O N T H E P E R I O D I C C H A N G E I N T H E S E N S I T I V I T Y O F T H E R E T I N A

BY

ROY A LIND

A Thesis presented to the
University of Manitoba.

May 1928.

To Dr. Frank Allen, I wish to gratefully acknowledge my indebtedness for not only the suggestion of this subject and the generous advise, but also for that teaching in the art of research.

CONTENTS

On the Periodic Change in the Sensitivity of the Retina.

1.

Historical.

PERHAPS no other science has passed through its stages of history with such drastic controversy as that branch relating to color vision. It is true that the science of color vision, with the exception of astronomy, goes back further in history than any other science. The reason for this protracted interest in color is of course very obvious. Color in nature is displayed on so magnificent a scale that the minds of all observant could not fail to be impressed.

The first inferences based on a supposed possibility or probability of an explanation regarding the origin of color and the nature of its perception were indeed not very promising. Among the earliest of philosophers there was a doubt whether objects be visible by means of anything that proceeds from them, or by something that issues from the eye of the spectator. For twenty centuries this was the debated question among philosophers who took sides with the leaders of their respective schools and vigorously upheld their theories. A complete absence of experiment in this as in other branches of science was accompanied by an astonishingly great variety of arguements and extravagant hypotheses to support their adopted opinions. Colors were ranked among bodies of which only the names were known. When philosophers were asked for example, why such a body was red, they answered that it was in virtue of a quality which made it appear red. However their speculations - which can hardly be considered otherwise- are of little value since the modern development of sciences, yet, the nature of their work is of sufficient interest to be worthy of mention here.

For the present purposes the history of color vision is here divided into four periods: first, from Pythagoras to Newton (540 B.C. - 1671 A.D.); second, from Newton to Thomas Young (1671 - 1801); third, from Young to Ewald Hering (1801 - 1874); fourth, from this last date to the present time.

First Period (540 B.C. - 1671 A.D.).

Recorded writings centuries before the Christian era, contain speculations on the visual process. The scientific records handed down from Babylon and Egypt do not give much information as to the formulation of hypotheses to support their adopted opinions; this may be due perhaps to the custom of jealousy of confining such knowledge to the guilds of priests. But the Greek philosophers from Pythagoras onward, with their marvellous aptitude for speculative inquiry manifested the most extraordinary ingenuity in devising explanations regarding the origin of color and the nature of its perception.

Among the more outstanding of the earlier writers and philosophers who presented views on the nature of light and colors and the process of vision were: Alcmaeon, Pythagoras, Empedocles, Plato, Aristotle, Epicurus, Alhazen, Roger Bacon, Descartes etc. In order to get an idea of the nature of their work only a brief outline of some of the hypotheses is attempted here because without doubt, a full review would require a volume.

Pythagoras and the Pythagorians, the second school of Grecian philosophers who flourished about 500 B.C. entertained a corpuscular theory of light; it was their opinion that vision is caused by particles continually flying from the surface of the bodies and entering the eye. But, on the other hand, Empedocles and Plato, a century later, put forward the doctrine that the cause of vision is something emitted by the eyewhich meeting with something else that proceeds from the object is thereby reflected again. In other words sight was considered a species of touch due to invisible feelers having their origin in the eye.

Aristotle (350 B.C.) maintained that light was incorporeal and he thought that colors were due to imperfect reflection from raindrops, the image of the sun being distorted and color only exhibited. He also urged that color is a mixture of darkness and white light; or, in modern terms that the mixture of something with nothing in varying proportions gives an infinite variety of something else. This hypotheses of Aristotle was enthusiastically adopted by the German poet Goethe and and advocated by him with an accompaniment of highly vituperative abuse directed against the illustrious Newton and his theory of color.

Epicurus (300 B.C.) and after him Lucretius (75 B.C.) beleived that we see by the intervention of light as we feel an object by means of a stick. Seneca, who flourished about 60 A.D., observed that sunlight shining through a piece of angular shaped glass gives the colors of the rainbow, which he explained as species of false color such as is observed on the neck of a pigeon; in his theory on the rainbow he supposes that the different colors are accounted for by supposing that they come partly from the sun, partly from the clouds, and form a mixture. Ptolemy, whose treatise on optics written about 150 A.D. is now lost, became the great authority on the subject to the time of Alhazen, an Arabian investigator about 1072, and he became the authority for the five succeeding centuries; his speculations do not however show any advance over those of the European philosophers.

Many as the various theories of color vision were during this first period or previous to the time of Newton, they were at the best nothing more than vague hypotheses. Priestly (On Vision, Light and Colors, p. 240) thus sums up the theories of color production to the time of Newton:

"The Pythagoreans called color the superficies of a body. Plato said it was a flame issuing from them. According to Zeno it is the first configuration of matter, and Aristotle said it was that which moved bodies actually transparent. Descartes very sensibly argued that color is a modification of light; but he supposed that the difference of color arises from the prevalence of the direct or rotary motion of the particles of which it consists. Father Grimaldi, Deschales, and many others thought that the differences of color depended upon the condensation and rarefaction of light. Malebranche was of the opinion that the differences in color depend upon the quick or slow vibrationsof a certain elastic medium filling the whole universe. Rohault imagined that the different colors were made by the rays of light entering the eye at different angles with respect to the optic axis; and from the phenomena of the rainbow he pretended to calculate the precise angle that constituted each particular color. Lastly Dr. Hooke, the rival of Newton, imagined that color is caused by the sensation of the oblique or uneven pulse of light; and this being capable of no more than two varieties, he concluded that there could be no more than two primary colors."

Second Period (1671 - 1802).

In the Second Period of the history of color vision the first definite steps toward the appreciation of the science of color were made. Up to the time of Newton's decisive experiment it was far from obvious that white light is very complex in its nature; and failure to discover this resulted in the confusion of mind exhibited by writers on light and color. Kepler was the first to discover the compound nature of solar light, but comparitively little attention was paid to his observations. Boyle also mentions in his work on the theory of colors published 1663, experiments on passing rays of light through a glass prism; this experiment in Boyle's hands were not very illuminating as he claimed that the colors obtained were not real. This same experiment a few years performed by Newton attracted more attention, and his theories were accepted by scientific men of the time.

It was in the year 1666 that Isaac Newton carried out at Cambridge the experiments on the decomposition of white light by a prism which were to inform us as to the true nature of light and color. As a source of light he used the brightest of all possible sources, namely the sun. Its rays were admitted into a darkened room at Trinity College through a hole in the shutter. A glass prism was placed inside the room close up to the hole with its refracting edge horizontal and pointing downwards, so as to receive the rays, they were refracted or bent upwards, and the image of the sun appeared higher up on the other wall. It was in this way that Newton proved the homogeneous nature of white light. The following quotations from some of his papers will give his general view on color vision.

"The rays of light to speak properly are not colored. In them is nothing else than a certain power and disposition to stir up a sensation of this or that color."

"To the same degree of refrangibility ever belongs the same color, and to the same color ever belongs the same degree of refrangibility."

"To explain colors I suppose that ..... the rays of light by impinging on the stiff refracting superficies, excite vibrations in the ether ..... of various bigness; the biggest, strongest or most potent rays, the largest vibrations; and others shorter according to their bigness, strength or power; and therefore the ends of the capillimenta of the optic nerve, which pave or face the retina, being such refracting superficies, when rays impinge upon them, they must there excite these vibrations which ..... will run along the aqueous pores or crystalline pith of the capillimenta through the optic nerve into the sensorium; and there, I suppose, affect the sense with various colors according to their bigness and mixture; the biggest and strongest colors, reds and yellows, the least with the weakest, blues and violets; the middle with green; and a confusion of all with white ..... ."

In 1690 Huygens proposed the hypothesis that light consisted in undulations of a delicate elastic medium. Euler showed how Newton's discoveries could be explained on the this basis, and deduced the result that simple colors in the spectrum were the effects of light of different frequencies of vibration. As a matter of fact, however, his first assumption was that the red vibrations were the faster ones, but subsequently he discovered his mistake. Hartley correctly supported this view in explaining the colors of thin plates. But a cruical test could not be made until the principle of interference had been discovered by Young and Fresnel; and it was this discovery also that led first to the general acceptance of the undulatory theory

Also during this period there were many other color theorists along with Waller and Tobias Mayer who worked with pigments by mixing them in various ways. The general conclusion that they arrived at were that the simple colors might correspond to three different kinds of light, red, yellow and blue.

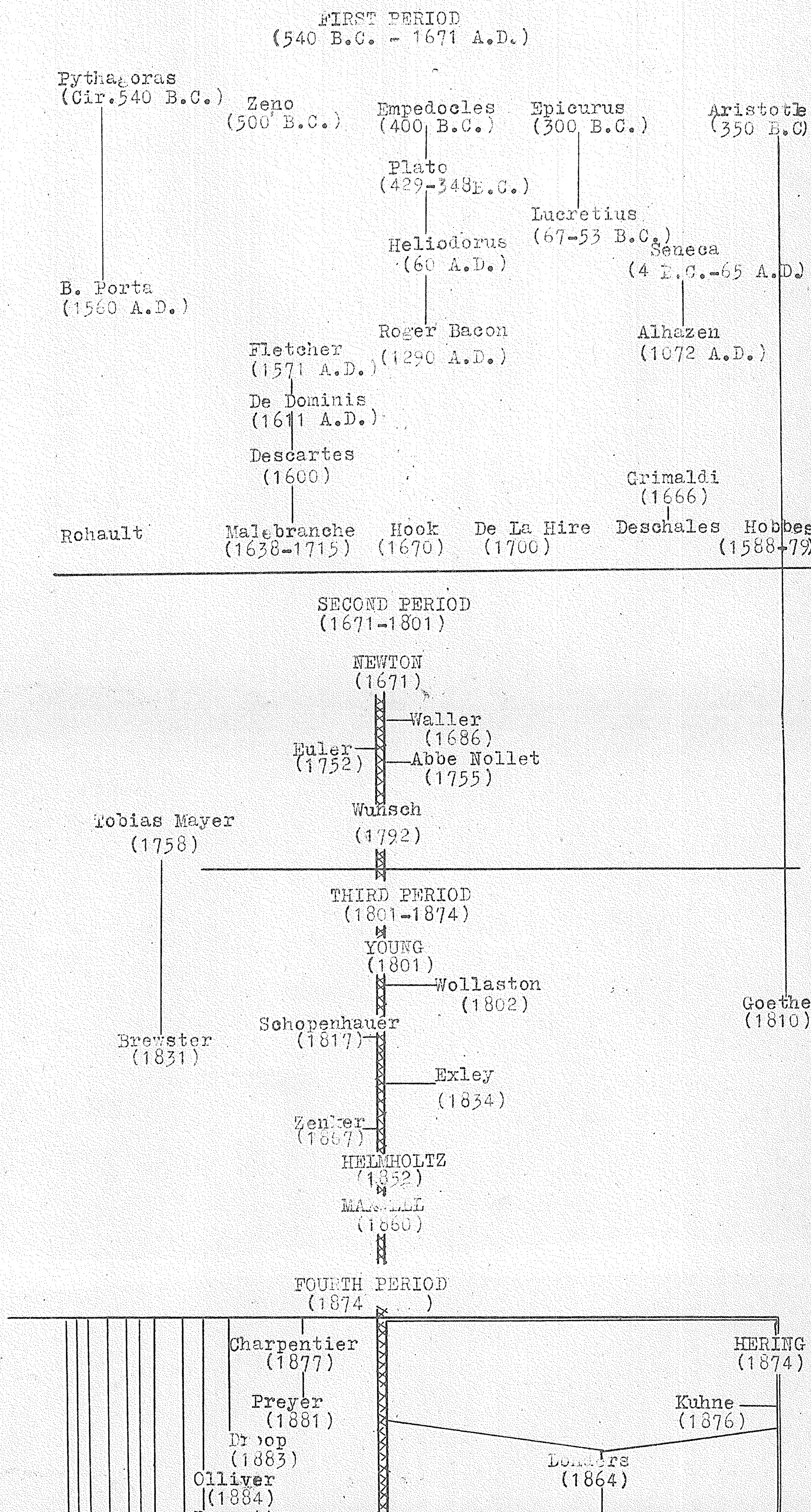
Wunsch in his work published 1792, showed by many experiments that there were not seven primary colors as some supposed by the number of spectrum colors given by Newton, nor yet five as others beleived. He was the first to select red, green and violet as primaries, as a result to which he was led by his experiments on the mixtures of the colored rays of the spectrum.

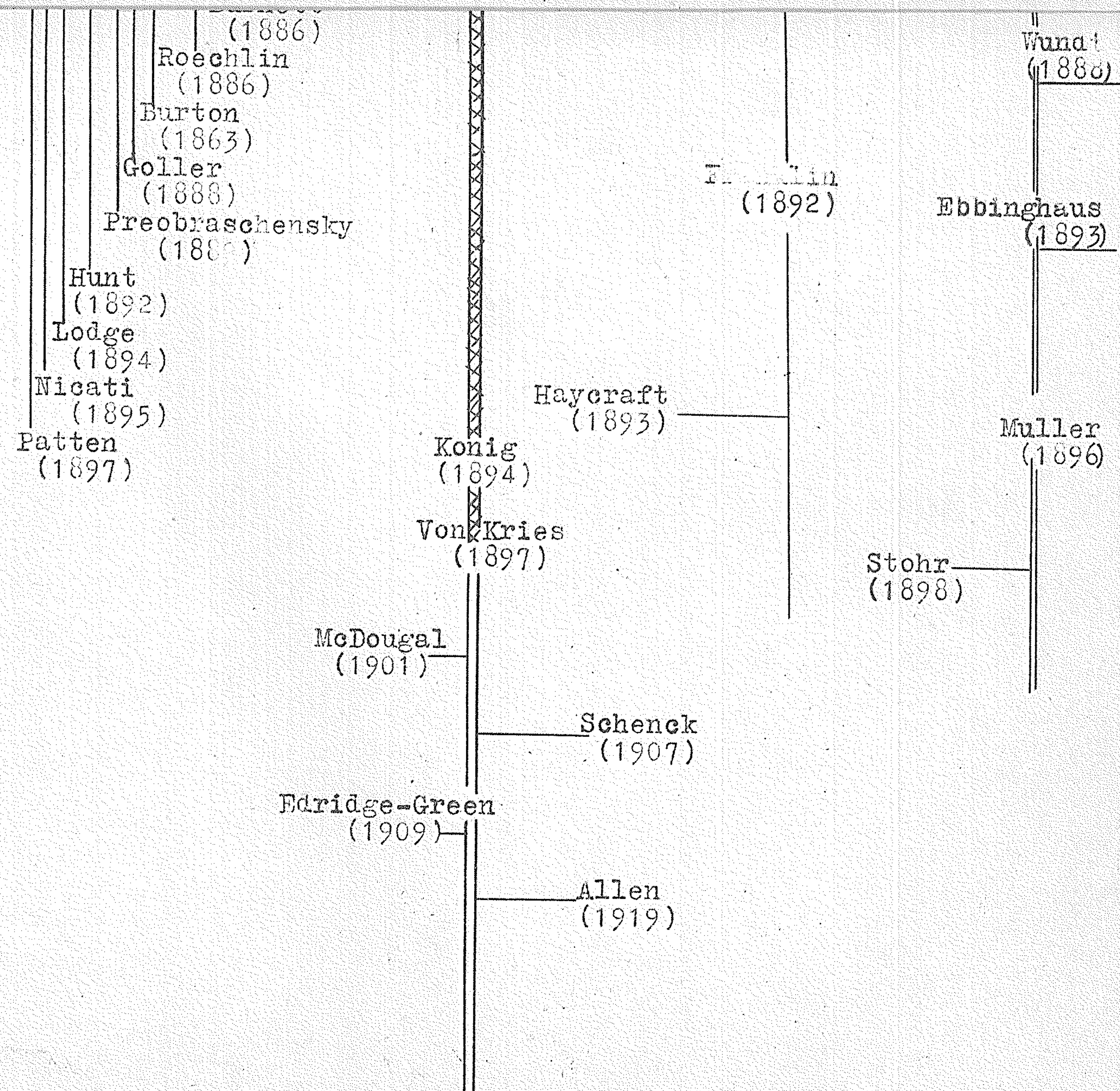
Third Period (1801 - 1874).

From this point on only those theories of prime importance which pertain to the subject of color vision will be dealt with. The process of color vision involves the physical cause, the physiological retinal process , and the psychological elements in the experience of sensations. As the knowledge of the three sciences involved in the process of color vision developed, theories of color vision became more and more intricate. In fact the various theories which are given credence at the present time are found on strict analysis to include in varying degrees the physiological process of vision, color vision, and the nature of perception. A theory of color vision must include all the foregoing factors, yet the dominating influence of one of these is usually perceptible in a given theory. Theories must be judged solely according to their efficacy as a working hypothesis. In so far as they serve the purpose of sign-posts pointing out the paths of future research so far are they of value. Sterile theories easily relinquish immortality. Fruitful theories hand down their immortal parts to their children while their ephemeral shell falls to pieces.

During this period there was added to the general problem of vision the interesting and important fact that it was necessary to assume only a limited number of color sensations to provide for the perception of an unlimited number of hues and tints of color. It is largely conflicting

HYPOTHESES OF COLOR VISION





(1886)
Roechlin
(1886)
Burton
(1863)
Goller
(1888)
Preobraschensky
Hunt
(1892)
Lodge
(1894)
Nicati
(1895)
Patten
(1897)
Konig
(1894)
Von Kries
(1897)
McDougal
(1901)
Schenck
(1907)
Edridge-Green
(1909)
Allen
(1919)
(1892)
Haycraft
(1893)
Wundt
(1888)
Ebbinghaus
(1893)
Muller
(1896)
Stohr
(1898)

views as to the number and nature of these primary color processes that cause the battlefield of color vision to be so littered with the remains of the dialectically slain.

That this is no mere figure of speech may be seen from the genealogical tree of color vision in the accompanying table. This also has the advantage of exhibiting the main line of development from Newton, and the subsidiary line due to Hering together with the positions of theories of secondary importance. Some guiding principle such as this diagram affords will enable the reader of the volumnous literature of color vision to trace his steps without confusion.

The Young-Helmholtz theory, a three component theory was first propounded by Thomas Young in 1801 who is credited for its conception, but it seriously lacked experimental foundation until after the epoch-making work of Helmholtz, and since that time it has become known as the Young-Helmholtz theory.

Young, in his work published 1802, selected red, yellow and blue as the three simple color sensations with no other basis than current scientific opinion. Owing to celebrated but misconstructed observations by Wallaston[1] of the dark lines in the solar spectrum , Young modified his theory by selecting red, green and violet as primaries, quite

1. 1802 - William Hyde Wallaston, "A method of examining refractive index and dispersive power by prismatic reflection." Phil. Trans. Vol. 92, p.378

independently, however of Wunsch. This theory he further confirmed by experiments, after which it remained in obscurity until Maxwell and Helmholtz brought it to attention of scientists and made it the basis of their investigation.

Young seems to have been the first to attribute a definite physiological significance to the three primary colors, the precise hues or wavelengths of which he had no means of determining. His general principles were modified and made definite by the experimental researches of Helmholtz, Maxwell, Konig and others.

YOUNG-HELMHOLTZ THEORY - From the fact that any color sensation could be produced by the mixture, in suitable proportions, of light of three given wavelengths, Thomas Young was led to suppose that there existed three primary sensations, and Helmholtz has supposed that the reason for this is that the eye is furnished with three sets of nerves, one set which, when excited, gives the sensation of red, another of green, and the third of violet. The hypothesis then is that color sensations depend upon the action of three independent physiological processes involving the three sets of nerves. When more than one set of nerves is excited, then a mixed sensation is produced, the character of which depends on the degree to which each set of nerves has been excited.

According to the Young-Helmholtz theory of vision it is supposed that each set of nerves, the red say, transmits the sensation of red to the brain, whatever the manner in which they may have been stimulated. Thus the red nerves are effected not only by red light but also, to a smaller extent, by light of other wavelengths; the impression produced on the brain is however, always that of red light.

It has been found possible, by studying color sensations of the normal-eyed and color-blind persons, to draw three curves showing the sensitiveness of the three primary sets of nerves to stimulation by light of different wave lengths. Such sensation curves were obtained by Koenig and Abney. It will be seen from these curves that the sensation of red can be stimulated by light of all wave lengths, as is also very nearly the case with the green nerves. The violet nerves, however, are not at all affected by the red end of the spectrum.

This theory explains the main facts of color vision, although many details uncovered by experimenters have not yet been reconciled with it to the entire satisfaction of many scientists. After-images are explained by assuming fatigue of one or more of the processes in varying degrees. For instance after fatiguing the eye to green light a white surface appears an unsaturated purple - pink. Many of the observed facts in the study of after-images are only approximately concilable with this theory. The problem of simultaneous contrast offered no difficulties to Helmholtz, because he assumed that the phenomena is the result of false judgement.

Color-blindness is explained by assuming that one or more of the three processes are absent, the remaining process (or processes), if necessary, being 'redistributed' to some extent. This theory has some advantages in explaining the cases of red and green blindness by assuming the absence of the corresponding process and if necessary a slight modification of the other two. It fails to explain total color-blindness, however.

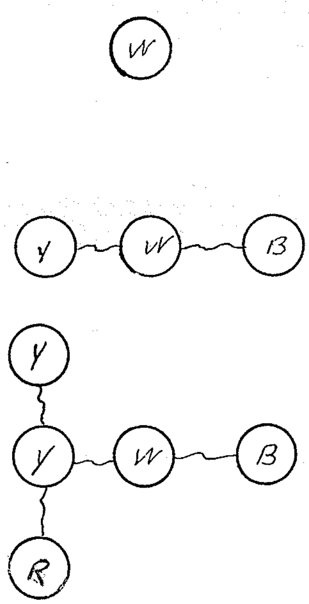
Fourth Period (1874 -)

The fourth period of the history of color vision opens with the hypothesis of Hering, the great rival of the Young-Helmholtz theory, and originating a new branch as compared to that of the Young-Helmholtz theory which follows the main line of development from Newton. This hypothesis of Herring was proposed in a series of six papers in 1874.

The principal foundation of this theory consists of facts such as those of contrast, and the apparent simplicity of black, white, and yellow as well as red, green, and blue. Herring assumes six psychophysical processes corresponding to six primary sensations which may be arranged in complementary pairs, namely, white and black, red and green, yellow and blue. In order to account for these six fundamental sensations he assumes the presence somewhere in the retinocerebral apparatus of three distinct photochemical substances. Each substance is capable of building up (anabolism) or of breaking down (katabolism) under the influence of radiant energy or its effects. The building up of the black-white substance causes a sensation of blackness, and the breaking down of the substance, a sensation of whiteness. Likewise anabolism of the red-green substance is connected with the sensation of green and katabolism with red sensation. Similarly, the buildingup, of the third substance produces blue, and the breaking down is connected with yellow sensation. For example, red rays cause a breaking down of the red-green substance, with the result that red sensation is experienced. These substances are not present in equal amounts. All the rays of the visible spectrum have a breaking down action on the black-white substance, but different rays in different degrees. Mixed light appears colorless when it acts on the blue-yellow or red-green substance with equal breaking down or building up power. The effects are not complementary merely but antagonistic. For example, fundamental red and green do not produce white by their combination, but merely destroy each other's effect and leave visible the white which is already there. This is not strictly true of the white-black antagonism, for their actions do not destroy each other but give rise to a series of grays. Each visual sensation is really a mixture of all six fundamental sensations. The one of the six which has relatively the greatest weight gives the character and name to the mixed sensation.

Many observed facts concerning after-images are said to agree with the theory. For example, if the eye be stimulated by blue rays, anabolism will take place in the yellow-blue substance and the accumulation of the substance results. If now yellow rays are permitted to stimulate the same area of retina, the breaking down of the yellow-blue s substance proceeds at a greater rate and the sensation is greatly augmented. Conversely yellow decreases the amount of the substance and increases the rate of the anabolism under the subsequent stimulation of the blue rays. Positive after-images are explained by assuming a continuation of the anabolic (or katabolic) change for a brief period owing to chemical inertia. All the general phenomena of after-images are explained but the theory must be modified in order to explain some of the data on color-blindness.

Ladd-Franklin theory - In this theory the rods and cones are used. Colorless sensations white, gray and black, are assumed to be caused by a primitive photo-chemical substance which is composed of many 'gray' molecules. The molecules consist of a firm inner core to which is loosely attached an outer range of atoms. These atoms are 'torn off' in decomposition and the sensation ensues. The cause of the 'tearing off' of the atoms is the ether vibrations which are in the visible spectrum, the middle part having the more powerful effect. These molecules exist in their primitive state only in the rods, but upon dissociation they cause colorless sensation. In the cones the gray molecule undergo development and for some reason only a portion ofnthe molecule becomes dissociated by rays of a given wave-length of color. The evolution of the gray molecule is assumed to take place in three stages diagrammatically shown here. In the



first stage the gray molecule exists, but is so constructed that it is disintegrated by light of all colors, thus producing a white or a gray sensation. In the second stage the molecule has become more complex and contains two groupings..The dissociation of one of the latter causes a yellow sensation and the other, blue. Their simultaneous dissociation causes a sensation of white or gray. Molecules are assumed to exist in this stage in the outer zone of the retina, where neither red nor green can be perceived as such. In the third stage the yellow grouping is divided into two new combinations, the dissociation of one giving rise to red sensation. If the red and the green are dissociated simultaneously, yellow sensation results, while all three (red, green, and blue) together produce gray.

Duplicity Theory.- This theory, which attempts to differentiate colorless and color vision, is chiefly associated with the name of Von Kries. It is based upon the anatomical evidence of the existence of 'rods' and 'cones' in the retina. The former are assumed to be responsible for achromatic sensations and the latter for both achromatic and chromatic sensations. The rod action is supposed to be largely responsible for light of sensation at twilight illumination and is in general more responsive to rays of shorter wave-length. The cones, however, are supposed only to act under stimuli of brightness represented by the range above twilight illumination and not to be greatly increased in sensitiveness by dark adaptation. Examination of the retina shows that the cones alone exist in the very center of the retina, the fovea centralis, and rods appear just outside of this and predominate in the outer zones. The chief observed facts that this theory explains fairly satisfactorily (perhaps because it was built up from these facts) are (1) colorless vision over the whole retina in dim light, for instance in moonlight, (2) the decreased sensitivity of the fovea in twilight, (3) the shift in the maximum of the luminosity curve of the eye (Purkinje effect) at low illumination, (4) the absence of such a shift for foveal vision, (5) no achromatic threshold is found for any light for foveal vision, (6) no achromatic threshold for red light for any region of the retina, and (7) colorless vision over the whole retina in the case of the totally color-blind.

Edridge-Green Theory.- Professor Edridge-Green's theory assumes that the visual purple is the sole visual substance. Visual purple is to be found in the rods only and the rods are concerned merely with the formation of visual purple and take no part in visual sensations. (This is contrary to the Duplicity Theory which holds that the rods are the visual organs for scotopic vision.) Ths cones of the retina are insensitive to light, but sensitive to the changes in the visual purple. Light falling upon the retina liberates the visual purple from the rods, and it is diffused into the fovea and other parts of rod and cone layers of the retina. The decomposition of the visual purple by the light chemically stimulates the ends of the cones (probably through the electricity which is produced) and a visual impulse is set up which is conveyed through the optic nerve to the brain. The visual impulses caused by the different rays of light differ in character just as the rays of light differ in wave-length. Then in the impulse itself we have the physiological basis of sensation of light, and in the quality of the impulse the physiological basis of the sensation of color. It is also assumed that the quality of the impulse is perceived by a special perceptive center in the brain within the power of of perceiving differences possessed by that center or portion of that center. According to this view the rods are not concerned with transmiting visual impulses, but only with the visual purple and its diffusion.

McDougall's Theory.- McDougall has modified the Young-Helmholtz theory. He accepts the three fundamental colors, red,green and blue, but adds an independent mechinism for white having its retinal seat in the rods. McDougall thus assumes a seperate retino-cerebral apparatus for each of the three photopic colors of red, green and blue, and for the scotopic white element. He further assumes that each eye has its own set of four such systems quite independent of the other. The sensation of black is experienced when "complete fading" occurs and the visual cortex is at rest.

II

Oscillatory Effect

The results of the recent investigations in color vision by Allen[1] may thus be generalized. Every light stimulus acting upon the retina, generates in the visual receptors nervous impulses which ascend by afferent nerves to the visual centers in the cortex where a sensation of light and color is produced. At some point in the reflex arc, probably in the synaptic junctions of the afferent and efferent nerves, additional nervous impulses are evoked, which descend by the efferent nerves to all parts of both retinas, by means of which the sensitiveness of the visual receptors is controlled. These efferent impulses are of two kinds, one of which enhances and the other depresses the sensitiveness of the receptors. The result of these actions is the production of a state of sensitiveness which is the measure of the excess of the one process over the other. The receptors themselves when stimulated by light give a three-fold response, resulting in the production of three fundamental color sensations corresponding to the red, green and violet colors of the spectrum. Every ray of light stimulates all three color sensations in varying degrees, and the efferent impulses generally depress or enhance the sensations in varying amounts.

For years it has been an observed fact that the sensitiveness of the receptors in the nervous system fluctuates as though it were in accordance with some periodic regularity. This can be readily shown to be so by numerous

1. J.O.S.A. and R.S.I. Vol. 13. No. 4, Oct. 1926.

experiments employing any of the senses or combination of senses, and even in the higher mental process. Simple and easily performed experiments to illustrate this phenomenon are: Hold your watch away from your ear at a point where you can 'just barely hear the tick' and observe that the sound periodically appears and disappears, and this fluctuation is continued as long as you listen; this shows the periodicity existing in the auditory sense. In order to show the fluctuations present in the visual sense such experiments as the observation of faint a faint visual stimulus readily show that there is a periodicity in the visual sense. It will also be noticed in any typical learning curve that the rate of increase of efficiency with respect to time does not vary in uniform degrees but shows decided periods of greater and less readiness of the nervous system to respond to the stimulus, or this can be expressed in other words as a variation in attention and hence, it has led psychologists to say that attention flows in waves. In this natural periodicity lies the foundation for rhythm in poetry and music, and even in plastic and graphic arts. It gives satisfactory explanation to numerous phenomena in color vision which recently had been only partially explained. But all forms of skilful, natural, and effective mental work in daily routine are organized upon the same principle; that is, the conscious task naturally divides itself into units adapted to the natural pulsations of attention; and not only is this a single periodicity but it can be shown that periodicities within periodicities are also present, ranging from the smallest fluctuation for a duration of a fractional part of a second within large fluctuations extending over a period of years.

The explanation of these fluctuations has been variously given as due to fatigue in the sense organs, either of the muscles or the sensory endings, to fatigue of the sensory regions in the cortex, or to changes in blood supply to the cortex, and even to fluctuations of mental energy.

Actual measurements of this periodic change in the sensitivity of the sense organs of the muscles have been worked through by Allen and O'Donoghue.[1] These experiments were based upon the fact that a voluntary, practically isometric, contraction of a skeletal muscle is followed by a very noticeable contraction of considerable duration and of an involuntary nature in the same muscle. This phenomena is termed 'post contraction'. The muscle or muscle group chosen is the deltoid levator complex, in which the phenomenon has been previously studied.

The apparatus by which the intensity and duration of the initial stimulus of the voluntary contraction and the magnitude of the duration of the post contraction is measured, is as follows. To a hanger of an initial weight of 50 grm. on to which could be slipped a series of heavy slotted weights, thus providing a way of varying the load as desired, was attached a thin steel wire, and

1. Quart. Jour. Exp. Phys. Vol. XVIII. No 3. 1927.

to the other end of the wire a stirrup padded upon the inside to receive the fingers. The wire was passed over a grooved pulley borne upon a stand which allowed its height to be adjusted to suit the requirements of the subject. The pulley, stand, and weight-carrier were placed upon the left of the person and the stirrup on the right. They were arranged in such a manner that when the stirrup pad was adjusted across the penultimate phalanges of the fingers of the right hand and the carrier with its load just lifted of the ground, the right arm remained vertical, the wire from the stirrup of the pulley passing horizontally in fromt of the thighs. It is extremely easy to lift the weight of the ground, and to maintain it in a constant position for a long period of time without consciously watching it, and, moreover, the alteration in magnitude of the forse, caused by moving the weight up and down slightly, is so infinitessimal as to be negligible, whereas a similar range of movement upon a spring might perceptibly alter the pull. Again, the raising of the weight ¼ to ½ inch from the ground occupies such a minute fraction of the total time the weight isnupheld that, even although this action is isotonic, its effect can be entirely disregarded. This, then, provided a means of applying a stimulus that could be readily and accurately measured or varied, which would call forth a nearly perfect isometric contraction. The utilization of known weights supported for known times makes the conditions constant and capable of exact repetition.

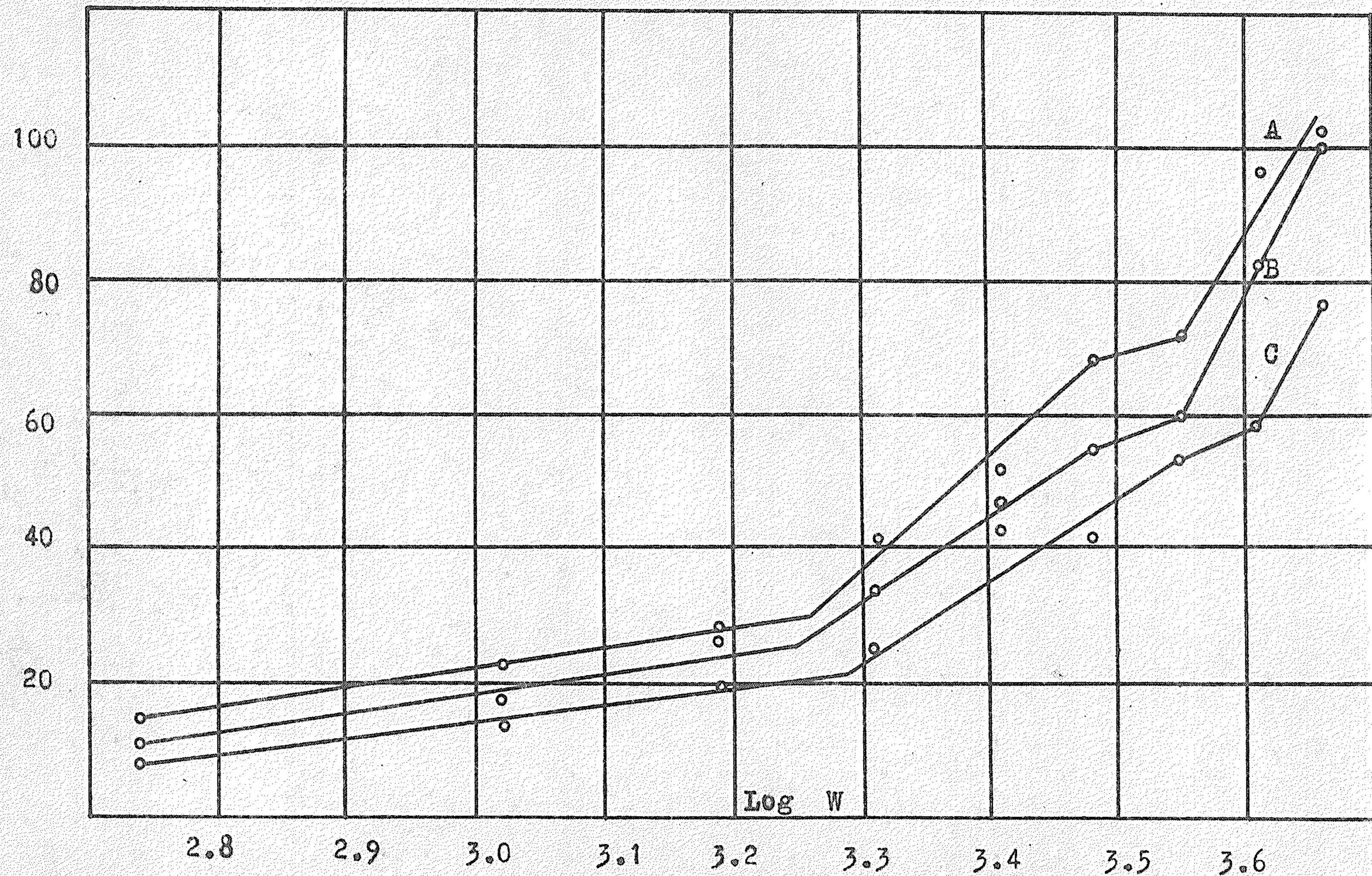
The duration of the stimulus presented no difficulty; it was measured by means of a metronome beating seconds. This was set in front of the subject so that sight, as well as hearing, could be utilized in coounting the time, and it had additional advantage of providing a simple distraction which prevented too much attention being directed to the movement of the arm; a desirable feature.

The arm, with fingers extended, was allowed to was allowed to rise during post contraction, and the height reached was measured by taking the angle from the vertical traversed by the arm. To this end, a board screen was erected, and on it a semi-circle drawn with the level of the shoulder-joint as thecentre and the arm-length as the radius, the centre being at the edge of the screen. This was graduated in degrees, and a glass-topped drawing-pin stuck into the screen at the level of the finger-tips at the end of the post contraction rise.

To perform the experiment the subject stands upright with his right shoulder so close to the screen that the joint is opposite the center of the semicircle and the thumb will almost touch the board while the fingers are traversing the scale. A series of experiments with varying weights were made and the results plotted with the weights as the abscissae and the angles of rise as the ordinates; this did not appear significant beyond showing that, in general, the greater the weight used the higher the arm would rise. When, however, the common logarithms of the weights were used as abscissae it was immediately seen that the curve resulting was of the same general type as that previously found in the experiments upon sight, hearing, taste and touch.

Normal Curve.- In order to study the ordinary results of the experimental procedure, a number of readings were taken from different subjects. In each case the length of stimulation was 10 seconds, and an interval left for recovery; the results plotted in the form of graphs, were designated 'normal curves'. A succession of weights of 500 grm., 700 grm., 1 kg., 1.5 kg., 2 kg., 2.5 kg., 3 kg., 4 kg., and 4.5 kg., were employed; to each of these the initial weight of the hanger, i.e. 50 grm. must be added. For the length of time chosen it was found t that the weights below 550 grm. failed to elicit consistent results, so this may be regarded as the threshold of efficient stimulation.

After several normal curves had been taken by different individuals on various days it was found that each individual has his own curve which, as a rule, is distinctive and not coincident with that of another. Although each person has a typical form and position of the curve, and a mean normal graph can be obtained by plotting the means of a series of readings, yet the seperate graphs, taken on seperate days under slightly different conditions, exhibit a moderately wide range of variation. This does not seem to apply to curves taken on the same day, unless some noticeably external disturbance has taken place, and therefore in subsequent



B Normal A Augmentation C Depression (C.H.O'D.)

experiments a normal for the day is obtained with which comparisons can fairly be made.

Augmentation Curve.- If a normal curve be taken, and then after a rest of 20 minutes a similar series of readings be repeated with the same arm, the curve they yield is raised noticeably above the normal throughout, although of the same type. This indicates a direct, ipselateral augmentation of the end results. In the accompanying figure the normal for the day is indicated B; A is the augmentation curve, and as will be seen, the whole curve is found to be shifted up and every individual reading is higher than the corresponding one in B.

Inhibition Curve.- If a normal curve be taken and then immediately a similar set of readings repeated with the same arm, the resultant curve is significantly below the normal throughout, although of the same type. This indicates that the augmentation phenomenon is preceded by a direct ipselateral inhibition. An analagous situation to this had previously been found by Allen and Hollenberg in the tactile sense, where a considerable manifestation of augmentation followed a kind of inhibition effect. In the accompanying figure, C is the inhibition curve.

In further investigations with similar methods of measurements and procedure it was found that stimulation of one area of a sensory field will produce inhibition and augmentation effects in adjacent, but not previously stimulated, areas of the same field. These two effects are known as transferred or indirect inhibition and transferred or indirect augmentation respectively. It was also found that a stimulation of an area of one side of the body will bring about inhibition and augmentation in the corresponding part on the other side of the body. These effects are known as direct crossed inhibition and direct crossed augmentation respectively. Furthermore, it has been conceived as theoretically possible, although not as yet encountered experimentally, that transferred crossed inhibition and transferred crossed augmentation exist. These latter two effects should be brought about by stimulation of one area of a sensory field on one side of the body and the inhibition and augmentation effects arising not only in its exact counterpart, but also adjacent areas on the other side.

It was found in direct inhibition, the first type mentioned here, that immediately following a set of stimulations the responsiveness of the muscles was lowered. In direct augmentation, also the first type mentioned, it was found that after an interval of 20 minutes had elapsed following a set of stimulations a quite noticeable augmentation existed in the response. In all of these experiments it was noticed that a stimulation of a certain magnitude has first an immediate or primary inhibition, then post-contraction, which is succeeded by a secondary inhibition period manifested at any rate 3 minutes later. This is both ipselateral and contralateral. It is followed by an augmentation period both ipse- and contralateral, which can be detected 17 or 20 minutes later. Obviously, them, at some point between 3 and 20 minutes the normal condition should be restored and this was found to be so when a point arbitrarly taken at 10 minutes was tested; the results yielded a fairly good normal curve and showed no marked signs of either inhibition or augmentation. Furthermore, the augmentation period is succeeded by a return to the normal, but it has not as yet been determined whether there are further inhibition or augmentation periods intervening.

It is clear, then, that starting at normal we have first primary inhibition, then return to normal, then post-contraction, then secondary inhibition and augmentation with the normal state intervening, and then a return to the normal again. This succession may well be termed the oscillatory effect since it recalls the oscillations of a pendulum coming to rest, only apparently by these experiments it has fewer excursions.

A similar phenomenon to the oscillatory effect occurs in sight according to Parsons (19, p. 129) who records it in the following way: "The longer the 'fatigue,' the lower is the capacity for discriminating flicker, and the more intense is the process of recovery. After the recovery there is 'over-compensation,' which is greater the longer the period of fatigue. If inhibition were inserted for 'fatigue' and augmentation for 'over-compensation', we will then have a direct statement of the oscillatory effect. Roaf[1] mentions

1. Quart. Jour. Exp. Phy., Vol. XVIII., No.3, 1927.

in his work on the influence of colored lights on the sensitivity of the eye, that he drew the recovery curve in order to get some idea of the initial effect of a stimulus. Some of the records suggest that the recovery is phasic; or, in other words, indicates the presence of the oscillatory effect. Roaf obviously attached no significance to this result.

III

Periodic Change in the Sensitivity of the Retina

The experiments now to be described are those relating to the actual measurements of the sensitivity existing in the visual receptors after some stimulus had been allowed to act upon the retina. The measurements were taken at varying intervals of time for a period of about thirty minutes after the cessation of the applied stimulus.

For the purpose of measurement of the sensitivity of the retina the apparatus was essentially the same as that originally devised by E. L. Nichols[1] and employed and described by Allen[2] in one of his papers. Light from an acetylene flame, which can be maintained at the same luminosity by means of a manometer that indicates the pressure og the gas at any time, passed through a disk with two opposite open sectors of ninety degrees each. The light was then focused upon the slit of the collimeter of a Hilger spectrometer, fitted with four prisms equivalent to three of sixty degrees

1. E. L. Nicholsn Am. Jour. Sci., 28; 1884.

2. Phys. Rev. Vol.IX, 1900; p. 259.

each. The light was viewed through an eyepiece, at the other end, which has adjustable shutters that cut off all the spectrum except a narrow rectangular band of the desired wave length. The speed of the sectored disk was recorded by electrical means. Every 50 revolutions a contact was made by one of the two small indices on a speed counter that closed a circuit in which there was an electro magnet that on drawing a clapper down made a mark on the rotating drum. The time that was taken up during each reading was also recorded on the same drum. A clock was used, whose pendulum by a mercury contact made an electrical connection every half second with another electro magnet that drew a clapper down making a mark on the same drum just a little distance below the mark made by every 50 revolutions of the sectored disk.

The speed of the disk was controlled by means of a leather thong acting as a brake on the shaft of the motor. The wave length was determined by turning the telescope of the spectrometer through any desired angle. In this way any wave length whatever could be used and the speed for critical frequency maintained; the number of revolutions could be obtained and the time for them is recorded along side each other. Thus it is very simple to calculate the critical frequency of flicker for any wave length of light and determine the duration of a single flash of light upon the eye.

When the light is viewed through the eye-piece, and the disk is being turned slowly, there is a flickering of the light, but as the disk is turned more rapidly a speed is reached, which is different with different luminosities, where the flickering is perceived as a just continuous sensation. This is called the critical frequency of flicker for whatever wave length you are viewing. The greater the luminosity of the light in the spectrometer then the greater will be the critical frequency. This can be explained in a very elementary way if we consider our every day experience in perceiving moving objects. In mid-day we can see plainly any dark object that is moving or oscillating unless it is too minute and the speed of its movement too great, but in twilight if we try to do the same thing under the same circumstances we are very apt to experience some difficulty and at night it will be impossible to see this same object unless it moves very slowly or is not moving at all. When this is applied to the colors of the spectrum we find that at both ends of the spectrum where the intensity of the light is the least the disk must turn comparitively slowly, even moreso at the violet end than the red, so as to see the flicker it causes, while in the central portions, i.e., in the yellow and green, the disk causes a flicker even when ratated at a fairly high speed. From this we can see that the greater the critical frequency of flicker is, the shorter will be the duration of a single flash of light upon the retina; or, in other words, the duration of the maximum intensity of the sensation varies inversely as the critical frequency of flicker.

The apparatus with which the measurements that will be discussed in this paper, were taken, was set up in a room that was well illuminated with ordinary daylight. Great care was taken to have direct sunlight excluded from the room and at no time was the eye stimulated on account of fixation on any particular luminous object whilst the readings were being taken. Measuremants were not attempted if it was too cloudy or dull or towards sunset, and never with artificial lighting.

The taking of observations was more or less a matter of routine after one had accustomed himself to the procedure; yet with every sitting great care and precision were necessary. A diaphragm was on the eye-piece of the spectrometer and a narrow portion of the spectrum was isolated. The motor was started and one could distinctly see a flickering of that portion of the spectrum, but on releasing the friction brake the speed of the rotation of the motor was increased until the flickering just disappeared and a uniform band of color was seen. The motor was maintained at this speed and the two circuits were closed so that the clock and speed counter would register on the rotating drum.

The time sufficient for 100 revolutions of the disk was convenient for computing the time of duration of a single flash of light, but in one sitting ther would be from 100 to 800 recorded. It all depended on the luminosity or wave length of the light one was observing. The extreme long wave lengths and the extreme short ones allowed but comitively few revolutions of the disk while the drum was rotated once. The wave lengths in and near the central spectral region, however, allowed seven or eight hundred revolutions of the disk to one rotation of the drum.

In determining a normal persistency reading for a certain wave length, the eye was rested for three minutes in an ordinary lighted room after each observation. Two observations were made for each normal reading of a particular wave length, and if, after computing the results, it was found that they differed an appreciable amount additional observations were made.

In making the measurement for a normal persistency reading the following procedure was adapted. A narrow rectangular patch of the spectrum was isolated by the shutter eye-piece when the spectrometer was set. The mean wave length of this narrow band of light was known. The spectral color was observed until the critical frequency was reached and then recorded. During the recording period great care was taken to fixate the color directly so that the eye would not wander. The eye was then rested in ordinary day light for about three minutes before the second chronographic reading of the same wave length was taken. Since the spectrum, upon which all these measurements were made, was not very brilliant and the time taken for one reading was only about a half a minute, the eye was not likely to become appreciably stimulated.

The normal persistency reading was the standard with which readings for abnormal conditions of the eye were to be compared. It was discovered by Ferry[1] and subsequently in another manner by Porter[2], that the duration of the sensation of undiminished brightness of a flash of light, at critical frequency of flicker, depends only on the luminosity of the light and in no way on the wave length. The Ferry-Porter law, as it is known, is represented by the equation, $D = \frac{I}{k \log L k_1}$, where D is the persistence of vision, L the luminosity, and k and k_1 are constants. Also, it is known (Rivers) " that the point of fusion of intermittent stimuli, so as to produce a continuous sensation, depends, not on the physical intensities of the stimuli, but on the physiological intensities as determined by the condition and nature of the stimulated retina". We are justified, therefore, in interpreting an elevation of an abnormal reading above a normal reading with respect to the duration of a flash of light at critical frequency of flicker, as a decrease in physiological brightness occuring in the corresponding part of the spectrum; a depression below the normal reading as an increase in brightness; and a coincidence between them as indicating no change whatever. And also, it may be said, that in the case of naturally abnormal eyes, the persistency reading of the color impression to which the retina is abnormal, is abnormally increased or decreased, thus affording a method of determining the wave lengths to which the retina is incapable of responding normally.

The spectrum used for stimulation was obtained from a D. C. arc light and a Browning spectrometer with

From p.32. 1. Am. Jour. Sci. 44. 1892

2. Proc. Roy. Soc. 63. 1898; 70. 1902.

two prisms. A narrow but quite long rectangular portion of the spectrum was isolated with a shutter eye-piece, and the wave length for the center of this band is taken as the wave lenght of the stimulating color. The eye-piece was fitted with a sheild mainly for the purpose of supporting the head and to keep the eye from wandering. The center of the retina alone was used for both stimulation and measurement of sensitivity.

At the outset it was a matter of conjecture as to whether the oscillatory effect in the sensitivity of the retina could be definitely obtained. In previous experiments it has been shown that the effect of every stimulus acting upon the retina altered the state of sensitiveness of the receptors. But in all these experiments there was a failure to recognize the time interval between the initial stimulus and the taking of readings, and hence, a failure to take into account the oscillatory effect; this may well be the explanation of many of the contradictory results that have been recorded in the investigations of the sensory activities, particulary in vision.

In order to determine the amount of increasing and decreasing sensitivity in the visual receptors, after an initial stimulus had been allowed to act, the normal sensitivity of the eye was obtained with which the abnormal sensitivity of the eye may be compared. The procedure for obtaining the normal sensitivity has already been outlined and in all the oscillatory experiments the wave length used for measuring the sensitivity of the eye when in either normal or abnormal condition was .687μ. In most cases this same wave length was used for stimulation; the reason for choosing this particular wave length at the outset of the experimental work was that Allen[1] found .687μ to give the greatest reflex effects. One case is to be discussed where white light was used for stimulation.

The procedure for making observations was practically the same for all the oscillatory curves obtained. All the instruments were placed in adjustment and in readiness for recording the speed of the disk, the time of duration of the stimulus and the time of the intervals at which measurements were made to determine the variations in the sensitiveness of the retina after the stimulus had been allowed to act. A satisfactory observation was then made in order to determine the normal sensitivity of the retina. The normal sensitivity was that determined with the eye in adaptation of the diffused day light of the room; this brightness was subject to some variation owing to the bright spring sunshine and frequent falling of new snow which, without doubt, caused slight variations in the normal which was determined previous to the taking of each set of readings. After the normal value was determined the eye was exposed to the stimulating light for different intervals, the exact time being recorded either by counting the minute beats of a

1. On Reflex Visual Sensations, Vol. 5, Nos. 3and 4.

metronome or by an assistant, the latter being the more preferable. Immediately after the stimulation measurements were commenced for the determination of the abnormal sensitivity. The interval elapsing between the completion of the stimulation and the first measurement was never less than approximately 15 seconds, the time being spent in changing from one instrument to the other and in adjusting the speed of the disk. The time required to complete a sufficient record for sensitivity was from 15 to 30 seconds depending upon the ability to determine the critical frequency of flicker. Now since the interval required to make the sensitivity record is very small and the intensity of the measuring source is also very small as compared to the intensity of stimulation, it may be said then that any effect caused by the measuring is so small that it may be negligible as compared to the effect set up by the stimulating source. The interval at which the measurements are taken are in the most cases somewhat regular, being every two to three minutes. At least three hours, and usuall one night, intervened between the taking of two different sets of readings.

In each curve the ordinates represent the duration of one individual flash of light at critical frequency, or this may be termed as a measurement of the sensitivity. The abscissae represent the interval after the cessation of the stimulation. The normal sensitivity or reference curve is shown throughout as a dashed line, and the other curve, that which is obtained with the eye in its abnormal condition, as a continuous line. With no exception all curves determining the sensitivity of the eye either in its normal condition or abnormal condition were made with the right eye of the author. In all curves the right eye was acted upon by stimulation except the one case where the left eye was stimulated. The coincidences and divergences of the abnormal and normal curves show the effect of the stimulus under study as far as it can be shown by this method. An elevation of the abnormal above the normal curve is interpreted as a decrease in the physiological brightness or the sensitivity of the retina; a depression below the normal as an increase in brightness or the sensitivity of the retina; and coincidence between them as indicating no change whatever.

The results of stimulating the right eye with wave length .687 for 30 seconds and measurements made on the right eye with wave length .687 are shown in curves A, B, and C, Fig. I. The measurements are given in Table I. From the curves we see that the effect of stimulation is to cause a change in the sensitivity of the retina; this change appears to be periodic, and as it changes alternately between increased sensitivity and decreased sensitivity going through the normal sensitivity each time, it is then termed the oscillatory effect. In curve A the first reading was taken 4 minutes after the cessation of the stimulation and measurements were taken at every 4 minute interval, the full period of measurements lasting for 28 minutes. In Curve B the first

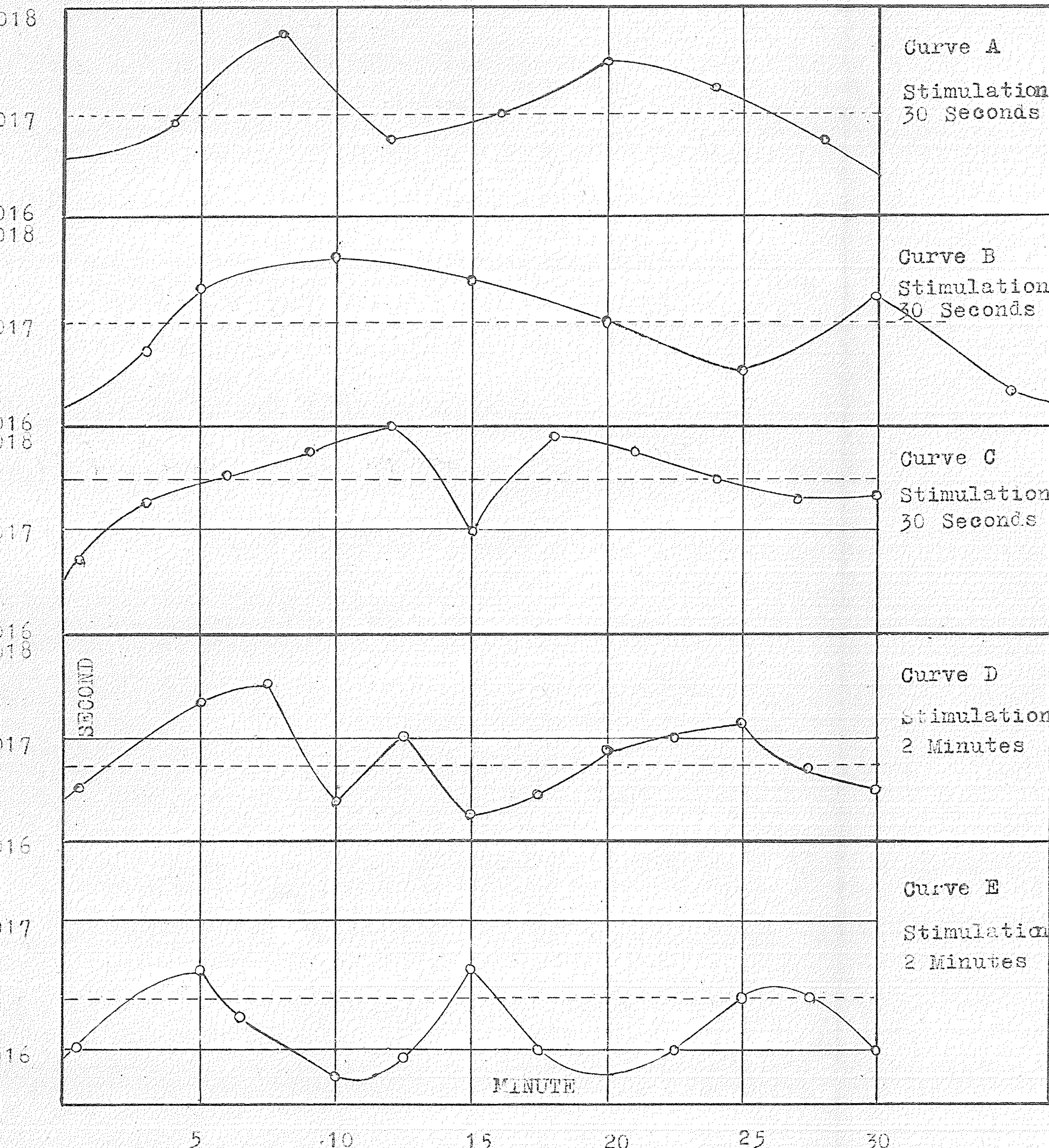
TABLE I

Oscillatory Curves

Right eye stimulated with wave length $.687\mu$. Measurements made on right eye with wave length $.687\mu$.

Curve A D(Sec.)		Curve B D		Curve C D	
.01700 N	T	.01700 N	T	.01750 N	T
.01690	4 Min.	.01670	3	.01670	0.5
.01775	8	.01730	5	.01725	3
.01675	12	.01760	10	.01750	6
.01700	16	.01740	15	.01775	9
.01750	20	.01700	20	.01800	12
.01725	24	.01654	25	.01700	15
.01675	28	.01725	30	.017900	18
		.01640	35	.01770	21
				.01750	24
				.01730	27
				.01736	30

OSCILLATORY CURVES R. A. L.



Right eye stimulated with wave length .687μ

Measurements made on right eye with wave length .687μ

Fig I

reading was taken 3 minutes after the cessation of stimulation and at intervals of 5 minutes for a full period of 35 minutes. In Curve C the first reading was taken immediately after cessation of the stimulus; the second reading after an interval of 5 minutes and then every 2½ minutes until a full period of 30 minutes was reached.

Hence, we see in Curves A, B, and C, regardless of the variations of the intervals at which the measurements for sensitivity were taken, the curves are essentially the same in their characteristics. The curves first start at increased sensitivity or enhancement, then crosses the normal value to reach a point in the decreased sensitivity region or to show depression or inhibition; from this inhibition region it again crosses the normal and falls into enhancement, then to normal, inhibition, normal, and at the end of the period for measuring the sensitivity, the curve ends up in the enhanced state of sensitivity. The period for measuring the sensitivity was the same practically for all curves, being from 30 to 35 minutes. By comparison of the three curves taken with the retina in its identical abnormal condition, it will be readily seen that they are similar in their counterpart characteristics which differ somewhat in size and interval over which they extend.

Another interesting feature to be noticed in these curves is that the first divergence showing enhancement is greater than the second enhancement, and that the third is greater than the second with the exception of the latter part of curve C. Also, the first divergence to show inhibition is greater than second divergence to show inhibition in all three curves. If now the mid points of the branches joining the maximum succeeding points of inhibition and enhancement a second oscillatory curve showing enhancements and inhibitions alternately will be obtained, along which the first or original oscillatory curve will follow. This shows that there is a periodicity within the first periodicity.

In Curves D and E of Fig. I and Curves A and B of Fig. II, the right eye was stimulated with wave length .687μ for 2minutes and measurements on the right eye with wave length .687μ. These curves in a similar manner to the three curves just mentioned, show the existence of the oscillatory effect. The immediate reading after the stimulation shows enhancement in all four curves. Again the periodicity within periodicity is quite easily seen with perhaps, an exception or so which is likely due to experimental arror or to some other extraneous stimulation acting upon the nervous system. The counterpart characteristics of these curves are all somewhat similar, and, by comparison with those for 30 second stimulation, it will be seen that for the same length of period there is one more additional period of inhibition and also another period of enhancement. Then the result of a longer stimulation by these curves show an increase in the vibration of the oscillatory effect. The measurements for the above curves are given in Tables II and III.

TABLE II

Oscillatory Curves

Right eye stimulated with wave length .687μ. Measurements made on right eye with wave length .687μ.

Curve D		Curve E		Curve A	
D	T	D	T	D	T
.01675 N		.01650 N		.01675 N	
.01650	0.5	.01600	0.5	.01600	0.5
.01733	5.0	.01675	5.0	.01637	2.0
.01750	7.5	.01633	7.5	.01675	5.0
.01637	10.0	.01575	10.0	.01600	7.0
.01700	12.5	.01592	12.5	.01650	10.0
.01625	15.0	.01675	15.0	.01700	12.0
.01644	17.5	.01600	17.5	.01680	15.0
.01687	20.0	.01600	22.5	.01570	17.0
.01700	22.5	.01650	25.0	.01650	20.0
.01713	25.0	.01650	27.5	.01733	22.0
.01670	27.5	.01600	30.0	.01675	25.0
.01650	30.0	Stimulation 2 Min.		.01650	27.0
Stimulation 2 Min.				.01625	30.0
				Stimulation 2 Min.	

TABLE III

Oscillatory Curves

Right eye stimulated with wave length .687μ for curve B.

Right eye stimulated with white light for curve C.

Left eye stimulated with wave length .687μ for curve D.

Measurements in each case were made on right eye with wave length .687μ.

Curve B		Curve C		Curve D	
D	T	D	T	D	T
.01675 N		.01625 N		.01700 N	
.01650	0.5	.01800	0.5	.01750	0.5
.01675	2.5	.01625	3.0	.01700	2.5
.01700	6.0	.01610	5.0	.01770	5.0
.01658	7.5	.01600	7.5	.01700	7.5
.01610	10.0	.01650	10.0	.01770	10.0
.01660	12.5	.01550	12.5	.01700	12.5
.01700	15.0	.01575	20.0	.01800	15.0
.01640	17.5	.01650	22.5	.01750	17.5
.01600	20.0	.01700	25.0	.01725	20.0
.01633	22.5	.01650	27.5	.01875	25.0
.01625	25.0	.01750	30.0	.01750	27.5
.01612	27.5			.01825	30.0
.01590	30.0				
.01625	32.5				
.01650	35.0				

Curve B: Stimulation 2 Min.

Curve C: Stimulation 15 Sec.

Curve D: Stimulation 3 Min.

OSCILLATORY CURVES R. A. L.

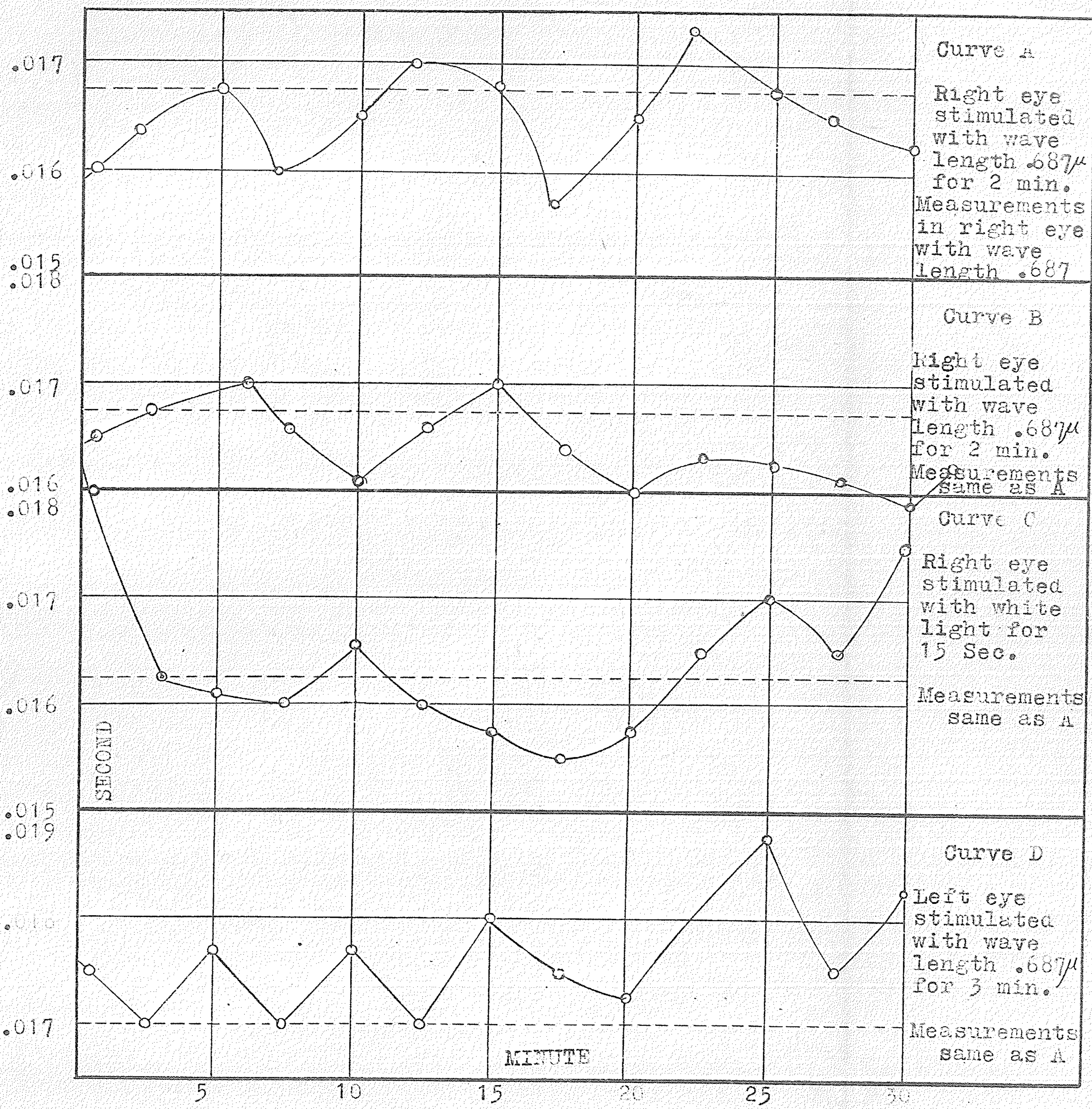


Fig. II

Curve C, Fig. II, was taken with an entirely different source of stimulation, being white light from an arc light for 15 seconds. The measurements are given in C, Table III, and were made in a similarnmanner as the above mentioned curves. This curve shows the oscillatory effect remarkably better than was expected owing to the increased intensity of the stimulation; but this curve is perhaps a more true representative of what actually takes place in the sensitivity of the receptors of the retina after the stimulus has been allowed to act than any of the other curves. The immediated reading shows a decided period of inhibition and this state of inhibition is continued for the first three minutes after the stimulation has ceased and then the curve crosses the normal into enhancement to take in that phase of its periodic trend. Again, in a similar manner as before, periodicity within periodicity can be traced.

Curve D, Fig.II, is the only curve taken by the author where the left eye has been acted upon by the stimulus and measurements made upon the right as before. The time of stimulation was 3 minutes with .687μ. The readings are given in D, Table III. The oscillatory effect is very well defined and the number of vibrations for the period is even greater than the curve taken for a 2 minute stimulation. This may be on account of the longer duration of the stimulation. The tendency to show a periodicity within periodicity is also somewhat defined. However, the main feature of this curve is to show that the oscillatory effect exists in the right eye after a stimulation in the left. The curve differs from the other curves with the exception of curve C, Fig.II, in that its first reading immediately after stimulation was found to be in the region of inhibition; another difference in this curve is that all the readings were at normal or in the region of inhibition, never showing an increase in the sensitivity although it likely would have done so had the period for making the measurements been extended.

The curves so far discussed are those obtained by the author (R. A. L.) who possesses normal color vision. The curves that will be discussed now are those obtained by a subject (D. C. A.) whose color vision is said to be anomalous, being super sensitive for the red and green sensations.

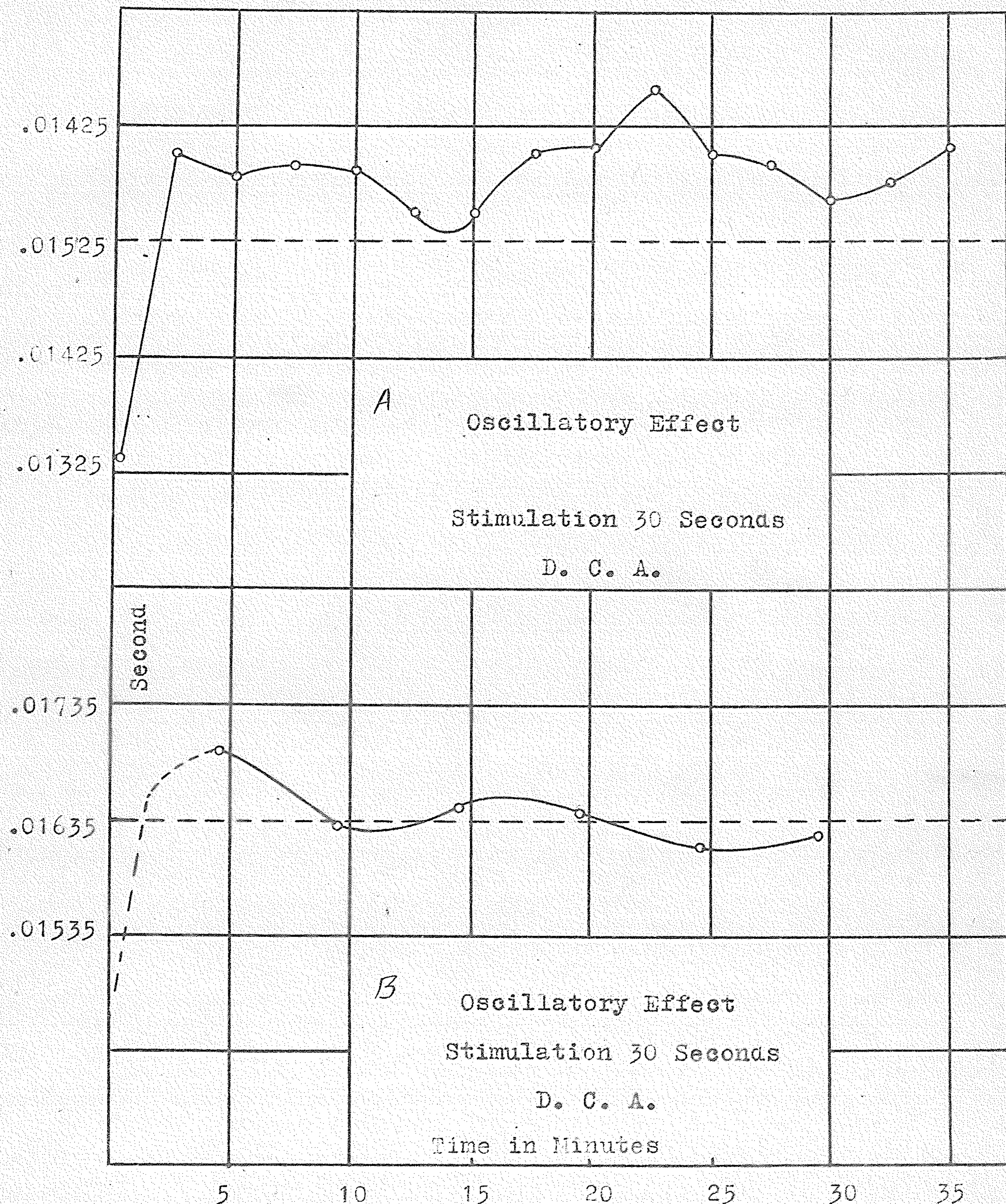
The effect of a 30 second stimulation for D.C.A. the subject with anomalous vision, is shown in Curves A and B, Fig. III. Stimulation and measurements were made on the right eye; the readings are given in A and B, Table IV. The distinct oscillations in the curve are well defined but by comparing with curves taken by the author, the first enhanced period is relatively greater than any of the author's curves. This same relative difference is found to be so in the immediate readings after stimulation in all curves obtained under similar conditions. The reason for this is perhaps due to an over development of the efferent impulses which enhance the sensitiveness of the receptors. In both curves there is a similarity between the characteristics of the vibrations of each.

TABLE IV

Oscillatory Curves

Right eye stimulated with wave length .687μ. Measurements made on right eye with wave length .687μ.

Curve A		Curve B		Curve C	
D	T	D	T	D	T
.01525 N		.01635 N		.01645 N	
.01335	0.25	.01665	4.5	.01500	0.25
.01600	2.5	.01630	9.5	.01645	2.5
.01580	5.0	.01645	14.5	.01685	5.0
.01590	7.5	.01640	19.5	.01675	7.5
.01585	10.0	.01610	24.5	.01645	10.0
.01550	12.5	.01620	29.5	.01615	12.5
.01550	15.0	Stimulation 30 Sec.		.01645	15.0
.01605	17.5			.01690	17.5
.01655	20.0			.01655	20.0
.01600	22.5			.01685	22.5
.01590	25.0			.01620	25.0
.01560	27.5			.01590	27.5
.01575	30.0			.01610	30.0
.01605	32.5			Stimulation 1 Min.	
Stimulation 30 Sec.					



Right eye stimulated with wave length .687 μ

Measurements made on right eye with wave length .687 μ

Fig. III

In Curves C and D, Fig. IV, the stimulation is for 1 minute; the readings are given in C, Table IV, and D, Table V. Here, with a longer duration, the curve seem to be vibrating a little bit faster as compared to the curves for 30 second stimulation for the same length of period over which measurements were taken. In Curves E and F, Fig. V, the duration of stimulation is 2 minutes; the readings are given in E and F, Table V. Again, the curves seem to be vibrating somewhat faster than those for the shorter duration of stimulation.

In Curves G and H, Fig. VI, and in Curves I and J, Fig. VII, the stimulation is 3 minutes and 4 minutes respectively. The measurements, obtained in a similar manner as before, are given in G and H, Table VI, I, Table VI, and J, Table VII. The oscillatory effect in thes curves as in previous curves, is very well defined. With the longer duration of stimulation, it appears that the vibrations are increased in number for the particular period over which the measurements are taken; but, by a comparison of the curves for 3 and 4 minute stimulation, there is no further increase in the number of the vibrations. Hence, it appears that there is a set limit for the time of duration of stimulation when the maximum number of vibrations can be obtained for a certain definite measuring period. In Curve J, Fig. VII, there is an interesting feature which clearly shows the effect of an extraneous stimulation, i.e. aside from the ordinary room stimulation where silence is a necessary factor in order to obtain oscillatory curves.

TABLE V

Oscillatory Curves

Right eye stimulated with wave length .68μ. Measurements made on right eye with wave length .68μ.

Curve D		Curve E		Curve F	
D	T	D	T	D	T
.01615 N		.01620 N		.01550 N	
.01500	0.25	.01410	0.25	.01360	0.25
.01605	2.5	.01590	2.5	.01483	2.5
.01610	5.0	.01590	5.0	.01536	5.0
.01660	7.5	.01640	7.5	.01520	7.5
.01550	10.0	.01610	10.0	.01520	10.0
.01580	12.5	.01610	12.5	.01613	12.5
.01605	15.0	.01670	15.0	.01543	15.0
.01660	17.5	.01650	17.5	.01616	17.5
.01505	20.0	.01590	20.0	.01586	20.0
.01615	22.5	.01670	22.5	.01533	22.5
.01615	25.0	.01610	25.0	.01550	25.0
.01605	27.5	.01570	27.5	.01560	27.5
.01660	30.0	.01640	30.0	.01590	30.0
Stimulation 1 Min.		Stimulation 2 Min.		Stimulation 2 Min.	

TABLE VI

Oscillatory Curves

Right eye stimulated with wave length .687μ. Measurements made on right eye with wave lenght .687μ.

Curve G D	Curve G T	Curve H D	Curve H T	Curve I D	Curve I T
.01540 N		.01585 N		.01630 N	
.01370	0.25	.01316	0.25	.01270	0.25
.01606	2.5	.01540	2.5	.01630	2.5
.01630	5.0	.01590	5.0	.01620	5.0
.01665	7.5	.01640	7.5	.01630	7.5
.01625	10.0	.01655	10.0	.01645	10.0
.01575	12.5	.01620	12.5	.01655	12.5
.01620	15.0	.01640	15.0	.01710	15.0
.01640	17.5	.01635	17.5	.01630	17.5
.01635	20.0	.01610	20.0	.01630	20.0
.01493	22.5	.01675	22.5	.01690	22.5
.01560	25.0	.01620	25.0	.01620	25.0
.01523	27.5	.01640	27.5	.01625	27.5
.01566	30.0	.01640	30.0	.01645	30.0
.01545	32.5	.01660	32.5	.01655	32.5
.01660	35.0	.01615	35.0	.01680	35.0
.01610	37.5	Stimulation 3 Min.		.01640	37.5
.01615	40.0			.01645	40.0
Stimulation 3 Min.				Stimulation 4 Min.	

TABLE VII

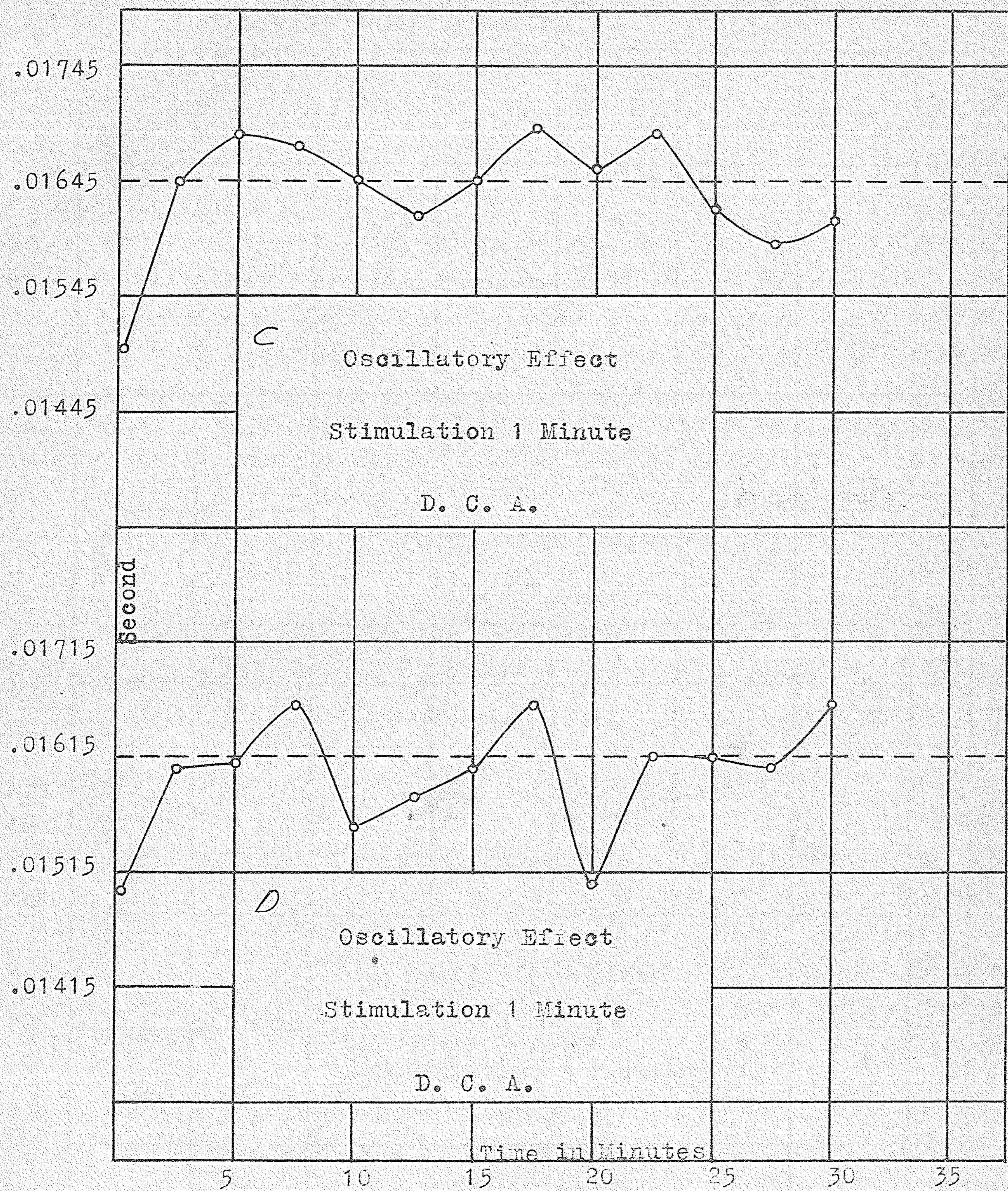
Oscillatory Curves

Right eye stimulated with wave length .687μ for curve J.

Left eye stimulated with wave length .687μ for curves K and L.

Measurements made on right eye with wave length .687μ.

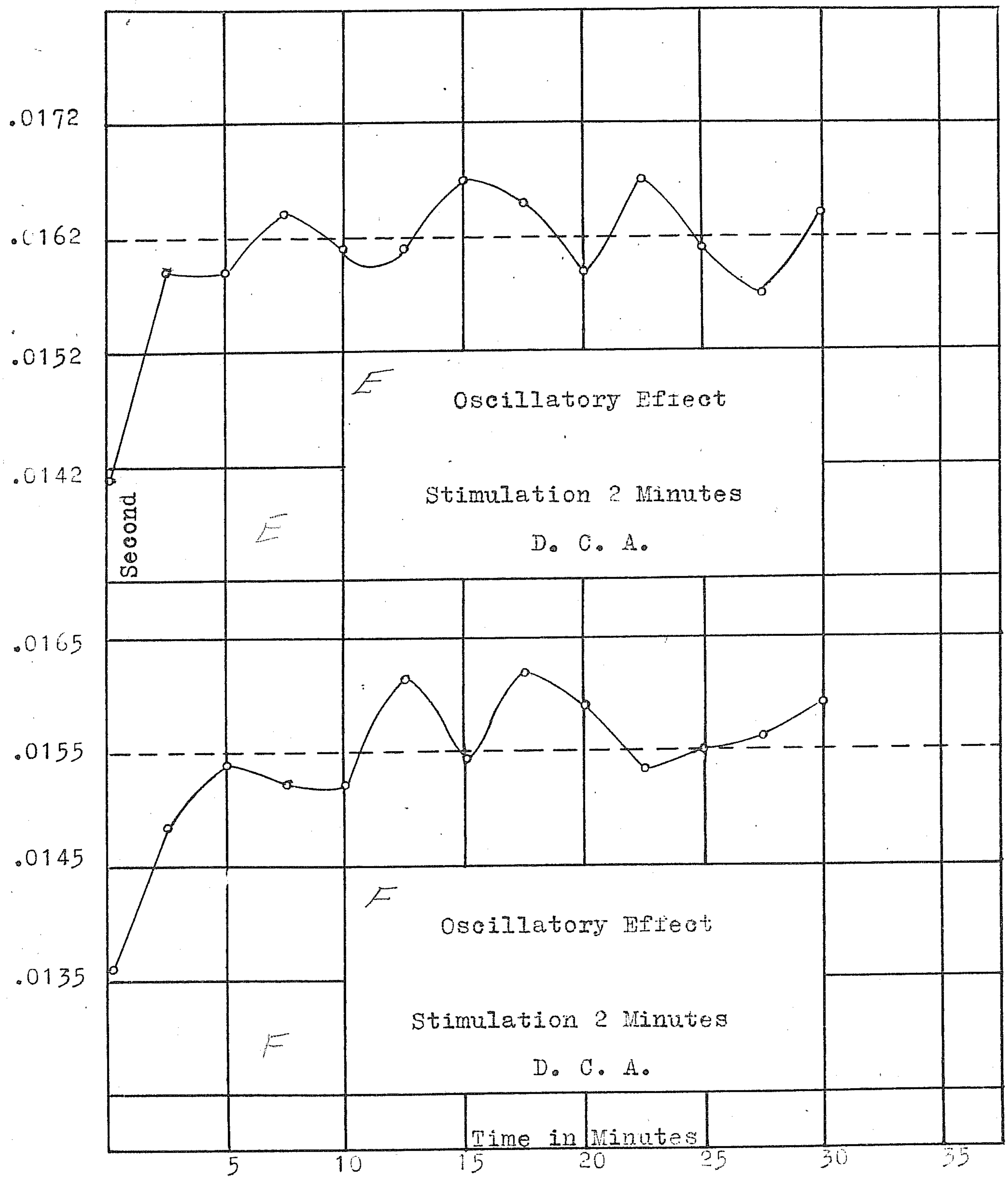
Curve J		Curve K		Curve L	
D	T	D	T	D	T
.01580 N		.01590 N		.01550 N	
.01280	0.25	.01690	0.25	.01570	0.25
.01560	2.5	.01675	2.5	.01595	2.5
.01623	5.0	.01645	5.0	.01600	5.0
.01570	7.5	.01515	7.5	.01615	7.5
.01566	10.0	.01605	10.0	.01620	10.0
.01630	12.5	.01665	12.5	.01585	12.5
.01600	15.0	.01645	15.0	.01583	15.0
.01593	17.5	.01625	17.5	.01615	17.5
.01536	20.0	.01640	20.0	.01675	20.0
.01610	22.5	.01620	22.5	.01610	22.5
.01500	25.0	.01615	25.0	.01565	25.0
.01410	27.5	.01645	27.5	.01545	27.5
.01525	30.0	.01625	30.0	.01620	30.0
.01590	32.5	.01565	32.5	.01670	32.5
.01610	35.0	.01650	35.0	.01655	35.0
.01580	37.5	Stimulation 3 Min.		Stimulation 4 Min.	
Stimulation 4 Min.					



Right eye stimulated with wave length .687 μ

Measurements made on right eye with wave length .687 μ

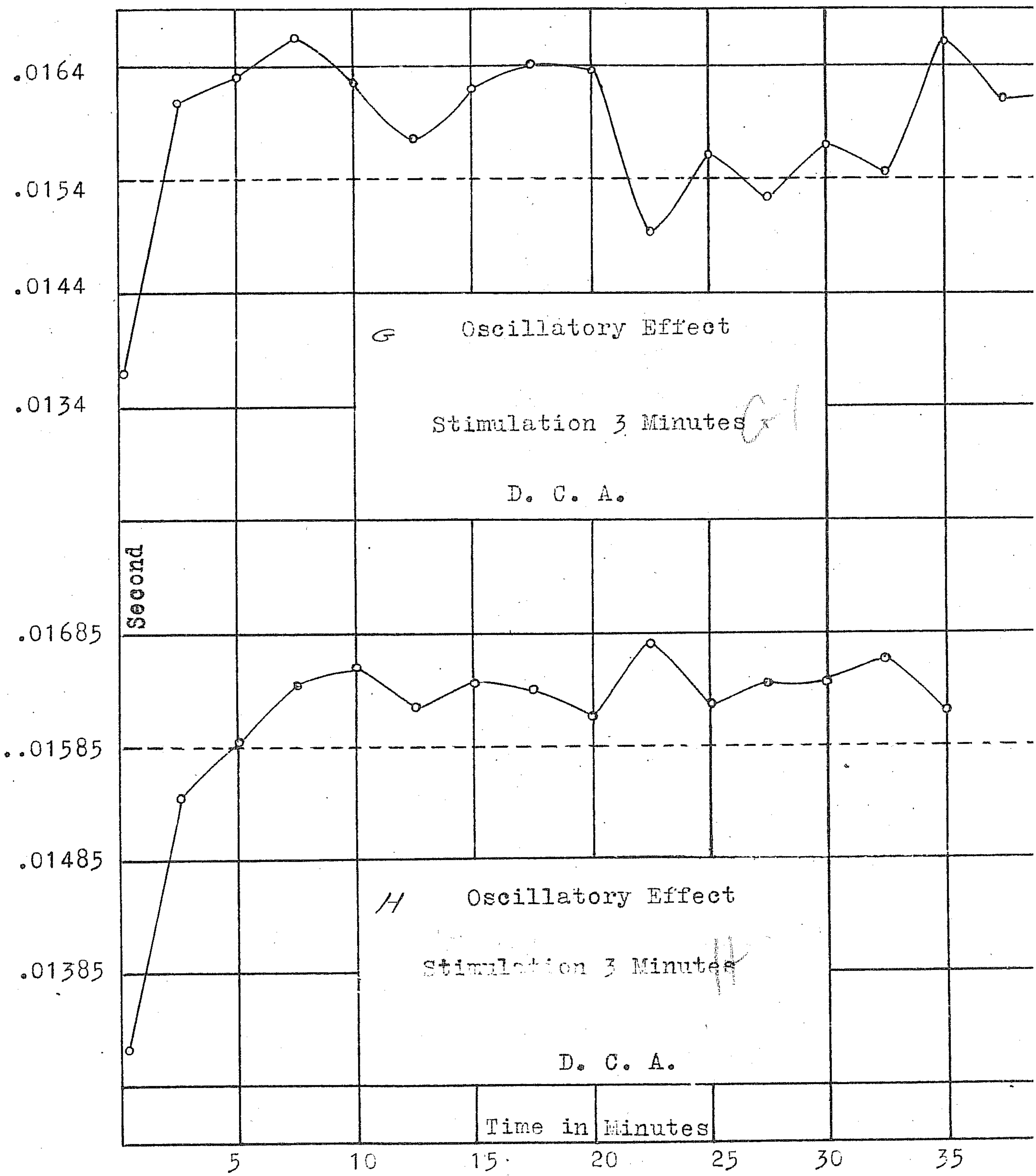
Fig. IV



Right eye stimulated wave length .687 μ

Measurements made on right eye with wave length .687 μ

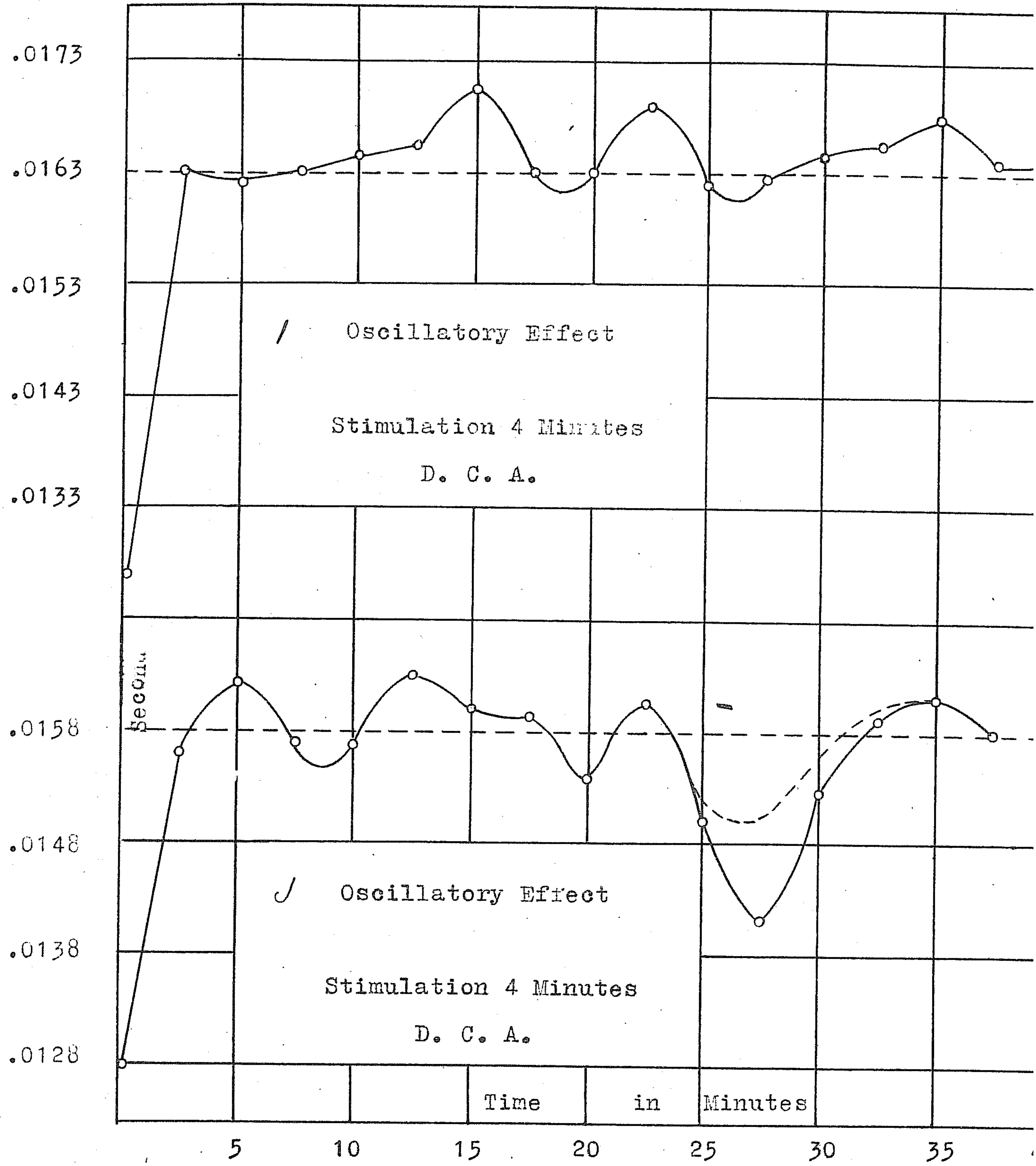
Fig. V



Right eye stimulated with wave length .687 μ

Measurements made on right eye with wave length .687 μ

Fig. VI



Right eye stimulated with wave length .687 μ

Measurements made on right eye with wave length .687 μ

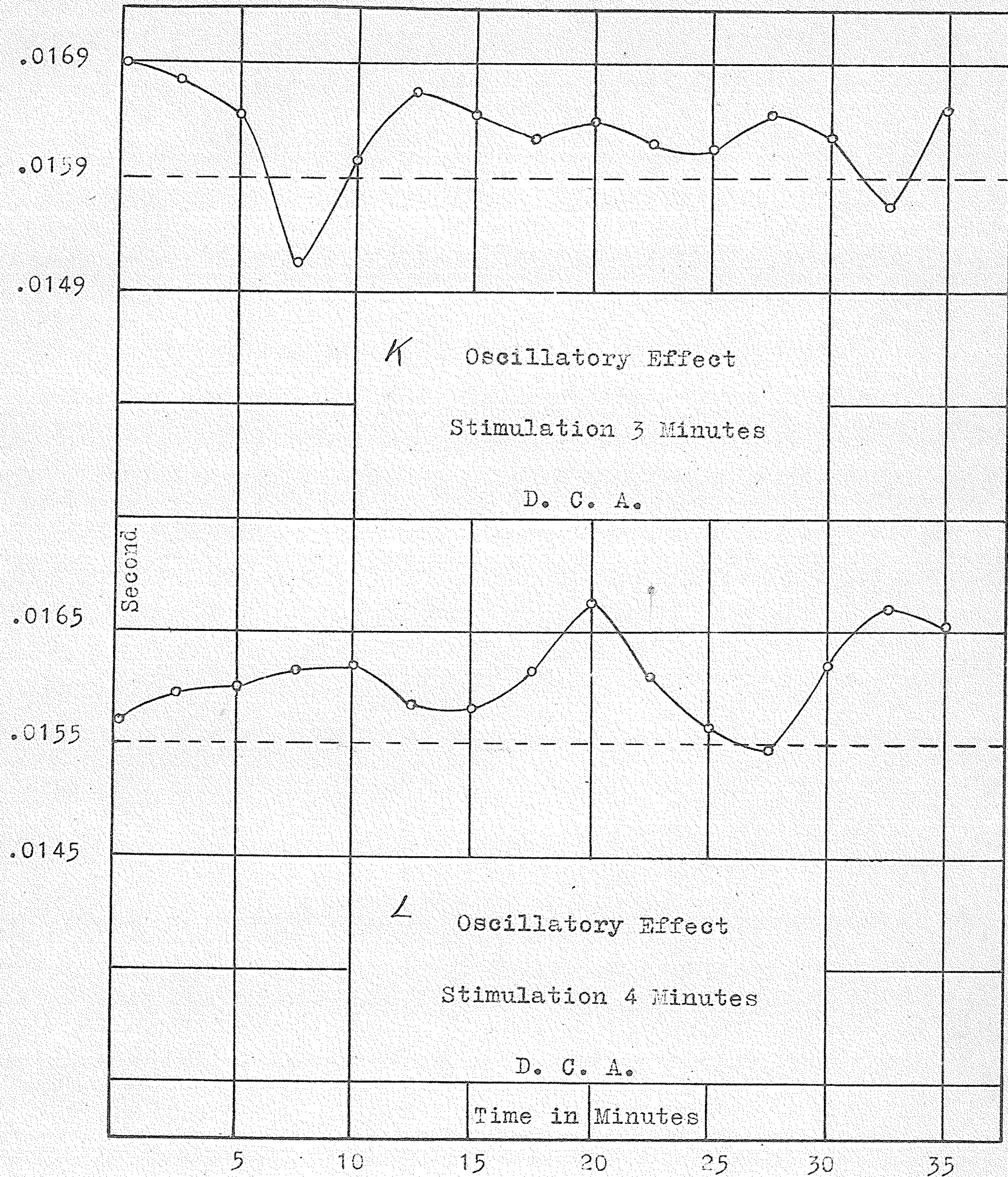
Fig. VII

In this curve the last divergence from normal showing an enhancement appears to be very much exagerated and a dotted line was drawn which the curve would have probably followed had not the extraneous stimulation in the form of a person entering the room occured just as the 25 minute interval measurement was being taken.

In Fig. VII, Curves K and L show the result of 3 and 4 minute stimulation on the left eye. The measurements given in K and L, Table VII, were obtained by the right eye in a similar manner as measurements obtained for previous curves. These curves differ from the others in that the region of decreased sensitivity or inhibition contain the majority of the points, but regardless of this fact the oscillatory effect is shown very clearly. Also, it may be noticed by comparing these curves with the others where the right eye was stimulated for the same duration of time, it appears that the vibrations are somewhat opposite in phase.

In the majority of the curves obtained by D. C. A. it can be similarly shown as in the case of the author's curves, that there is a tendency for the vibration of these curves to follow another long drawn out vibratratory curve, or it may be stated that the curves show periodicity within periodicity.

In the curve shown in Fig. IX, the measurements of the sensitivity of the retina after stimulation were ta taken continuously. The stimulation was for 2 minutes on the right eye and the measurements were made by the same eye.



Left eye stimulated with wave length .687 μ

Measurements made on right eye with wave length .687 μ

Fig VIII

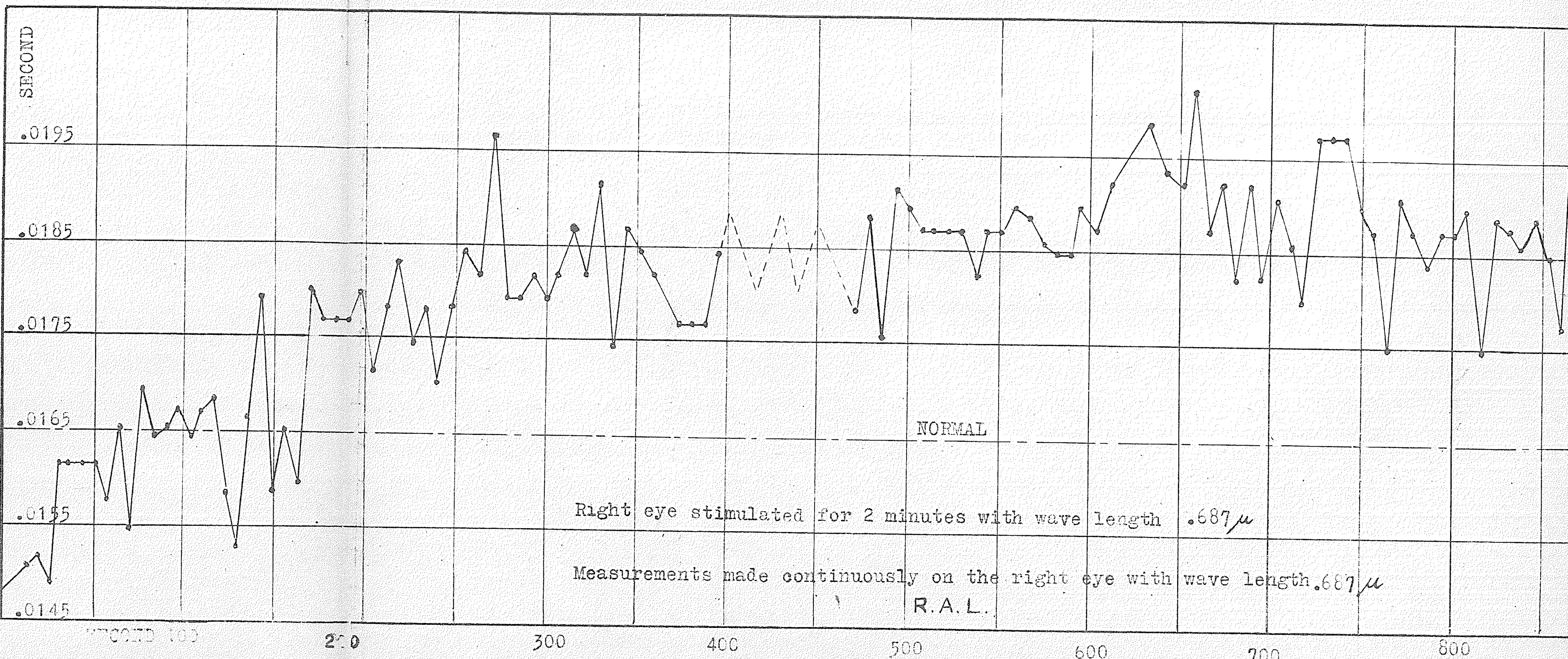

SECOND
.0195
.0185
.0175
.0165
.0155
.0145
NORMAL
Right eye stimulated for 2 minutes with wave length .687 μ
Measurements made continuously on the right eye with wave length .687 μ
R.A.L.
200
300
400
500
600
700
800

Fig. IX

In order to take measurements continuously the speed of the disk was continuously adjusted as it varied with the change in the sensitivity for observing the critical frequency of flicker. The records of the number of revolutions of the disk and the time in seconds were taken as one continuous set of readings. The mean time intervals for successive 100 revolutions of the disk, measured from the time of cessation of the stimulation, are taken as the points representing the sensitivity for the same 100 revolution period. The measurements are given in Table VIII. The curve shows a large number of oscillations for the measuring period of 870 seconds. The general trend of the curve starts at enhancement, crosses the normal, and rises to inhibition. In obtaining curves like this there is bound to be slight experimental errors in keeping the rotation of the disk at the exact speed necessary for critical frequency. It seem then that this may be an explanation for all the small oscillations whilst all the large oscillations are due to a changing sensitivity of the retina. Still another way to account for the oscillations is by the resultant effect of two different oscillatory curves, the one set up by the first stimulation of 2 minutes and the other, the oscillatory effect set up by the stimulation from the source of the light used for measuring the sensitivity. There are certain horizontal portions representing a constant state of sensitivity of the retina which may be due to the two oscillatory curves in opposite phase, and the large oscillations a resultant effect of two

TABLE VII

Right eye stimulated for 2 minutes with wave length .687μ.

Measurements made continuously on right eye with .687μ.

D	T
.0151	13.2
.0154	19.3
.0149	25.4
.0164	31.6
.0164	44.7
.0164	51.3
.0158	57.7
.0166	64.17
.0155	70.6
.0170	77.1
.0165	83.4
.0166	90,0
.0168	96.0
.0165	103.2
.0166	109.9
.0169	116.6
.0159	123.2
.0153	129.1
.0167	135.9
.0180	142.4
.0159	149.7
.0166	156.2
.0160	162.7
.0183	169.6
.0175	176.8
.0175	183.9
.0175	186.9
.0175	191.0
.0181	198.1
.0174	205.3
.0179	212.4
.0184	219.7
.0175	226.9
.0179	233.9
.0171	240.9
.0179	248.4
.0185	263.7
.01975	271.3
.0180	278.9
.0180	286.1
.0183	293.4
.0180	300.6
.0183	307.9
.0187	315.3
.0183	322.7
.0193	330.2
.0175	337.5
.0188	344.8

D	T
.0185	352.2
.0183	359.7
.0183	367.1
.0178	374.1
.0178	381.1
.0178	388.4
.0185	395.7
.0179	471.6
.0189	478.6
.0176	486.2
.0194	493.1
.0190	500.7
.0188	508.3
.0188	515.8
.0188	523.3
.0188	530.8
.01825	538.2
.0188	545.6
.0188	553.1
.0190	560.7
.0189	568.4
.0186	575.8
.0185	583.1
.0185	590.7
.0190	598.2
.0188	605.8
.0193	613.4
.0190	621.0
.0193	628.7
.0199	636.5
.0194	644.3
.0193	652.1
.0203	660.0
.0188	667.8
.0193	675.4
.0183	682.8
.0193	690.4
.0183	697.9
.0191	705.3
.0186	712.8
.0180	719.6
.0198	727.7
.0198	735.6
.0198	743.5
.0190	751.2
.0187	558.3
.01750	766.0

D	T
.0191	773.3
.0188	780.8
.0184	788.3
.0188	795.8
.0188	803.3
.0190	810.8
.0175	818.1
.0189	825.3
.0189	832.9
.0186	840.4
.0189	847.8
.0185	856.3
.0178	862.6
.0195	866.5
.0193	870.0

oscillatory curves in the same phase. That the curve starts in enhancement, crosses the normal and remains in inhibition seem quite correct from the fact that there is a constant stimulation. As this constant stimulation is carried on longer the curve tends to go more and more into inhibition and its final maximum state of fatigue is nothing more than inhibition to the fullest extent. But in reaching this maximum state of inhibition or fatigue, the sensitivity has a periodic variation.

IV

Summary of Results

The oscillatory curves which have been described were practically all obtained under the same nervous conditions, but there are many minor differences which tend to reduce the regularity of the curves. These may be attributed to extraneous stimulation to the nervous system either at the time of taking measurements or just previous. In order to determine as to whether the previous state of the nervous system had any direct bearing on the form of the curves, the history of the observer was noted for at least two hours previous to the taking of the readings. For the first half-hour before taking readings the observer remained in the room where observations were made in order to become quite adapted to the luminosity of the room. During this period also, the nerves were never excited in any way that would likely have an effect upon the readings. No definite relation between the previous history of the observer which was always under quite normal conditions, and the results obtained could be found. Hence, the nervous system must have been under a fairly constant condition each time before the procedure of making readings for a curve was commenced. The variations from the regularity in these curves seems then, to come from extraneous stimuli whilst readings are in progress. The room in which the readings were taken, was as nearly as possible kept under ideal conditions to prevent extraneous stimulation, but the occasional glancing around the room by the observer at different objects during the interval elapsing between the measurements, must have been sufficient to stimulate and consequently set up other minor oscillatory effects. Every object viewed at will stimulate to a certain extent although it may be very small, and from this stimulation the regularity of the oscillatory will be changed to show some irregularities. In order to get greater regularity, for it seems that the curve should be naturally regular, more ideal conditions, free from stimulations of any sort, must be sought for. Another effect upon the oscillatory curve wouldbe the change of season, daylight illumination and snow falls together with probable variations in the physical conditions of the observer.

Of all the curves obtained, they all show decided oscillations existing in the sensitivity of the retina after the action of some stimulation. The oscillatory effect is also shown to be crossed when the left eye was stimulated and the right eye was tested for sensitivity. Up to a certain limit, the longer the duration, the more rapid does the sensitivity of the retina change.

Generally, it may be said that whenever a light stimulus acts upon the retina, nervous impulses are generated in the visual receptors which ascend by the afferent nerves to the visual cortex where the sensation of light and color is produced. At some point in the reflex arc, probably in the synaptic junction of the afferent and efferent nerves, additional nervous impulses are evoked which descend by the efferent nerves to all parts of both retinas, by means of which the sensitiveness of the visual receptors is controlled. These efferent impulses can either enhance or depress the sensitiveness and both are always present acting alternately until normal sensitivity is regained. The result of these actions determine the state of sensitiveness as it is measured for the instant; it is the excess of the one process over the other.

Thus we see that for every stimulus applied to any sensory receptor, impulses ascend by the afferent nerves nerves to the cortex where an interpretation of the sensation is produced. But, once a stimulus is allowed to act the sensitivity of the receptors is rendered into an abnormal state. Additional impulses are then evoked which descend by the efferent nerves, and are of such a kind that they tend to restore the abnormal sensitivity to one of normal sensitivity. In doing so they 'overshoot' the mark of normal sensitivity and render the sensitiveness of the receptors in an abnormal state of the opposite sense. Now impulses of the other kind are evoked which tend to restore the second state of abnormal sensitivity to one of normal sensitivity, but in doing so, overshoots the normal sensitivity mark and renders the sensitivity of the receptors in an abnormal state of the first kind. Again, the same process is repeated over and over, and if allowed to act without a disruption by a further stimulation, the change in the sensitivity of the receptors would oscillate back and forth until it eventually would come to rest at the normal state. The impulses that are evoked which descend by the efferent nerves to the receptors, are of two kinds; they both tend to restore the abnormal sensitivity to the normal state, but on arriving at this state, they both go a little too far, the one kind enhances the sensitivity and the other depresses the sensitivity. Hence, there is always a force one way or the other tending to return the sensitivity to a normal state through a series of oscillations, after a stimulating impulse has been allowed to act.

V

Applications

In an explanation of the process of learning or any work of routine, mental or physical, an interesting application of the oscillatory effect arises. A typical learning curve for card sorting is shown in Fig. X. The abscissae represent represent intervals at which the measurements of the efficiency were taken and the ordinates represent efficiency. The increase of efficiency with respect

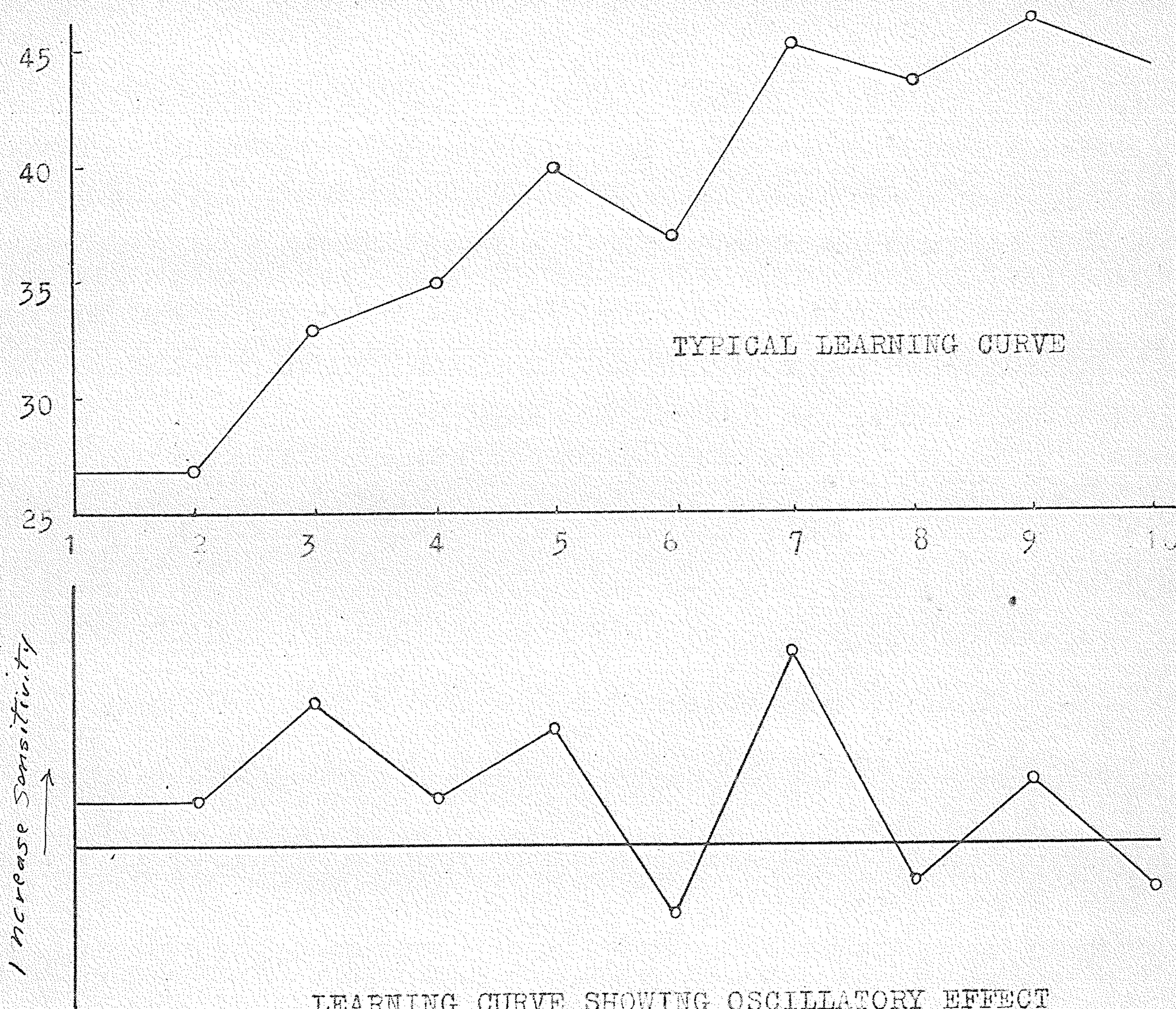

45
40
35
30
25
1
2
3
4
5
6
7
8
9
TYPICAL LEARNING CURVE
Increase Sensitivity
LEARNING CURVE SHOWING OSCILLATORY EFFECT

Fig X

to time does not vary uniformly but has increases followed by smaller increases or even regressions in the efficiency. In the learning curve there is a constant stimulation in the form of the subject's actual performance of the work which is being measured. A new oscillatory effect is continually being established at every infinitely small period of stimulation. All these infinitely small oscillatory effects as a result of all the infinitely small successive periods of stimulation will be compounded together to form a resultant oscillatory effect; this resultant oscillatory effect governs the variations in the sensitivity of the receptors and hence, the variations in the increase of efficiency in the learning curve. This oscillatory effect governing the variations in the learning curve has been drawn in the same figure just below the learning curve. The curve was constructed on the plan that with an increase in efficiency, the oscillatory curve must necessarily have been in an enhanced state, with regressions an inhibited state and plateaus the normal sensitivity.

According to this, the oscillatory effect is the bases of all learning. With an increase in sensitivity, as governed by the oscillatory effect established by a stimulation, there is an increase in efficiency, and with a decrease in sensitivity a decrease in efficiency. Suppose now that the oscillatory effect is inexistent, then there would be no increases or decreases in efficiency as a result a stimulation, and we would be living always in a normal state or on a mental or physical plateau.

Many phenomena in color vision can be explained by the oscillatory effect. To account for color phenomena many theories have been devised to suit its particular objective in explaining a series of these phenomena. The theory employing the oscillatory effect in the nervous system can account for a large number of these color phenomena. A stimulus will establish the oscillatory effect, resulting in an oscillatory change in the sensitivity of the retina. While the retina is undergoing these various changes of sensitivity, there is no doubt that phenomena ranging from the very simple to the most complex, are bound to arise. Many of these phenomena have never been investigated far enough in order to determine what other changes in the phenomena would occur as the sensitivity of the retina changed in accordance with the oscillatory effect. It must also be remembered that phenomena employing the visual sense are more likely to be observed than those employing any other senses, owing to the great sensitivity of the receptors; phenomena would occur in vision more than any other sense because every ray of light stimulates all three color sensations in varying degrees, causing a variation in the efferent impulses and hence, a variation in the oscillatory effects for each sensation.

VI

Normal and Abnormal Vision

Since the discovery of color-blindness much curiosity has been aroused which gradually led to a careful examination of its peculiarities. In the latter half of the nineteenth century the subject was enormously increased by consideration that in travel by land and sea human life is often dependent upon the correct perception of color signals by those in charge of trains and vessels. From this economic standpoint the subject has been developed to perhaps a high degree of excellence as is necessary. But the most interesting aspect of abnormal color vision is that of its relation to the exceedingly involved and complex question of the nature of our perception of light and color.

The investigation to be discussed from this point on was undertaken with the object of finding out the nature and magnitude of the variations of abnormal from normal color vision as far as they can be shown by comparing the corresponding measurements of the persistence of vision of the rays of the spectrum.

A detailed discription of the apparatus used and the manner of taking a normal persistency reading has already been described above in Section III. In brief, however, the method consists in rotating a sectored disk in front of a slit of a spectrometer at such a speed that the complete fusion of intermittent flashes of color of the part of the spectrum under observation is obtained. The speed of the disk is electrically recorded on a chronograph which enables the duration of the greatest intensity of light stimulation to be very accurately determined. The time of fusion varies from point to point through the spectrum, but it is dependent, however, only upon the intensity of the light and the sensitiveness of the retina. During the recording period great care was taken to fixate the color directly so that the eye would not wander.

After each reading taken, the eye was then rested in ordinary diffused light of the room for about 3 minutes before the second chronographic reading was taken. Since the spectrum upon which all these measurements were made, was not very brilliant and the time taken for one reading was about 30 seconds or less, the eye was not likely to become appreciably stimulated. To make the complete measurements for a persistency curve, observations were made on fifteen points of the spectrum, the longest wave length to be recorded was .74μ and the shortest .42μ.

The persistency curve for a subject possessing normal color vision is the standard with which curves for subjects possessing abnormal color vision are to be compared. These curves are shown graphically by having ordinates represent the persistence of vision for various parts of the spectrum in seconds, and the abscissae represent the different wave lengths.

An elevation of the abnormal curve above the normal is interpreted as a decrease in the physiological brightness in the corresponding part of the spectrum; a depression below the normal as an increase in the brightness; and a coincidence between them as indicating no change whatever. In the case of naturally abnormal eyes, the persistence of color impressions to which the retina responds abnormally, is increased or decreased, thus affording a method of determining the wave lengths to which to which the retina is incapable of responding normally.

At the outset of the experimental study it was the author's task to obtain a persistency curve for his

his particular type of vision which did not seem to be defective in any way. There was but little difficulty experienced in getting a satisfactory curve with the exception of becoming accustomed to taking readings, as was indicated by slight deviations. However, after two or three practice curves had been obtained, it was found that the persistency curve remained almost constant.

Two sets of persistency curves, it will be noticed, are made use of; the reason for this is that during the time the investigations were being carried on the luminosity of the spectrum was changed owing doubtless, to some variation of the intensity or quality of light from the acetylene flame. The pressure of the gas was quite constant, and in addition, to the measurements of another observer at the same time there was also a change to a small degree in some of his measurements. These reasons are sufficient to assign the cause of the slight change in the readings as due to some variation in the character of the light itself, not to any inconsistency of the retinal process.

A comparison of the two persistency curves obtained by the author (R. A. L.) is shown in Fig. XI. The readings are given in Tables IX and X. These two curves are practically the same, differing only slightly in the branches for the violet sensation. The apparent smoothness of these of these two curves is very significant and that is a characteristic of all curves showing normal color vision.

TABLE IX

Persistency Curves

	Normal Vision R. A. L.	Anomalous Vision D. C. A.	Color Blind in Red-Violet
	D (Sec.)	D	D
.74	.0219	.0212	.0237
.72	.0200	.0189	.0218
.70	.0180	.0171	.0196
.68	.0168	.0154	.0164
.66	.0152	.0146	.0144
.64	.0142	.0142	.0145
.63		.0136	
.62	.0132	.0130	.0131
.61		.0121	
.59	.0123	.0116	.0128
.55	.0129	.0120	.0137
.53	.0137	.0130	.0142
.50	.0160	.0156	.0174
.48	.0184	.0185	.0214
.46	.0209	.0207	.0263
.44	.0240	.0243	.0291
.42	.0272	.0284	.0329

TABLE X

Persistency Curves

	Normal Vision R.A.L.	Anomalous Vision D.C.A.	Red-Violet Color Blind Subject
	D(Sec)	D	D
.74	.0220	.0215	.0237
.72	.0200	.0194	.0218
.70	.0180	.0172	.0196
.68	.0165	.0158	.0164
.66	.0154	.0144	.0144
.64	.0141	.0138	.0145
.63		.0136	
.62	.0132	.0131	.0131
.61		.0125	
.59	.0125	.0119	.0128
.55	.0129	.0126	.0137
.54		.0132	
.53	.0136	.0137	.0142
.50	.0165	.0169	.0174
.48	.0190	.0195	.0214
.46	.0220	.0221	.0263
.44	.0250	.0251	.0291
.42	.0285	.0283	.0329

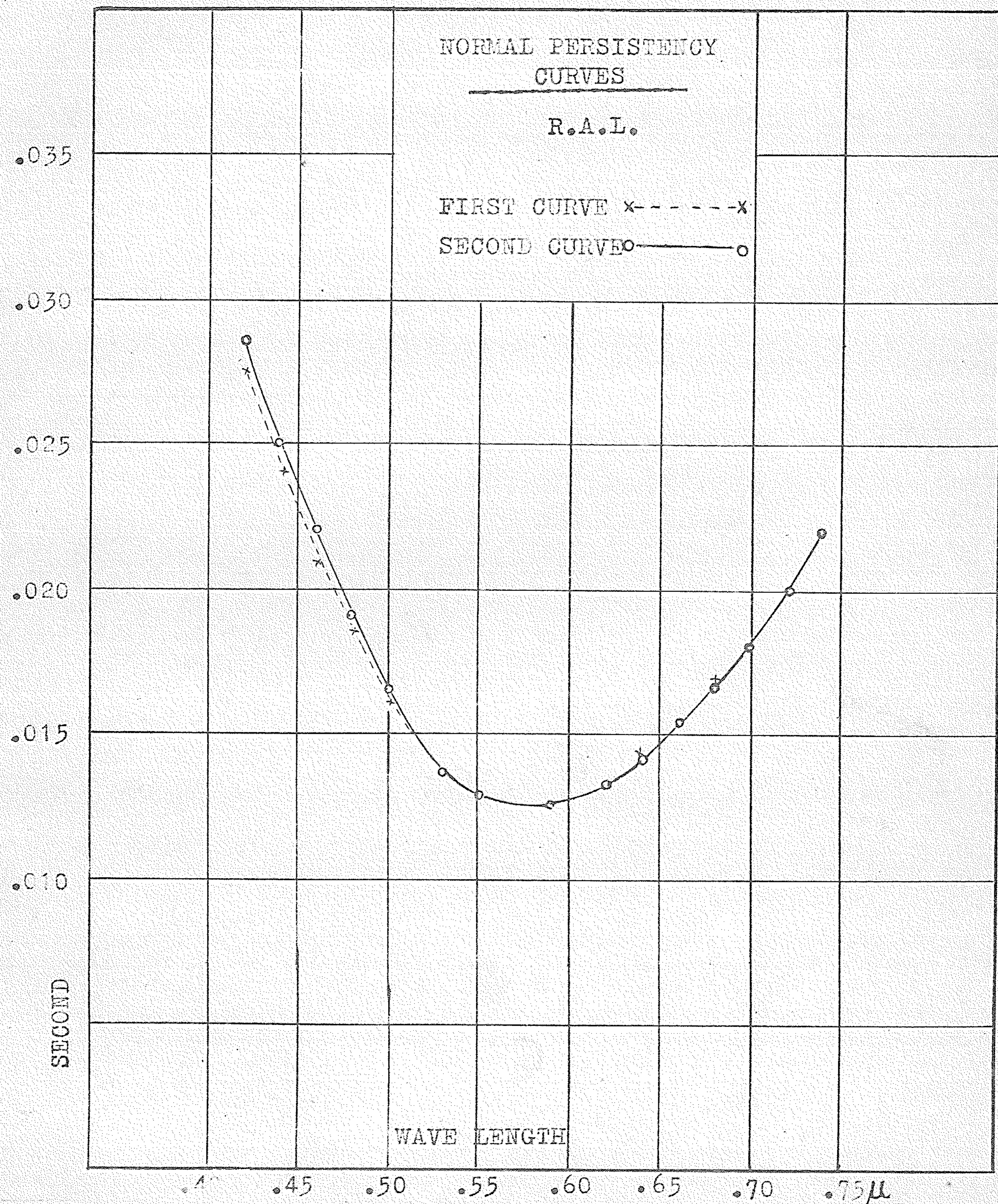

NORMAL PERSISTENCY CURVES
R.A.L.
FIRST CURVE
SECOND CURVE
.035
.030
.025
.020
.015
.010
SECOND
WAVE LENGTH
.45
.50
.55
.60
.65
.70
.75μ

Fig. XI.

The first case of abnormal color vision to be studied was that of a red-violet color blind subject. This subject when examined by the wool and card test, showed the usual indications of red-violet color blindness, but his vision for the green sensation was found to be normal. Unfortunately, two persistency curves, i.e., the one using the original gas and the other with the gas changed, could not be obtained. The two persistency curves for normal vision are so nearly the same that the persistency curve for the color-blind subject can be compared with either one; the characteristic variations are still essentially the same. The persistency readings for the color blind subject are given in both Tables IX and X. The curve is shown as a continuous line marked with crosses in Figs. XII and XIII.

Mr. D. C. A. was unaware of his vision being different from that of normal color vision; at all times, he never experienced any difficulty whatsoever in discriminating between colors. After taking a complete set of readings throughout the spectrum range, it was noticed that there was some irregularity tending to reduce the smoothness of the curve. A second and third set of readings were obtained, but always the same curve was obtained. By comparing the curve with subjects who are anomalous in their vision, a great similarity was found. Additional readings were taken in the region of the 'hump', or the region where the irregularity of the curve from smoothness occured; in this way the exact shape and size of the 'hump' was determined. The two sets of readings for the subject (D. C. A.) are given

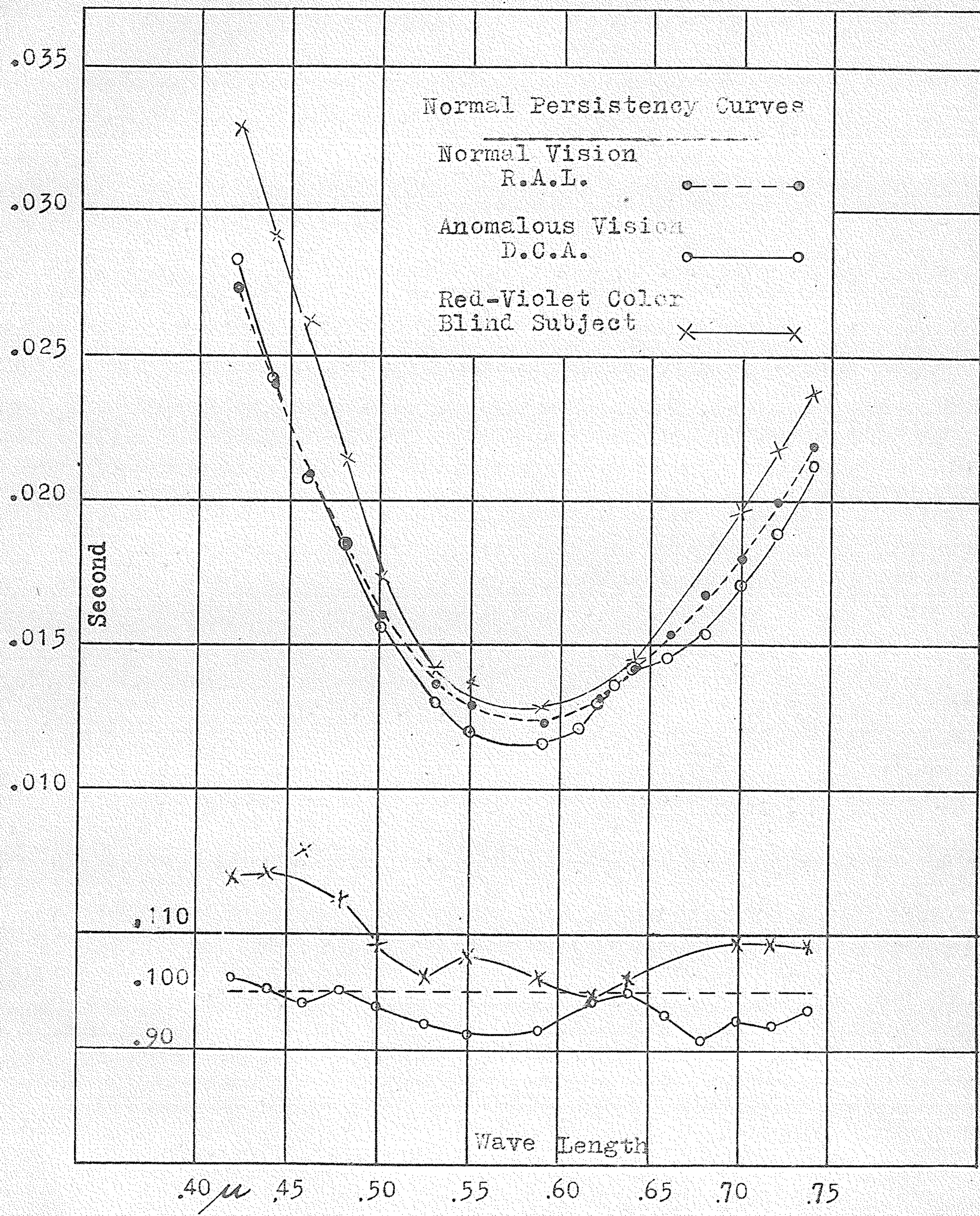

Normal Persistency Curves
Normal Vision
R.A.L.
Anomalous Vision
D.C.A.
Red-Violet Color
Blind Subject
Second
.035
.030
.025
.020
.015
.010
.110
.100
.90
Wave Length
.40 μ
.45
.50
.55
.60
.65
.70
.75

Fig. XII

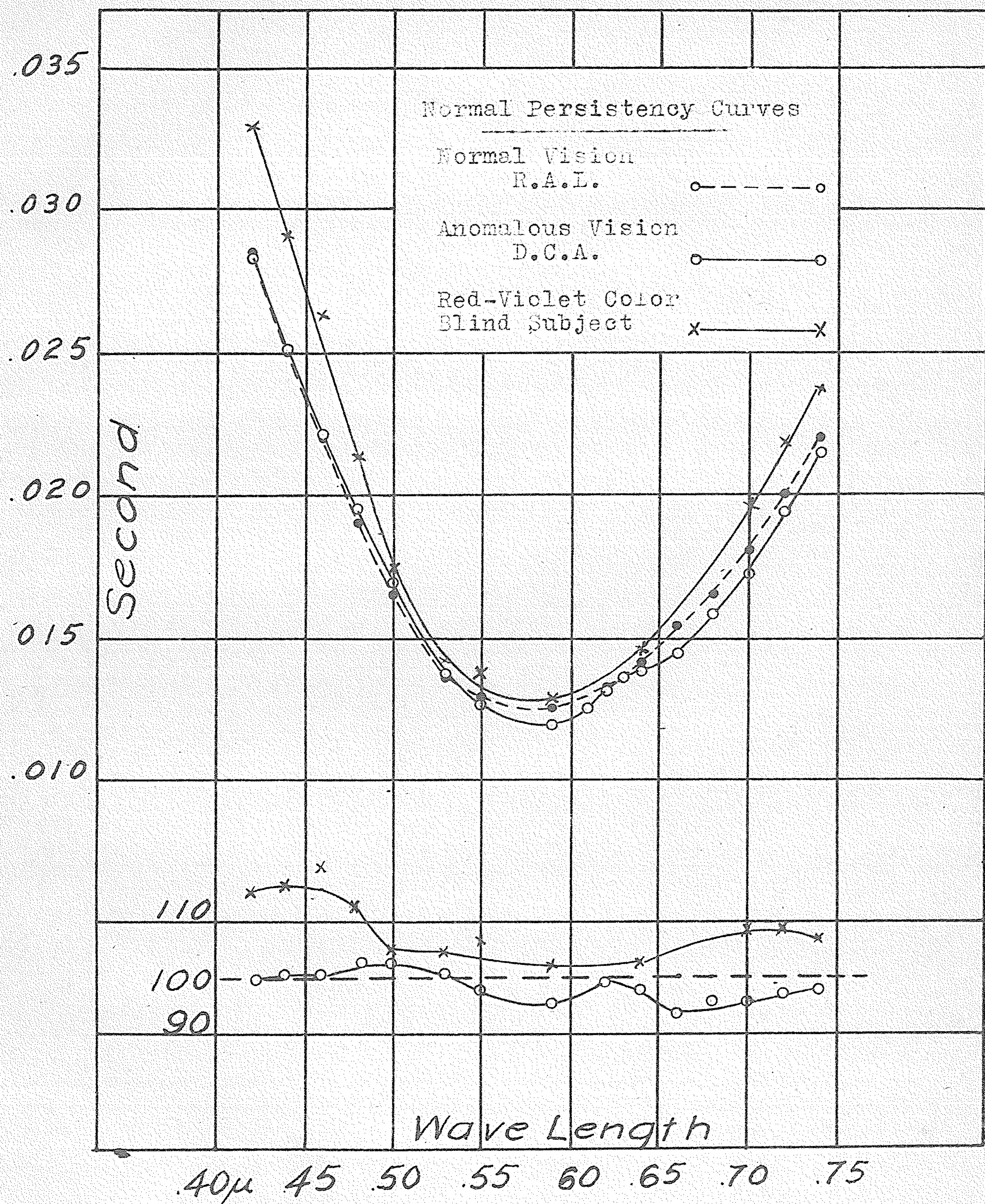

Normal Persistency Curves
Normal Vision
R.A.L.
Anomalous Vision
D.C.A.
Red-Violet Color
Blind Subject
.035
.030
.025
.020
.015
.010
Second
110
100
90
Wave Length
.40μ
45
.50
.55
60
.65
.70
.75

Fig. XVIII.

in Tables IX and X; the curves are shown by the continuous line with circles in Figs. XII and XIII.

By comparing the curves obtained by subjects of normal color vision, red-violet color blindness, and anomalous vision, and exact relation between them can be readily seen. All these curves are obtained with the same apparatus under identical conditions, and the subjects are all of about the same age. With such a situation it may be said that the results obtained by comparison represent the exact differences in the retinal physiological brightness for corresponding parts of the spectrum.

In comparing the curve for red-violet color blindness with the curve for normal color vision, it will be seen that two parts of the curve are evidently abnormal; one an elevation in the red extending to wave length .63μ in both Figs. XII and XIII, and a similar elevation but even more pronounced in the violet extending from .525μ in Fig. XII and .50μ in Fig. XIII, to the end of the violet. The depression of the curve between the elevations indicates an increased brightness of the spectrum to the subject. The position of this brightest part does not coincide with the normal, but the reason for this is perhaps due to insufficient time for the subject to repeat the set of readings in which a lowering is likely to have occured.

The curve for anomalous vision (D. C. A.) is also compared with the normal on the same figure as that of the comparison of normal and color-blind vision curves. It will be seen that the curve for anomalous vision is identical to the normal through the violet to wave length .50μ Fig. XII and .53μ Fig. XIII, at which the depression begins extending to wave length .64μ Fig. XII and .62μ Fig. XIII, where it just touches the normal and begins another depression extending to the end of the red.

From these curves it is clearly seen that each subject possesses his own particular type of color vision. The red-violet color-blind subject can be said to be subsensitive in the red and violet sensations, and the subject possessing anomalous color vision, super sensitive for the red and green sensations. Theoretically, it seems possible, from the fact that every retina possesses three fundamental color sensations, that several different types of color-blindness as well as several different types of anomalous vision can be obtained. The anticipated types of subsensitiveness may be represented as follows: Red, Green, Violet, Red-Green, Red-Violet, Green-Violet, and Red-Green-Violet; i.e. subsensitiveness in one sensation, two sensations, or three sensations. In a similar manner seven types of super-sensitiveness are anticipated.

Allen[1] has made a close study of color-blindness and determined the persistency curves of about twenty-six cases. Among them no less than six out of the possible seven types of subsensitiveness were found. In the case of violet subsensitiveness, none as yet have been found.

The subject who possesses anomalous vision mentioned here is super- sensitive for the red and green sensations; several other subjects of this same type of super sensitivity has been found, but the remaining six types of super-sensitiveness have never as yet been detected.

From these investigations it is seen that every light stimulus acting upon the retina, generates in the visual receptors nervous impulses which ascend by the afferent nerves to the visual centers in the cortex where the sensation of light and color is produced. As soon as the stimulus acts upon the retina, additional impulses at some point in the reflex arc, probably in the synaptic junctions of the afferent and efferent nerves, are evoked which descend by the efferent nerves to all parts of both retinas, by means of which the sensitiveness is controlled. These impulses evoked in the efferent nerves, or the so called reflex actions, immediately tend to restore to normal sensitivity any change in the sensitivity that may be caused by the action of the stimulus. This tendency to restore the normal sensitivity is carried on at the same time as the stimulus acts, and even when the stimulus has ceased to act the restoration is continued by a periodic change between super-sensitivity and subsensitivity passing through the normal sensitivity for each change until the normal sensitivity is reached; this is clearly shown in the oscillatory curves.

If the reflex actions which tend to restore subsensitiveness to normal sensitiveness are over-developed with respect to the reflex actions which tend to restore the super-sensitiveness, the resultant effect produced is super-sensitiveness in comparison to the resultant effect when the reflex actions are both equally developed. Similarly, it follows, if the reflex actions tending to ~~restore~~ reduce supersensitiveness are overdeveloped with respect to those reflex actions tending to restore subsensitiveness, the resultant effect is subsensitive in comparison to the resultant effect produced by two equally developed reflex actions.

Hence, for normal color vision the reflex actions are considered to be in a state of equilibrium. For colorblindness the reflex actions are unbalanced so that the resultant effect produced is subsensitive in comparison to the resultant effect produced by the reflex actions for normal color vision. For anomalous color vision the reflex actions are also unbalanced, only in this case the resultant effect of the actions is supersensitive in comparison with the resultant effect produced for normal color vision.