THE OSCILLATORY SENSITIVENESS
OF THE RETINA IN NORMAL AND ABNORMAL COLOR VISION

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The history of color vision dates from the time of Pythagoras and the Pythagoreans, 540 B.C., the second school of Grecian philosophers, who were of the opinion that vision is caused by particles continually flying from the surface of bodies and entering the eye.

Empedocles and Plato, on the other hand, maintained that the cause of vision is something emitted by the eye, which meeting with something else proceeding from the object is reflected back again. This may be considered a species of touch due to invisible feelers having their origin in the eye.

Aristotle, 350 B.C. held the opinion that light is incorporeal, that is,,a mere quality, otherwise if it were a real substance, its motion in passing from east to west could not be insensible though it may escape our notice in a smaller distance. He thought that colors from rainbows and halos were caused by an imperfect reflection from raindrops, the image of the sun being distorted and color only exhibited. Aristotle also taught that black and white were the colors from which all others were derived, an idea, which in a modified form, persisted to the time of Goethe.

Epicurus, 300 B. C., and later Lucretius, 75 B. C., believed that we see by the intervention of light as we feel an object with a stick. Seneca observed that sunlight shining through an angular piece of glass gives the colors of the rainbow, which he explained as a species of false color.

Ptolemy's treatise on optics written 150 A. D. became the great authority on the subject until the time of Al Hazen, (965-1038 A. D.), an Arabian. Al Hazen defines the colors of the rainbow to be three, but with Seneca supposes them to be produced by a mixture of sun's light with blackness of the cloud from which it is reflected. His speculations on color, however, do not show any advance over those of the European philosophers.

As it is impossible to trace in detail in this brief historical review, the development of theories of color vision throughout the ages, I am passing over the centuries until the time of the 17th century with its outstanding feature, the work of the celebrated Isaac Newton. The 17th century marks a period of great activity in all branches of science and one notes the names of many individuals such as Descartes, Boyle, Grimaldi, Huyghens and others who did pioneer work and undoubtedly contributed to the knowledge of the nature of light and colors, but their works in this respect have been to some extent overshadowed by the discoveries of Newton and the authority which he carried. Descartes established and published the laws of the refraction of light. The facts had previously been recorded by W. Snell in a manuscript, but not published. Descartes made a decided advance over de Dominis in the knowledge of the formation of the rainbow and corrected errors in the explanation of the second bow, but Newton writes: "Whilst they understood not the true origin of colors its necessary to pursue it here a little further," which he proceeded to do in the light of his discovery of the compound nature of light and of the entirely dependable relationship between color of a homogeneous ray and its refrangibility.

Boyle published a work on the theory of colors in 1663, a year before Newton began to consider and experiment upon the nature of color. He passed rays of sunlight through a triangular prism and discussed the rainbow painted on the wall; he says: "Nor will it follow that because there remains no footsteps of the color upon the object when the prism is removed, that therefore the color was not real, since the light was truly modified by the refraction and reflection it suffered in its trajection through the prism;" this same experiment a few years later in Newton's hands was incomparably more illuminating, yet Boyle's work is of great interest and value as a review of the many different theories of color held then and previously. Boyle said that he taught only "that the beams of light modified by the bodies whence they are sent (reflected or refracted) to the eye produce there that kind of sensation men commonly call color."

In the work of Grimaldi, published 1665, there is nothing new in regard to the subject of color or color vision. The author appears to have been the first investigator to assert that the transmission of light is not instantaneous, thereby definitely predicting Römers demonstration of the velocity of light.

The following quotations from several of Newton's papers will give his general views on color vision.

"The rays of light to speakproperly 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 the 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 with the strongest colors, red and yellows, the least with the weakest, blues and violets; the middle with green; and a confusion of all with white *****."

The only prominent writer of the eighteenth century advocated the undulatory of light was Leonhard Euler (1707-1783).[1] He explained diversity in colors by the dif-

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[1] Memoiren der Berliner Akademie, 1746.

ference in duration of vibrations and thus strongly opposed the doctrine of light corpuscles. He suggested a means of producing achromatic lenses but was unable to produce one himself.

Tobias Meyer, 1758, was the first to give utterance to the view that the three primitive colors might correspond to three different kinds of light, red, yellow and blue, each of which furnished rays of all refrangibilities. According to this, at every point in the solar spectrum, red, yellow and blue rays are mixed together which do not differ in refrangibility and therefore cannot be separated by the prism.

Wunsch, 1792, was the first to select red, green and violet as primary colors, a result to which he was led by his experiments on mixtures.of the colored rays of the spectrum.

Thomas Young, 1801, propounded a theory that color sensations depend upon three independent physiological processes involving three primary substances or sets of nerves. In his first paper, he selected red, yellow and blue as the three simple color sensations with no other basis than current scientific opinion. Owing to the celebrated but misconstrued observations by Wollaston of the dark lines in the solar spectrum, Young modified his theory by selecting red, green and violet as primaries, quite independently of Wunsch. This theory he further confirmed by experiments, after which it remained in obscurity until resusciated in 1860 by Helmholtz and Maxwell. His general principles were modified and made definite by the experimental researches of Helmholtz, Maxwell, Konig, Allen and others. These do not all agree upon the hues selected as the primary colors, and Maxwell in particular selects a blue as the third of his triad of fundamentals.

"The referring of all colors," says Helmholtz, "to the three primitive ones has, in the case of the different observers, three different senses:

"1. That the different colors were such as permitted of the formation of all others from their combinations."

"2. Or, as supposed by Mayer and Brewster, that the primitive colors correspond to three different kinds of objective light."

"3. Or, as supposed by Young, that they correspond to three primitive modes of sensation experienced by the visual nerves, and from which the remaining sensations of color are composed."

The following condensed extract will give a general idea of the views of Thomas Exley, 1834.

"The atoms of light have equal velocities but unequal momenta and spheres of repulsion; hence they ought to produce different effects or sensations on the delicate organ of vision. Probably those ethereal atoms which penetrate deepest into the sensitive part of the eye to produce their greatest effect give the red color, and those which pierce to the least depth produce violet, and those intermediate in proportion. Therefore the atoms which have the greatest absolute force and the least sphere of repulsion will cause a red color and others according to one or other or to the proportion of both these circumstances will produce the same or other colors."

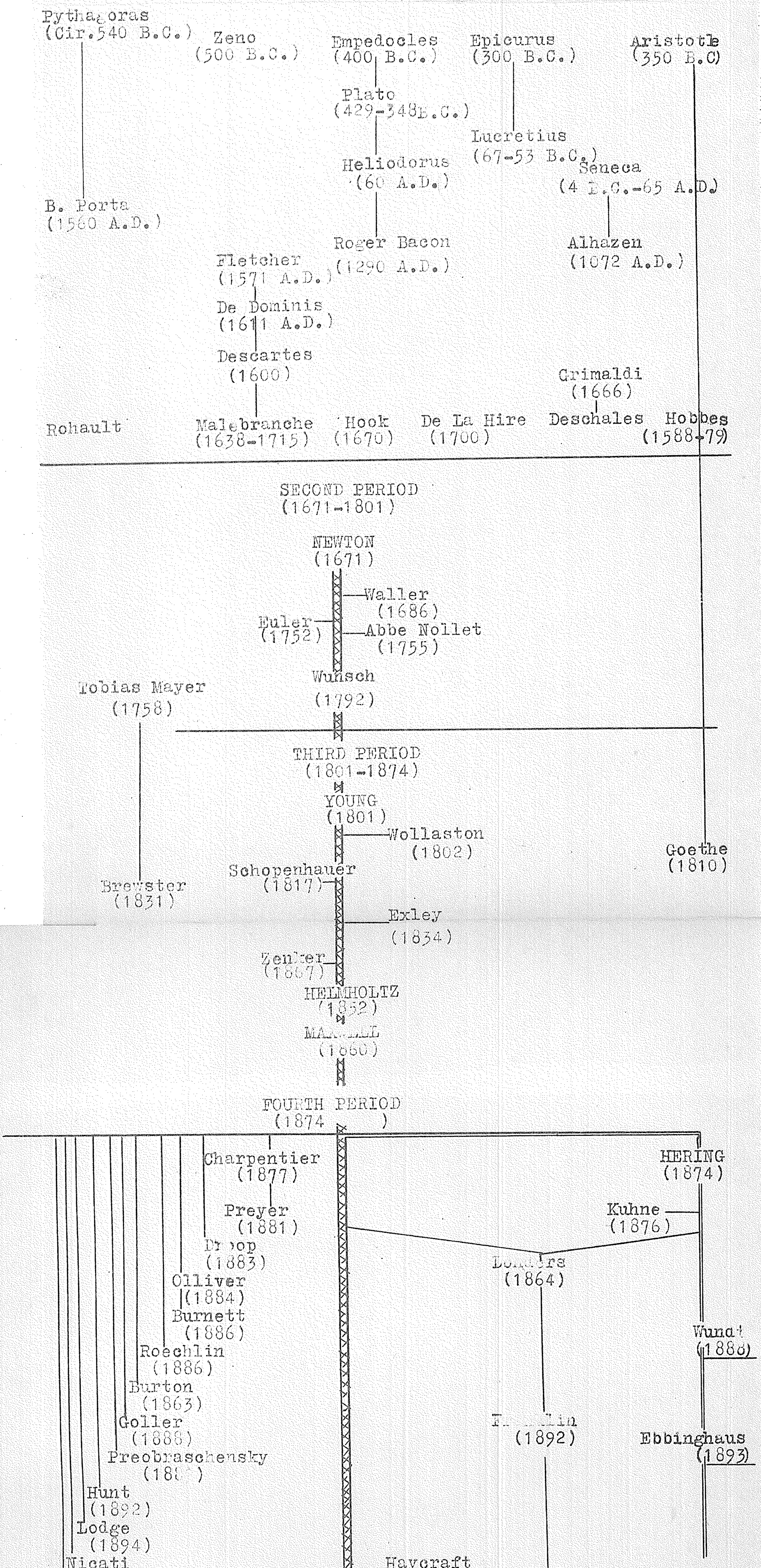
From this point on, I shall deal only with color theories of outstanding importance. The genealogical tree of color vision exhibits the main line of development from Newton, and the subsidiary line due to Hering together with theories of lesser importance.

The Hering theory, adopted largely by psychologists, provides three antagonistic pairs of color sensations, red-green, yellow-blue and white-black. In order to account for these six fundamental sensations, he assumes the presence somewhere in the retinocerebral apparatus of three distinct substances. Each substance is capable of building up (anabolism) or of breaking down (katabolism) under the influence of radiant energy or its effects. Thus the building up of the red-green substance causes a sensation of green, and the breaking- down of this substance, a sensation of red. Similarly anabolism of the white-black substances is connected with the sensation of blackness and katabolism with the sensation of whiteness.

In the evolutionary Ladd-Franklin theory, colorless sensations white, gray and black, are assumed to be caused by a primary photo-chemical substance which is composed of many "gray" molecules. These exist in their primitive state in the rods, but upon dissociation they cause the colorless sensation. In the cones the gray molecules undergo development and for some reason only a portion of the molecule becomes dissociated by rays of a given wave length. The evolution of the gray molecule takes place in three stages as represented diagrammatically. In the first stage the gray molecule exists, but is so constructed, that it is disintegrated by light of all wave lengths, thus producing a white and gray sensation. In the second stage the molecule contains two groupings, the dissociation of one causing a yellow sensation and the other,blue. Their simultaneous dissociation causes 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 are perceived as such. In the third stage of development, the yellow grouping is divided into two new combinations, the dissociation of one giving the sensation

HYPOTHESES OF COLOR VISION

FIRST PERIOD
(540 B.C. - 1671 A.D.)



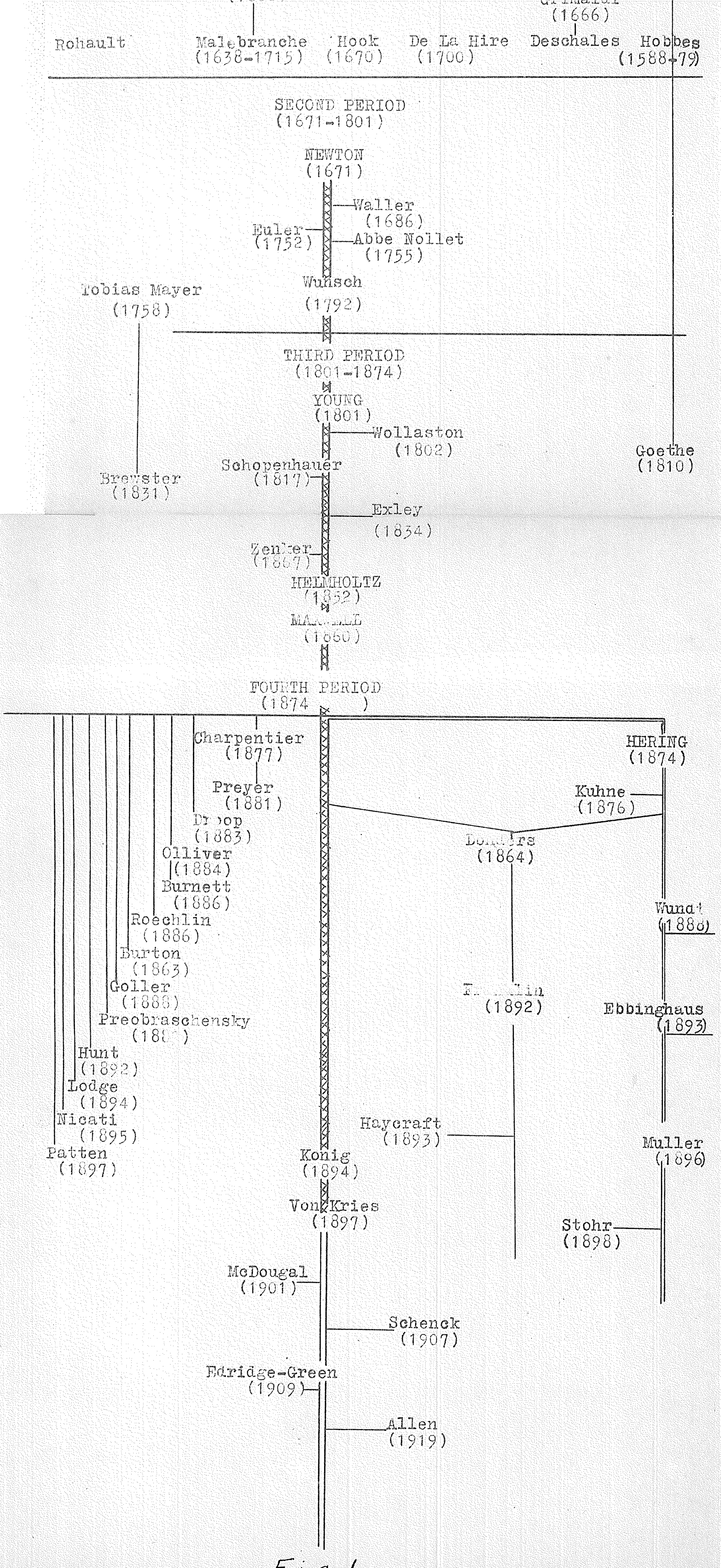
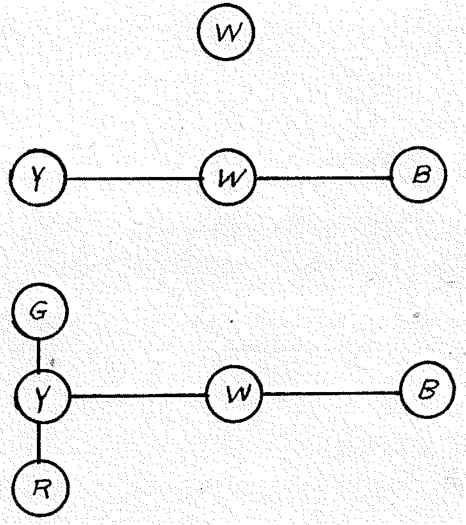

(1666)
Rohault
Malebranche
(1638-1715)
Hook
(1670)
De La Hire
(1700)
Deschales
Hobbes
(1588-79)
SECOND PERIOD
(1671-1801)
NEWTON
(1671)
Waller
(1686)
Euler
(1752)
Abbe Nollet
(1755)
Tobias Mayer
(1758)
Wunsch
(1792)
THIRD PERIOD
(1801-1874)
YOUNG
(1801)
Wollaston
(1802)
Goethe
(1810)
Schopenhauer
(1817)
Brewster
(1831)
Exley
(1834)
Zenker
(1867)
HELMHOLTZ
(1852)
MAXWELL
(1860)
FOURTH PERIOD
(1874)
Charpentier
(1877)
Preyer
(1881)
Droop
(1883)
Olliver
(1884)
Burnett
(1886)
Roechlin
(1886)
Burton
(1863)
Goller
(1888)
Preobraschensky
(188)
Hunt
(1892)
Lodge
(1894)
Nicati
(1895)
Patten
(1897)
HERING
(1874)
Kuhne
(1876)
Donders
(1864)
Wundt
(1888)
Franklin
(1892)
Ebbinghaus
(1893)
Haycraft
(1893)
Muller
(1896)
Konig
(1894)
Von Kries
(1897)
Stohr
(1898)
McDougal
(1901)
Schenck
(1907)
Edridge-Green
(1909)
Allen
(1919)

Fig. 1.

of green, and the other, the sensation of red. The yellow sensation results when the red and green are dissociated simultaneously. The sensation of gray is produced when all three (red, green and blue) are dissociated simultaneously.



The Duplicity theory is usually associated with the name of von Kries. It is based upon anatomical evidence of the existence of 'rods' and 'cones' in the retina. In the very centre of the retina, the fovea centralis, there is a small area in which there are cones only while just outside of this area both rods and cones appear, the rods becoming predominant towards the periphery of the retina. It is assumed that the rods are responsible for achromatic sensations and the cones for both achromatic and chromatic sensations. The rods are supposed to be largely responsible for scotopia or twilight vision and the cones for photopia or light adaptation of the eye. The duplicity theory does not attempt to explain color vision, but is of interest because of its attempt to separate vision into chromatic and achromatic processes.

Boll discovered a photochemical substance in the retina of the eye which has been named the visual purple. This substance is present in the rods only. Edridge-Green has attempted to weave the visual purple into a theory of color vision. Light impinging on the retina liberates the visual purple from the rods and is diffused into the fovea and other parts of the rod and cone layer of the retina. The decomposition of the visual purple stimulates the ends of the cones setting up a visual impulse which is transmitted to the brain via the optic nerve. He further assumes that the visual impulses caused by the different rays of light differ in character just as the rays of light differ in wave length. "In the impulse itself we have the physiological basis of the sensation of light, and in the quality of the impulse, the physiological basis of the sensation of color. The impulse being conveyed along the optic nerve to the brain, stimulates the visual centre causing a sensation of light, then passing on to the color-perceiving centre, causes a sensation of color.[1]

Description of Apparatus.

The apparatus used for obtaining the persistency curves for the three types of vision was the same as that used and described by Allen in one of his papers. The source of light was an acetylene flame, the luminosity of which was kept constant by means of a manometer that indicates the pressure of gas at any time. Between the light and the spectrometer, there was a 90° sectored disc, the opposite sectors being cut out. The disc was mounted on the shaft of a motor. The light was viewed through an eye piece, on the four prism Hilger Spectrometer. In the eye piece there were adjustable shutters which isolated a narrow rectangular band of the desired wave length. The sectored disc was rotated by means of a D. C. motor, the speed of which was recorded by electrical means. Every fifty revolutions, a contact was made by one end of a long diametral arm which completed an electrical circuit and thereby making an electromagnet that on attracting the armature made a dot on a sheet of paper on a drum rotating at uniform speed. The time taken for each fifty revolutions of the motor was also recorded. A clock was used having a mercury cup into which a wire dipped every half second, thus completing a similar circuit

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[1] Hunterian Lectures on Color Vision and Color Blindness, P. 10. sqq.

to the above one and registering every half second on the rotating drum just below the former marks made every fifty revolutions of the motor. Due to the speed of the disc, air currents would disturb the flame unless isolated. This was done by having the flame in a box without a lid and having a glass window in the side.

The speed of the disc was controlled by means of a friction brake acting on a pulley mounted on the shaft of the motor. The desired wave length was obtained by turning the telescope through a definite angle. In this manner, we were able to use any wave length in the visible spectrum and maintain the necessary speed of the disc for the critical frequency of flicker and have both the speed and time recorded. Thus we may calculate the critical frequency of flicker for a particular wave length of light and determine the duration of a single flash upon the retina of the eye.

As the disc is rotated slowly, there is a flickering sensation produced when the light is viewed through the eye piece. As the disc is rotated more rapidly, a certain speed is reached where the flickering just stops and a continuous sensation results. This speed is named the critical frequency of flicker and is of different values for different wave lengths of light. The critical frequency will be greater for light of greater luminosity in the spectrometer. Then in the brightest part of the spectrum which is in the yellow and green, we find that the critical frequency is a maximum. At the ends of the spectrum, the luminosity is less particularly so at the violet end as may be seen by referring to the normal curve. It is evident that the retina of the eye is more sensitive to light of greater luminosity since it is necessary to rotate the disc faster to produce a continuous sensation. Thus the greater the critical frequency of flicker, the shorter will be the duration of a single flash of light upon the retina i. e., the duration of the maximum intensity of the sensation varies inversely as the critical frequency of flicker.

The room in which measurements were made was well illuminated with daylight, there being four windows in it. Readings were taken with both eyes open i. e., both eyes in daylight adaptation and only during the bright part of the day when the sun was above the horizon. Direct sunlight was excluded from the room and at no time while taking readings was the eye stimulated by staring at any particular luminous object.

The method of taking readings was routing work once one accustomed himself to it. although with every sitting, great care and precision were necessary. A shield was attached to the eye piece which exactly fitted around the eye and thereby shielded it from all extraneous light. The motor was started and one could see a distinct flickering at first but on releasing the friction brake, the speed was increased just to the point where flickering ceased and a continuous sensation resulted. The motor was maintained at this speed and the two circuits were closed, viz: that of the clock and the speed counter. Also a string was pulledsimultaneously thus releasing the mechanism which set the drum in uniform rotation. After one complete revolution of the drum, a bell sounded and then the drum was stopped and the recorder reset for another reading.

After each observation the eye was rested three minutes during the time the persistency curve was taken. The time required to make one reading was about thirty-five seconds and the spectrum on which these measurements were made was not of sufficient brightness to stimulate the eye to any appreciable extent.

In reducing the chronographic record to the duration of a single flash of light upon the retina, the time required for 100 revolutions of the disc was found to be most convenient for calculation. For the wave lengths at the extreme ends of the visible spectrum, only one value for the duration was obtained for each reading since the discsrotated very little more than 100 times while the drum made one revolution. As the brightest part of the spectrum is approached, the number of revolutions of the disc varies from about 200 to 800 for one revolution of the drum. Thus knowing the number of revolutions and the time taken, we may calculate the time for one revolution of the disc and to obtain the duration of one flash, we divide the above result by four, since the disc has two opaque sectors.

Persistency Curves:

The same apparatus and the same method was used to obtain persistency curves for the three general types of vision i. e., normal, anomalous and color blind vision. Fifteen different wave lengths were sufficient to determine the curve but in the case of the author who discovered that he was anomalous in his vision, additional readings were taken for intermediate wave lengths to ascertain definitely the anomaly. The character of the curves were determined by the first set of readings; but for the sake of smoothness, which is the obvious characteristic of the spectrum, additional readings were taken for all doubtful or apparently misplaced points. As all conditions were constant, there was no limit to the number of determinations which might be made.

The persistency curves obtained by plotting wave lengths as abscissal and persistence of vision as ordinates, show that the duration of these light impulses varies as some inverse function of the luminosity of the color observed.

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."

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 the critical frequency of flicker, depends only on the luminosity of the light and in no way on the wave length. The Ferry-Porter law, $D = \frac{1}{k \log L + k_1}$ where D is the persistence of vision, L the luminosity, and k and k_1 two constants.

We are justified, therefore, in interpreting an elevation of the abnormal curve above the normal as a decrease in the physiological brightness occurring in the corresponding part of the spectrum; a depression below the normal as an increase in the brightness; and coincidence between them as indicating no change whatever.

Mr. H. A. L., who possesses normal color vision, experienced little difficulty in obtaining a normal curve, after he had once familiarized himself with the method of procedure. He obtained a smooth curve throughout the

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[1] Am. Jour. Sci. 44, 1892.

[2] Proc. Roy. Soc. 63, 1898; 70; 1902.

Persistency Curves.

	Normal Vision R. A. L. D (sec.)	Anomalous Vision D. C. A. D (sec.)	Red-Violet Color blind subject D (sec.)
.74 μ	.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	.0264	.0329

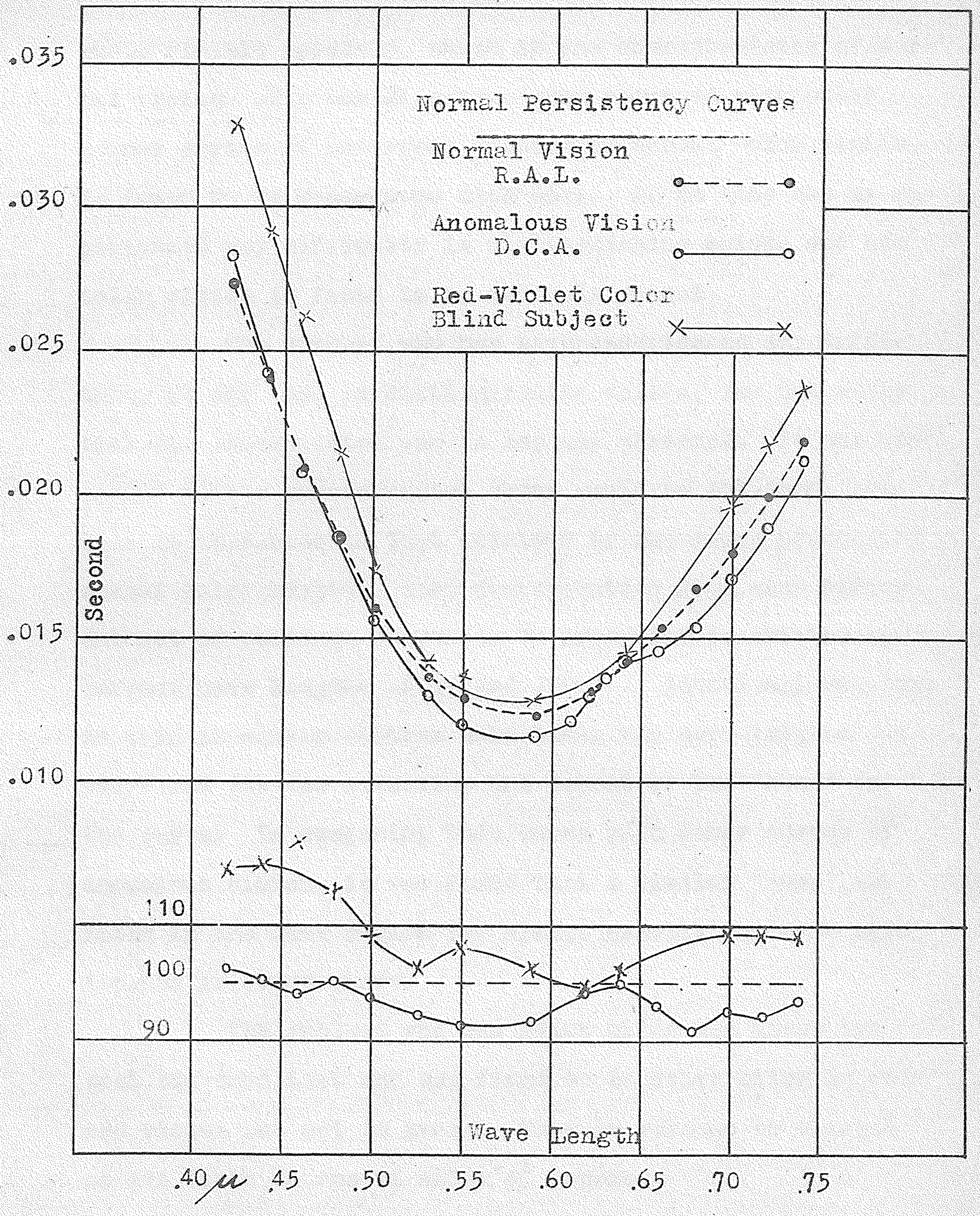

.035
.030
.025
.020
.015
.010
110
100
90
Second
Normal Persistency Curves
Normal Vision
R.A.L.
Anomalous Vision
D.C.A.
Red-Violet Color
Blind Subject
Wave Length
.40 μ
.45
.50
.55
.60
.65
.70
.75

FIG. 2.

whole visible spectrum, which is one characteristic of normal vision. His normal curve, when compared with other normal curves of observers possessing normal color vision, is found to be synonymous with them. At no time has he experienced any difficulty in distinguishing colors and his color vision is found to be entirely normal.

The author, who has neverexperienced any difficulty at any time in distinguishing colors, was not aware that his color vision was in any way abnormal. It was expected that a smooth normal curve would be obtained, similar in character to that obtained by observers possessing normal color vision. Each curve plotted from each different set of readings proves to be irregular in smoothness between wave lengths $.61\mu$ and $.66\mu$. Additional readings in this irregular section were taken for wave lengths $.62\mu$, $.63\mu$ and $.64\mu$ to determine the extent of the 'hump' in the curve. In comparing this curve with other curves of anomalous vision, it was found that a similar 'hump' existed in the same region for almost exactly the same wave lengths in every curve.

The subject who was color blind was given the wool and card test and was found to be color blind in red and violet but not in green. Thus he belongs to class 5 as set forth in one of Allen's[1] papers.

[1] Allen. Phys. Review Vol. XV, 1902.

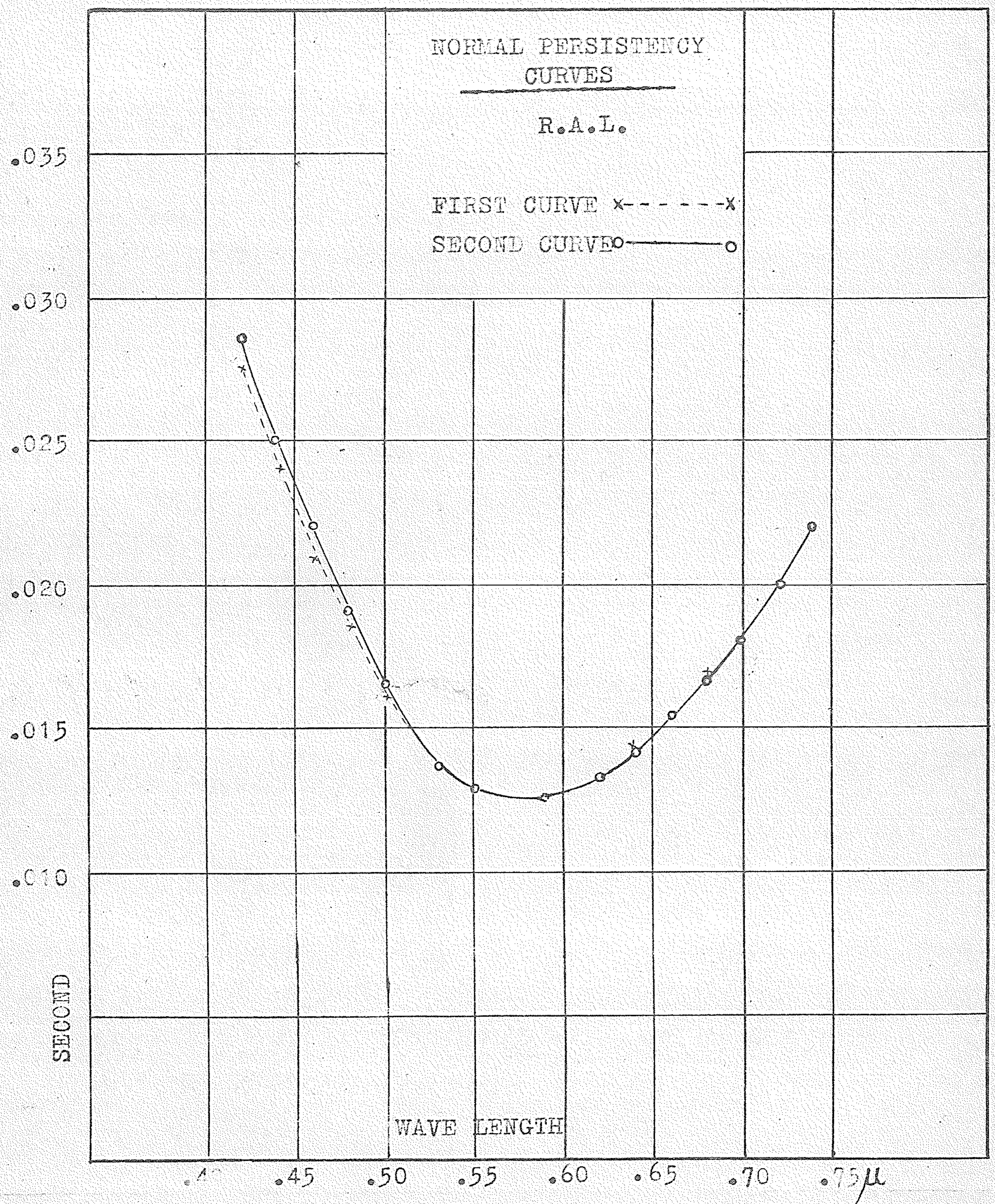

NORMAL PERSISTENCY CURVES
R.A.L.
FIRST CURVE
SECOND CURVE
.035
.030
.025
.020
.015
.010
SECOND
WAVE LENGTH
.40
.45
.50
.55
.60
.65
.70
.75μ

FIG. 3.

The three normal curves for normal vision, anomalous vision, and red-violet color blind vision are plotted on the same graph in Fig. 2. A second set of curves for normal and anomalous vision was obtained, which it is thought to be more accurate than the first set obtained. A comparison of the two curves for normal vision in Fig. 3 shows that the curves are almost identical except in the vi violet region where the second curve is slightly elevated. A comparison of the two normal curves for anomalous vision was made and the curves were found to be exactly the same in character. Between the time of taking the first set of readings and the second set of readings the acetylene generator was charged with a fresh supply of carbide. The second set of curves taken with the new gas proved to be the same in character and therefore we are justified in plotting on the same graph in Fig. 4, the curve for red-violet color blindness, although this curve was taken only with the first supply of acetylene gas.

Persistency Curves.

	Normal vision R. A. L. D (sec.)	Anomalous vision D. C. A. D (sec.)	Red-Violet color blind subject D (sec.)
.74 μ	.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

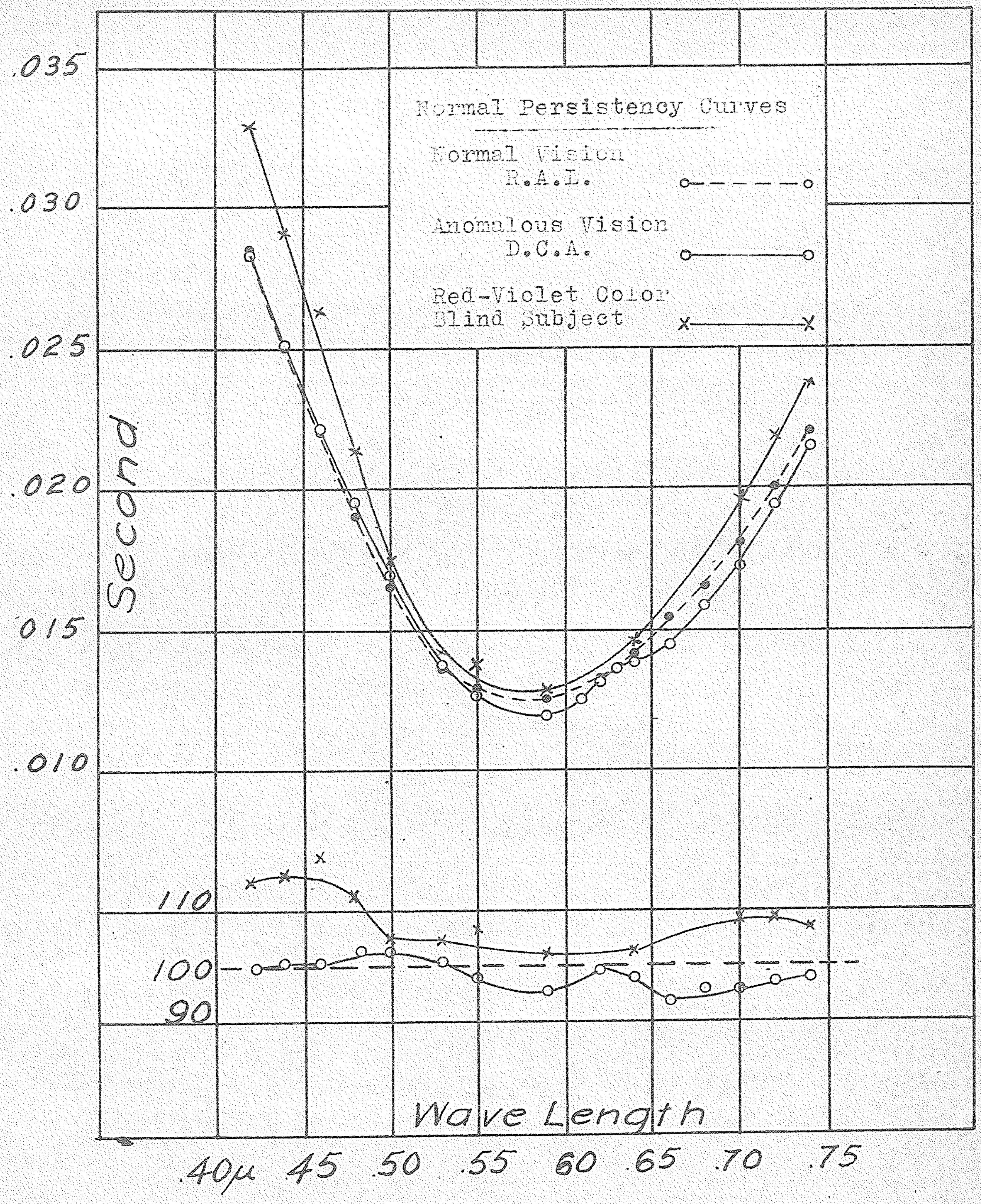
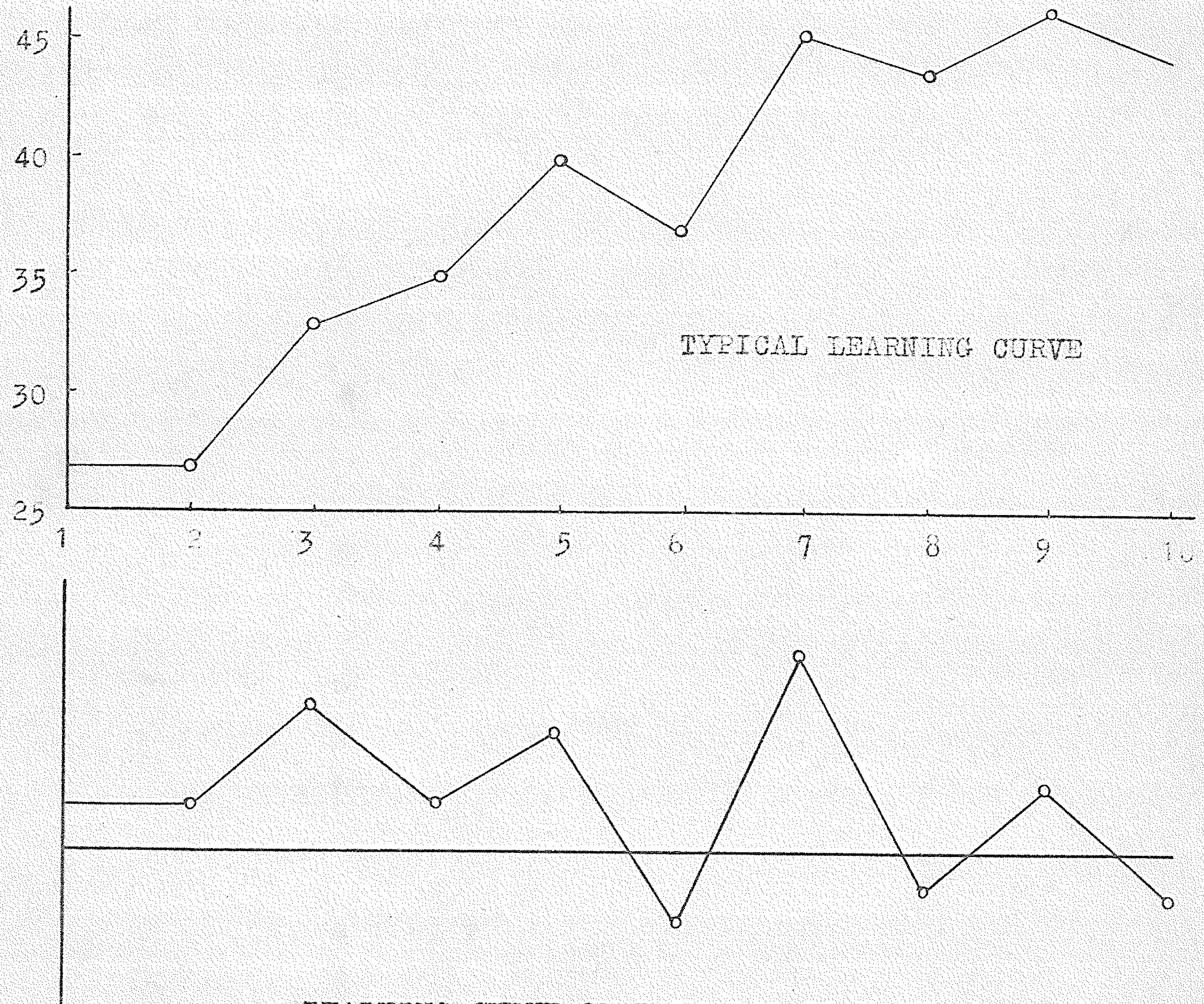

Normal Persistency Curves
Normal Vision R.A.L.
Anomalous Vision D.C.A.
Red-Violet Color Blind Subject
.035
.030
.025
.020
.015
.010
110
100
90
Second
Wave Length
.40μ
45
.50
.55
60
.65
.70
.75

FIG. 4.

Oscillatory Effect.

A stimulus applied to any sensory receptor arouses a sensation in the corresponding central organs, and in addition evokes simultaneously two sets of efferent impulses, one of which enhances and the other depresses the sensitiveness of the receptors of the whole sensory system, the degree of enhancement or depression being the measure of the excess of one process over the other. On this view the sensitivity of the receptors and the state of the sensory tonus are normally controlled by the efferent nervous system, which is further controlled by the intensity of the stimulus.

It has long been known that there is a fluctuation in sensitivity of the receptors of the nervous system, as will readily be seen by the frequent references to it in psychology books. As an example, if one listens to the ticking of a watch or the faint tone of a telephone at a little distance, it will be observed that the sound will be heard for an instant and then will disappear, and these alternations will continue as long as one listens. Thus we have the fluctuation in sensitivity of the auditory sense.



LEARNING CURVE SHOWING OSCILLATORY EFFECT

FIG. 5.

In a typical learning curve,[1] Fig. 5, where the ordinates represent efficiency in card-sorting and abscissae represent equal periods of time, it will be noticed that the efficiency does not increase constantly with an increase in periods of time. It fluctuates, both decreasing and increasing, with the rise of the learning curve. In the lower part of Fig. 5, the learning curve is reduced to show the fluctuations in efficiency with respect to the X-axis, a point above the line indicating an increase in efficiency and a point below, a decrease. A part of the learning curve parallel to the X-axis is named a 'plateau' and indicates a period of no progress in learning. From the above example we are led to believe that there is a fluctuation in the sensitivity of the nervous system controlling the muscles and visual receptors. It was only recently that the correct explanation of the fluctuations of the sensitiveness of the nervous system controlling the muscles was elucidated by Allen. In the muscle experiment performed by Allen and O'Donoghue,[2] a definite oscillatory effect was established and absolute measurements obtained. In this research a weight, (to which was attached a piano wire which passed over a pulley, and had a stirrup attached to the end of the wire,) was lifted just off the ground. The stirrup was adjusted across the penultimate phalanges

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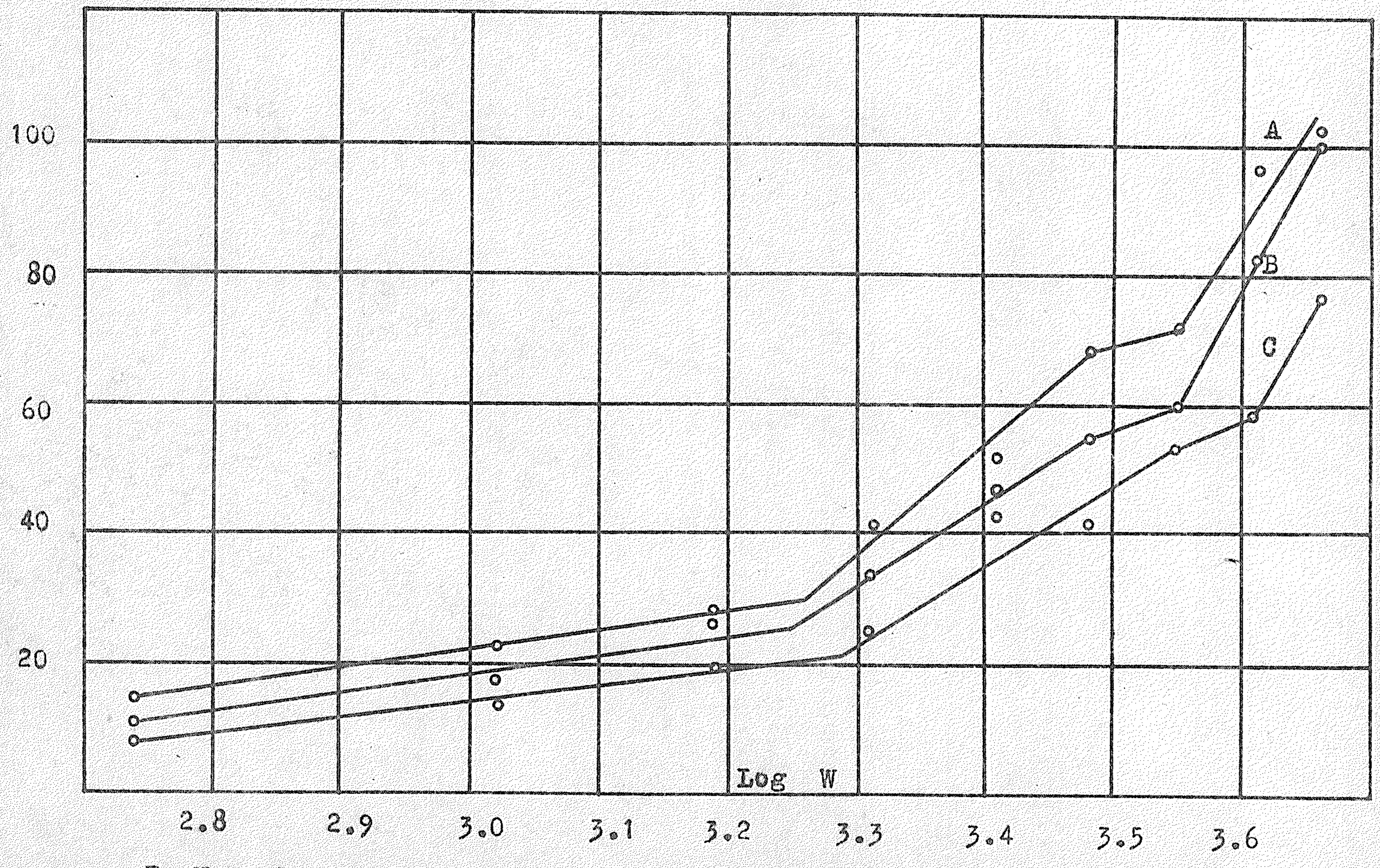
[1] Reproduced from Psychology of learning - Pyle.

[2] Quar. Jo. Exp. Physiol. Vol. XVIII, 1927.



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

FIG. 6.

of the fingers of the right hand and the arm moved slightly away from the body, the arm however remaining in a vertical position. Thus the weight was lifted for a definite interval of time,(varying with the experimenter), after which the stirrup was released from the fingers. Immediately after the cessation of voluntary contraction of the skeletal muscle there is a latent period of some seconds and this is followed by an involuntary post-contraction of the skeletal muscle and the arm, with the fingers extended, was allowed to rise. The height reached was measured by taking the angle from the vertical. By plotting the angles of rise against the logarithm of weights lifted, a normal curve was obtained having several branches, (see Fig. 6). After half the readings had been taken to obtain a normal curve, an interruption occurred, and the subject had to discontinue the experiment for a period of 20 minutes during which he sat at a desk and rested his arm. When the experiment was resumed, it was found that the remaining series of readings were much higher than those in a previous normal curve taken the same day, and showed a very striking discontinuity from their predecessors. From previous investigations by Allen of visual, auditory, gustatory and tactile sensations, he found an "enhancement" effect had been observed to follow at an interval after certain stimulations and in order to determine whether a similar effect was present in muscles, a series of curves was obtained. To ascertain that the rise in the second part of the curve described above was not due to faulty readings, a series of normal curves was obtained and all proved to be the same in character. Immediately after readings for a normal curve (B, Fig. 6) were taken, a second curve (C, Fig. 6) was obtained and then a complete rest for 20 minutes was taken before a third curve (A, Fig. 6) was obtained. This curve A was elevated above the normal in all its branches and every individual reading was higher than the corresponding one in the normal curve. Thus the "enhancement" or "augmentation" effect was obtained.

A comparable manifestation of enhancement or augmentation had already been obtained by Allen and Hollenberg[1] in the tactile sense, and, since it followed a kind of inhibition or fatigue effect, was termed by them "post-fatigue enhancement." Obviously, then, the next step was to see if the enhancement in the muscle experiment was preceded by such a fatigue effect. Such, was the purpose of taking the second curve just described. It was found that the curve obtained fell below the normal as a whole and that every individual reading was lower, as is clearly shown in Fig.6. This was called an inhibition effect.

A similar phenomenon tp the augmentation or en-

[1] Quar. Jo. Exp. Physiol. Vol. XIV, 1924.

hancement effect in muscles, occurs in sight according to Parsons,[1] who records it in the following way: "The longer the 'fatigue,' the lower is the capacity for discriminating the 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." By inserting inhibition for "fatigue" and augmentation for "over-compensation" in this, we have a statement of the effect. Sherrington also recognises the phenomenon in a general way for he says of inhibition ",,....that it seems to predispose the tissue to a greater functional activity thereafter,

The characteristic manifestation of the phenomenon vaguely referred to as "over-compensation" or pre-disposition to greater activity was obvious in the muscle experiments. Immediately after the cessation of voluntary contraction there is a latent period of some seconds and this is followed by post-contraction. 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. It is followed by an augmentation period which can be detected 17 or 20 minutes later. Obviously, then, at some point between the 3 and 20 minutes we should be able to find the normal condition restored. A point arbitrarily

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[1] Color Vision. J. H. Parsons. 1924. P. 129.

taken at 10 minutes for one investigator was tested and the mean results yielded a fairly good normal curve showing no marked signs of either inhibition or augmentation.

It is clear, then, that starting at normal we have first primary inhibition, then a return to normal, then post-contraction, then secondary inhibition and augmentation, 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 in coming to rest, only it has far fewer excursions.

The problem was suggested to determine whether a visual oscillatory effect existed and if so to measure the extent of the oscillations. It then became of interest to determine definitely the effect upon both normal and abnormal vision.

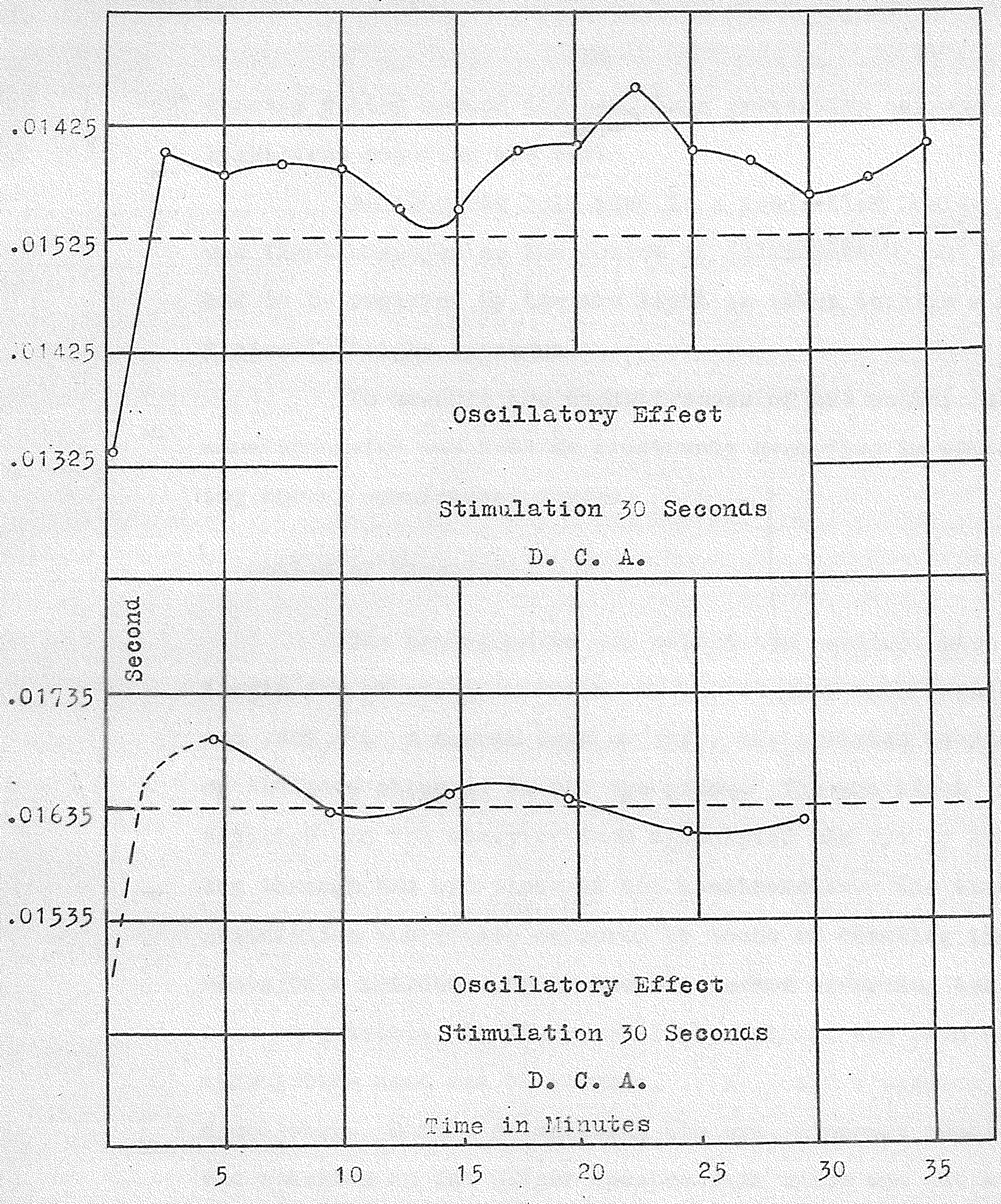
Description of Apparatus for the Oscillatory Effect.

The apparatus used for stimulating the eye consisted of a two prism Browning Spectrometer and a D. C. arc light. The prisms in the spectrometer were set at minimum deviation and then the spectrometer was calibrated by means of Fraunhofer lines and a hydrogen Geissler tube. A calibration curve was obtained by plotting wave lengths as ordinates and the angle through which the telescope moved as abscissae. Thus the telescope could be set at any required wave length. The eye piece was fitted with a shield that

30 seconds stimulation of right eye with .687 μ
measurements made with .687 μ on right eye.

D. C. A.

D (sec.)	Time (after stimulation)	D (sec.)	Time (after stimulation)
.01525	normal reading	.01635	normal reading
.01336	10 (sec.)	.01665	4.5 (min.)
.01600	2.5 (min.)	.01630	9.5
.01580	5.0	.01645	14.5
.01590	7.5	.01640	19.5
.01585	10.0	.01610	24.5
.01550	12.5	.01620	29.5
.01550	15.0		
.01605	17.5		
.01655	20.0		
.01600	22.5		
.01590	25.0		
.01560	27.5		
.01575	30.0		
.01605	32.5		



Right eye stimulated with wave length .687 μ

Measurements made on right eye with wave length .687 μ

FIG. 7.

exactly fitted around the eye, thus preventing extraneous light from entering the eye.

An electric bulb used in a projection lantern was first employed as the source of illumination, but this had to be replaced by the arc light in order to give a sufficiently bright spectrum.

To measure the sensitiveness of the retina, the same apparatus was used as previously described in obtaining normal persistency curves.

Method of Procedure.

The spectrometer was set at the required wave length for stimulation which, in the case of this research, was .687 μ. A narrow band of color was isolated by means of shutters attached to the eye piece. The arc light was adjusted and the observer then stimulated his eye by looking through the eye piece of the spectrometer. The time of stimulation was either measured by means of counting the beats of a metronome or by another person observing the time on a watch. In the case of the author, the time of stimulation used was 30 seconds, 1, 2, 3 and 4 minutes respectively. Before stimulating the eye, a normal reading was obtained on the Hilger spectrometer which was set at wave length .687 μ. Immediately after stimulation, the observer took readings on the Hilger spectrometer to measure

1 minute stimulation of right eye with .687 μ

measurements made with .687 μ on right eye.

D. C. A.

D (sec.)	Time (after stimulation)	D (sec.)	Time (after stimulation)
.01645	Normal reading	.01615	Normal reading
.0150	10 (sec.)	.01500	10 (sec.)
.01645	2.5 (min.)	.01605	2.5 (min.)
.01685	5.0	.01610	5.0
.01675	7.5	.01660	7.5
.01645	10.0	.01555	10.0
.01615	12.5	.01580	12.5
.01645	15.0	.01605	15.0
.01690	17.5	.01660	17.5
.01655	20.0	.01595	20.0
.01685	22.5	.01615	22.5
.01620	25.0	.01615	25.0
.01590	27.5	.01605	27.5
.01610	30.0	.01660	30.0

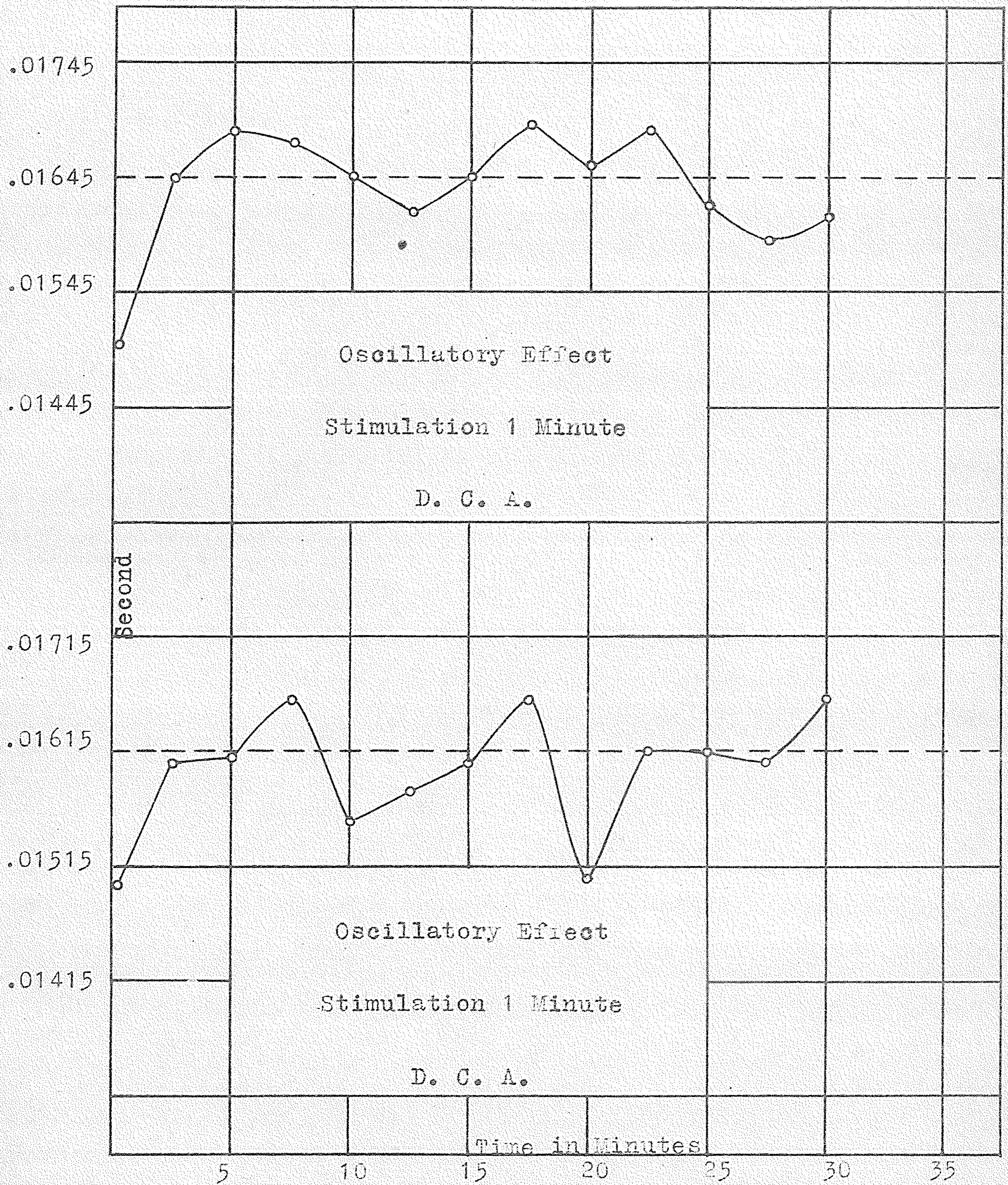


FIG. 8.

Right eye stimulated with wave length .687 μ

Measurements made on right eye with wave length .687 μ the sensitiveness of the retina. Every 2.5 minutes for a period of 30 and in some cases 40 minutes after stimulation, measurements were made to determine the sensitivity of the retina.

By plotting the duration D, of the light stimulus used in measuring the sensitivity as ordinates and time intervals after stimulation at which the readings were taken, as abscissae a curve was obtained. On any particular day, no more than two curves were obtained, one in the morning and one in the afternoon. Thus the time interval between curves would be at least three hours. Frequently only one curve a day was obtained.

Discussion of Oscillatory Curves and Theoretical Considerations.

In this research, the wave length .687 μ was selected for stimulation, since in one of Allen's papers[1] it was found that greatest reflex effects were obtained in one eye when the other was stimulated with this particular wave length. Stimulation from this wave length of light leaves practically no after images. If wave length .589 μ had been selected it would be practically impossible to make measurement on the Hilger spectrometer on account of after images.

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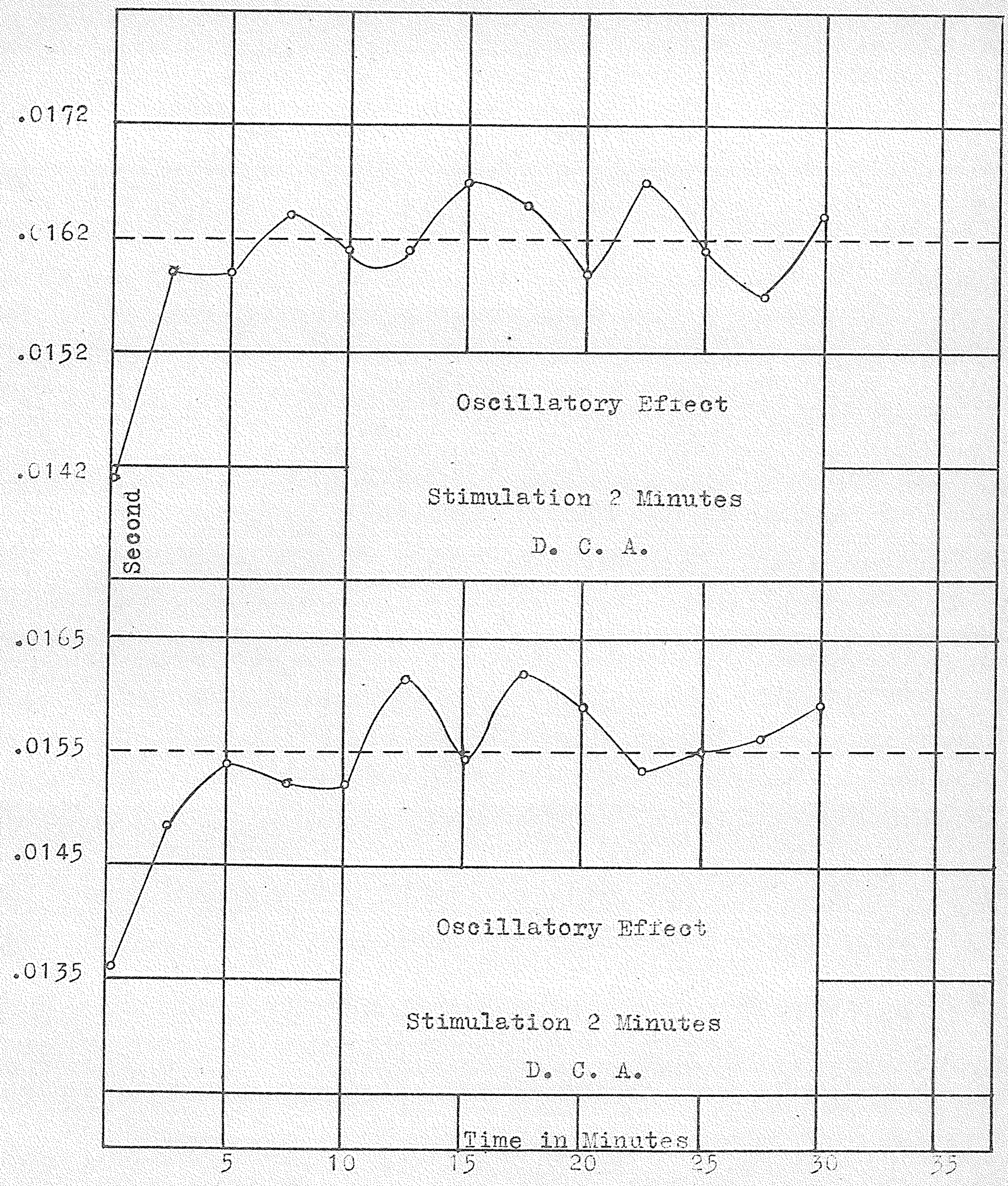
[1] On Reflex Visual Sensations. Am. Jo. of Physiol. Optics. Vol. 5. No's 3 and 4.

2 minute stimulation of right eye with .687 μ

measurements made with .687 μ on right eye.

D. C. A.

D (sec.)	Time (after stimulation)	D (sec.)	Time (after stimulation)
.01620	Normal reading	.01550	Normal reading
.01410	10 (sec.)	.01360	10 (sec.)
.01590	2.5 (min.)	.01483	2.5 (min.)
.01590	5.0	.01536	5.0
.01640	7.5	.01520	7.5
.01610	10.0	.01520	10.0
.01610	12.5	.01613	12.5
.01670	15.0	.01543	15.0
.01650	17.5	.01616	17.5
.01590	20.0	.01586	20.0
.01670	22.5	.01533	22.5
.01610	25.0	.01550	25.0
.01570	27.5	.01560	27.5
.01640	30.0	.01590	30.0



Right eye stimulated wave length .687 μ

Measurements made on right eye with wave length .687 μ

FIG. 9.

At first readings were taken every 5 minutes after stimulation for a period of 30 minutes. A fluctuation of the sensitivity of retina was obtained as shown in Fig. 7, the lower curve. The time of stimulation first used was 30 seconds. It will be seen that the oscillations were not very great and it was thought that points indicating the peak of the amplitude were being missed so that readings were taken every 2.5 minutes after stimulation. In the upper curve Fig. 7, it will be noticed that there are more decided oscillations and therefore since we have more points, we are better able to draw the form of the oscillations. In the lower curve, a reading was not taken immediately after stimulation and the dotted line indicates what is thought to be the beginning of the oscillatory curve. The dotted line parallel to the X-axis indicates the normal reading taken just before the stimulation of the eye was begun. A point below the normal dotted line indicates an increase in sensitivity of the retina or enhancement and a point above, a decrease in sensitivity or inhibition.

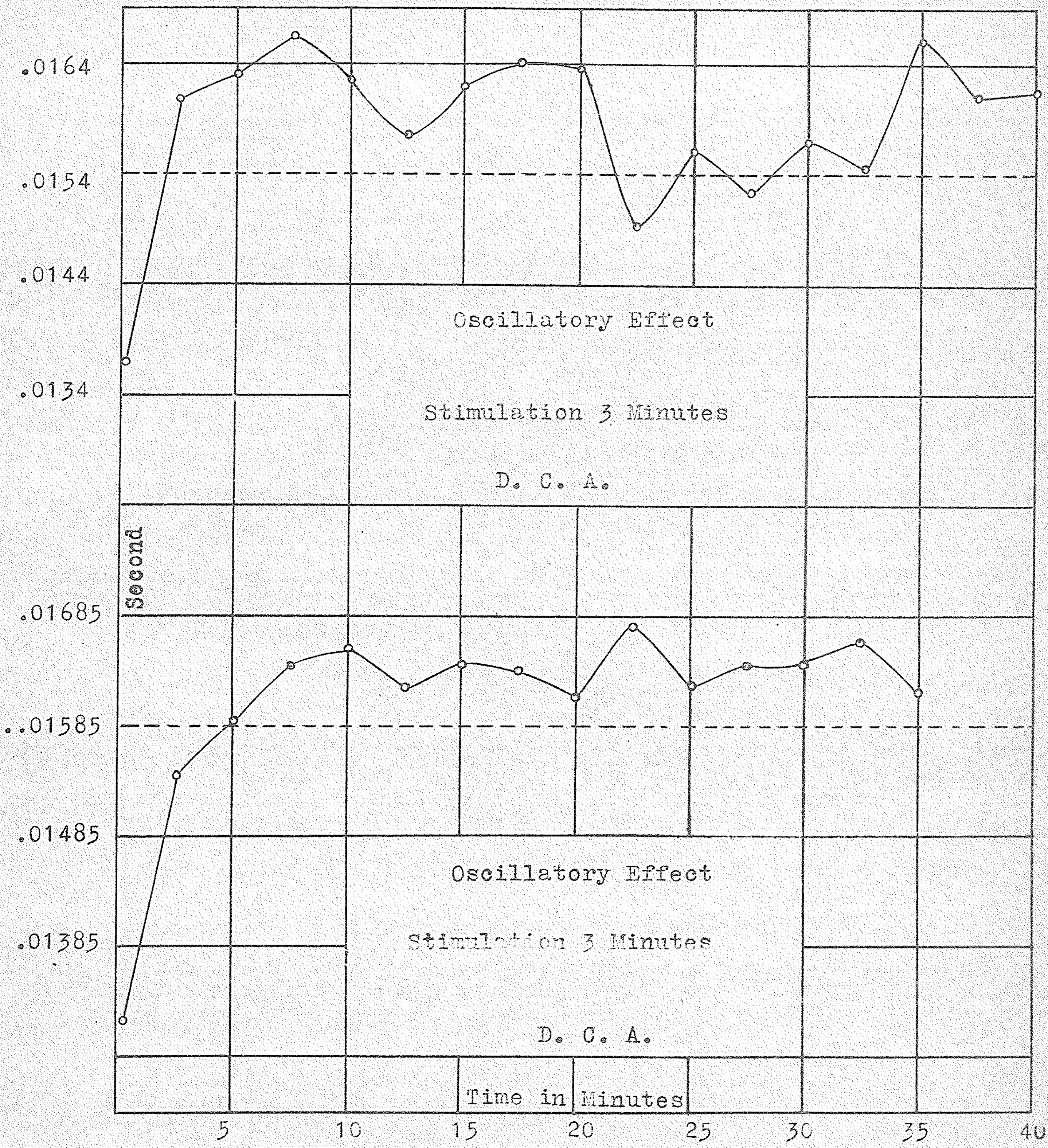
In Fig. 8, there are two oscillatory curves for one minute stimulation of the eye. Immediately after stimulation the sensitivity is enhanced. A point is obtained at a considerable distance below the normal dotted line showing the degree of enhancement. Both upper and lower curves show well defined oscillations for a period of 30

3 minute stimulation of right eye with .687 μ

measurements made with .687 μ on right eye.

D. C. A.

D (sec.)	Time (after stimulation	D (sec.)	Time (after stimulation
.01540	Normal reading	.01585	Normal reading
.01370	10 (sec.)	.01316	10 (sec.)
.01606	2.5 (min.)	.01540	2.5 (min.)
.01630	5.0	.01590	5.0
.01665	7.5	.01640	7.5
.01625	10.0	.01655	10.0
.01375	12.5	.01620	12.5
.01620	15.0	.01640	15.0
.01640	17.5	.01635	17.5
.01635	20.0	.01610	20.0
.01493	22.5	.01675	22.5
.01560	25.0	.01620	25.0
.01523	27.5	.01640	27.5
.01566	30.0	.01640	30.0
.01545	32.5	.01660	32.5
.01660	35.0	.01615	35.0
.01610	37.5		
.01615	40.0		



Right eye stimulated with wave length .687 μ

Measurements made on right eye with wave length .687 μ

FIG. 10.

minutes after stimulation.

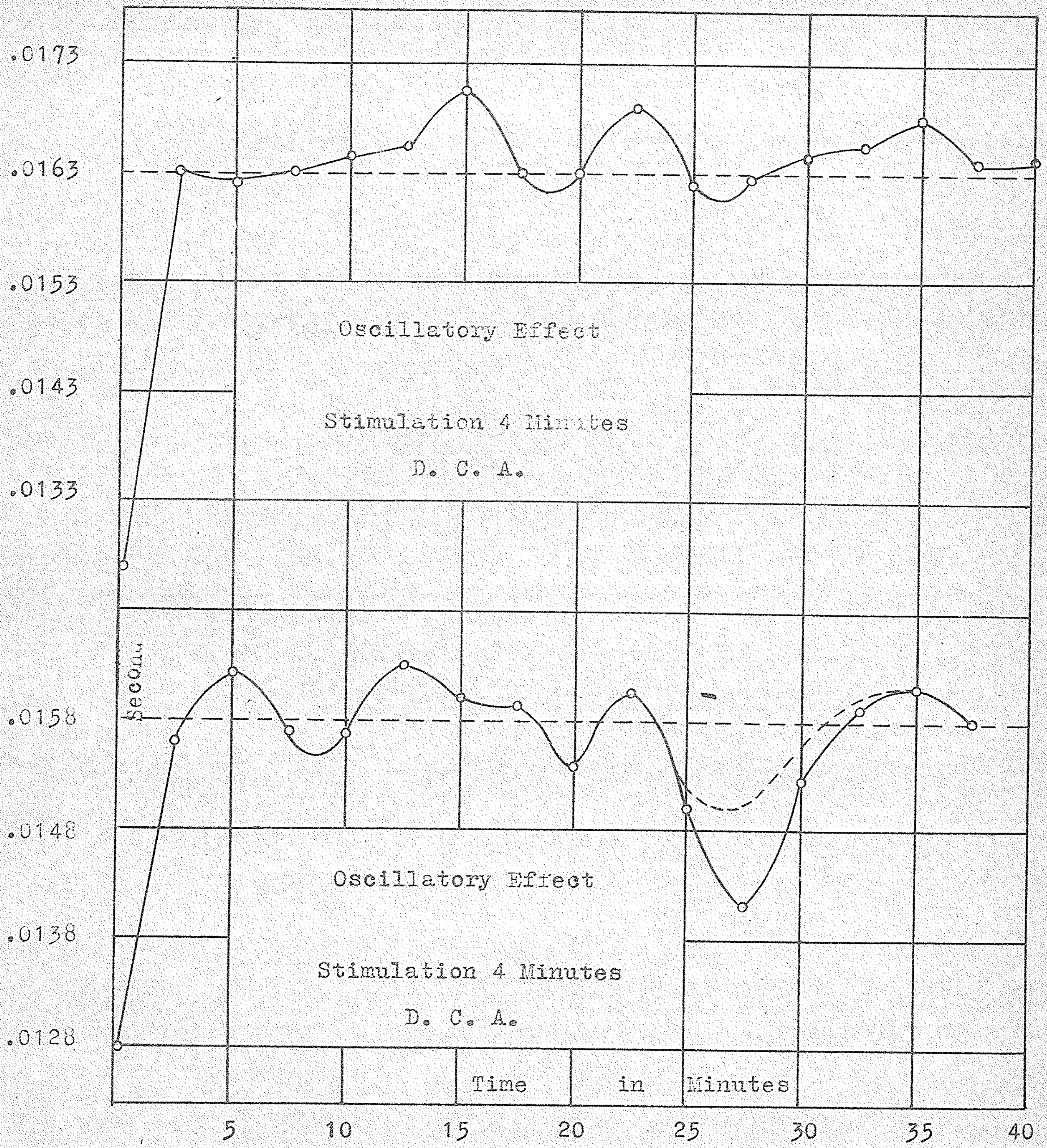
Fig. 9 is the oscillatory effect of a 2 minute stimulation. Again in both curves, the reading taken immediately after stimulation indicates enhancement. In the upper curve, the point at 5 minutes after stimulation indicates enhancement, but at a time of 7.5 minutes the curve indicates inhibition. A higher inhibition point appears at 15 minutes. Another point of almost equal inhibition appears at 22.5 minutes. It will be noticed that the parts of the curve below the normal indicating enhancement gradually increase in amplitude as we pass to the right. The lower curve in the same figure shows the same characteristics. The enhancement increases and the inhibition decreases. If a smooth curve were to be drawn between the highest and lowest points of all the oscillations, a second curve would be obtained, which in the case of the upper curve, Fig. 9, the part of it in inhibition extends for a period of 30 minutes. It is thought that if the readings were taken for an additional period and the smooth curve extended, that it would represent a periodicity of which part would be inhibition and another part enhancement. Thus we may say that we have a periodicity within a periodicity. Again in the lower curve, Fig. 9, we have a periodicity within a periodicity exactly similar in character. In both of these curves we have well defined pscillations.

4 minute stimulation of right eye with .687 μ

measurement of D made with .687 μ on right eye.

D. C. A.

D (sec.)	Time (after stimulation)	D (sec.)	Time (after stimulation)
.01630	Normal reading	.01580	Normal reading
.01270	10 (sec.)	.01280	10(sec,)
.01630	2.5 (min.)	.01560	2.5 (min.)
.01620	5.0	.01623	5.0
.01630	7.5	.01570	7.5
.01645	10.0	.01566	10.0
.01655	12.5	.01630	12.5
.01710	15.0	.01600	15.0
.01630	17.5	.01593	17.5
.01630	20.0	.01536	20.0
.01690	22.5	.01610	22.5
.01620	25.0	.01600	25.0
.01625	27.5	.01410	27.5
.01645	30.0	.01525	30.0
.01655	32.5	.01590	32.5
.01680	35.0	.01610	35.0
.01640	37.5	.01580	37.5
.01645	40.0		



Right eye stimulated with wave length .687 μ

Measurements made on right eye with wave length .687 μ

FIG. 11.

In Fig. 10, we have two oscillatory curves for a 3 minute stimulation of the eye. By drawing a smooth curve through the oscillations as described above we are able to obtain three branches. Immediately upon stimulation we obtain the characteristic point in enhancement with a sudden rise in the curve to inhibition. The curve lowers to inhibition at 27.5 minutes after stimulation again rising to inhibition for the last branch. This illustrates the periodicity within a periodicity very well. The lower curve in the same figure does not show as decided oscillations as the upper curve. All the oscillations in this curve except the first part of the curve represent inhibition; i. e., varying degrees of inhibition.

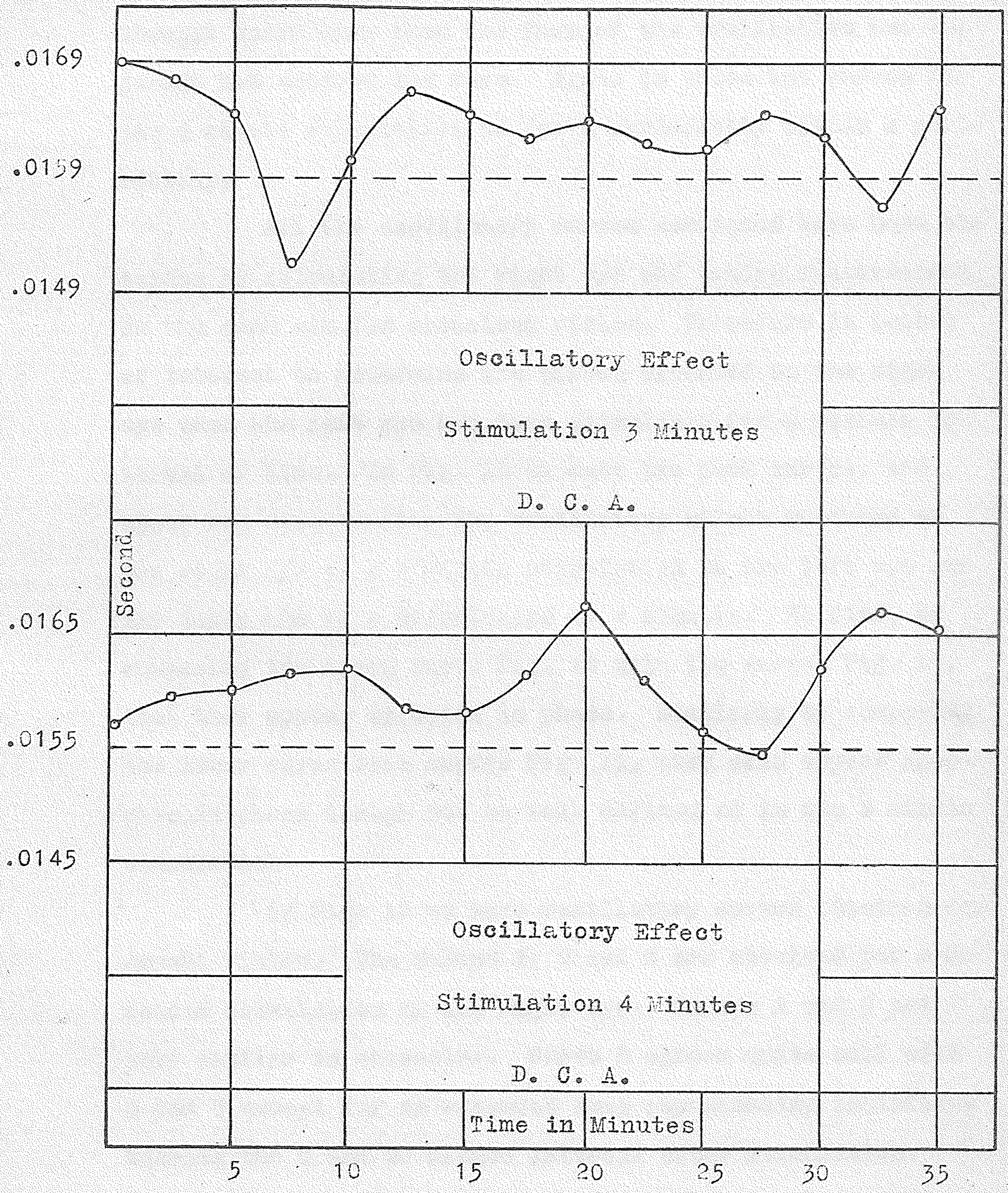
Two oscillatory curves for a stimulation of 4 minutes are plotted in Fig. 11. Both the upper and lower curves show oscillations above and below the normal. The first point, obtained immediately after stimulation, shows greater enhancement than any of the previous curves. In the lower curve at the time 27.5 minutes we have a decided depression. At the time, 24 minutes after stimulation, a person entered the laboratory where these measurements were made, walked across the room, back again and then left without uttering a word. It is thought, however, that there was a certain effect produced upon the nervous system which shows in the oscillatory curve. The dotted line indicates what is

Stimulation of left eye with .687 µ

measurements made with .687 µ on right eye.

D. G. A.

3 minute stimulation		4 minute stimulation	
D (sec.)	Time (after stimulation)	D (sec.)	Time (after stimulation)
.01590	normal reading	.01550	normal reading
.01690	10 (sec.)	.01670	10 (sec.)
.01675	2.5 (min.)	.01595	2.5 (min.)
.01645	5.0	.01600	5.0
.01515	7.5	.01615	7.5
.01605	10.0	.01620	10.0
.01665	12.5	.01585	12.5
.01645	15.0	.01583	15.0
.01625	17.5	.01615	17.5
.01640	20.0	.01675	20.0
.01620	22.5	.01610	22.5
.01615	25.0	.01565	25.0
.01645	27.5	.01545	27.5
.01625	30.0	.01620	30.0
.01565	32.5	.01670	32.5
.01650	35.0	.01655	35.0



Left eye stimulated with wave length .687 μ

Measurements made on right eye with wave length .687 μ
FIG. 12.

thought would have been the form of the oscillation had the person not entered the room. Again in these two curves for the 4 minute stimulation we get a periodicity within a periodicity.

All the oscillatory curves mentioned have been obtained by stimulating the right eye and taking measurements on the same eye for anomalous vision. Therefore it became of interest to determine the effect produced on the right eye when the left eye had been stimulated for a certain interval of time. In Fig. 12 we have two such curves, the upper one representing the oscillatory effect produced on the right eye by a 3 minute stimulation on the left eye and the lower one by a stimulation of 4 minutes. We find, by comparing the upper curve Fig. 12 with the curves Fig. 10, that they appear opposite in phase. Similarly by comparing the lower curve with curves Fig. 11, they also appear opposite in phase though not as well defined as in the 3 minute stimulation.

In Fig. 13 we have oscillatory curves obtained for normal vision. The curves A, B and C are obtained for a 30 second stimulation on the right eye. Curves A and C are very similar in character. Curve B agrees quite well with A and C except for an extended loop representing inhibition between the 5 and 20 minute interval after stimulation. Curves D and E, Fig. 13 and A and B, Fig. 14, represent

OSCILLATORY CURVES.

30 seconds stimulation of right eye with .667 μ.

Measurements made on right eye with wave length .667 μ.

R. A. L.

Curve A. D (sec.)	Time (after stimulation)	Curve C. D (sec.)	Time (after stimulation)
.01700	normal reading	.01750	normal reading
.01690	4 (min.)	.01670	0.5
.01775	8	.01725	3
.01675	12	.01750	6
.01700	16	.01775	9
.01750	20	.01800	12
.01725	24	.01700	15
.01675	28	.01790	18
Curve B.		.01770	21
.01700	normal reading	.01750	24
.01670	3	.01750	27
.01730	5	.01736	30
.01760	10		
.01740	15		
.01700	20		
.01654	25		
.01725	30		
.01640	35		

Oscillatory Curves.

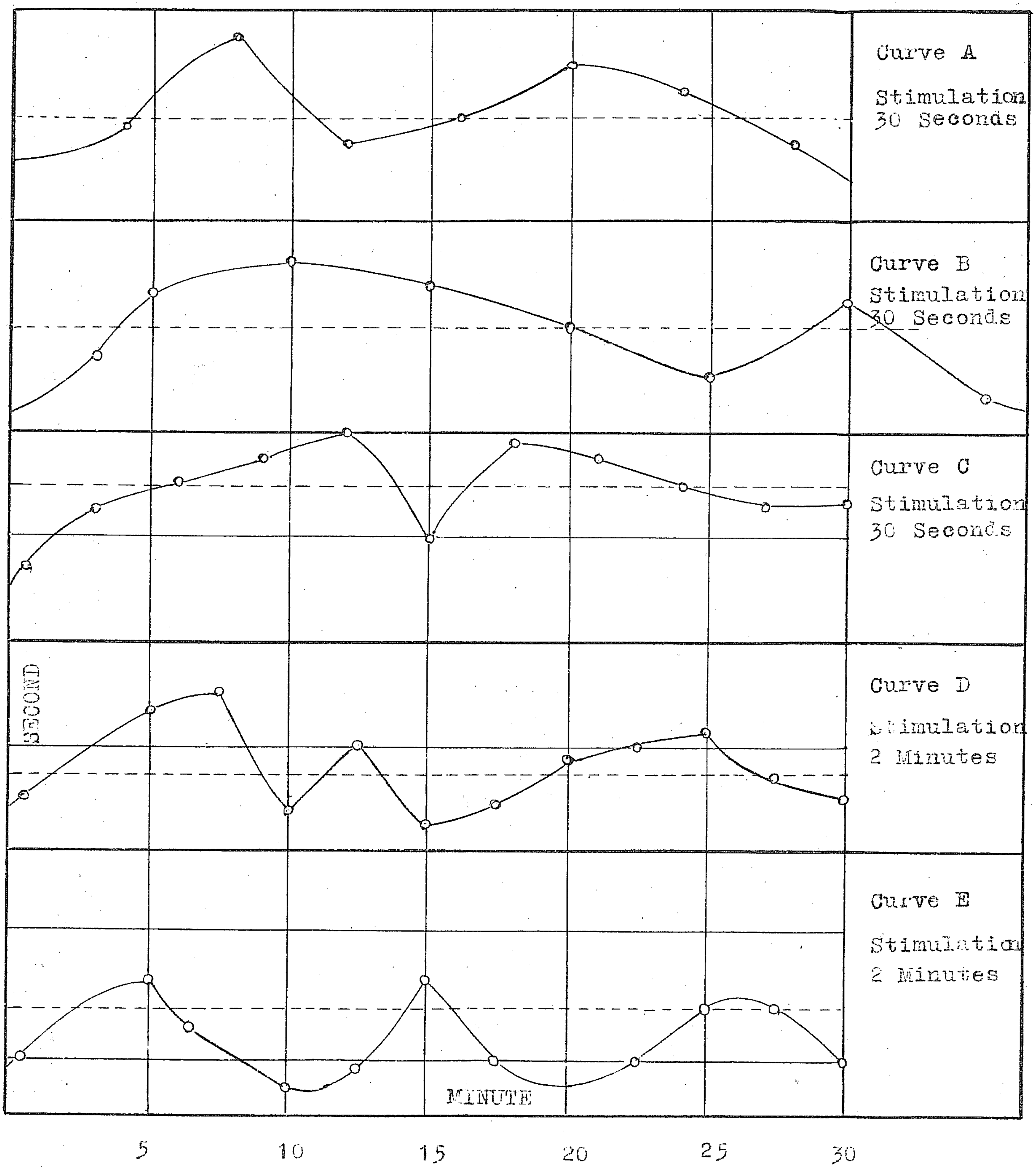
R. A. L.

Right eye stimulated for 2 minutes with wave length .667 μ.

Measurements made on right eye with wave length .667 μ.

Curve D		Curve E		Curve A	
D(sec.)	Time	D(sec.)	Time	D(sec.)	Time
.01675 normal		.01650 normal		.01675 normal	
.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	.01660	15.0
.01687	20.0	.01600	22.5	.01670	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			.01650	27.0
				.01625	30.0

OSCILLATORY CURVES R. A. L.



Right eye stimulated with wave length .687μ

Measurements made on right eye with wave length .687μ

Fig. 13.

oscillations for a 2 minute stimulation. We have well defined oscillations from which we are able to show a periodicity within a periodicity.

Curve C, Fig. 14, shows the oscillatory effect produced in the right eye when the same eye has been stimulated with white light for 15 seconds.

In curve D, there is an oscillatory effect produced in the right eye by a stimulation of 3 minutes in the left. We have no other curve for normal vision of the same time of stimulation with which to compare. It is thought, however, that a similar characteristic would be displayed as in anomalous vision, i. e., it would appear opposite in phase.

A curve, (Fig. 15), for normal vision was obtained, readings being taken continuously for a period of 15 minutes on the right eye. The right eye was first stimulated for 2 minutes. It will be seen that the curve consists of a large number of oscillations. In all probability, some of the smaller oscillations are due to experimental error, but undoubtedly the larger oscillations are true oscillations. The curve gradually rises from enhancement to inhibition, which is exactly what is to be expected since, first, we have a stimulation, then measurements are made under constant stimulation, though of less intensity than the primary stimulation. After the general form of the curve rises to in-

Oscillatory Curves.

R. A. L.

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

Right eye stimulated with white light for curve C.

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

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

Curve B		Curve C		Curve D	
D(sec.)	Time	D(sec.)	Time	D(sec.)	Time
.01675 normal		.01625 normal		.01700 normal	
.01650	0.5	.01600	0.5	.01750	0.5
.01675	2.5	.01625	3.0	.01700	2.5
.01700	6.0	.01610	5.0	.01770	5.0
.01656	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	.01675	25.0
.01625	25.0	.01750	30.0	.01750	27.5
.01612	27.5	Stimulation 15 sec.		.01825	30.0
.01590	30.0			Stimulation 3 min.	
.01625	32.5				
.01650	35.0				
Stimulation 2 min.					

OSCILLATORY CURVES R. A. L.

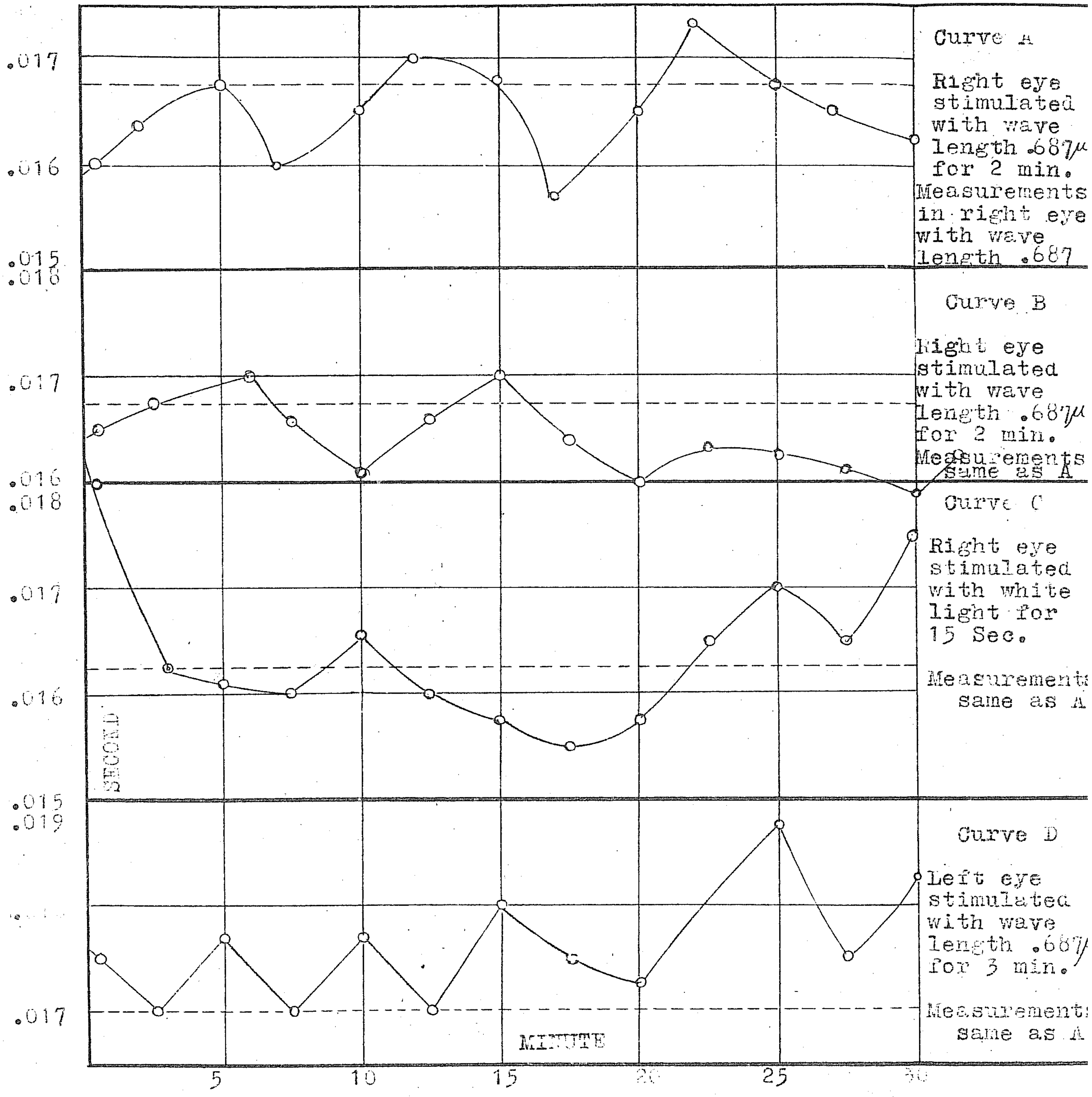


Fig. 14.

hibition, it remains on the inhibitory side of the normal, there being certain oscillations in the degrees of inhibition.

Sufficient data has been obtained for both anomalous and normal vision to definitely establish a visual oscillatory effect. We may use the analogy of a pendulum coming to rest to explain the oscillatory effect as was done in the case of the muscle experiment. Whenever the nervous system is disturbed, it tends to restore itself, but in doing so, does not stop at the normal condition but goes past it. Thus when the eye has been stimulated, the reading taken immediately after represents enhancement. The inhibitory forces tend to restore the visual nervous system to the normal condition, but in doing so, the normal is reached and passed, as indicated by readings taken which represent inhibition. Then the enhancing forces are brought into play, acting in the opposite direction to the inhibitory. Thus we have the curve, which represents the sensitivity of the retina, oscillating until the normal balance between the inhibitory and enhancing forces is restored. The oscillations in the curve would become continually smaller until the normal reading was constant, i. e., theoretically.

There is a certain effect produced upon the retina by the light with which measurements are made. This light, which is probably of β — intensity, will produce an oscilatory effect itself. This however, would be small compared

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

Measurements made continuously on right eye with .687 μ.

R. A. L.

D	T	D	T	D	T
.0151	13.2	.0185	352.2	.0191	773.3
.0154	19.3	.0183	359.7	.0188	780.8
.0149	25.4	.0183	367.1	.0184	788.3
.0164	31.6	.0178	374.1	.0188	795.8
.0164	44.7	.0178	381.1	.0188	803.3
.0164	51.3	.0178	388.4	.0190	810.8
.0156	57.7	.0185	395.7	.0175	818.1
.0166	64.17			.0189	825.3
.0155	70.6	.0179	471.6	.0188	832.9
.0170	77.1	.0189	478.6	.0186	840.4
.0165	83.4	.0178	486.2	.0189	847.8
.0166	90.0	.0194	493.1	.0185	856.3
.0168	96.0	.0190	500.7	.0178	862.6
.0165	103.2	.0188	508.3	.0195	866.5
.0166	109.9	.0188	515.8	.0193	870.0
.0169	116.6	.0188	523.3		
.0159	123.2	.0188	530.8		
.0153	129.1	.01825	538.2		
.0167	135.9	.0188	545.6		
.0180	142.4	.0188	553.1.		
.0159	149.7	.0190	560.7		
.0166	156.2	.0189	568.4		
.0160	162.7	.0186	575.8		
.0163	169.6	.0185	583.1		
.0175	176.8	.0185	590.7		
.0175.	183.9	.0190	598.2		
.0175	186.9	.0188	605.8		
.0178	191.0	.0193	613.4		
.0181	198.1	.0190	621.0		
.0174	205.3	.0193	628.7		
.0179	212.4	.0199	636.5		
.0184	219.7	.0194	644.3		
.0175	226.9	.0193	652.1		
.0179	233.9	.0203	660.0		
.0171	240.9	.0188	667.8		
.0179	248.4	.0193	675.4		
.0165	263.7	.0183	682.8		
.01675	271.3	.0193	690.4		
.0180	278.9	.0183	697.9		
.0180	286.1	.0191	705.3		
.0183	293.4	.0186	712.8		
.0180	300.6	.0180	719.6		
.0183	307.9	.0198	727.7		
.0187	315.3	.0198	735.6		
.0183	322.7	.0198	743.5		
.0193	330.2	.0190	751.2		
.0175	337.8	.0187	558.3		
.01888	344.8	.01750	766.0		

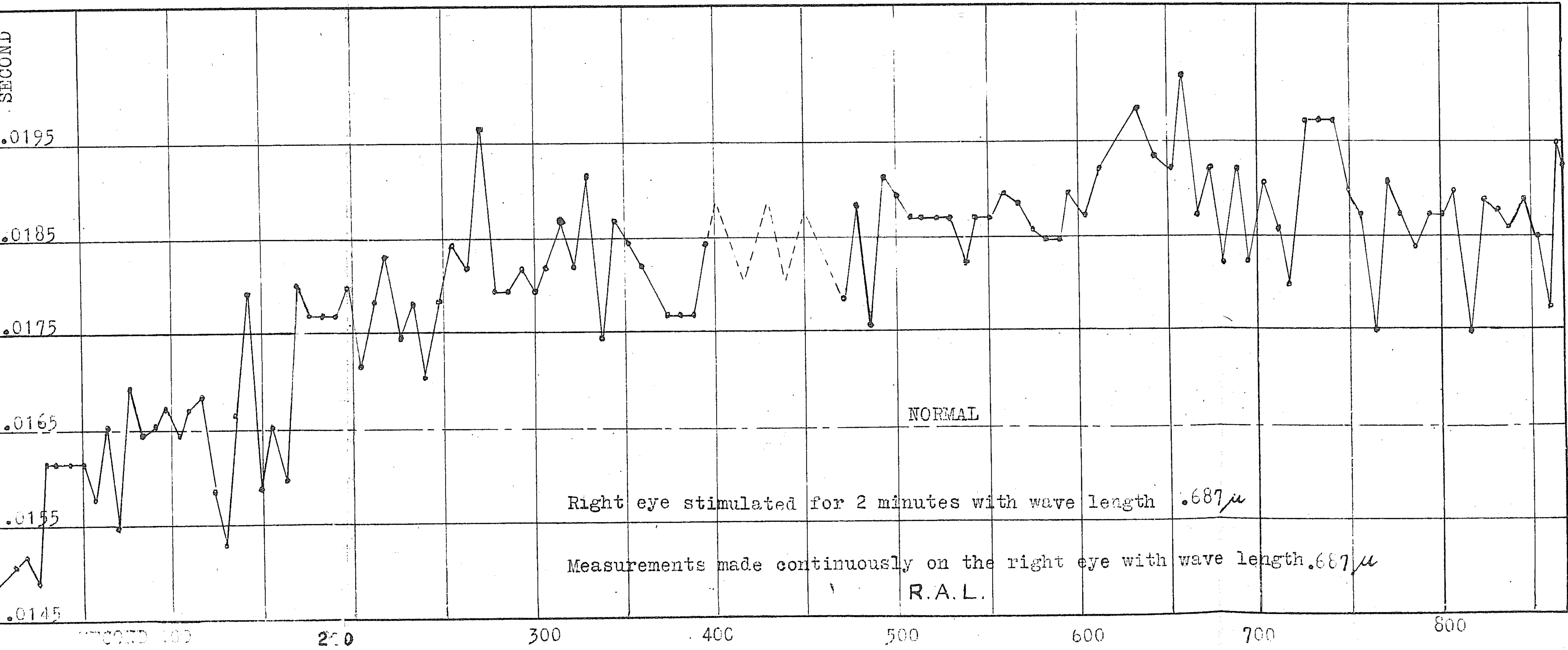

SECOND
.0195
.0185
.0175
.0165
.0155
.0145
NORMAL
Right eye stimulated for 2 minutes with wave length .687μ
Measurements made continuously on the right eye with wave length .687μ
R.A.L.
200
300
400
500
600
700
800

Fig. 15

with the oscillatory effect produced by the primary stimulus. Readings were made every 2.5 minutes so that the effect must necessarily be small. In Fig. 15, an effect of the light of β — intensity must be produced since the eye is being continually stimulated for a period of 15 minutes. In all the other oscillatory curves the eye is rested between each reading.

Roaf[1] has studied the sensitivity of the eye for light of various wave lengths by employing threshold values. In his paper, he states: "The threshold for a spectral region was measured by a photometric wedge and one collimator of the double apparatus used for color discrimination measurements. The increase in the threshold as a result of exposure to a bright light was considered to be a measure of the decrease in sensitivity. As there was always a variable time-interval between the end of the exposure to the bright light and the measurement of the threshold, a second series of measurements were made, in which the movements of the photometric wedge were recorded on a smoked drum along with a time-marker and a signal. The signal was operated at the end of the pre-exposure, and again whenever the light of the spectroscope was seen to just vanish from the centre of the after image, due to the exposure to the bright light. Readings were continued until the sensitivity had practically returned to its resting value. By this method the recovery

[1] Quar. Jo. Exp. Physiop. Vol. XVIII, 1927.

curve could be drawn and some idea of the initial effect obtained. Some of the records suggest that the recovery is phasic .... "

The "phasic recovery" is evidently an example of the visual oscillatory effect. Roaf, however, seems not to have attached any particular significance to the phenomenon.

Parsons[1] records under the title of recurrent vision, that the sensational response to a single short-lived stimulus is not a single, equally short-lived light sensation. Except in the case of a very feeble stimulus it is a "series of pulses of sensation of diminishing intensity rapidly succeeding one another" . C. A. Young found that when a discharge from a powerful electric machine momentarily illuminates a room the objects may be seen, not once only, but two, three, or four times in rapid succession, although the spark is single. Thus we observe that a stimulus gives rise to a rhythmical response.

Parsons, further states, that analogy with other physiological processes would lead us to the conclusion that the positive after-images results from a persistence of those processes which have been set in action by the primary stimulus, and that the negative after-image

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[1] Color Vision - J. H. Parsons

is the expression of a diminished excitability of the stimulated area to fresh stimuli. Under suitable conditions, with the eyes motionless, the negative image disappears and reappears at intervals of three or four seconds, sometimes alternating with positive images. With prolonged or strong stimuli, the condition of altered sensibility of the affected part of the retina may persist materially longer than the apparent after-image.

The above is just another illustration of the oscillatory effect.

Experiments on the cutaneous sensation had been conducted some time previously to this work on the visual oscillatory effect. The fingers of one hand were immersed in a beaker of hot water, kept at a constant temperature. The water was uncomfortably warm but not hot enough to cause injury tom the skin. It was found that there were intervals in which the fingers felt alternately hot and cold. The fingers of the other hand were treated in a similar manner. The effect of a cold bath was tried. Thev fingers of one hand were immersed in this bath and again we obtained intervals of alternately cold and warm sensations. This is a fine example of the oscillatory effect in the cutaneous sensation.

Depression and enhancement of other sensations has been obtained by other investigators. We consider that sufficient information has been gained to believe that a similar phenomenon exists in every sense organ.

In certain industrial factories, employees are given periods of rest in the morning and afternoon, the employers having found that more satisfactory work is accomplished. This is evidently an application of the oscillatory effect although the employers are probably not aware of the phenomenon and its scientific explanation.

Discussion of Persistency Curves and Theoretical Considerations

From the results obtained for the three general types of vision i.e. normal, anomalous and color blind vision we are able to formulate a theory of color vision to account for all three types. This theory is a modification of the Young-Helmholtz theory.

From the fact that any color sensation could be produced by a mixture, in suitable proportions, of light of three given wave lengths, Thomas Young was led to suppose that there existed three primary color 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. 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, it is supposed that each set of nerves, thev 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 affected not only by red light but also, to a smaller extent by light of other wave lengths, the impression producedoon the brain is,phowever always that of red light.

To explain color blindness, it was assumed that one or more of these sets of nerves is missing depending upon the number of sensations in which the person is color blind. Thus a red blind person is one in which the red nerves are insensitive. Hence such a person was assumed to possess only the violet and green sensations.

There are seven possible types of color blindness according to the Young-Helmholtz theory. A person may be color blind in any one of the three sensations, red, green or violet, or a combination of any two or color blind in all three sensations to which the appellation of total color blindness has been applied. Six out of the seven possible cases have been found,[1] the only case not having been found is that for violet blindness.

Persons with normal color vision and of not widely different ages have the same persistency curve under similar circumstances. The persistency curves of the

[1] Allen. Phys. Review 1902.

color blind always have the characteristic elevations either one or two in number, which occur in general in those portions of the curve corresponding to the red, green and violet regions of the spectrum.

In order to explain color blindness on a modified form of the Young-Helmholtz theory, we are not assuming that one or more of the primary sensations or sets of nerves is missing , but that the inhibitory actions for the sensation in which the person is color blind are excessively developed over the enhansing actions. Thus the person is sub-sensitive in the particular sensation or sensations in which he is color blind. This may readily be observed by the two elevations in the red and violet regions for the red-violet color blind person in Fig. 4. Now in this case, inhibition is developed to a greater degree than enhancement for these sensations, while for the green sensation , inhibition and enhancement are equally developed as in the normal eye. It will be noticed that the curve for the color blind person does not coincide with the curve for normal vision in the green region. This is due to lack of experience in taking readings for the curve. With readings taken for a period of three weeks or more, it is found that there is a lowering of the curve to a minimum value. Thus the readings for thecurves of normal and anomalous vision were taken for a sufficient period of time to determine this minimum value while for the color blind person they were not. In order to observe more easily the departures from the curve for normal vision, the curves are plotted at the bottom of Figs. 3 & 4. An arbitrary value of 100 is given to the curve for normal vision and the other two curves plotted correspondingly.

For anomalous vision or as **this** phenomenon of color vision is usually referred to, anomalous trichromatism, we see from the curves Fig.4 that there are **two** depressions in the red and green regions. The orange part of the curve coincides with the curve for normal vision. The violet region of curves for both anomalous and normal vision coincide exceptionally well. There is however a slight elevation between the green and violet i.e. in the blue.

Since an elevation in the persistency curve above the normal indicates a decrease in sensitivity, we may therefor term the anamalous vision as super-sensitive in the red and green sensations and normal in the violet. The term anomalous trichromatism is rather misleading as one would naturally think that the vision was anomalous in all three sensations whereas it is abnormal in the two, red and green sensations only and normal in the third, violet.

In accordance with our theory explaining the types of color blindness, we are also able to explain anomalous vision satisfactorily . In the red and green sensations the enhancing actions are developed to a greater degree than the inhibitory and therefore in these two sensations the person possessing anomalous vision is super-sensitive. In the violet sensation we have a normal state existing i.e. equally developed inhibitory and enhancing actions.

This theory is further supported by the results obtained from the oscillatory effect. By comparing the curves in Figs. 9 & 13 we observe that for the same time of stimulation with the same wave length of light .687 μ. the reading taken immediately after stimulation shows far greater enhancement for anomalous vision than for normal vision. Thus we have a greater sensitivity in the red and green sensations for anomalous than for normal color vision.

We may now term color blind vision as sub-sensitive vision and anomalous as super-sensitive vision in the particular sensations where elevations and depressions occur respectively.

Since there have been over eighty theories of color vision formulated, it simplifies matters to have one theory which satisfactorily explains the three general types of vision. We must not assume however, that we have the complete truth, but by being able to explain the three general types of vision on the modified form of the Young-Helmholtz is a decided step towards it.

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April 1928.