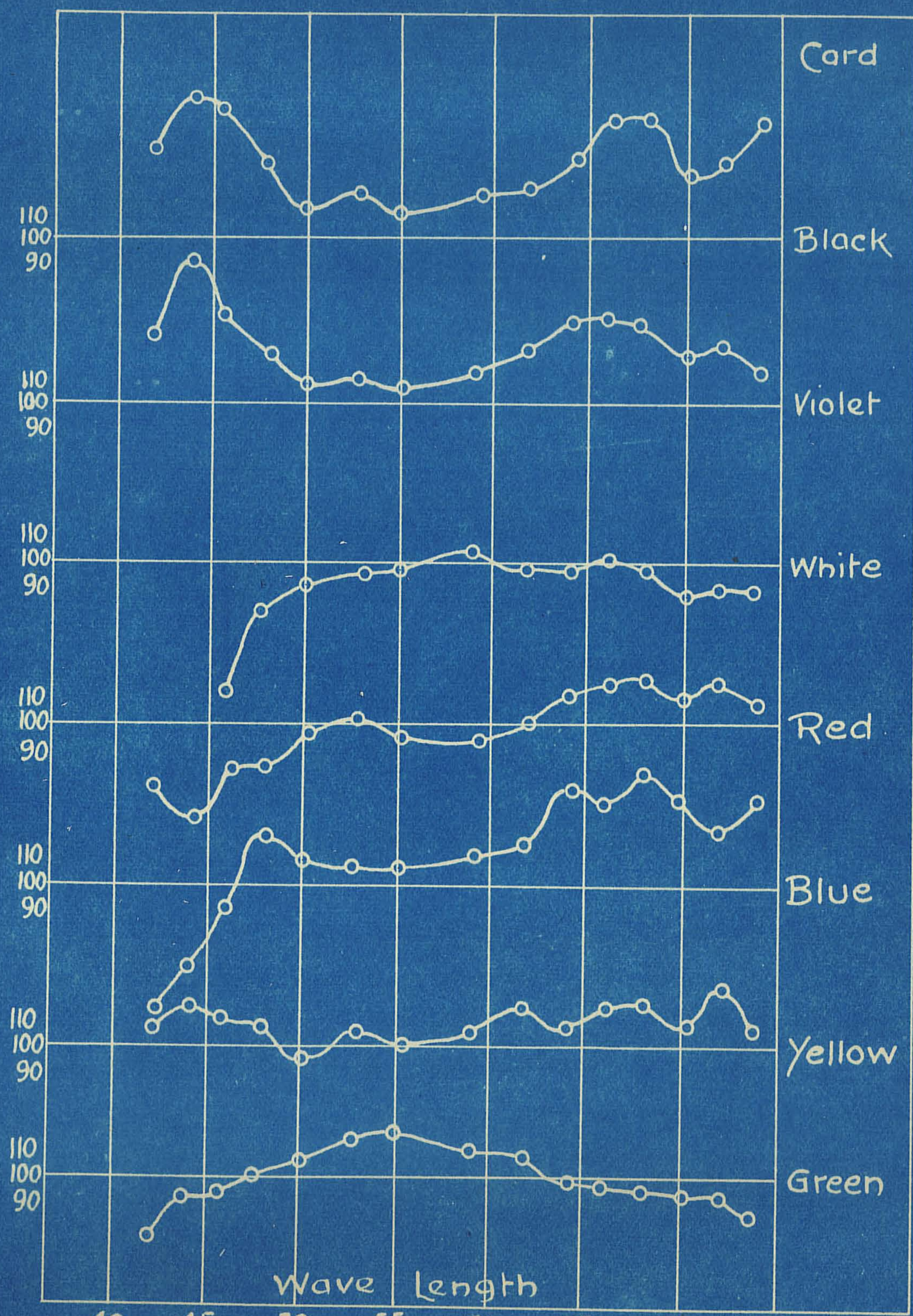
The enhancement indicated in the Red and a portion of the Yellow and Violet may be explained by the reflex action of white light of a moderate intensity on the sensitivity of the central portion of the retina. It has already been shown by Allen, and others, that a stimulus of moderate intensity has a resultant effect on the sensitivity of the receptors of enhancement rather than depression.

The reflex impulses of enhancement due to the action of the stimulus overbalance the impulses of fatigue for the same portion of the retina. This is in accordance with the Ferry-Porter law, namely, $\frac{1}{D} = k \log S + k_1$, in which a stimulus S of low intensity produces an effect of fatigue or depression, and conversely a stimulus S of moderate intensity produces enhancement of the sensitivity of the receptors, resulting in a displacement of the fatigue curve below the Normal in portions corresponding to the colour areas most prominently affected.

TABLE II CARD DATA

λ	NORMAL	WHITE	BLACK	RED	GREEN	BLUE	VIOLET	YELLOW
	sec.	Sec.	Sec.	Sec.	Sec.	Sec.	Sec.	Sec.
74	·0260	·0252	·0285	·0262	·0247	·0287	·0270	·0262
72	·0210	·0202	·0232	·0222	·0202	·0227	·0227	·0226
70	·0177	·0168	·0196	·0185	·0172	·0202	·0190	·0182
68	·0152	·0150	·0187	·0167	·0146	·0188	·0175	·0164
66	·0145	·0145	·0182	·0157	·0142	·0182	·0172	·0155
64	·0140	·0138	·0165	·0150	·0138	·0190	·0165	·0147
62	·0127	·0125	·0142	·0127	·0132	·0139	·0140	·0137
59	·0107	·0110	·0120	·0102	·0114	·0115	·0115	·0110
55	·0120	·0117	·0128	·0115	·0132	·0125	·0120	·0122
53	·0130	·0127	·0142	·0130	·0140	·0135	·0137	·0132
50	·0160	·0152	·0168	·0158	·0164	·0172	·0162	·0155
48	·0190	·0175	·0212	·0177	·0188	·0205	·0205	·0195
46	·0235	·0200	·0270	·0220	·0230	·0228	·0262	·0245
44	·0290	·0232	·0332	·0260	·0280	·0265	·0337	·0300
42	·0360	·0307	·0385	·0340	·0340	·0324	·0362	·0368

CHART DATA
FIG III



FATIGUE CURVES.

SECTION VI.

The cards used to obtain the effect of fatigue in the following experiments were pieces of coloured cardboard ten inches square. Their colour-reflecting property was examined by means of a straight vision spectroscope equipped with a vernier scale, reading in millimetres. A pointer attached to the scale measured, approximately, lengths of the various coloured bands reflected by the cards.

Examination of the white card revealed a continuous spectrum of medium intensity stretching from seven to fifty-five millimetres.

The Black card revealed only slight traces of red and green bands of very low intensity.

The Red card gave a prominent colour band of a dull red hue between five and fifteen millimetres. This tapered off to a faint orange from fifteen to ninteen millimetres. A dull green band occurred between nineteen and thirty-two millimetres, followed by a gap, which graded into Violet at fifty millimetres.

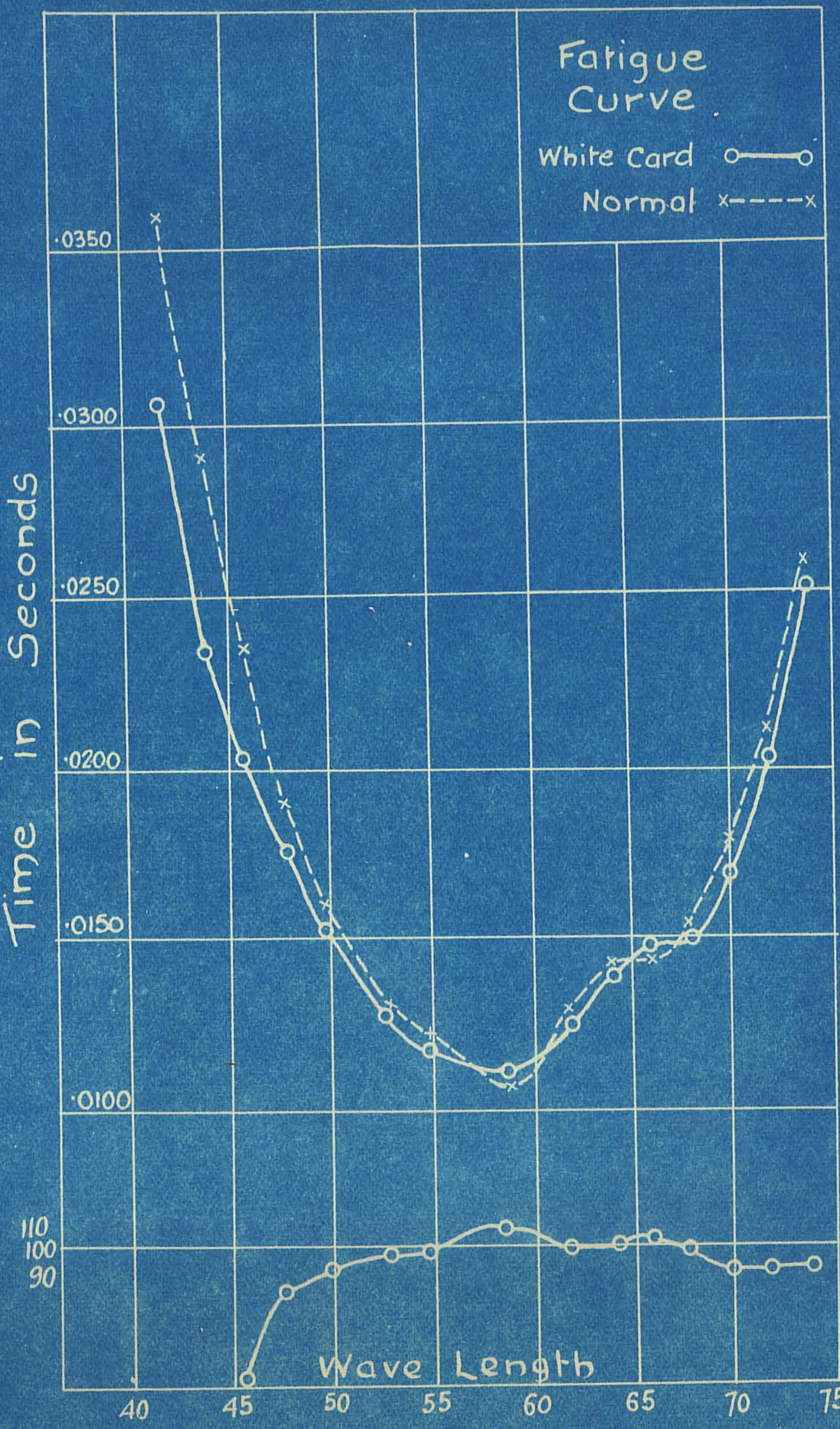
The Yellow card gave an almost continuous spectrum of very weak intensity. From seven to fifteen millimetres the red was moderately bright, the predominant band of colour being the Orange between fifteen and twenty-one millimetres. Green occurred between twenty-one and thirty-four millimetres, Blue between thirty-four and forty millimetres, and a Violet of dim intensity between forty and fifty-two millimetres.

The Green Card gave a bright band of seven to eighteen millimetres in the Red, and another of Green from twenty-one to thirty-four millimetres. The Violet and Orange readings were so faint as to be almost negligible, with a slight appearance of Blue between thirty-four and thirty-seven millimetres.

The Blue card showed only very slight traces of Red and no yellow whatever. The Green and Blue bands were well marked between nineteen to thirty-five millimetres and thirty-five to forty-five millimetres. The Violet was invisible, no trace of colour could be seen beyond forty-five millimetres.

The Violet card gave a prominent band of Violet between forty and fifty-four millimetres. The Red was only faintly prominent between five and fifteen millimetres. Green was slight between nineteen and thirty-seven millimetres, while Orange and Blue were barely distinguishable.

FIG. IV


Fatigue Curve
White Card
Normal
Time in Seconds
·0350
·0300
·0250
·0200
·0150
·0100
110
100
90
Wave Length
40
45
50
55
60
65
70
75

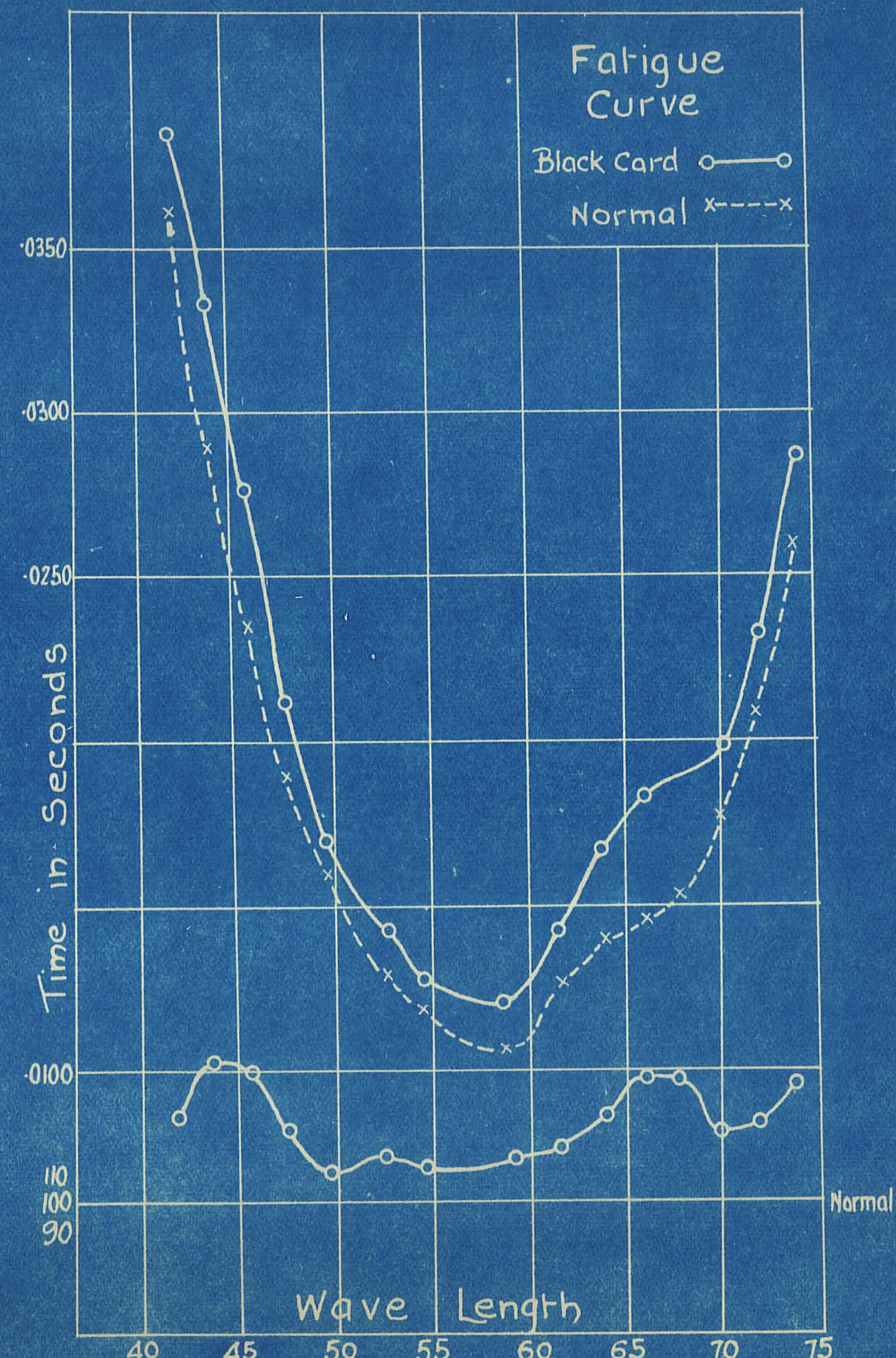
All the fatigue curves in this section are shown plotted in condensed form in Figure III, and were obtained from the data of seven cards shown in Table III. The data were obtained by directing the right eye through Tube #2 at the coloured cards on the background. The right eye was exposed in this manner for approximately three minutes, then a chronograph record was made.for the same eye with the spectrometer. The various cards were hung on the background used in the previous part of the work, at approximately the same distance from the eye. On directing the right eye through the tube and focussing the attention on a small pencil mark on the card, the eye could distinguish only a circular spot of colour. This spot as seen by the right eye seemed brighter than the same coloured card as seen by the left eye. The brightness of the spot seemed to be due to a whiter appearance of the colour, in other words, it appeared to be less saturated to the right eye than to the normal left eye.

Since the characteristic effect of fatigue in normal vision is a diminution in brightness, an elevation from the normal curve will always indicate what sensations are directly affected or fatigued, and a depression below the normal curve will always indicate what sensations are feflexly affected or enhanced.

The first card used was white in colour. The curve obtained is shown plotted with the Normal in Figure IV. The reduced curve at the bottom shows what sensations are predominantly affected, and is obtained by assigning a nominal value of 166 to the normal reading and reducing the fatigue reading in proportion.

Although the curve still retains the characteristic shape of the normal type, it will be seen that it is displaced below the Normal in all portions

FIG. V

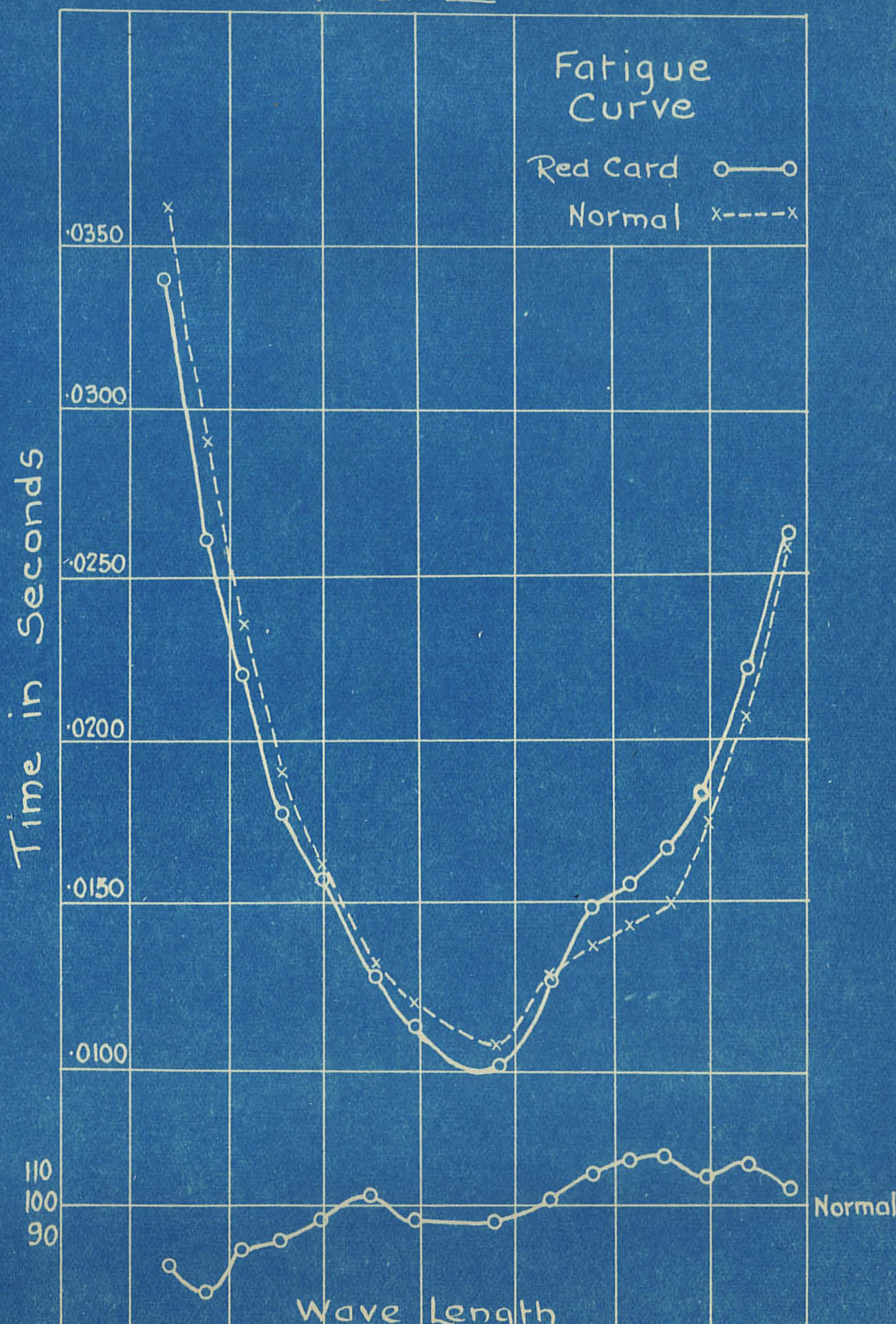

Fatigue Curve
Black Card o—o
Normal x----x
·0350
·0300
·0250
·0100
110
100
90
Normal
Time in Seconds
Wave Length
40
45
50
55
60
65
70
75

with the exception of a single wave-length .58μ. The displacement is considerable in the Violet, and there are two minor displacements in portions corresponding to Red and Green sensations. These displacements all indicate enhancement, the single displacement at .58μ showing depression or fatigue may be due to a discrepancy in reading or due to its position in the brightest portion of the spectrum. Coincidence with the Normal curve occurs at wave-lengths .55μ, and practically throughout the anomalous region .62μ to .66μ.

This type of curve indicates that a stimulating white light of moderate intensity produces an enhancing effect in the sensitivity of the receptors affected. The enhancement is greatest in dimmest portions of the spectrum where the subsequent stimulus is of very low intensity. The greater enhancement of the Violet over the Red sensation seems tobshow that the dimmer the spectrum colour the greater is the enhancement produced due to the reflex effect of the white card. The curve coincides very closely with the Normal in the central or brightest portions of spectrum, only the extreme ends showing enhancement by a depression below the line. In these two sensations, therefore, we have the reflex effect of enhancement overbalancing the direct effect of fatigue. In the case of wave-length .58μ the direct effect of fatigue is not overbalanced by the reflex impulses, due perhaps to the rapidity with which the effect produced by fatigue disappears under the influence of the brightest portions of the spectrum.

The next card used to fatigue the eye was dull black in colour. The results obtained are shown in Figure V where the Fatigue and Normal curves are plotted together. We find that here there is the opposite effect to that of the white card, the curve showing a general depression throughout the whole spectrum. The effect as before is most pronounced at both ends of the spectrum, and not very well marked in the most luminous area. Although the appearance of the spectrum to the dark-adapted, right eye was such as to suggest an increase in the luminosity, yet the true effect is shown by the actual

FIG. VI


Fatigue Curve
Red Card
Normal
·0350
·0300
·0250
·0200
·0150
·0100
110
100
90
Normal
Time in Seconds
Wave Length
40
45
50
55
60
65
70
75

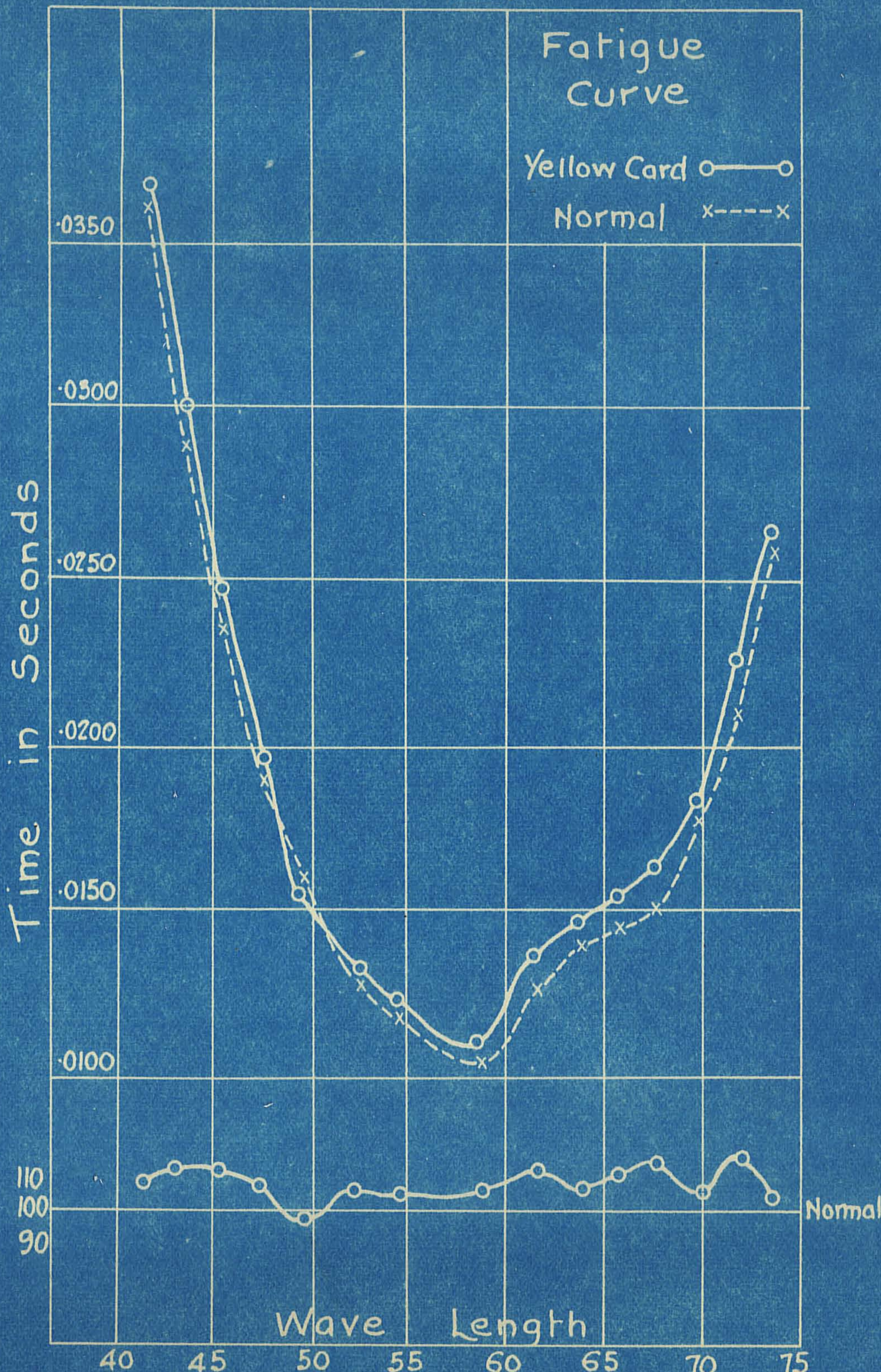
measurements. Therefore, the reflex effect of enhancement due to stimulation by a black surface is dominated by the direct effect of fatigue produced by the same surface. The retina of the eye is therefore less sensitive to the succeeding light stimulus, although the luminosity appears to be greater. The dark-adapted state may rapidly disappear under the influence of the bright spectral colours and be retarded by those of lower intensity, which may explain the characteristic elevations at either end of the spectrum and the approximation to the Normal in the central portions.

The black card was replaced by one of dull red colour, and the curve obtained is shown with the Normal in Figure VI. It was first noticed at this point that colour contrast effects were noticeable with the left eye. The borders of the Red card were tinged with green which passed off into the background after an interval of a minute or two. The curve itself shows depression over the red area predominantly at wave-lengths .68 μ and .72 μ. Two definite enhancements were shown by depressions of the curve below the Normal, between wave-lengths .55 μ and .58 μ or the green sensation, and also between wave-lengths .42 μ and .50 μ, or the violet sensation. Again the coincidence occurs with the Normal curve lying closely to wave-lengths .53 μ and .62 μ.

The red card itself produces a direct effect of depression and a reflex effect of enhancement in the Red sensation, but in this particular case the reflex effect is overbalanced by the direct effect, the net result of the two actions is shown by the elevation of the curve in the Red portion of the spectrum. The reflex effect of enhancement predominates, however, over the direct effect of fatigue in the Green and Violet sensations as shown by depression of the curve below the Normal.

The next card used was of a bright yellow colour. The data obtained

FIG VII

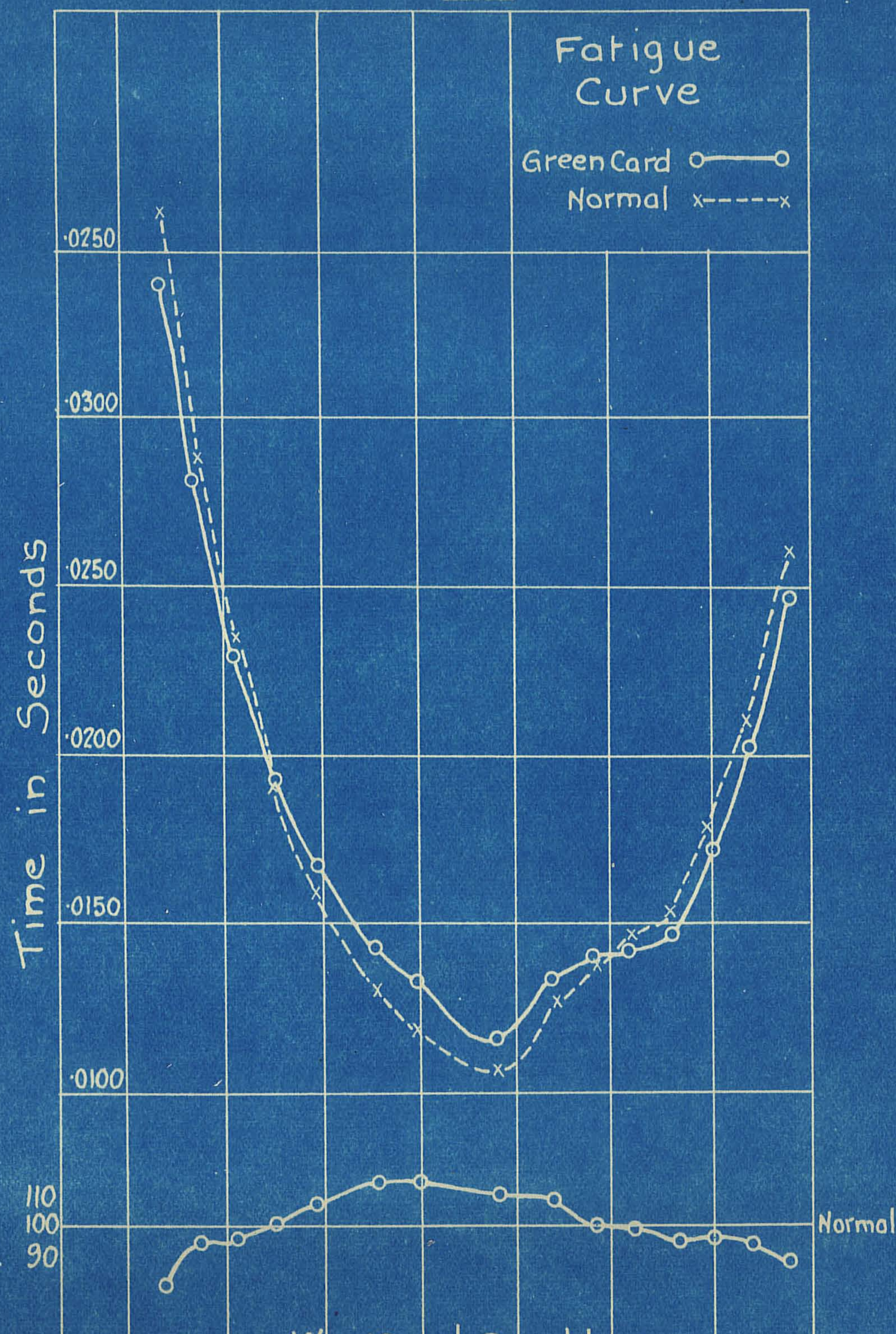

Fatigue Curve
Yellow Card o——o
Normal x----x
·0350
·0300
·0250
·0200
·0150
·0100
Time in Seconds
110
100
90
Normal
Wave Length
40
45
50
55
60
65
70
75

using this card is shown plotted with the Normal in Figure VII. The curve shows a general elevation throughout the whole spectrum, the only coincidence with the Normal occurring at wave-length .55μ. Two prominent elevations occur in regions corresponding to Red and Violet sensations. A slight elevation occurs at wave-length .53μ, which is followed by a small depression at .50μ. The net result of these two seems to favour coincidence with the Normal for the Green sensation.

The unusual feature is the elevation of the curve in the Violet region rather than the expected depression. It was thought that the Violet band would be depressed below the Normal to the enhancement by the Reflex Action of the Yellow card. The Red and Green sensations show an elevation in the curve, the green, however, being somewhat doubtful. The Red sensation is therefore depressed in sensitivity by the direct or fatiguing action of the yellow stimulus. This curve was repeated with the same result, showing perfect agreement as to form but differing slightly in the amount of the variation from the Normal.

The next card chosen was of a bright apple green colour. The data obtained are plotted with the Normal in Figure VIII. The curve obtained is as expected. The reflex and fatigue effects being very well shown, by one prominent elevation covering the green sensation, with two depressions corresponding to the Red and Violet sensations. The direct effect of a Green stimulus is shown by the elevation in the curve for the green wave-lengths, indicating fatigue of the receptors for Green. The reflex effect is shown by depression of the ends of the spectrum indicating enhancement of the receptors for Red and Violet. Another important feature is the position of the coincidènce points with the Normal. These correspond approximately with those obtained in the previous figures, at wave-lengths .50μ and .64μ.

FIG VIII


Fatigue Curve
Green Card
Normal
·0250
·0300
·0250
·0200
·0150
·0100
Time in Seconds
110
100
90
Normal
Wave Length
40
45
50
55
60
65
70
75

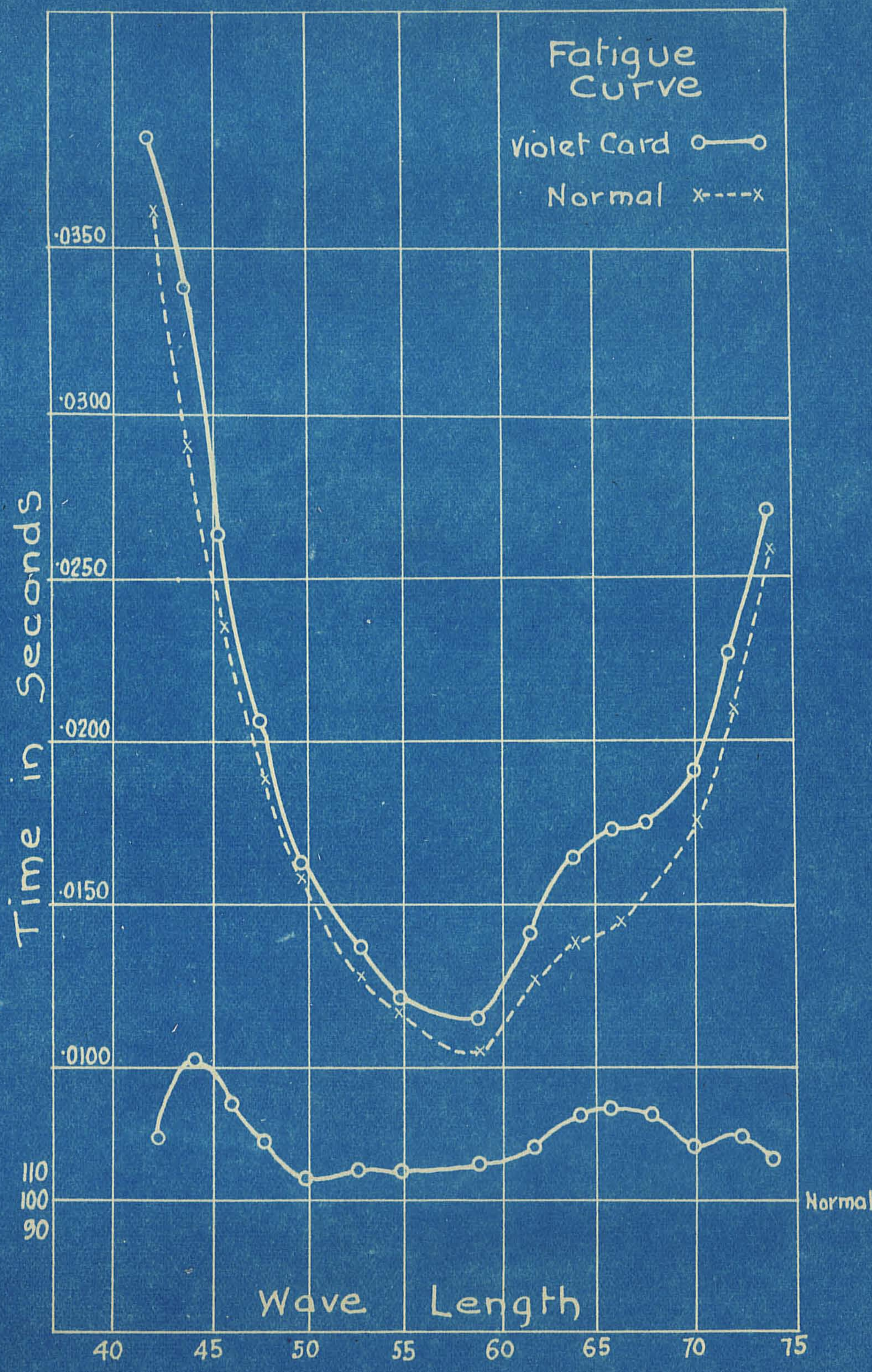
The next card used was of a deep blue colour. The data obtained are plotted with the Normal in Figure IX. This curve shows a very prominent elevation in the Red and Green sensations, with a pronounced depression of the Violet. These results would indicate that the direct effect of the Blue card predominates on the Red and Green sensations, the major effect being at wave-length .48 which probably corresponds to the Blue card. The reflex effect predominates on the Violet sensation showing enhancement of these receptors by depression below the Normal. The blue card has a dim stimulus somewhat like the Violet and Black cards, therefore the curve resembles those obtained from low stimuli. This is shown by pronounced variation from the Normal in the dim ends of the spectrum, and shows least variation under the influence of the brighter or central portion. Also by the fact that the curve as a whole is raised above the Normal everywhere except in the extreme Violet region.

This enhancement of the Violet is peculiar uhtil we find on examination of the sensation curves of Konig and Abney, that at the intersection of the Green and Violet (or Blue) sensations a very small change of wave-length transfers the predominating stimulus from Green to Violet, in this case the Green sensation must be the predominant stimulus, which is directly affected showing fatigue while the Violet sensation is reflexly affected showing enhancement.

The last card used was a dark Violet colour. The data obtained is plotted with the Normal in Figure X, the curve showing general depression over all the colour sensations, with pronounced effects in the Red and Violet portions.

The weak stimulus from the Violet card resulted in a direct and reflex combination wherein the direct overbalances the reflex with consequent depress-

FIG X

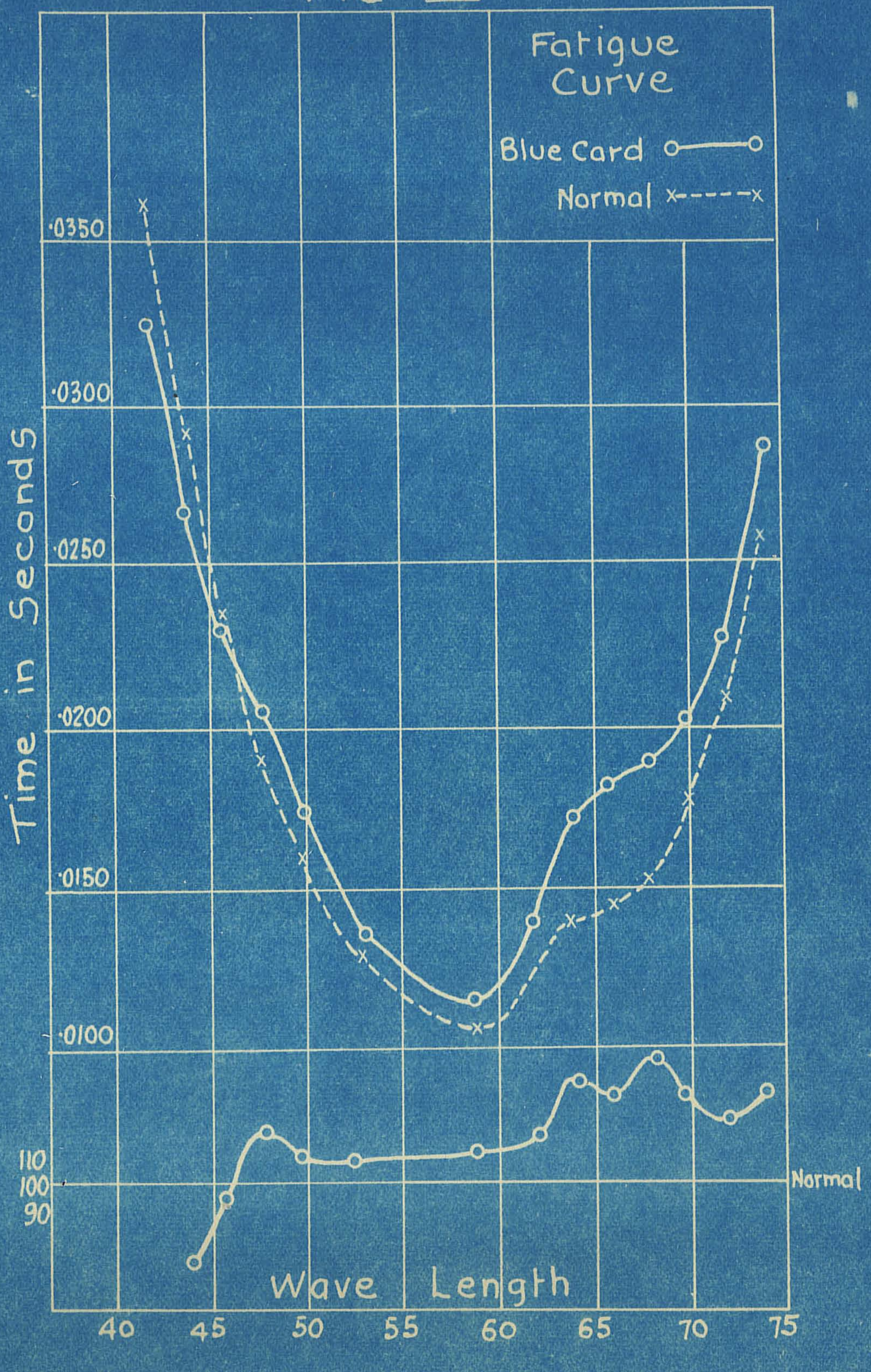

Fatigue Curve
Violet Card o—o
Normal x----x
·0350
·0300
·0250
·0200
·0150
·0100
110
100
90
Normal
Time in Seconds
Wave Length
40
45
50
55
60
65
70
75

ion or fatigue in the sensitivity of the receptors for all colour sensations. The dominant effect in the Violet is due to the direct action of fatigue by the Violet card on the receptors corresponding to the Violet sensation. The curve is almost coincident with the Normal at wave-length .50 μ.

The pronounced elevation in the Red end of the spectrum indicates the effect of the direct action on the Red sensation by a Violet card over-balancing the reflex action on the Red sensation by the same card. The similarity between the results obtained from this card and those of the Black and Blue cards will be at once apparent. The prolonged effect in the Red sensation by the Violet card may be due to the greater saturation of the red reflected from this card than from the others.

Another point of interest is the regularity of the occurrence of the coincidence points of the Fatigue Curves with the Normal. These points correspond in a moderate degree with those obtained by Allen using colours obtained from an acetylene flame to fatigue the eye. They were called by him equilibrium colours, since their action on the receptors was neither reflex nor direct, and fatigue curves showed no enhancement or depression of the sensitivity of the receptors for any wave-lengths in the spectrum.

FIG IX


Fatigue Curve
Blue Card o———o
Normal x- - - - -x
·0350
·0300
·0250
·0200
·0150
·0100
Time in Seconds
110
100
90
Normal
Wave Length
40
45
50
55
60
65
70
75

THEORETICAL CONSIDERATIONS.

SECTION VII.

The Two-fold Effect of Light Stimulation.

Before applying the experimental results to the theories of colour vision, it will be advantageous to summarize briefly present views regarding the two-fold action of light stimuli on the retina.

It is held that the first effect is due to the direct action of the light on the visual mechanism, and this action produces fatigue, that is a diminution in the response of the receptors of the retina to light stimulation. This direct action stimulates all three color sensations suggested by Helmholtz, namely Red, Green and Violet.

When the exciting colors are Red, Green or Violet one sensation is predominantly affected. For example, when the stimulating color is red, the red sensation is affected, but when the stimulating color is green, the green sensation is affected, and when the stimulating color is violet the violet sensation is affected.

When the exciting colors are Yellow, Orange, or Blue two sensations in each case are directly involved. If the stimulating color is blue for instance, the green and violet sensations are affected.

The stimulating colors Red, Green and Violet are said to be simple colors. The stimulating colors Orange, Yellow and Blue are said to be compound colors.

It is supposed that there is a second effect called the Reflex, which produces enhancement of the three sensations, Red, Green and Violet. The predominant effect of the Reflex impulse is upon the sensations complementary to the acting color. If the acting color for instance is Red, the reflex enhancement occurs predominantly in the Green and Violet sensations. If the acting color is compound in character such as Blue, Orange or Yellow, the reflex enhancement occurs in the remaining sensation unstimulated by the direct action of the acting color. For example if Blue is the stimulating color, the reflex enhancement occurs in the Red sensation, because the Green and Violet sensations are directly affected.

Thërefore the predominant direct and reflex effects are complementary to each other in action.

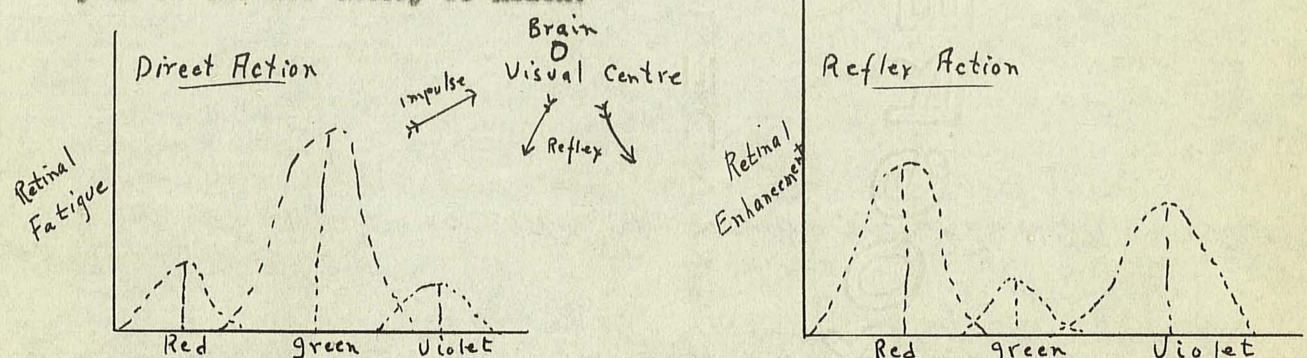
The reflex influences are transferred from one eye to the other, and from one retinal area to adjoining portions of the same retina, but no evidence has been found that fatigue from the direct action of light was transferred from eye to eye or from area to area on a single retina.

The theory in detail is as follows:-

When light of a certain wave-length, for example, .590 μ strikes the retina of the eye, three distinct colour sensations are excited, although not all in the same degree of magnitude. In other words, it is impossible to excite only one colour. This phenomenon has been shown to be true for other senses, especially that of taste, where by arousing the sensation sour we also excite the sensations sweet, bitter, salt, though to a less degree.

It is true that when light falls on the rods and cones of the retina it fatigues them, in other words, the direct effect of the light is one of fatigue, and when the same colour is viewed as in a spectrum its physiological brightness is lowered. But it is also true that when light stimulates the retina there is produced a reflex effect which has the tendency to increase the receptor powers of all the fundamental sensations. Thus the colours complementary to that which produced the fatigue will have their physiological brightness enhanced due to this reflex action. Therefore we see that the one impulse travelling to the brain returns as two separate impulses which affect all these fundamental sensations.

In normal vision if we see green as the fatiguing colour, the reflex action tending toward the enhancement of this colour is overbalanced by the direct effect, and the result is a fatigue of the green sensation, but the reflex action on the red and violet overbalances that of the direct action, and enhancement of these two complementary sensations is the result. This shows that light has a dual action upon the retina, which is the essential part of the new theory of Allen.



The enhancing effect is so much weaker than the direct effectthat it is not easily perceived without the aid of such apparatus as has been previously described. Another important point is the fact that the direct effect influences all three sensations of that part of the retina upon which the light falls. The reflex effect enhances every part of each retina with regard to all the sensations. It matters not whether the right or left eye be fatigued. If the readings are taken with the right eye we still have enhancement of all sensations in each eye due to reflex action.

The conclusions derived from the experimental results of this research are dependent on the validity of several assumptions.

The first important assumption was that relating the critical frequency of flicker to the luminosity of the colour measured. This relationship is given by the Ferry-Porter Law, which states that the critical frequency of flicker is equal to the log of the intensity of the stimulation, with the aid of certain constants which depend on the physical factors of the instruments used to produce the stimulus.

This in turn is dependent on the fact as proved by Porter that, "the duration of the undiminished sensation produced by different spectral hues depends solely on the luminosity of the colors and not on their wave-frequency." Therefore the measurement of the critical frequency of a color is independent of the Wave-frequency. On what then does the luminosity of a color depend?

The basis of the Episcotister method of measuring brightness is the Talbot-Plateau Law, which gives the relation between the brightness of the individual stimuli and the resultant sensation, as "the resultant impression is the mean of the periodic impressions."

Another important assumption used in explaining fatigue of a sensation, is the fact that variations in the critical frequency of flicker for a particular wave-length can be directly related to fatigue or enhancement of a color sensation corresponding to that wave-length. May not the variation in the measurement of the critical frequency of flicker as obtained for fatigue and normal readings be due to the effect of fixating a moderately bright surface for some time, and immediately focussing the eye on a spot of color which may be of greater or less luminosity than the surface itself?

Variations in readings may also be due to areal effects, for example in the so-called fatiguing of the eye by means of the large tubes, we stimulate a large portion of the retina including some of the periphery. The effect of this fatigue is then measured on that portion of the retina which is directly stimulated by the small slit of color seen in the spectrometer, which may be foveal, or foveal and macular entirely. That portion of the retina remaining unstimulated following fatigue by a white light may have a physiological effect on the central portion of the retina on which the readings of the spectrometer depend.

With these basic facts in mind, the experimental results may be considered, with special regard to Anomalous Trichromatism, Color Contrast and the Color Theories of Young-Helmholtz-Hering and MacDougall. The experimental results which have now been considered, fully verify Allen's theory of the dual action of light in arousing visual sensations. The curves obtained show that in addition to the direct effect of light which tends to produce fatigue, there is also a reflex effect which tends toward the enhancement of the Complementary color sensations.

A comparison of the writer's normal persistency curve with that obtained by Allen indicates that an abnormality exists for the writer, since Allen's curve has been fully confirmed by other investigators whose results therefore appear as those having normal color vision. The writer has experienced no phenomena, apart from these experiments, to indicate that his vision was in any way abnormal. Ordinary Wool and Card tests indicate no traces of color abnormality. Nevertheless between the wave-lengths .60μ and .66μ we find an elevation existing above the smooth type of persistency curve.

The greatest departure from the normal occurs in the Green and Yellow region, or that part which corresponds predominantly to the Green sensation. The least departure from the normal type occurs in the Orange and Red regions, where the writer's curve is elevated toward the normal type such as Allen's. The writer's curve is practically identical with that obtained by W.A. Anderson, who possessed anomalous trichromatic vision, many of his readings coincide exactly with the writer's, chiefly in the orange, yellow, green and blue portions of the spectrum. A comparison of the writer's curve and that obtained by A. Hollenberg indicates the difference between the type of curve obtained by an anomal-

TABLE IV

λ	NORMAL writer. Sec.	NORMAL W.A. ANDERSON. Sec.	NORMAL F. ALLEN Sec.	NORMAL A. HOLLENBERG. Sec.	VARIATION of. WRITER And ALLEN. Sec.
74.	.0260	.0301	.0335	.0386	.0075
72.	.0210	.0249	.0287	.0316	.0077
70.	.0179	.0199	.0244	.0266	.0067
68.	.0152	.0158	---	.0229	---
66.	.0145	.0147	.0174	.0182	.0029
64.	.0140	.0136	---	.0160	---
62.	.0127	.0125	.0152	.0147	.0025
59.	.0107	.0111	.0148	.0133	.0041
55.	.0120	.0118	.0155	.0131	.0035
53.	.0130	.0126	.0165	.0138	.0035
50.	.0160	.0150	.0207	.0163	.0049
48.	.0190	.0187	.0255	.0191	.0065
46.	.0235	.0233	.0305 ap.	.0230	.0070
44.	.0290	.0300	.0350 ap.	.0287	.0060
42.	.0360	.0404	.0431	.0372	.0071

ous trichromat and one who is Red-Green color blind.

The color-blind curve shows extreme variation throughout the red and green regions with but slight elevation in the violet portion of the curve, where the two types of curve are practically identical.

A comparison of the results obtained by F. Allen, normal; A. Hollenberg, color-blind; and W.A. Anderson, anomalous trichromat, is given in Table IV.

An examination of Konig's sensation curves indicates that direct stimulation of the green sensation beyond wave-length .66μ is very small, thus in the region .60μ to .66μ the green sensation falls to zero. The abnormality in the writer's curve would appear therefore to be due to a deviation of the green sensation curve, rather than the red, from that of the normal type. The abnormality is due to an over-sensitiveness of the green sensation to wave-lengths of the yellow and green regions of the spectrum, and to an under-sensitiveness of the same sensation to wave-lengths between .60μ and .66μ. In this respect the writer is classed as an Anomalous Trichromat.

The phenomenon of Anomalous Trichromatism has been explained, in part, by supposition of a shift in one of the sensation curves, but the phenomenon cannot be fully studied unless both the direct and reflex action of a light stimulus is taken into consideration. Since direct stimulation of the retina is always accompanied by a sensory reflex, an abnormal development of this reflex would produce anomalous results in color vision. In general, therefore, anomalous trichromatism may be due to an abnormal ratio of the direct stimulation of the sensations to their reflex enhancement. Since the ratio depends to a slight degree on the intensity and duration of a stimulus it is conceivable that some persons would agree with a normal result in one set of circumstances and be anomalous in another. The latter phase is probably most easily detected after prolonged stimulation since the reflex sensation, which may be set up in a small fraction of a second, increases with continued stimulation until a maximum is reached.

Examination of the reduced fatigue curves at the bottom of the figures, indicates a decided tendency to divide, in most cases into three regions, these regions probably indicating the existence of three fundamental color sensations corresponding in the main to Red, Green and Violet colors. Color vision is essentially trichromatic. This fact has been recognized by various experimenters in color vision for some time, as shown by the early researches of Newton, who believed that color vision consisted of three distinct parts which could account for all the color sensations. Later work by Young resulted in a Trichromatic theory with the fundamental color sensations Red, Yellow and Blue. This theory was modified and extended by Helmholtz to finally consist of three fundamental color sensations,namely, Red, Green and Violet.

This theory in its final form originated from a study of color mixtures, which are explained in a very satisfactory manner. Anomalous trichromatism was recognized and explained as a partial reduction in one or more of the sensations, or in some cases, to a shift of one of the sensation curves. The theory lacks, however, adequate explanation of the various types of color-blindness with normal luminosity curves, while patial induction: simultaneous and successive contrast are regarded as "illusions of judgment." With this theory as the basis for the addition of the principle of reflex visual sensations, simple and satisfactory explanations are offered for these various phenomena of color vision. They are probably due to balances set up in the visual mechanism between the direct action of the light stimulus and the complementary reflex enhancements released by the same stimuli.

Hering also recognised that the nature of color vision was essentially trichromatic, but in order to explain satisfactorily phenomena associated with simultaneous and successive contrast, introduced his theory assuming the existence of three photochemical substances in the retina, one substance corresponding to each pair of the sensations, i.e. Black-White, Red-Green and Yellow-Blue. The first named sensation in each pair is supposed to arise from the breaking down of the photochemical substance, the rebuilding of the same substance gives rise to the last named sensation. Hence we have six primary sensations corresponding to three pairs of physiological processes. In the explanation of color contrast, this theory assumes, not a complementary action, but rather an antagonistic process whereby the net result arising from a stimulation is due to the one sensation of the six which produces relatively the greatest effect. The necessity for a white-black substance to explain the underlying whiteness of a color, is unnecessary with the introduction of the reflex principles.

The reflex and direct action of light produce their full effect without destroying each other, the net result is that due to a combination of the two actions. Those colors varying from black to white or the grey series results from the stimulation of the three fundamental sensations, red, green and violet, while the whiteness underlying spectral colors may be due to the stimulation by reflex action and direct action of the three fundamental sensations with a resultant effect of white combined with the spectral color stimulus. Equal stimulation of all three sensations then would result in a sensation of white, whether it be by a combination of reflex and direct actions or by individual direct and reflex actions. The existence of a reflex principle which affects predominantly the complementary color sensations explains fully the phenomenon of color contrast which Hering recognized as an essential feature of color perception, and erroneously explained by Helmholtz as an "illusion of judgment."

MacDougall's theory supports the three-component theory of color vision. He supplements the original theory of Young by the addition of an independent white mechanism, and accepts the view that a special black-exciting process is unnecessary, the sensation of black occurring when complete fading occurs. His theory explains simultaneous contrast by inhibition of the stimulating color with the consequent production of a complementary colors. This feature is related to the principle of reflex visual sensations, and offers further evidence toward its verification.

The phenomena of color contrast can be explained satisfactorily by coupling the trichromatic theory with the principle of reflex visual sensations. Simultaneous binocular color contrast is based on the fact that reflex effects are transferred from eye to eye or from one part of one retina to another with equal facility. Thus the pinkish tinge to the border of the green card, when fatiguing the eye through the tube, is caused by the reflex enhancement of the red sensation, the complementary of green, mixed with the white of the background, and this gave the appearance of pink. Thus the colors are seen as if mixed to a greater or less extent with their complementaries giving rise to a modification of that color which is known as color contrast.

Uniocular contrast can be explained in an identical manner, with the exceptions that the direct and reflex effects are confined to areas on the same retina. This principle offers an explanation of color contrast which is independent of movement of material particles, or flow of visual purple, so characteristic of other theories, which are highly improbable on account of the rapidity with which such motions or flow would be required to travel in order to account for phenomena taking place in a very small fraction of a second. In fact the transfer of material particles from the retina of one eye to that of the other would be a physical impossibility.

Contrast is a phenomenon of fundamental importance, therefore every theory of Color Vision should offer a satisfactory explanation of it. The Young-Helmholtz theory in combination with the Principles of Reflex Visual Sensations discovered by Dr. Frank Allen fully explain all phenomena related to this portion of Color Vision.

This research is one of a series, initiated by Professor Frank Allen, on Reflex Visual Sensations and Color Vision. I desire to express by thanks to Professor Allen for apparatus placed at my disposal, and for suggestions and guidance regarding the interpretation of the results.

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