A DISCUSSION OF A POSSIBLE RELATION AMONG THE CONSTANTS OF THE PORTER EFFECT ALONG WITH FOVEAL AND PERIPHERAL LUMINOSITY CURVES FOR AN ANOMALOUS TRICHROMAT ON SPECTRA OF DECREASING INTENSITIES.

H. A. BLAIR.

A thesis submitted to the University of Manitoba as a partial requirement for the Master of Science degree.

April 1927.

This is a part of the work being done or directed by Professor Frank Allen on the application of physical measurement to investigations on the organs of sense. The writer wishes to record his appreciation of Professor Allen's teaching in the art of research.

SECTION 1

A PROBABLE RELATION OF THE CONSTANTS IN THE PORTER EFFECT.

A PROBABLE RELATION OF THE CONSTANTS
IN THE PORTER EFFECT

It has been confirmed by many observers that the Ferry-Porter law (1),

$$1/D = K \log I + C$$

represents the relation between the intensity of a light stimulus, I, and the critical frequency of flicker 1/D, where D is the duration of an individual stimulus when a succession of like stimuli are frequent enough to give a continuous sensation.

Recently it has been shown by Allen (2) that instead of there being only two branches in the graphical representation of the law on semi-logarithmic scale that there are in some cases at least four or five branches if the intensity range is large enough. Allen has named the branches by means of Greek letters in alphabetical succession, the first branch for the lowest intensity being called the alpha branch, and the corresponding range of intensity, the alpha intensity. He has also called the phenomenon represented by the Ferry-Porter law the Porter effect, and the graph for any particular color a Porter graph.

(1) Ferry, Am. Jour. Sci, 3 p. 44; 1892.
    Porter, Proc. Roy. Soc., 70, p. 313; 1901.

(2) J.O.S.A. & R.S.I. 13, Oct. 1926.

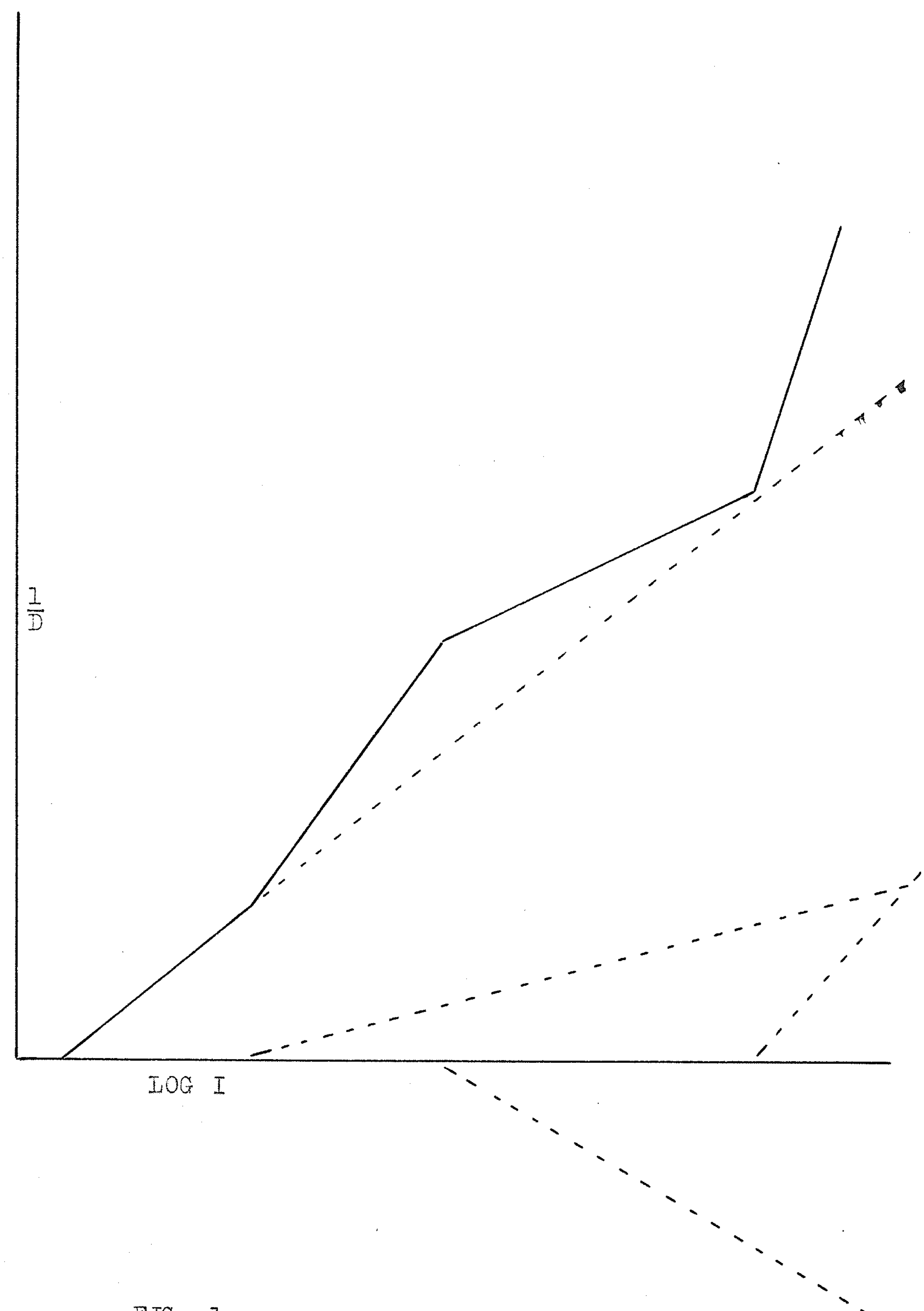


FIG. 1

A Porter graph has the form shown by the full line in fig. 1. It is evident that it may be considered to be built up of the dotted components, and it is not improbable that the graph does actually represent the summation of a number of actions with different thresholds.

After obtaining the alpha branch, which represents the initial reaction after vision starts, and which may be represented by the equation,

$$n_1 = k_1 \log I - c_1$$

it is seen that the beta branch may be due to the entrance of a new reaction,

$$n_2 = k_2 \log I - c_2$$

which is added to the initial reaction to give the complete effect shown by the beta branch.

The likelihood that this is true is supported by the fact that the alpha branch and the beta branch have always been found to meet, and it may be readily imagined that cases would arise in which they did not meet if each represented an independent reaction. That is, cases might be expected where there would be a "blind", interval if the alpha reaction stopped too soon, or if the beta reaction did not start as soon as the alpha reaction stopped.

After crossing the beta interval of intensity the gamma branch, whose slope is smaller than that of the beta branch, may be considered to be due to the entering of a new reaction of the form,

$$n' = -k' \log I + c'$$

and in a similar way may all the branches be formed whatever their number, the particular type of equation used for each new branch being determined by whether the slope increases or decreases.

Since when $n = 0$ in the equations of the type,

$$n = k \log I - c$$

$$c = k \log I_0$$

where I_0 is the threshold intensity for this particular reaction these equations may be written in the form,

$$n = k \log I - k \log I_0$$

or

$$n = k \log \frac{I}{I_0}$$

Similarly when $n = 0$ in the equations of the type,

$$n = k \log I + c$$

$$c = k \log I_0$$

so that these equations may be written in the form,

$$n = -k \log I + k \log I_0$$

or

$$n = k \log \frac{I_0}{I}$$

Hence the equation of the complete Porter graph may be written,

$$n_1 + n_2 + \cdots\cdots + n' + n'' + n''' \quad \cdots\cdots = 1/D$$

$$= k_1 \log I/I_1 + k_2 \log I/I_2 + \cdots\cdots k' \log I'/I + k'' \log I''/I + \cdots$$

$$= \log \frac{I^{k_1 + k_2 + k_3 + \cdots\cdots}}{I^{k' + k'' + k''' + \cdots\cdots}} K$$

where K represents the product of the threshold values of I, or

$$1/D = \log I^{K_1 + k_2 + \cdots\cdots - k' - k'' - k''' - \cdots\cdots} \cdot K$$

which may be written,

$$1/D = C \log (I \cdot K)$$

where C and K take on new values for each branch. Also C will be slope of any branch when I is plotted on semi-logarithmic scale.

In regard to the slopes two cases may arise:-

(1) The k's may be all different and have no simple relation to each other, in which case the different values of C will have no simple relation.

(2) The k's may be all multiples of an elementary constant in which case will $C = c\,(m-n)$ where m and n are integers and c is the elementary constant.

If the second case be true the equation of any branch may be written,

$$1/D = c\,(m-n) \log (I \cdot K)$$

and this will give rise to three main conditions, viz.,

$(m-n) = 0$, $(m-n) =$ positive integer, and $(m-n) =$ negative integer. When $(m-n) = 0$ the equation will reduce to the form,

$$1/D = \log (I^0 \cdot K) = \log K$$

and $1/D$ will be a constant for a range of increasing intensities, i.e., the branch of the Porter graph under consideration will be parallel to the log I axis. This case has been found to occur in vision. (1)

When $(m-n) =$ positive integer the usual case in vision will occur, i.e., $1/D$ will increase as the intensity increases.

When $(m-N) =$ negative integer $1/D$ will decrease as the intensity increases. This case has been also found in vision (2) but is unusual. The corresponding measurements, however, on the gustatory organs have given this form of graph always.(3)

That these conditions exist supports the assumption that the Porter graph is built up in the way supposed, but they might also exist if the k's were independent, although the case $(m-n) = 0$ would be very unlikely, or rather the case of zero slope would be very unlikely.

(1) Ives, Phil.Mag., 24 p.352;1912.
Allen, Phil.Mag., 38 p. 81;1919.

(2) Ives, Phil.Mag., 24 p.352;1912.

(3) Allen & Weinberg, Quar.Jour.Exp.Physiol., 14, p. 351, 1924.

The conclusive evidence must be obtained from an examination of the slopes of a set of Porter graphs to see if they are of the form c(m-n) = c . integer.

The question immediately is raised as to whether the supposed elementary constant may be the same for all wave lengths, or if each wave length has a different one. The physical complexity of light, and the facts of color mixture perhaps point to the likelihood of there being a common constant for all lights since the constant, if it exists, is, no doubt, a property of the nervous system.

The first set of Porter graphs examined for this relation was Allen's (1). Unfortunately, as is usual with spectral measurements, the relation between the physical intensities for the different wave lengths is not known. That is the intensity range for the Porter graph of each wave length is probably different to the rest. The relation between the intensity ranges can only be obtained from a knowledge of the composition of the light used along with the dispersion of the instrument.

However, the slopes were measured as carefully as possible from a large scale graph with the object of seeing if the relation held good for each wave length at least.

(1) J.O.S.A. & R.S.I. Vol. 13, 1926.

The graphs used in making the measurements are those of fig. 2 and fig. 2(a). Fig. 2 is for measurements on the blue end of the spectrum and fig. 2(a) is for the corresponding measurements on the red end of the spectrum as indicated by the wave lengths on the right hand side of the sheets. 1/D is the critical frequency and log I is the logarithm of the intensity of the light on an arbitrary scale. As was pointed out before, the range of intensities for any one wave length is not likely the same as the range for any other and the relation is not known.

As will be noted, most of the lines are very accurately defined experimentally, and these were the only ones whose slopes were measured. Even in these cases, however, there remains often a certain amount of choice in the way the line may be drawn, but it is not to be expected that the error in these cases will be very large, especially with the longer lines. Apart from this the actual measurements were made to about two or three parts in one thousand in general, and since the vertical projection of each line was divided by the horizontal projection to get the slope in each case it is likely that the error in the slopes will not exceed .005 as far as measurement is concerned. No estimate can be made very well as to error due to latitude in drawing the lines, but probably the slopes can be considered to be accurate to

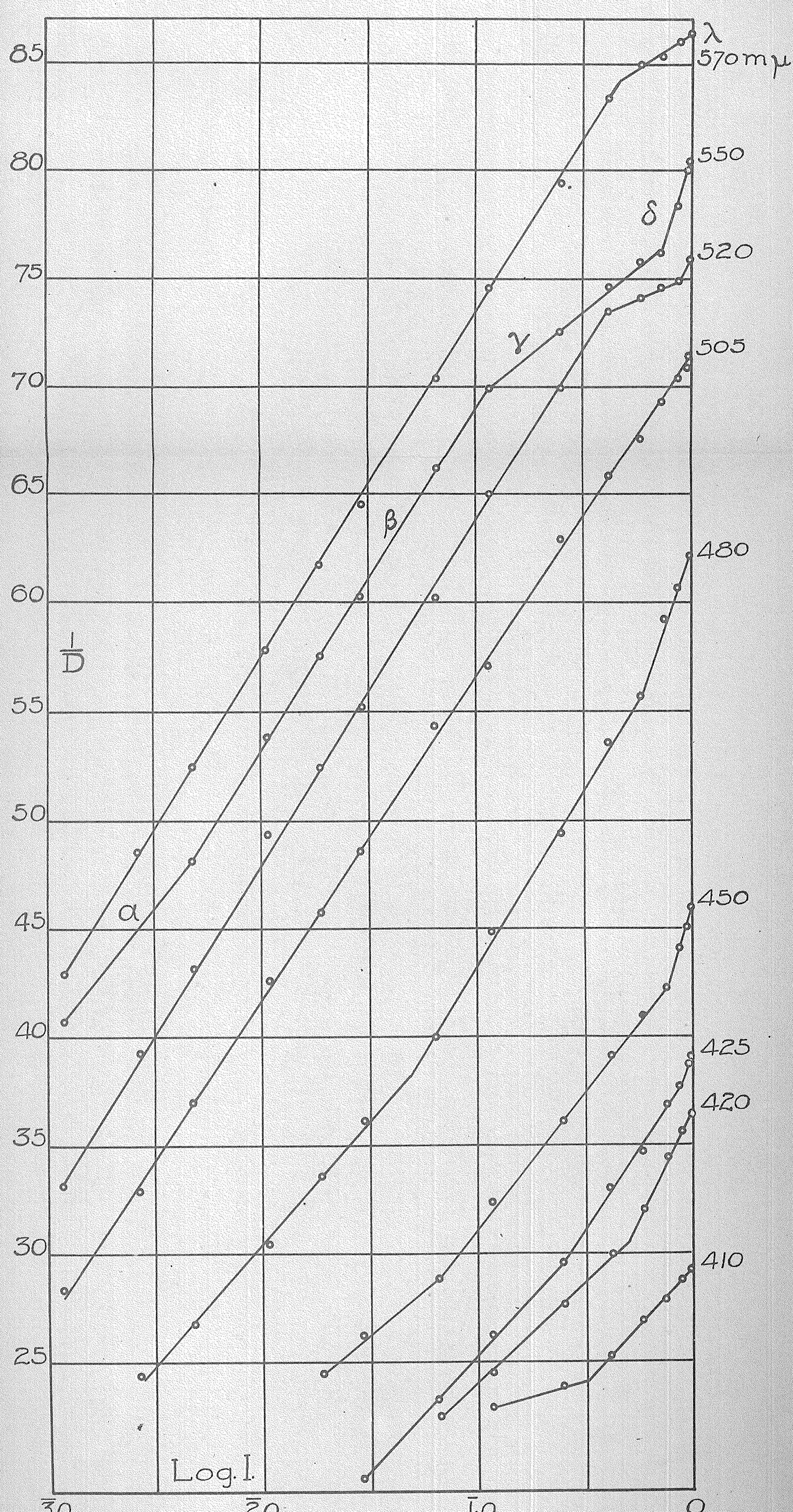

λ
570 mμ
550
520
505
480
450
425
420
410
α
β
γ
δ
1/D
Log. I.
85
80
75
70
65
60
55
50
45
40
35
30
25
$\bar{3}.0$
$\bar{2}.0$
$\bar{1}.0$
0

FIG. 2

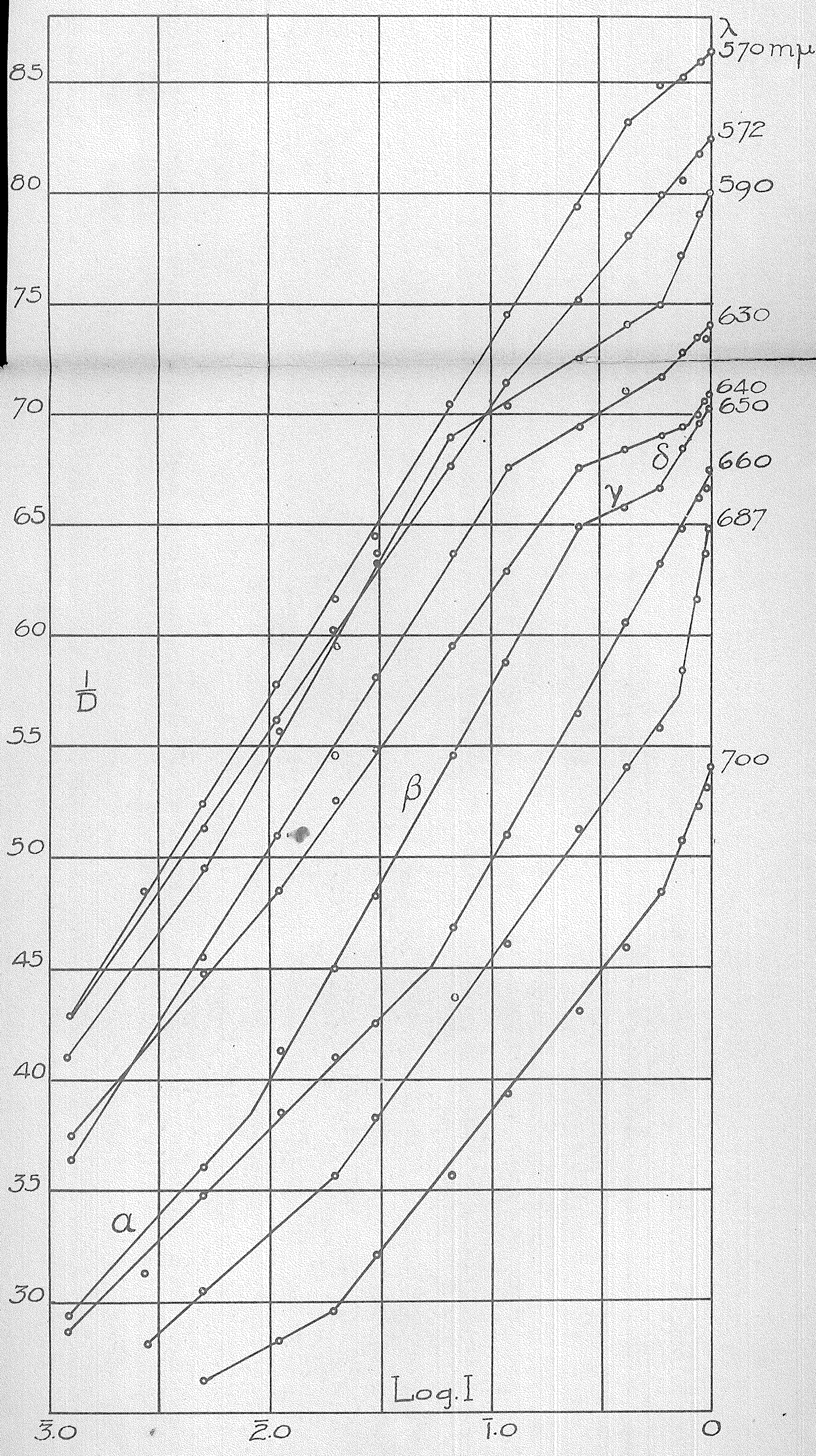

λ
570 mμ
572
590
630
640
650
660
687
700
85
80
75
70
65
60
55
50
45
40
35
30
$\frac{1}{D}$
α
β
γ
δ
Log. I
$\bar{3}.0$
$\bar{2}.0$
$\bar{1}.0$
0

FIG. 2 (a)

These graphs are better determined experimentally in general, probably, than those in vision, since the branches usually contain considerably more measured points. Thus the error in this case due to latitude in drawing the graphs is probably somewhat reduced. The measuring of the longer branches could be usually done to about two or three parts in one thousand, so the slopes of value about unity should not be inaccurate to more than about .002 or .003. With larger or smaller slopes the error may be a little greater than this.

It will be noticed on examining fig. 3 that the lower parts of graphs D and E are probably composed of two branches each instead of one as drawn there. When the slopes were being measured these were drawn as two separate branches in each case, although they were not very well defined, and the slopes are given in the table in that way.

A factor was sought for Hollenberg's first set of curves by taking differences between nearly equal slopes, as was done with the corresponding values in vision, thus:- .924-.911 = .013 .911-.858 = .053, which contains .013 four times approximately; hence .013 is a probable factor if the supposed relation exists. The advantage of doing this was that the method of obtaining the factor was independent of the factors of the slopes themselves.

The factor .013 was tried for that set of slopes, and was found to divide quite well as is shown in the table considering the accuracy of the slopes as previously discussed. c(m-n) is .013 times the integer which most nearly gives the value of the slope. The row marked "Difference" gives the difference between the measured slope and c(m-n) while (m-n) is the integer.

The same factor .013 was also tried on the two well defined branches of the lower curves in fig. 3, i.e., (D, 1 and E, 1, in the table) which are thought to represent the deep tactile response, and it was found to divide quite well. This was not particularly surprising, but it was very surprising to find that the same factor .013 divided not only into the slopes of all Hollenberg's graphs as evenly as could be expected, but that it divided equally well into Allen's slopes, and into Weinberg's. Allen's and Hollenberg's measurements were made on the fingers while Weinberg's were made on the lip, so not only does the factor appear to be applicable to different persons on the same parts of the body, but even to different parts of the body as well.

It is necessary to consider the probability of getting the results obtained if the slopes in reality are unrelated since this is about the only way of determining the soundness of the assumption that c is a factor of all the slopes, as has been indicated by the table. It will be remembered in the following discussion that c from the way it was determined has the property of being a factor taken at random as far as the measured slopes are concerned.

In all there were twenty measureable slopes that were considered to be sufficiently well defined. Since the factor is .013 the possible differences in dividing it into numbers taken at random are 0 plus or minus .001, plus or minus .002 .... .006, so there are thirteen possible differences and the probability of getting a 0 difference in any one division is one-thirteenth, and the probability of any other difference two-thirteenths.

In the following table is given the number of each of the various differences actually obtained along with the probable number if the slopes were unrelated.

Difference	Prob. in any one division	Prob. No. of these	Actual Number
0	1/13	20/13	4
.001	2/13	40/13	7
.002	Do.	Do.	4
.003	Do.	Do.	1
.004	Do.	Do.	1
.005	Do.	Do.	2
.006	Do.	Do.	1

It will be observed that the actual number of differences exceeds the probable number for the small differences, while the probable number exceeds the actual number for the large differences. This would indicate that the slopes are not unrelated, but are multiples of .013 as supposed. Furthermore, the probability of getting four 0 differences in twenty-two divisions of unrelated numbers by the factor .013 taken at random is,

$$_{20}C_4 \, (1/13)^4 \cdot (12/13)^{16} = .043 \text{ approx.}$$

and the prob bility of seven .001 differences under the same condition is,

$$_{20}C_7 \, (2/13)^7 \cdot (11/13)^{13} = .018 \text{ approx.}$$

and the probability of four .002 differences similarly is,

$$_{20}C_4 \, (2/13)^4 \cdot (11/13)^{16} = .187 \text{ approx.}$$

also the probability of these particular differences occurring together is the product of their separate probabilities, which is .00014 or 1/7000 approximately. And this is the probability of obtaining these small differencs, if the slopes be unrelated. But these differences are those unavoidable in measurement, and are the ones which indicate the assumption that .013 is a common factor to be true; hence the probability that the relation is not true is 1/7000. Thus it may be concluded with a fair degree of confidence that the slopes are all multiples of the common factor .013.

These results are extremely interesting in two ways, first, that the factor applies to fatigue curves and to enhancement curves in the same individual, and, second, that the factor applies to different individuals as well. The first result will now be considered.

In fig. 4, here, is a set of Hollenberg's graphs due in each case to measurements taken on the volar face of the terminal phalanx of the index finger. The differences of position of the graphs are due to fatigue or reflex enhancement effects, as described in the paper. It will be noticed from Table 2, where the slope relations are shown, that the only graph whose main branch is parallel to the normal is that of the graph D, which represents post-fatigue enhancement. The slopes of the remaining fatigue and enhancement curves are not parallel to the normal. If the view is adopted here, as it was in discussing vision and taste, that the total reaction shown by the graph is a sum of a definite integral number of a fundamental elementary reactionsof the form,

$$d = \pm c \log P/P_0$$

then from the above it may be concluded that fatigue or enhancement does not change only the thresholds, but it may change the number of the elementary reactions as well.

There is no evidence as yet in fact that change of threshold occurs at all in reflex effects.

That the same factor should apply to three different people equally well is either a remarkable co-incidence or an indication that part of the sense mechanism in all normal individuals is identically the same. The Porter effect itself is not the same in the cases considered here, i.e., the normal Porter graph of one person does not co-incide with that of another, nor is this to be expected since the availability of the receptors and perhaps their aggregation will, no doubt, be different in different individuals. What these results perhaps do indicate, however, is that the unit mechanism of the system which conveys the message to the brain is the same in all individuals.

Since it is generally conceded that the nervous system is not merely a conductor of energy from the receptor, but rather that the activation of the receptor does something analogous to the closing of a circuit, thus releasing an impulse whose energy is derived from within the nerve system itself, the conclusion reached above is perhaps not contrary to established opinion. If the nerve impulse should be an electric current derived from a sort of battery it is very probable indeed that the unit mechanism of conduction should obey the same laws in all persons since the electro-motive force of the battery would likely be independent of the conformation of the battery, and of the amount of the essential chemicals present, the two things which would perhaps be most likely to differ in different individuals.

Taking the results obtained from a consideration of all three of the senses together it is evident, as has been suggested, that one of the interpretations of the slope relations is that the Porter effect is due to the summation of integral numbers of like positive and negative elementary effects, which may begin at different thresholds. The idea of there being different thresholds is perhaps not unacceptable, but the idea of the elementary reaction does not seem to be in agreement with the "all or none" principle.

If a single one of these supposed elementary effects be considered alone its' origin may be taken mathematically to be at its' threshold intensity, so that the equation may be written,

$$r = c \log I.$$

There is no experimental evidence that this function is continuous, hence the successive ordinates may be considered to be due to the addition of small steps. On the "all or none" principle it might be assumed also that the successive values of the sensation would be due to the addition of the effects caused by individual nerve fibres functioning to full capacity. However, the increment in sensation due to the addition of the effect of an additional nerve fibre would likely be in each case the same. At the same time it would be expected that the same amount of external stimulus, i.e., the same amount of I would be required to cause the activity of each nerve fibre. Hence the increments in sensation would likely be due to equal increments in I. But this is not a logarithmic relation, and is incompatible with the relation above. However, it is equally incompatible with the Ferry-Porter law, which is well established; hence the "all or none" principle may be for the present neglected, unless it may include in its' scope the additional requirement that the nerve fibres are all different, and differ in such a way that the order of magnitude of their impulses is logarithmic. The complexity of this relation is further augmented by the requirement that as the intensity of the stimulus is increased the nerve fibres must come into activity in the specific order of their magnitude, giving on the whole a complexity not usually found.

There remains to interpret the equation,

$$r = c \log I$$

as representing a reaction r which is a continuous function of the intensity. This necessitates a mechanism working on a contrary principle to the "all or none" law. If the Porter effect is due to the summation of these effects in the manner supposed at the beginning of the section, the mechanism must be supposed capable of responding to the complete range of intensities encountered after its' threshold. However, since

$$\frac{dr}{dI} = c/I$$

it is evident that the rate of increase of the reaction with increase of intensity becomes smaller and smaller as I becomes larger and larger, so that the mechanism need not necessarily be considered to have an infinite capacity of reacting to stimulus.

Returning to the Porter effect with these assumptions it may then be considered to be due to the combined activity of integral numbers of these supposed mechanisms whose separate activities are represented by,

$$r = c \log I$$

and the only further requirement is that all the machanisms starting to react at any threshold have the effect of the stimulus equally divided among them, a requirement not opposed to conclusions drawn from probability considerations. Experimental confirmation of the truth of this hypothesis might be considered sufficient if it were shown that starting from one threshold Porter effects could be obtained, by varying such conditions as the area stimulated, whose graphs when plotted on semi-logarithmic scale would have slopes which were integral multiples of a factor. This has not been attempted for vision, but figs. 3 and 4 in this section, the touch graphs, indicate that the lower branches converge to a point, the required effect. Also in fig. 3 of Allen's and Weinberg's (1) paper on taste the taste graphs also converge to a point, but this latter evidence might be objected to on the ground that the converging graphs do not represent the same sensation. If a similar effect is obtainable in vision, the results will be very convincing in factor of the hypothesis unless other evidence exists which is opposed.

The "all or none" law, which was disregarded as being incompatible with previous assumptions can now be shown to be a possible special case of the hypothesis as follows:- It will be remembered that in the geometrical analysis of the Porter effect in vision that the equation,

$$1/D = c\,(m-n)\log I + K$$

was considered for the special case in which $(m-n) = 0$, i.e., where

$$1/D = \text{constant.}$$

This case was also shown to exist in vision. One example also occurs here (v. fig.3 sec. 2, wave length .64). In this case 1/D does not increase as the intensity increases and if, as usual, 1/D is considered a measure of sensation it will be readily seen that if this case were encountered alone it might be interpreted as indicating a general "all or none" law, for here the same response is elicited by a series of stimuli of increasing strength. These few cases in vision can only be considered as possible rather than

(1) The Gustatory Sensory Reflex. By Frank Allen & Mollie Weinberg. Quar.Jour.Exp.Physiol. Vol.XV, Oct. 1925.

probable explanations of the "all or none" principle, but they at least suggest a solution to a problem that has presented considerable difficulty.

The evidence that the elementary factor c of this discussion applies to all the taste sensation graphs and to all the touch graphs points to the probability that in vision the same factor will apply to the graphs of all the colors when they are plotted on equal intensity scale. The experimental verification of this supposition may be of considerable interest in connection with the elucidation of the problem of color, for since $1/D$ is conceded to measure luminosity the luminosity of a given green light for instance may be written,

$$L_g = c\ (m-n) \log (I \cdot K)$$

and the luminosity of a given red light may be written,

$$L_r = c\ (p-q) \log (I \cdot K')$$

Now by suitable changes in I these may be made equal; then will,

$$(m-n) \log (I \cdot K) = (p-q) \log I \cdot K')$$

and the two sides of the equation differ only by color. Since the color cannot be dependent on I there remains for it to depend on $(m-n)$ and $(p-q)$ the differences of positive and negative elementary reactions, or on K and K', the threshold factors, or on both. A dependence on thresholds alone speaks of different kinds of receptors, while a dependence on differences of numbers of elementary reactions alone perhaps indicates different kinds of nerves.

The only experimental reflex fatigue and enhancement Porter graphs whose determination is sufficiently accurate for the purpose of slope determination are those in touch. In vision they have never been obtained as yet, but probably may be with no great difficulty. There are only three reflex graphs as yet obtained in touch with two branches, C, fig.4 and C, fig. 5 here, and C, fig. 5 of Allen's and Hollenberg's paper (1). These three graphs all have their change in slope at approximately the same value of the stimulus as the change in slope of the normal. These may be taken to indicate no change in threshold, but only a change in the number of elementary components, compared with the normal. The direct fatigue graph A, fig. 4, also has its' change of slope at approximately the same value of the pressure as the normal, but the fatigue graph A, fig. 5, (Allen's and Hollenberg's paper) has its' change of slope at a higher pressure than the normal. This latter indicates a threshold change in addition to the change in number of the component reactions, and the comment of Allen and Hollenberg was this:- "This displacement of the break in continuity may possibly be adduced as evidence that the change in physiological sensitiveness is in the end organ proper and not in the

(1) On the Tactile Sensory Reflex. Frank Allen & A.Hollenberg, Quar.Jour. Exp. Physiol. Vol. XIV No. 4, Oct. 1924.

synaptic resistance of the arc. " (1).

Since change of threshold seems likely to be due to a change in the receptor, while changes in the number of components seems more likely to be due to changes in the nerve system, these results all taken together perhaps indicate that in reflex effects the number of component reactions alone is changed, while in direct fatigue the receptor may be changed as well as the number of component reactions.

This conclusion is perhaps not in support of one of the subsidiary hypotheses of Allen's reflex theory, viz., that the sensitivity of the receptors is controlled by the efferent nerve impulses. It suggests rather that the nerve mechanism is controlled by the efferent impulses, while the receptors are affected by direct stimulation only. The experimental data, however, is too meagre to indicate a definite decision, especially since the equilibrium color effects in vision give excellent confirmation of Allen's hypothesis.

In review of this discussion may it not be said that the integral relation of the slopes of the branches of the Porter graphs appears to be at least fairly probable? The hypothesis advanced concerning the way in which the Porter effect is built is is, of course, not the only interpreation of the slope relationship. It is,

(1) On the Tactile Sensory Reflex. Frank Allen & A. Hollenberg, Quar. Jour. Exp. Physiol. Vol. XIV No. 4, Oct. 1924, p.364.

however, perhaps the most simple on the whole that suggests itself, and there is perhaps sufficient experimental evidence of its' plausibility to warrant its' being further tested experimentally along the line already indicated at least.

SECTION 2.

CRITICAL FREQUENCY MEASUREMENTS ON THE CENTRAL PART OF THE EYE FOR SPECTRA OF DECREASING INTENSITIES.

CRITICAL FREQUENCY MEASUREMENTS FOR THE CENTRAL PART OF THE EYE ON SPECTRA OF DECREASING INTENSITIES

The measurements here discussed were made on spectra obtained from a constant pressure acetylene gas flame by means of a Hilger constant deviation wave length spectrometer. Between the source of light and the collimator was a pair of Nicol prisms by means of which the intensity of the light was controlled. Between the slit of the spectrometer and the eye-piece, which was of the open type, a blackened disc of two sectors of 90^{0} was rotated by means of an electric motor. An electric chronograph registered the movement of the disc along with the time. Surrounding the eye-piece was a cardboard back-ground of neutral cream color resembling that of the walls of the room. Thus while the readings were being taken with the right eye, the left eye was under the same influence of illumination as were both eyes between the readings, that is in ordinary interior daylight.

It was assumed that a measure of the sensation was given by the critical frequency of flicker, so the duration of the stimulus was measured when the frequency of the stimuli was so great, and just so great, that the stimuli gave a continuous sensation. Hence the speed of the rotating disc was measured when it was rotating just fast enough so that the eye was conscious of no flicker. From this was calculated the duration of each stimulus. This duration may be called the critical duration D. 1/D gives the number of these stimuli required per second, i.e., 1/D is the critical frequency of flicker.

The measurements were made with the object of seeing if the Purkinje effect could be obtained by viewing spectra of decreasing intensities while the eye was maintained in daylight adaptation.

To maintain daylight adaptation the readings which occupied about one-half minute each were taken every four minutes so that for over three minutes between readings the eye was exposed to the light of the room. It was found that a second reading on the same wave length did not differ from a first after this interval, so that it was assumed that the eye recovered its' condition during the interval.

The measurements were made in each case during the latter part of the morning, or in the early afternoon, and only on bright days. It was found that the duration for any particular wave length and intensity was frequently the same from day to day, and seldom varied more than .002 or .003 seconds. At least two measurements were made on each setting, and the mean result was taken. It was found that in general two consecutive readings would agree to .001 or .002 seconds, and were quite frequently identically the same.

In Fig. 1 are plotted the values of the critical durations with the wave lengths to which they apply. These are not luminosity curves, which would be obtained by plotting 1/D along with the wave length, but are commonly called normal curves, since they may be used as reference curves to indicate the magnitude of fatigue or enhancement effects.

The lower curve was taken with the Nicols parallel, and the intensity under this condition was called 1. The successive curves from bottom to top were taken with decreasing intensities as indicated in the data, the intensity being taken as proportional to the co-sine squared of the angle between the Nicol prisms. It should be noted that this relation between the intensities is applicable only to one particular or rather each particular wave length, as an intensity 1 for any one wave length is not necessarily the same intensity as intensity 1 for any other wave length. This is due to the fact that the parent intensity at the gas flame is not equally divided among all the different wave lengths.

It will be readily observed that at no intensity was there a maximum sensation obtained except with wave length .580μ. Thus it must be concluded that for the author's eye, when the measurements are made by this method and with daylight adaptation, that the maximum intensity of the spectrum lies always between .570μ and .590μ regardless of the intensity of the spectrum. This is in agreement with the results obtained by various observers (1) using different methods.

(1) Helmholtz treatise Phys. Optics Vol. 11, Eng. Ed. 1924, page 361.

Allen (1) by the same method, but with a different instrument found a slight shift of the maximum toward the blue end as the intensity of the spectrum was decreased. This may be due to a property of the normal eye, or it may be due to a difference in size in the apertures of the spectrometers used. The area of the retina stimulated would be determined by this last factor, and since some observers (2) have concluded that the Purkinje phenomenon is absentonly within an area subtending one and one-half degrees it may be difficult to avoid experiencing it when a greater area is affected.

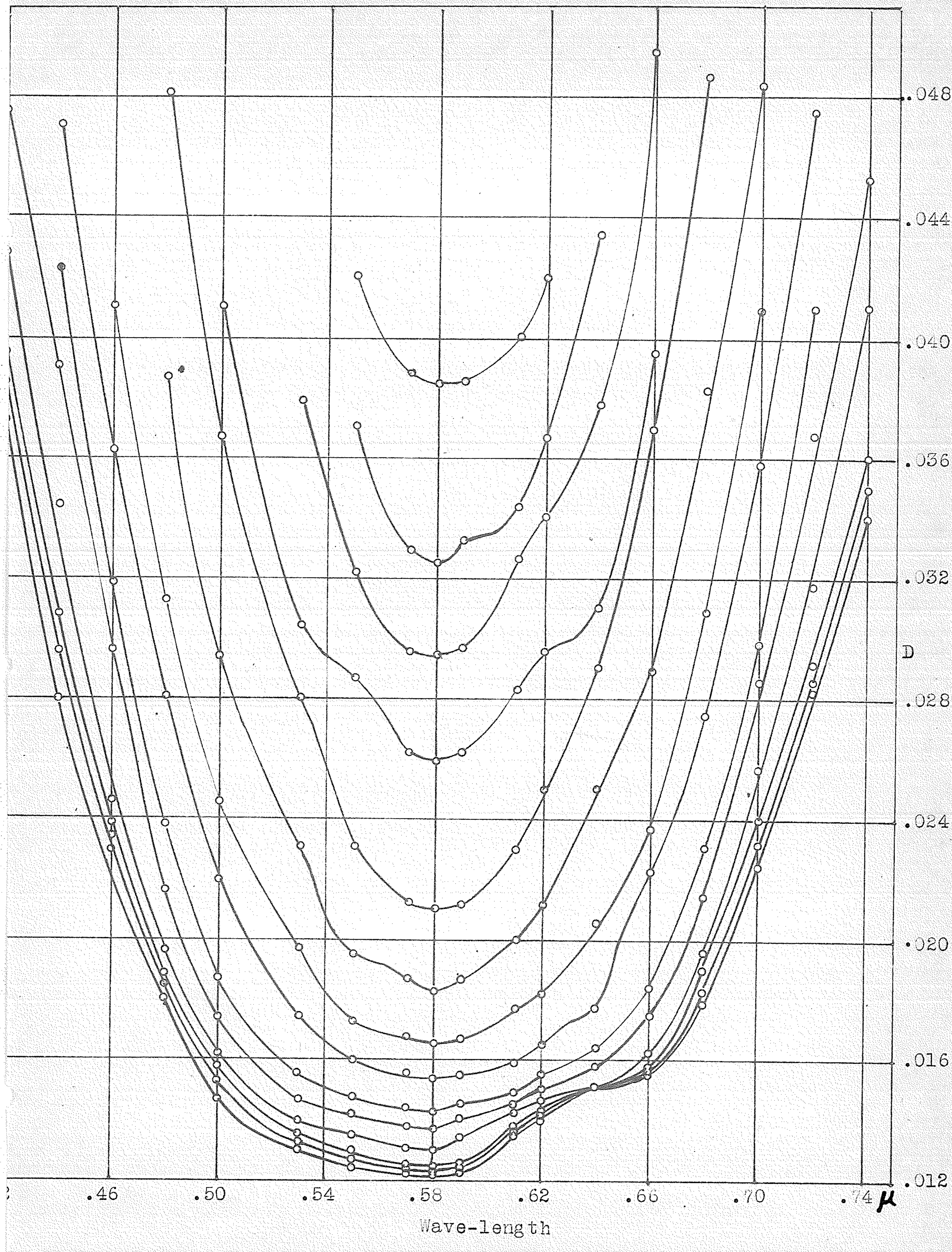
The normal curves in Fig. 1 (data table 1) show clearly that the writer has not the normal type of vision which when graphically represented is characterized by smooth parabola shaped curves (1). The writer's normal for the highest intensity resembles that of W. A. Anderson (3) in general appearance. Anderson found that the usual "white" equations were not valid for his eye in certain regions of frequency and the values he obtained when determining the anomalous equations led him to the conclusion that the green sensation was the most unusual.

(1) Phil. Mag. Vol. XXXViii, July 1919.

(2) Helmholtz Treatise Phys. Optics. Vol. 11, Eng. Ed. 1924 p. 361.

(3) W.A. Anderson, J.O.S.A. & R.S. Vol. 8 No. 6, June 1924.

FIGURE 1.



.048
.044
.040
.036
.032
D
.028
.024
.020
.016
.012
.46
.50
.54
.58
.62
.66
.70
.74
μ
Wave-length

Wave Length = .410

Branch			Method	
	Slope	.282		
	c	.094		
Alpha	c(m-n)	.282		
	(m-n)	3	.282/1	not a factor
	Slope	1.033	.282/2 = .141	Do.
	c	.094		
Beta	c(m-n)	1.034	.282/3 = .094	is a factor
	(m-n)	11		
Gamma	Same as Beta			

Wave Length = .420

Branch			Method
	Slope	.891	
	c	.099	
Alpha	c(m-n)	.891	
	(m-n)	9	
	Slope	1.985	
	c	.099	
Beta	c(m-n)	1.980	
	(m-n)	20	

The factor is likely nearly the same as for previous wave length, and probably bigger as the intensity range likely is greater, thus it may be .099 which divides evenly into the slope of the alpha branch.

Wave Length = .425

Branch			Method	
	Slope	1.031		
	c	.103		
Alpha	c(m-n)	1.030		
	(m-n)	10	1.444 - 1.031 = .413	
			.413	not a factor
	Slope	1.444	.413/2	= .206 is a factor
	c	.103	but .413/4	= .103 gives a value of c nearer the previous ones.
Beta	c(m-n)	1.442		
	(m-n)	14		
Gamma	Same as Beta			

Wave Length = .450

Branch		
	Slope	.789
	c	.087
Alpha	c(m-n)	.783
	(m-n)	9
	Slope	1.224
	c	.087
Beta	c(m-n)	1.218
	(m-n)	14
Gamma	Same as Beta	

Method

1.224 - .789	=	.435 not a factor
.435/2	=	.217 Do.
.435/3	=	.145 Do.
.435/4	=	.109 Do.
.435/5	=	.087 fairly nearly a factor.

Wave Length = .480

Branch		
	Slope	1.104
	c	.092
Alpha	c(m-n)	1.104
	(m-n)	12
	Slope	1.569
	c	.092
Beta	c(m-n)	1.564
	(m-n)	17
Gamma	Same as Beta	

Method

1.569 -1.104	=	.465 not a factor
.465/2	=	.233 Do.
.465/3	=	.155 Do.
.465/4	=	.116 Do.
.465/5	=	.093 not very good perhaps one slope is slightly wrong. Try .094 and .092. .092 is a factor.

Wave Length = .505

Branch		
	Slope	1.445
	c	.096
Alpha	c(m-n)	1.440
	(m-n)	15

Remaining Branches the same.

Method

Factor likely lies in value between that for Wave Length = .480 and Wave Length = .520, i.e., between .092 and .102.

1.445/15 = .096 approx., which may be the factor.

Wave Length = .520

Branch			Method
	Slope	1.538	
	c	.102	
Alpha	c(m-n)	1.530	
	(m-n)	15	
Beta	Same as Alpha		.408 not a factor
			.408/2 = .204 Do.
			.408/3 = .136 Do.
	Slope	.408	.408/4 = .102 is a factor
	c	.102	
Gamma	c(m-n)	.408	
	(m-n)	4	

Wave Length = .550

Branch		
Alpha	Poorly defined.	
	Slope	1.535
	c	.085
Beta	c(m-n)	1.530
	(m-h)	18
	Slope	.782
	c	.085
Gamma	c(m-n)	.765
	(m-n)	9
	Slope	2.900
	c	.085
Delta	c(m-n)	2.890
	(m-n)	34

Method

2.900 - 1.535 = 1.365
1.535 - 1.365 = .170 not a factor of .782.
.085 better, although it does not divide well into .782. However, this branch is not very well defined experimentally. Moreover .0853 is an almost exact factor of the beta slope and the delta slope, so it may well be considered that the Gamma branch is probably in error.

Wave Length = .570

Branch		
	Slope	1.543
	c	.020
Alpha	c(m-n)	1.540
	(m-n)	77
Beta	Same as Alpha	
Gamma	Same as Alpha	
	Slope	.782
	c	.020
Delta	c(m-n)	.780
	(m-n)	39

Method

1.543 - .782 = .761
.782 - .761 = .021 not a very good factor but .020 is.

The Alpha branch in this case is very well defined experimentally and the delta branch not very well, so it is possible that this factor which is very small is not the true one.

Wave Length = .572

Branch

	Slope	1.403
	c	.061
Alpha	c(m-n)	1.403
	(m-n)	23
Beta	Same as Alpha	
	Slope	1.159
	c	.061
Gamma	c(m-n)	1.159
	(m-n)	19
Delta	Same as Gamma	

Method

1.403 - 1.159	=	.244	
.244			not a factor.
.244/2	=	.122	Do.
.244/3	=	.081	Do.
.244/4	=	.061	is a factor

Note - The graph for .572 cuts that for .590. This may be due to the source of light being dimmer when the graph for .572 was being measured, which may account for this small factor.

Wave Length = .590

Branch

	Slope	1.719
	c	.123
Alpha	c(m-n)	1.722
	(m-n)	14
Beta	Same as Alpha	
	Slope	.614
	c	.123
Gamma	c(m-n)	.615
	(m-n)	5
	Slope	2.090
	c	.123
Delta	c(m-n)	2.091
	(m-n)	17

Method

2.090 - 1.719	=	.371	not a factor
.371/2	=	.185	Do.
.371/3	=	.123	is a factor.

Wave Length = .630

Branch		
	Slope	1.523
	c	.051
Alpha	c(m-n)	1.530
	(m-n)	30
Beta	Same as Alpha	
	Slope	.566
	c	.051
Gamma	c(m-n)	.561
	(m-n)	11
	Slope	1.070
	c	.051
Delta	c(m-n)	1.071
	(m-n)	21

Method

1.523 - 1.070 = .453
1.070 - .566 = .504
.504 - .453 = .051 which is almost an even factor.

Wave Length = .640

Branch		
	Slope	1.116
	c	.124
Alpha	c(m-n)	1.116
	(m-n)	9
	Slope	1.363
	c	.124
Beta	c(m-n)	1.368
	(m-n)	11
	Slope	.375
	c	.124
Gamma	c(m-n)	.372
	(m-n)	3

Method

1.363 - 1.116 = .247
.247 not a factor
.247/2 = .124 is a factor

Wave Length = .660

Branch		
	Slope	.973
	c	.122
Alpha	c(m-n)	.976
	(m-n)	8
Beta	Same as Alpha	
	Slope	1.096
	c	.122
Gamma	c(m-n)	1.098
	(m-n)	9

Method

1.096 - .973 = .123 almost a factor but .122 is better.

Wave Length = .687

Branch			Method
	Slope	.872	
	c	.124	
Alpha	c(m-n)	.868	1.359 - .872 = .487 not a factor
	(m-n)	7	.487/2 = .243 Do.
			.487/3 = .162 Do.
	Slope	1.359	.487/4 = .122 almost a factor
	c	.124	but .124 better.
Beta	c(m-n)	1.364	
	(m-n)	11	

Wave Length = .700

Branch			Method
	Slope	.525	
	c	.087	
Alpha	c(m-n)	.522	
	(m-n)	6	
Beta	Poorly defined.		.525 not a factor.
			.525/6 = .087 is a factor.
	Slope	2.435	
	c	.087	
Gamma	c(m-n)	2.436	
	(m-n)	28	

at least the second place of decimals and in many cases with no great error in the third.

In the tables following fig. 2(a) are given the slopes of the measureable branches for each wave length. Underneath the slope of each branch is given the factor c, which was found as shown under the heading "Method". c(m-n) is the integral multiple of c which most nearly is equal to the measured slope, and (m-n) is the integer. Allen concluded that there was no change in slope in going from one intensity range to another with some wave lengths, so the slopes of two or more different branches are given as having the same slope in several cases following him.

It will be readily seen on examining the table that in every case was a factor found which would divide as well as could be expected from the accuracy of measurement into all the slopes of each branch. Moreover the factor in about every case is comparatively large, the average value being about .100. It is especially important that the factor was in most cases found from differences and not by examining the slopes themselves for factors, so that the factor has in these instances the property of a number taken at random. If this consideration is neglected since the factor was sometimes found by factoring the slope of one of the branches of the graph there remains to find the probability that a factor of value about 100 will divide into another number or two other numbers taken at random. The reason for doing this is that if the slopes are not related the probability that they will appear to be related, as they do here, may perhaps be shown to be very small.

If any number greater than 50 taken at random be divided by 100 it will either go evenly, or there will be a positive or negative remainder of 1, 2, 3 .... 50; in all 101 possible differences, so the probability that it will divide evenly is 1/100 approximately. But this is the case in the tables where there are two slopes in the graph and a factor of value about 100 found from one divided evenly into the other. Again if there are three slopes to the graph and the factor divided evenly into the other two the probability that it will do so is $(1/100)^2 = 1/10,000$ if the slopes are unrelated.

In all there were fifteen graphs measured having at least two slopes. If they are considered to have only two, which will suffice, it will be seen from the consideration above, and assuming that the division was even in each case as it may well be assumed in general, considering the accuracy of the slope measurements, that the probability that in every case the chosen factor should divide evenly into the other is $(1/100)^{15}$, a very small probability indeed. Thus it may be concluded, since the probability that the relation would exist with unrelated slopes, is even smaller than this, that the slopes are related in the way assumed.

Whether the elementary constant c is the same for all colors cannot be determined from these data without knowing the intensity distribution of the spectrum. However, if the factors obtained for each graph be divided by suitable integers the resulting numbers show a regularity in their rate of increase with the wave length not unlike the rate of increase of the intensity of the spectrum with the wave length. This relation, which is shown in Table 2, would lead to the expectation that experiment will show the factor c to be the same for all colors. Discussion of the result of this will be postponed until the effects corresponding to the Porter effect in vision have been considered for taste and for touch.

At this point if the view advanced here that there are different thresholds be accepted there are two ways that the slope relations may be interpreted physically, first, the reaction which is shown by the Porter graph may be of such a nature that it is built up of a number of reactions each starting at different values of the intensity, these reactions being of the form,

$$n = \pm c \cdot \text{integer} \log I/I_0$$

Wave Length	Factor . 10^3	Integer	Quotient
.410	94	9	10.4
.420	99	9	11
.425	103	9	11.4
.450	87	7	12.4
.480	92	7	13.1
.505	96	7	13.7
.520	102	7	14.5
.550	85	5	17
.570	20	1	20
.572	61	3	20.3
.590	123	5	24.6
.630	51	2	25.5
.640	124	4	31
.660	122	3	40.6
.687	124	3	41.3
.700	87	2	43.5

TABLE 2

or, second, that there is only one kind of reaction in the visual system and that of the form,

$$r = \pm c \log I/I_0$$

and that each branch in turn is due to the starting off of a number of these elementary reactions acting together, so that their sum gives the Porter effect. The second alternative is perhaps the more probable as the first alternative makes necessary a large number of different types of reaction which is unlikely, especially since they must have the integral relation. In either case it is evident that the Porter effect is greatly restricted, i.e., 1/D can only increase along certain paths, as long as the thresholds remain fixed, these paths being represented by,

$$i_1 \cdot c \log I/I_0 \quad \text{or} \quad i_2 \cdot c \log I/I_0 \text{ etc.}$$

where i_1 and i_2 are integers, and it cannot increase along any other path, unless the factor c may change, and this is very unlikely as will be shown subsequently when discussing the corresponding effect in touch.

It will be remembered that in discussing the Porter graph equation, $1/D = c\,(m-n) \log (I \cdot K)$ one of the cases considered was that in which $(m-n) = -$ integer. This case is known in vision as was pointed out, but is unusual. When the gustatory reactions were measured, however, by the critical frequency method (1) it was found that a corresponding logarithmic relation existed and similar graphs to the Porter graph in vision were obtained, but in this case the equations of their branches were of the form,

$$1/D = -K \log Q + C.$$

where $1/D$ is the critical frequency, and Q is the quantity of electricity in the stimulus.

There is no evidence in this case that there are two different types of reactions, as was supposed in vision, since the slopes change from branch to branch in only one way, (fig. 3 page 393) (1); hence, if the complete graph is again considered to be built up of component effects with different thresholds, all the component reactions may be of the form,

$$n = -k \log Q + C$$

only. Also when $n = 0$ in these equations will c

$c = k \log Q_0$ where Q_0 is the threshold stimulus, so their

(1) The Gustatory Sensory Reflex. Frank Allen & Mollie Weinberg. Quar. Jour. Exp. Physiol. Vol. 15, 1925.

general form will be,

$$n = k \log Q_0/Q \quad \text{or} \quad n = -k \log Q/Q_0$$

and the equation of the complete graph will be,

$$1/D = n_1 + n_2 + \dots\dots = \log Q^{k_1 - k_2 - k_3} \cdot K$$

where K is the product of the threshold values. And if the k's should be multiples of a common factor it may be written,

$$1/D = c \cdot i \log (Q \cdot K)$$

where c is the elementary factor and i is an integer.

The slopes of the branches of the graphs of fig. 3, page 393, were measured to see if this relation existed. These lines are not so well defined experimentally as those in vision, and since the measurements were made on the figure in the paper which is on a small scale they cannot be considered to be nearly so accurate as the corresponding ones in vision. However, another measurement on the same branch could frequently be repeated to about .005, although in some cases the disagreement was larger and means were taken of two or three readings.

In Table 3 are given the measured values of the slopes in the rows marked "Slope". The slopes of the four graphs are given under the headings, "A", "B", "C" & "D", as they were named in the figure. The branches were numbered "1", "2" & "3" from the left. The row marked,

CURVE A

	c = .0355		
Branch	1	2	3
Slope	.356	.816	1.569
c . i	.355	.816	1.562
Diff.			.007
i.	10	23	44

CURVE B

				c = .1065		
Branch	1	2	3	1	2	3
Slope	.957	1.379	1.921	.957	1.379	1.921
c . i.	.958	1.384	1.917	.958	1.384	1.917
Diff.	.001	.005	.004	.001	.005	.004
i.	27	39	54	9	13	18

CURVE C

				c = .2485		
Branch	1	2	3	1	2	3
Slope	1.220	1.489	2.237	1.220	1.489	2.237
c . i	1.207	1.491	2.236	1.242	1.291	2.236
Diff.	.013	.002	.001	.022	.002	.001
i.	34	42	63	5	6	9

CURVE D

				c = .1065		
Branch	1	2	3	1	2	3
Slope	1.681	2.023	2.551	1.681	2.023	2.551
c . i	1.668	2.023	2.556	1.704	2.023	2.556
Diff.	.013	.000	.005	.023	.000	.005
i.	47	57	72	16	19	24

TABLE 3.

"c . i" is the product of the supposed factor c, and the integer i which most nearly gives the measured slope. The row marked "Diff." gives the difference between the measured slope and c . i while the row marked "i" gives the integer.

A factor was sought for the slopes by dividing the smallest one, .356, by integers, and dividing the result into the remaining slopes. .356/10 = .0355 approximately divided fairly well into the branches of A, so it was tried on the remaining branches with the results shown on the left hand side of the table.

It will be observed that the integers in Curve B are divisible by three so that three times the factor .0355 will divide equally well as shown on the right hand side opposite. Also the integers of Curve C are divisible by seven except for that of Branch 1 where the difference is very large anyway. The divisions of the slopes of this curve by seven times the factor .0355, i.e., .2485 are given on the right hand side of the table. In a similar way the slopes of D were divided by three times .0355 with the results shown again on the right.

As was pointed out before, the measurement of the slopes could not be done very accurately, nor are the branches in many cases well enough defined to give unquestionable results. However, there seems to be strong indication here that the slopes of any one branch at least are related in the way supposed, and fair indication that there is a common factor of all the slopes.

Further experimental work will have to be done with different people, and, if possible, giving better definition to the lines before it may be concluded as it is here suggested that in taste there is a reaction of only one kind, i.e.,

$$n = - c \log Q/Q_0$$

(where only the threshold value Q_0 may change) conforming exactly to Fechner's law, and that the sensation has a one to one correspondence with a sum of these elementary reactions. It is also suggested that the kind of sensation depends solely on the particular sum of these elementary reactions, although this is not necessary since it may only be that the conducting path of which this relation probably denotes a property is of the same kind in each case.

Measurements of a similar nature to those already discussed for vision and for taste have been made by Allen and Hollenberg (1) and Allen and Weinberg (2), on the tactile sensoria. The method in both cases was to use an intermittent jet of air as a stimulus and to measure the duration of a single pulse when the pulses were just frequent enough to give a continuous sensation.

They found that the relation,

$$D = k \log P + C$$

existed where D is the duration of a single pulse under the prescribed conditions and P is the pressure of the air stimulus. An examination of fig. 3, 4 and 5 will show that the resulting graphical representations are similar to those obtained in vision, and are different to those obtained in taste in that the change of slope on going from one branch to the other may be either to increase or decrease its' magnitude. That is, it may be considered that the resulting graphs may be built up in this case by the summation of reactions of either one or the other of two types conforming to the equations,

$$d_1 = -k_1 \log P + c_1$$

or

$$d' = k' \log P - c'$$

If in the first equation $d_1 = 0$ then $c_1 = k_1 \log P_0$ where P_0 is the threshold pressure for this

(1) Quar. Jour. Exp. Physiol. Vol. 14 No. 14, 1924

(2) Quar. Jour. Exp. Physiol. Vol. 15 Nos. 3 & 4, 1925.

reaction, and the equation may be written,

$$d_1 = -k_1 \log P + k_1 \log P_0$$

or $$d_1 = k_1 \log P_0/P$$

Also in the second type of equation if $d' = 0$ then $c' = k' \log P_0$ where P_0 is the threshold value of the pressure for this reaction, and the equation may be written,

$$d' = k' \log P - k' \log P_0$$

or $$d' = k' \log P/P_0$$

When a particular branch is considered its' equation may then be written,

$$D = d_1 + d_2 + \dots\dots d' + d'' + \dots\dots\dots\dots\dots$$

or

$$D = k_1 \log P_1/P + k_2 \log P_2/P + \dots k' \log P/P' + k'' \log P/P'' +$$

where P_1 etc. and P' etc. are threshold pressures. Or

$$D = \log \frac{P^{k' + k'' + \dots\dots\dots\dots}}{P^{k_1 + k_2 + k_3 \dots\dots}} \cdot K$$

where K is the product of the threshold values. Or

$$D = \log P^{k' + k'' + \dots\dots\dots -k_1 - k_2 - \dots\dots} \cdot K$$

or

$$D = C \log (P.K)$$

And if the k's are multiples of a common factor as suspected in vision the equation may be written:-

$$D = c(m-n) \log (P \cdot K)$$

where c is the elementary factor and m and n are integers.

Again as in vision this relation was tested by measuring the slopes of the different branches of the experimental graphs to see if they might be of the form c . integer.

Fortunately in this case the actual value of the stimulus for each measurement was known, so it was possible to plot all the data on the same scale, and this was done. That is, Allen's, Hollenberg's and Weinberg's data were all plotted on a large scale, and the slopes of all the reasonably well defined branches of the graphs were measured. Some of the same data plotted on a smaller scale are given in figs. 3, 4 and 5, and these show how well defined experimentally are a great number of the branches.

In table 2 are given the values of the various measured slopes, and the name of the person who determined the graphs is given in each case along with information as to where the results were originally published. In those cases in which the graphs are reproduced here that is also indicated. The curves are lettered A, B, etc. in the figures, and the corresponding letters are used to indicate them in the tables. The branches are numbered 1, 2, 3, etc. starting on the left.

HOLLENBERG'S CURVES

Quar. Jour. Exp. Physiol. Vol. 14, 1924 - data page 335 table 1. Graphs fig. 2, page 359, also given here fig. 3.

Graph	A	B		C	
Branch	1	1	2	1	2
Slope	.911	.924	2.538	.858	1.555
c(m-n)	.910	.923	2.535	.858	1.560
Diff.	.001	.001	.003	.000	.005
(m-n)	70	71	195	66	120

Graph	D			E		
Branch	1	2	3	1	2	3
Slope	.793	.485	.736	.713	.283	.486
c(m-n)	.793			.715		
Diff.	.000			.002		
(m-n)	61			55		

Data page 364, Graphs page 363, also given here fig. 4.

Graph	A		B	
Branch	1	2	1	2
Slope	.934	2.463	.858	1.555
c(m-n)	.936	2.462	.858	1.560
Diff.	.002	.001	.000	.005
(m-n)	72	174	66	120

Graph	C		D	E
Branch	1	2	1	1
Slope	.880	1.534	.852	.846
c(m-n)	.884	1.534	.858	.845
Diff.	.004	.000	.006	.001
(m-n)	68	108	66	65

TABLE 2.

ALLEN'S CURVES

Quar. Jour. Exp. Physiol. Vol. 14, 1924 - data page 355 table 1. Graph fig. 6, page 368, also given here fig. 5.

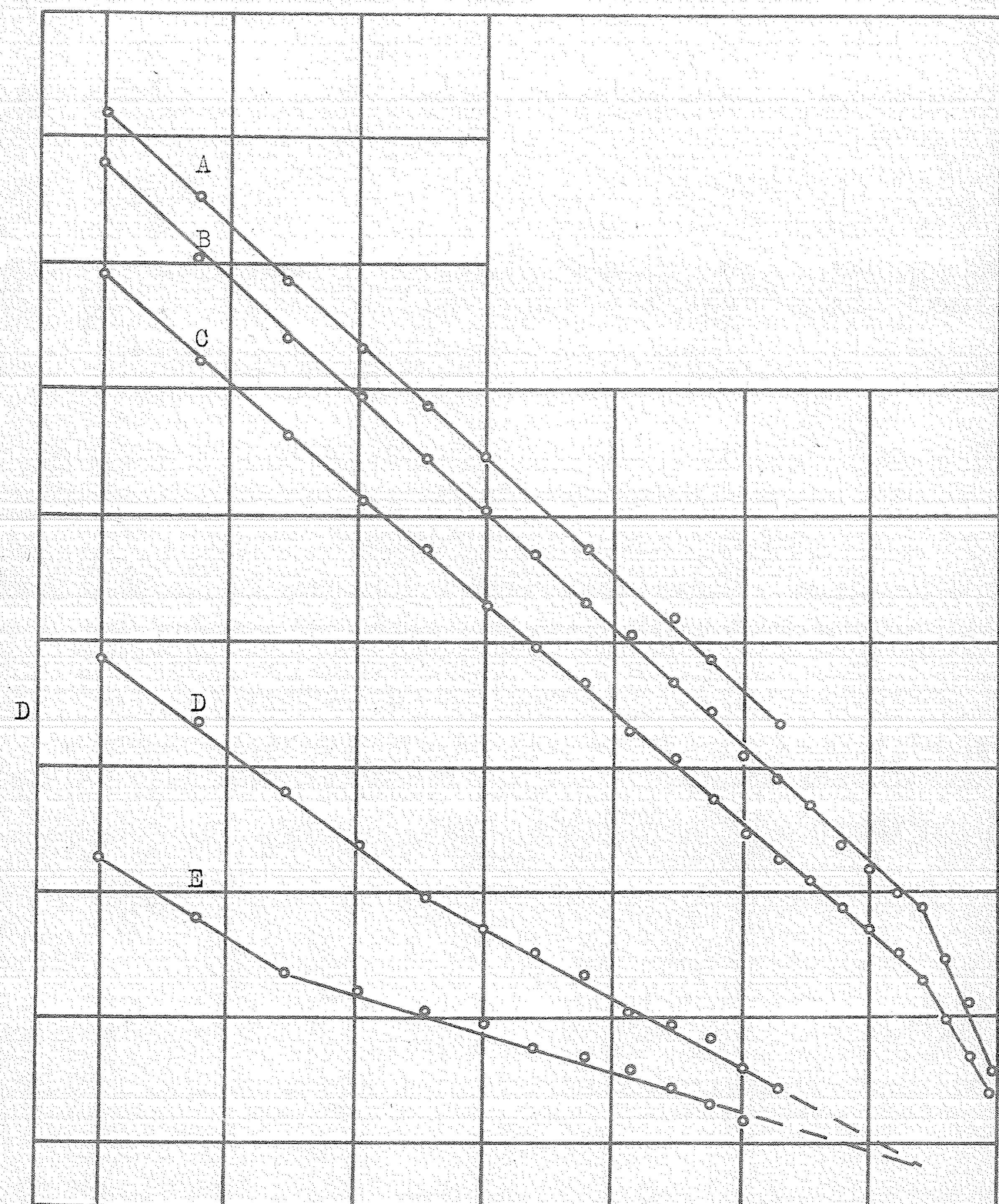
Graph	A	
Branch	1	2
Slope	1.041	2.679
c(m-n)	1.040	2.678
Diff.	.001	.001
(m-n)	80	208

WEINBERG'S CURVES

Quar. Jour. Exp. Physiol. Vol. 15, 1925 - data page 379. Graph fig. 2, page 381.

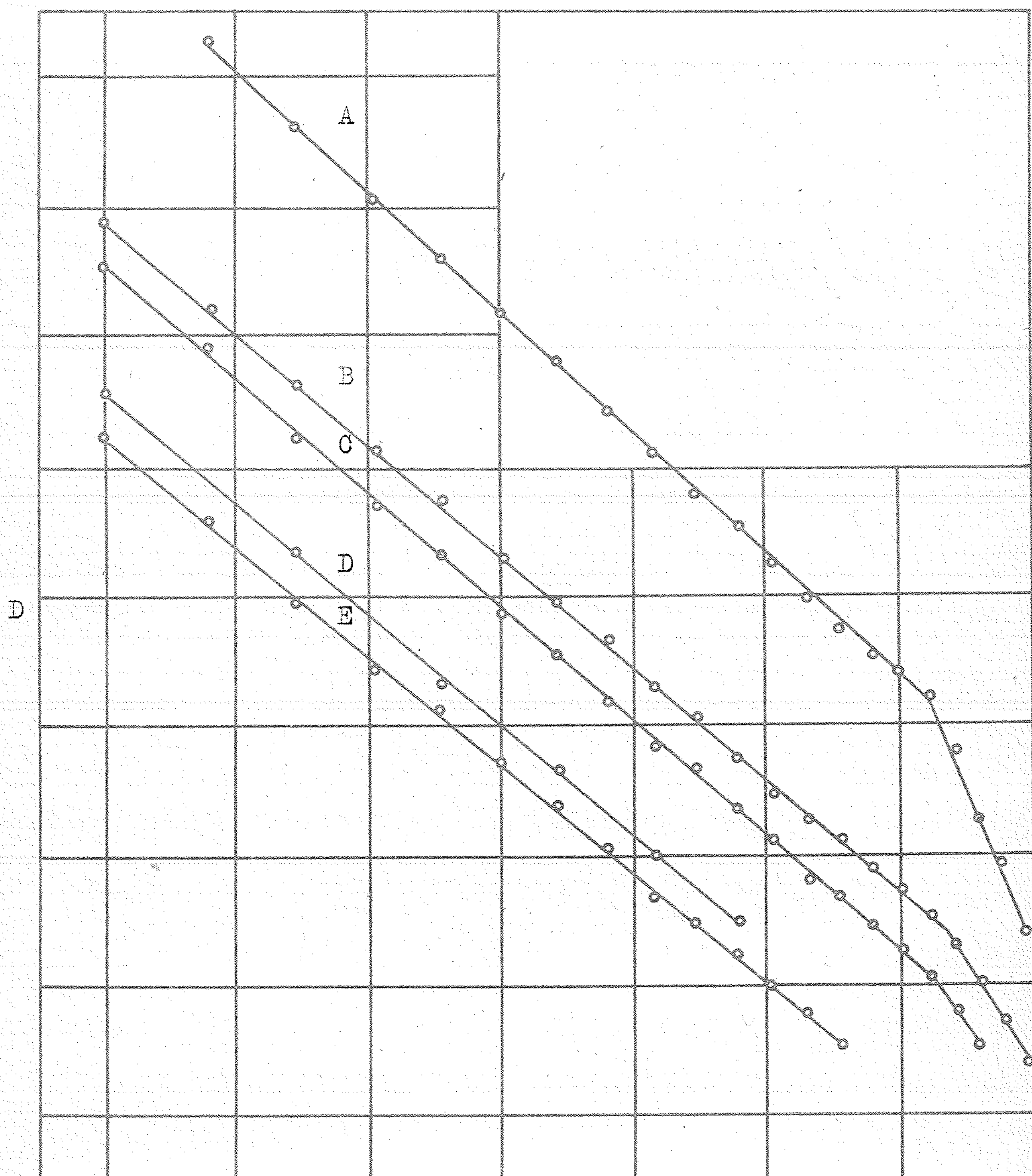
Graph	A			B	
Branch	1	2	3	1	2
Slope	.912	.638	.193	.104	.746
c(m-n)	.910	.637	.195	.104	.741
Diff.	.002	.001	.002	.000	.005
(m-n)	70	49	15	8	57

TABLE 2.



LOG P.

FIG. 3.



LOG P.

FIG. 4.

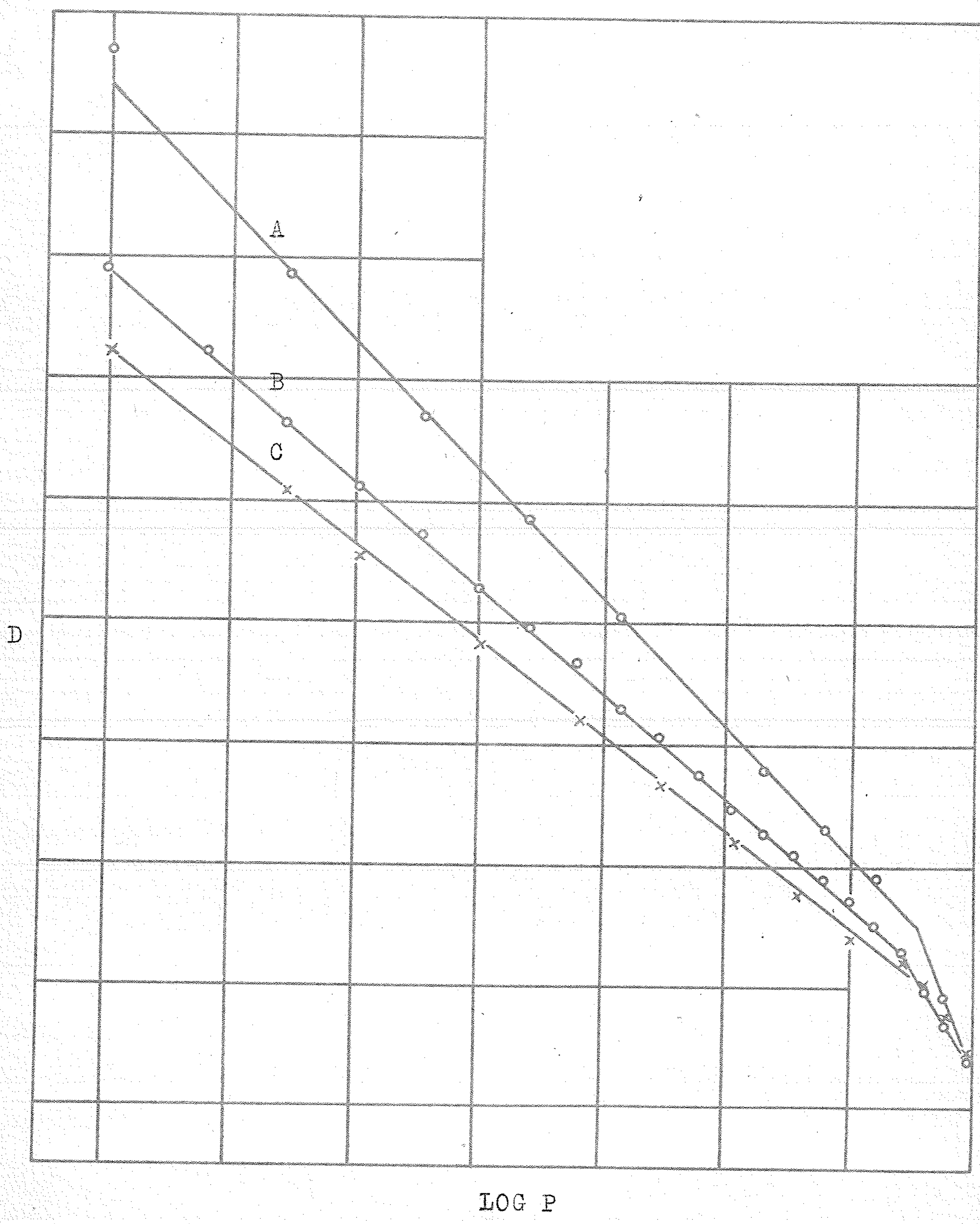


FIG. 5.

Wave length	$\alpha = 00^\circ$ D	$\alpha = 00^\circ$ 1/D	$\alpha = 15^\circ$ D	$\alpha = 15^\circ$ 1/D	$\alpha = 20^\circ$ D	$\alpha = 20^\circ$ 1/D
.74	.0341	29.32	.0350	28.57	.0361	27.70
.72	.0283	35.33	.0286	34.96	.0292	34.24
.70	.0225	44.44	.0232	43.10	.0240	41.66
.68-	.0179	58.65	.0183	54.64	.0190	52.63
.66	.0156	64.10	.0157	63.49	.0158	63.29
.64	.0152	65.78	.0152	65.78	.0152	65.78
.62	.0141	70.92	.0142	70.42	.0143	69.93
.61	.0135	74.07	.0136	73.52	.0138	72.46
.59	.0123	81.30	.0124	80.64	.0125	80.00
.58	.0122	81.96	.0123	81.30	.0124	80.64
.57	.0123	81.30	.0124	80.64	.0125	80.00
.55	.0124	80.64	.0127	78.74	.0130	76.92
.53	.0130	76.92	.0133	75.18	.0136	73.52
.50	.0147	68.02	.0153	65.35	.0158	63.29
.48	.0180	55.55	.0185	54.05	.0188	53.19
.46	.0229	43.66	.0234	42.73	.0238	42.01
.44	.0280	35.71	.0296	33.78	.0308	32.46
.42	.0373	26.80	.0385	25.97	.0395	25.31

TABLE 1

Wave length	$\alpha = 39^0$ D	1/D	$\alpha = 50^0$ D	1/D	$\alpha = 60^0$ D	1/D
.74	.0411	24.33	.0453	22.07	.0522	19.15
.72	.0318	31.44	.0368	27.17	.0410	24.39
.70	.0257	38.91	.0286	34.96	.0298	33.55
.68	.0196	51.02	.0214	46.72	.0231	43.29
.66	.0163	61.34	.0175	57.14	.0184	54.34
.64	.0152	65.78	.0158	63.29	.0164	60.97
.62	.0147	68.02	.0151	66.22	.0156	64.10
.61	.0143	69.93	.0146	68.49	.0149	67.11
.59	.0134	74.62	.0141	70.92	.0146	66.49
.58	.0130	76.92	.0137	72.99	.0143	69.93
.57	.0131	76.33	.0138	72.46	.0144	69.44
.55	.0135	74.07	.0142	70.42	.0148	67.56
.53	.0140	71.42	.0147	68.02	.0156	64.10
.50	.0162	61.72	.0174	57.47	.0187	53.47
.48	.0196	51.02	.0216	46.29	.0238	42.01
.46	.0245	40.81	.0296	33.78	.0318	31.44
.44	.0344	29.06	.0390	25.64	.0423	23.64
.42	.0428	23.36	.0476	21.00	.0507	19.72

TABLE 1 (a)

Wave length	α = 70°		α = 76°		α = 80°05'	
	D	1/D	D	1/D	D	1/D
.72	.0476	21.00	.0531	18.83		
.70	.0358	27.93	.0409	24.44	.0484	20.66
.68	.0275	36.36	.0309	32.36	.0383	26.10
.66	.0223	44.84	.0237	42.19	.0289	34.60
.64	.0718	56.17	.0206	48.43	.0250	40.00
.62	.0166	60.24	.0182	54.94	.0212	27.16
.61	.0159	62.89	.0177	56.49	.0200	50.00
.59	.0155	64.51	.0167	59.88	.0187	53.47
.58	.0154	64.93	.0166	60.24	.0183	54.64
.57	.0156	64.10	.0168	59.52	.0187	53.47
.55	.0160	62.50	.0173	57.80	.0195	51.28
.53	.0174	57.47	.0197	50.76	.0231	43.29
.50	.0220	45.45	.0246	40.65	.0294	34.01
.48	.0280	35.71	.0312	32.05	.0387	25.83
.46	.0362	27.62	.0410	24.39		
.44	.0471	21.23				

TABLE 1 (b)

Wave length	$\alpha = 83°05$ D	$\alpha = 83°05$ 1/D	$\alpha = 85°00'$ D	$\alpha = 85°00'$ 1/D	$\alpha = 86°00'$ D	$\alpha = 86°00'$ 1/D
.68	.0487	20.53				
.66	.0370	27.02	.0395	25.31	.0495	20.20
.64	.0291	34.36	.0311	32.15	.0378	26.45
.62	.0250	40.00	.0296	33.78	.0341	29.32
.61	.0230	43.47	.0283	35.33	.0327	30.58
.59	.0212	47.16	.0262	38.16	.0297	33.67
.58	.0210	47.61	.0259	38.61	.0294	34.01
.57	.0212	47.16	.0262	38.16	.0296	33.78
.55	.0231	43.29	.0287	34.84	.0322	31.05
.53	.0280	35.71	.0304	32.89	.0379	26.38
.50	.0367	27.24	.0410	24.39	.0557	17.95
.48	.0482	20.74				

Wave length	$\alpha = 86°35'$ D	$\alpha = 86°35'$ 1/D	$\alpha = 87°30'$ D	$\alpha = 87°30'$ 1/D
.64	.0434	23.41		
.62	.0367	27.24	.0420	23.80
.61	.0344	29.06	.0400	25.00
.59	.0313	31.94	.0386	25.90
.58	.0325	30.76	.0384	26.04
.57	.0329	30.39	.0388	25.77
.55	.0371	26.95	.0421	23.75

TABLE 1 (c)

The irregularity of the Author's curves throughout would lead to the conclusion that in his case at least all the sensations are affected, although they may not be all affected with all intensities.

In figs. 2 & 3 (data table 1) is plotted 1/D against k log $\cos.^2 \alpha$, where d is the angle between the nicol prisms and 1/D is the reciprocal of the duration. Since $\cos.^2 \alpha$ is a measure of the intensity I, and since from the Ferry-Porter law there is the relation,

$$1/D = k \log I + k'$$

it was expected that a series of broken lines with from one to four branches would result similar to those obtained by Allen (1) who discovered by using stronger lights and daylight adaptation the additional branches to the two formerly obtained by Ives. It was most surprising to find that instead of obtaining a few branches for each wave length showing that a particular equation,

$$1/D = k \log I + k'$$

held for considerable change in I as was found by Allen that in most cases there were from four to six branches which means that the equation holds for the anomalous trichromat only for small ranges of intensity without change of constants.

Allen's graphs which are given in figures 2 and 2 (a) of Section 1 are not greatly different in

(1) J.O.S.A. & R.S.I. Vol. 13, No. 4, Oct. 1926.

FIGURE 2.

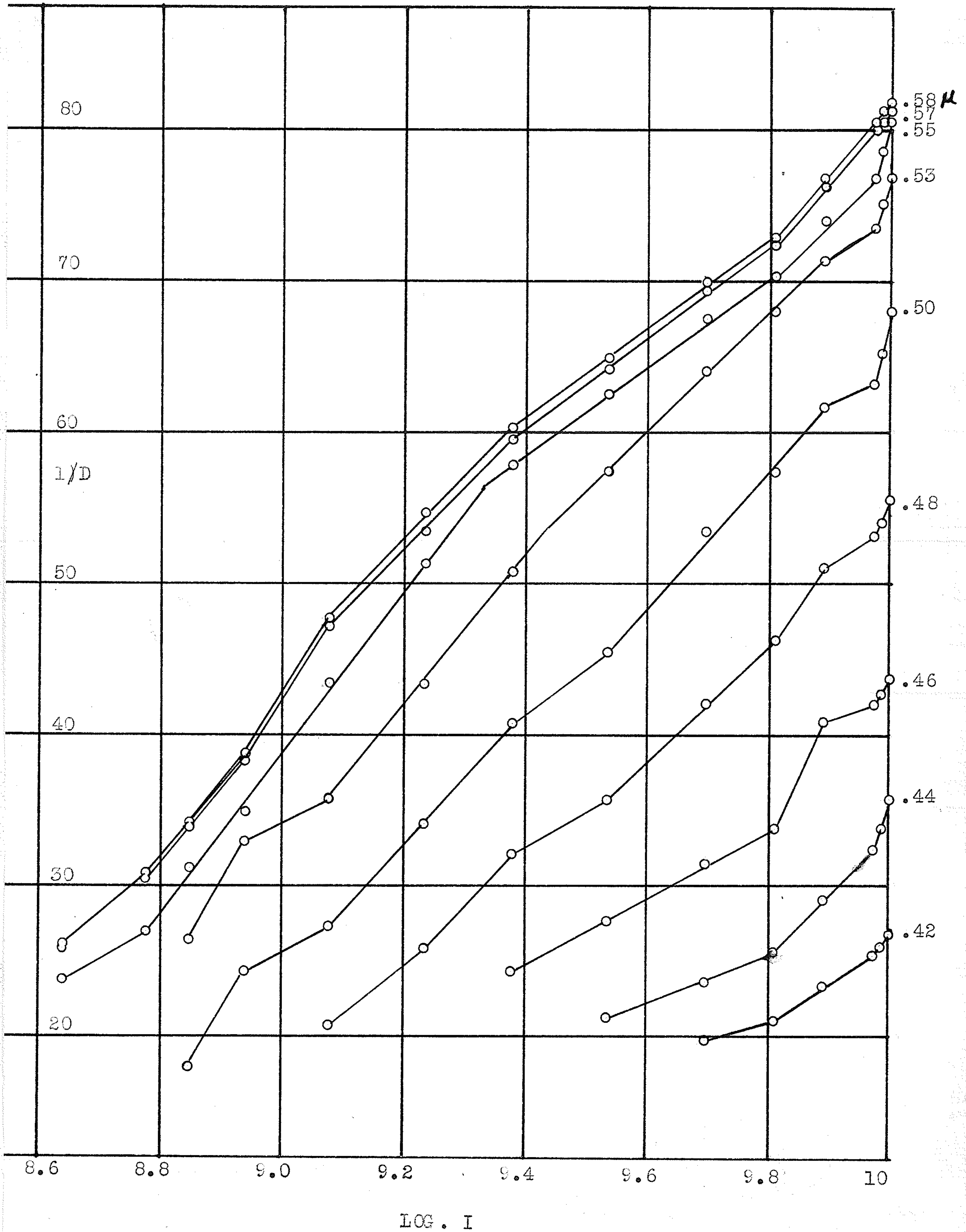
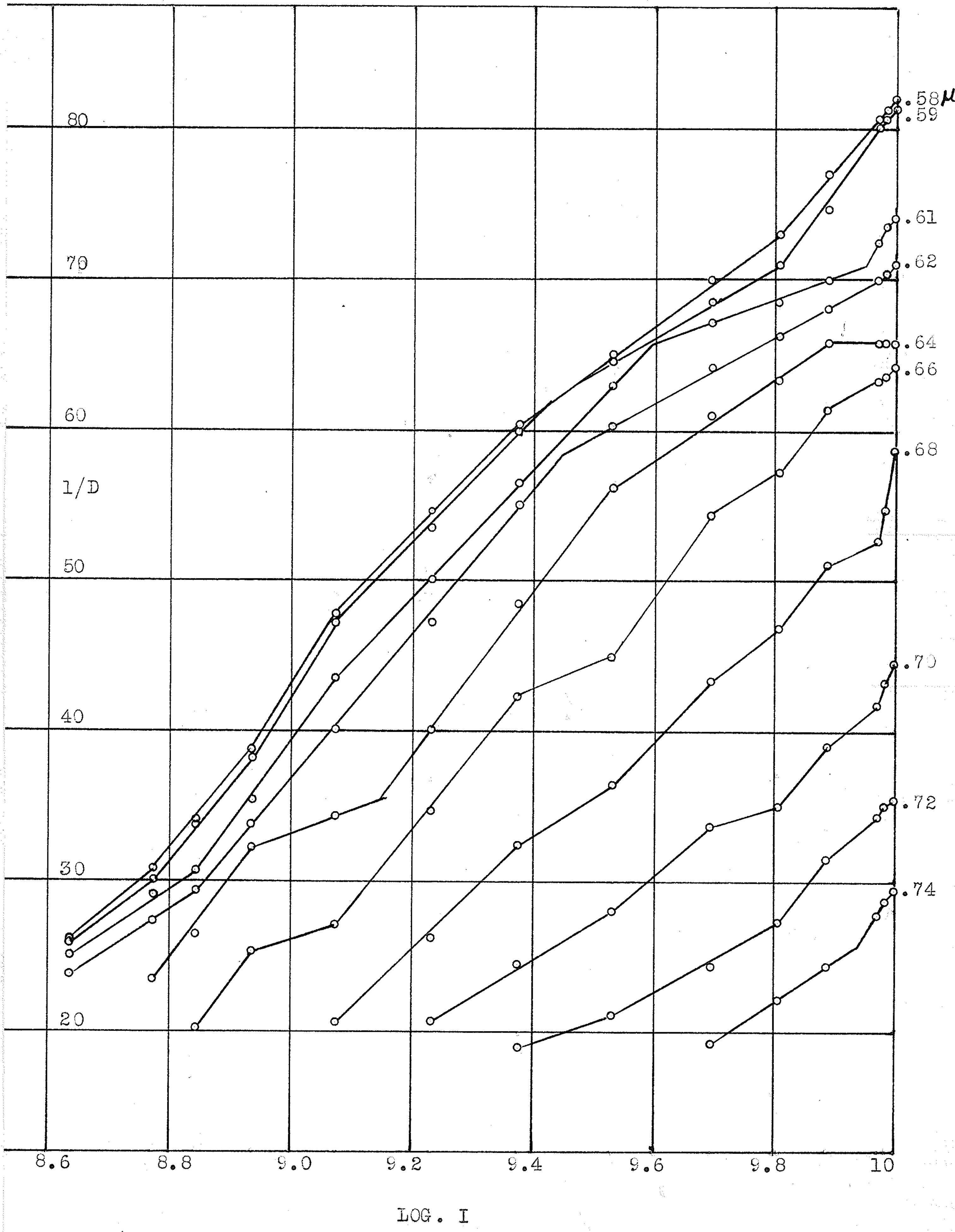

80
70
60
1/D
50
40
30
20
.58 μ
.57
.55
.53
.50
.48
.46
.44
.42
8.6
8.8
9.0
9.2
9.4
9.6
9.8
10
LOG. I

FIGURE 3.



80
70
60
1/D
50
40
30
20
.58μ
.59
.61
.62
.64
.66
.68
.70
.72
.74
8.6
8.8
9.0
9.2
9.4
9.6
9.8
10
LOG. I

their general character to these, but the branches of each graph are fewer in number. Allen's range of intensity was greater as he used a 250 W. Mazda lamp so the difference in the number of branches would perhaps be even greater than is shown by the graphs.

It is evident from a comparison of Allen's graphs with these that at least one of the differences between the normal trichromat and the anomalous trichromat is in the mechanism whose manifestations are the Porter effect. It is indeed perhaps not too much to expect that this is the only difference, or at least the principle difference.

If the conclusions reached in Section 1 be true, that there is not only one but a number of different threshold intensities, and that the Porter effect is due to the summation of an integral number of like elementary effects starting off from each threshold, there are at least three ways in which the anomalous trichromat may differ with the normal; first, his thresholds may be more numerous, second, the number of elementary reactions starting from each threshold may be different, or, third, the supposed elementary constant may be variable.

That the first difference exists is indicated by the greater number of branches in figs. 2 and 3. The second difference must be looked for in further experiment, i.e., the normal and the anomalous graphs must be obtained for the same wave lengths and the same intensity range and the results compared. The data here was sufficient to

Branch	Wave Length	.440 .0855	.500 .029	.530 .065	.550 .0662	.570 .149
1.	Slope	.428				
	c . i.	.428				
	Diff.	.000				
	i.	5				
2.	Slope	1.024			1.324	1.183
	c . i.	1.026			1.324	1.176
	Diff.	.002			.000	.007
	i.	12			20	8
3.	Slope		1.102	1.232	.728	
	c . i.		1.102	1.235	.728	
	Diff.		.000	.003	.000	
	i.		38	19	11	
4.	Slope			.975		1.023
	c . i.			.975		1.029
	Diff.			.000		.006
	i.			15		7
5.	Slope		1.130		3.654	.746
	c . i.		1.131		3.641	.735
	Diff.		.001		.013	.011
	i.		39		55	5
6.	Slope			3.160		1.172
	c . i.			3.185		1.176
	Diff.			.025		.004
	i.			49		8
7.	Slope		4.743			
	c . i.		4.743			
	Diff.		.000			
	i.		163			

TABLE 2.

Branch	Wave Length	.580	.610	.620	.640	.680
	c	.147	.0332	.024	.096	.970
1.	Slope			.672	1.342	.970
	c . i.			.672	1.344	.970
	Diff.			.000	.002	.000
	i.			28	14	1
2.	Slope			1.200	.377	
	c . i.			1.200	.384	
	Diff.			.000	.007	
	i.			50	4	
3.	Slope		1.062	.552	1.351	
	c . i.		1.062	.552	1.344	
	Diff.		.000	.000	.007	
	i.		32	23	14	
4.	Slope		.365		.669	
	c . i.		.365		.669	
	Diff.		.000		.000	
	i.		11		7	
5.	Slope	.739			.000	
	c . i.	.735				
	Diff.	.004				
	i.	5				
6.	Slope	1.172				
	c . i.	1.176				
	Diff.	.004				
	i.	8				
7.	Slope					5.815
	c . i.					5.820
	Diff.					.005
	i.					6

TABLE 2 (a)

test for the third difference, and this was done by measuring the slopes of the branches of the graphs and seeking a factor for them in the usual way.

Since the branches in this case are in general much shorter than Allen's measured in Section 1, it cannot be expected that as good agreement will be shown even though the same relation between the slopes exists.

In Table 2 are given the measured slopes of all the reasonably well defined branches when there were at least two such branches in the graph. The row marked, "Slope" gives the measured value of the slope. The row marked "(c . i)" gives the product of the factor c and the integer i which most nearly gives the measured slope, while, the row marked "Diff." gives the difference between this product and the measured slope. The branches were numbered 1, 2, 3, etc. from the left in each graph. The factor which is given at the top of each column was found either by dividing one of the slopes by integers or by taking the difference between two nearly equal slopes.

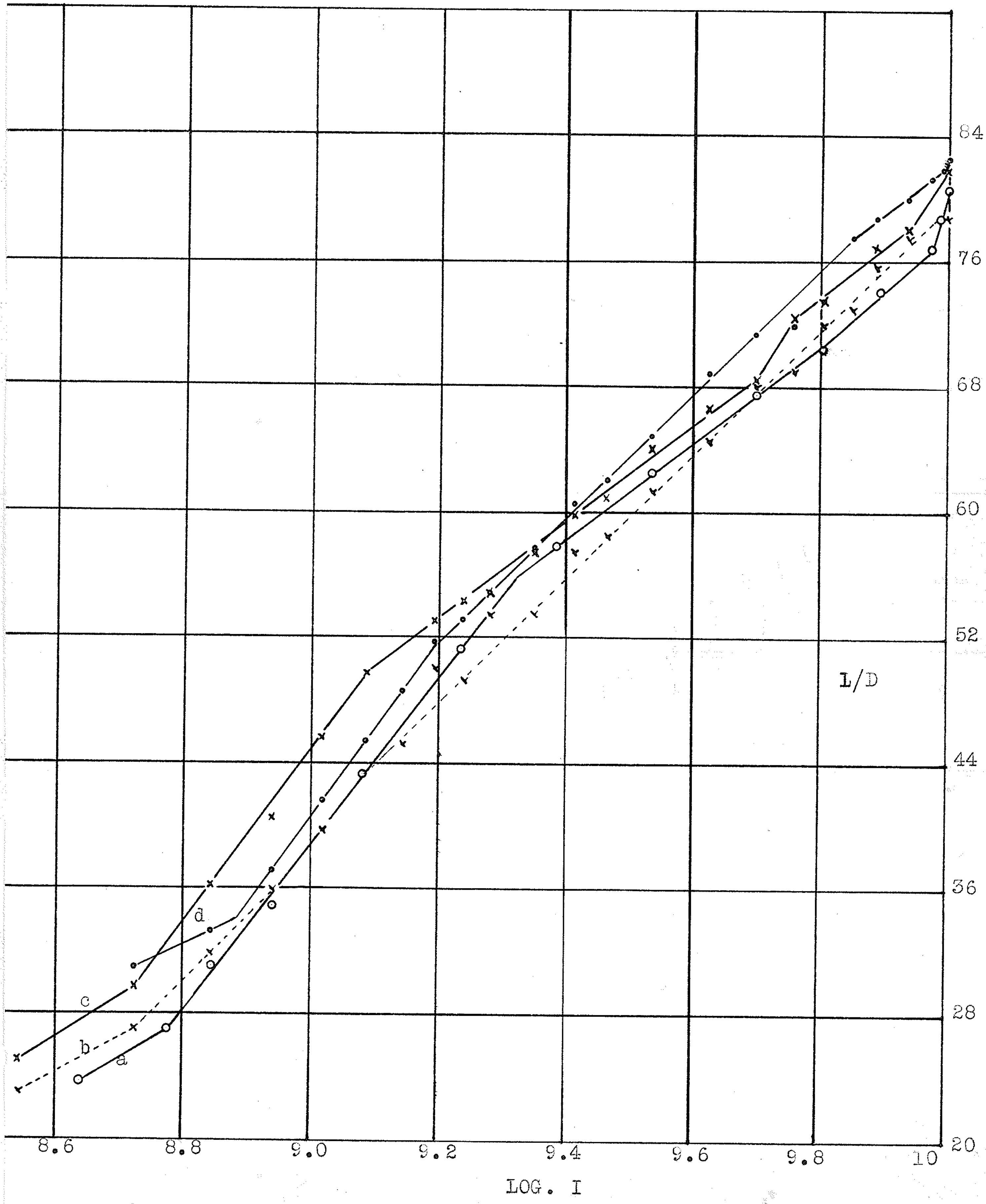
It will be observed from the table that there is fairly good indication that a similar relation exists between the slopes of the branches of these graphs to that found for the normal eye. If this be true, then anomalous trichromatism may perhaps be definitely associated with the unusual positions and numbers of the thresholds for the components of the Porter effect.

In Fig. 4 are plotted the Porter graphs for a single wave length, .55 μ, under different conditions of adaptation. The value of 1/D was plotted along with the logarithm of the intensity as in figures 2 and 3. These readings were made to obtain some idea of the changes in position of slope of the Porter graph with changes in adaptation.

Curve (a) is the original normal value copied from Figure 3. Curve (d) is also a normal curve taken under daylight adaptation, but as will be seen this curve shows considerable enhancement of the sensation compared with the original normal. This is probably due to treatment of the eye during the previous few days. It had been subjected to stimulation by bright sunlight on the snow and by an acetylene gas flame at a distance of twelve inches. Between these two curves there appears to be no simple relation except approximate parallelism of the branches which cut the abscissa log I = 9.0

The curve (b) was started with the room in darkness except for whatever light was spread from the acetylene flame, which was shielded on the side of the operator; objects in the room were poorly distinguishable. The readings were taken about every one and one-quarter minutes, and lasted one-half minute. The illumination of the room began to become greater due to the breaking of day when log I = 9.6 approx.

FIGURE 4.



PORTER GRAPHS, Wave length = .55

	K log I	Old Normal D	Old Normal 1/D	New Normal D	New Normal 1/D
00°00'	10.0000	.0124	80.64	.0121	82.64
10	9.9933	.		.0122	81.96
15	9.9849	.0127	78.74		
20	9.9729	.0130	76.92	.0123	81.30
30	9.9375			.0125	80.00
39	9.8905	.0135	74.07		
40	9.8842			.0127	78.74
45	9.8494			.0129	77.[illegible]
50	9.8080	.0142	70.42	.0136	73.52
55	9.7585	.0148	67.56	.0139	71.94
60	9.6989	.		.0140	71.42
65	9.6259			.0145	68.96
70	9.5340	.0160	62.50	.0154	64.93
73	9.4659	.		.0161	62.11
75	9.4129			.0165	60.60
76	9.3836	.0173	57.80		
77	9.3520			.0174	57.47
79	9.2805			.0182	54.94
80	9.2396			.0188	53.19
80 05	9.2360	.0195	51.28	.	
81	9.1943			.0195	51.82
82	9.1435			.0206	48.54
83	9.0858			.0220	45.45

TABLE 3

PORTER GRAPHS, Wave Length = .55 (Continued)

	K log I	Old Normal D	Old Normal 1/D	New Normal D	New Normal 1/D
83°05'	9.0807	.0231	43.29		
84	9.0192	.		.0240	41.66
85	8.9402	.0287	34.84	.0269	37.17
86	8.8435	.0322	31.05	.0330	33.33
86.35	8.7752	.0371	26.95		
87	8.7188			.0322	31.00
87.30	8.6396	.0421	23.75		

	K log I	Darkest D	Darkest 1/D	Lighter D	Lighter 1/D
00°00'	10.0000	.0122	81.96	.0127	78.74
10	9.9933	.0122	81.96	.0127	78.74
20	9.9729	.0129	77.51		
30	9.9375	.0128	78.12	.0129	77.51
40	9.8842	.0130	76.92	.0132	75.75
45	9.8494			.0137	72.99
50	9.8080	.0136	73.52	.0139	71.94
55	9.7585	.0138	72.46	.0145	68.96
60	9.6989	.0146	68.49	.0147	68.02
65	9.6259	.0150	66.66	.0155	64.51

TABLE 3 (a)

PORTER GRAPHS, Wave Length = .55 (Continued)

	K log I	Darkest D	Darkest I/D	Lighter D	Lighter I/D
70	9.5340	.0156	64.10	.0163	61.34
73	9.4659	.0164	60.97	.0171	58.47
75	9.4129	.0167	59.80	.0175	57.40
77	9.3520	.0173	57.80	.0187	53.47
79	9.2805	.0182	54.94	.0187	53.47
80	9.2396	.0184	54.34	.0203	49.26
81	9.9143	.0188	53.19	.0200	50.00
82	9.1433			.0221	45.24
83	9.0858	.0201	49.75	.0230	43.47
84	9.0192	.0219	45.66	.0252	39.68
85	8.9402	.0247	40.68	.0278	35.97
86	8.8435	.0276	36.23	.0313	31.94
87	8.7188	.0336	29.76	.0370	27.02
88	8.5428	.0400	25.00	.0435	22.98

TABLE 3 (b)

Curve (c) was taken immediately after (b) but in the reverse order, i.e., starting with the brightest intensity, and going to the lowest. The illumination of the room continued to become greater as the sun rose, but probably did not change much after the point when log I = 9.6 going down, so that if the portions of both curves (b) and (c) above log I = 9.6 be neglected it can be said that the curve (b) is for deep twilight adaptation, and the curve (c) of twilight adaptation obtained from sufficient lighting to render the objects in the room fairly clearly distinguishable.

Since the curve (d) was the normal curve for the author's eye at that time, it is readily seen that (b) shows considerable depression of the sensation throughout the whole range. The curve (c) shows depression for the greatest intensities, considerable enhancement for a range of the lesser intensities then depression for the least. These results show that partial darkness adaptation may give quite a variety of different effects, depending on its' amount.

The curve (b) shows a tendency to become less branched than the normal. This is according to expectations since measurements made by Ives and others with the dark adapted eye gave in general only two branches. This leads to the conclusion that the number of branches is in some way dependent on the state of adaptation of the eye; hence the different thresholds, if they exist, have their positions determined by adaptation. In the dark adapted eye the upper thresholds either come together so as to decrease their number, or some of them are raised so high that they are not passed when spectra of the usual intensities are used as stimuli. The shape of the curve (b) perhaps shows that both of these things may happen. This requires further experimental determination by taking measurements of the Porter effect with different degrees of adaptation.

It is also quite evident from the non-parallelism of the curves that threshold changes are not the only ones which take place on change of adaptation, but that the number of the elementary reactions starting at each threshold may change also, unless the elementary constant also varies with adaptation. As was shown from the discussion of the Porter effect in touch in Sec. 1, it is unlikely that the elementary constant would change as it did not change there with fatigue or enhancement. The conditions under which the measurements were taken were far from ideal since the state of adaptation was not well controlled, but the slopes were measured to see if they indicated the non changing of the supposed elementary constant.

In Table 2 are given the values of the slopes of the various graphs under the same headings (a) (b), etc. as they are named in the graph of fig. 4. The branches are numbered from the left 1, 2, 3. The row, "c . i" gives the

CURVE (a)

Branch	2	3	4	5
Slope	1.234	.757	.930	3.579
c . i.	1.229	.761	.936	3.569
Diff.	.005	.004	.006	.010
c	21	13	16	61

CURVE (b)

Branch	2	3	4
Slope	1.008	1.234	.984
c . i.	.995	1.229	.995
Diff.	.013	.005	.011
c	17	21	17

CURVE (c)

Branch	2	3
Slope	1.369	.765
c . i.	1.346	.761
Diff.	.023	.004
c	23	13

CURVE (d)

Branch	2	3	4
Slope	1.399	1.000	.762
c . i.	1.404	.995	.761
Diff.	.005	.005	.001
c	24	17	13

METHOD - 1.234 -.757 = .477
.477/8 = .059 fairly good, .0585 better.

TABLE 2.

product of the factor, and the integer which most nearly gives the measured slope, and the row marked, "Diff." gives the difference between (c . i) and the measured slope, while the row, "i" gives the integer. The factor was found as shown in the table.

The lower branches numbers 1 were considered to be insufficiently defined to draw any conclusions from, so they were not measured and some of the other branches were also omitted for the same reason.

It is evident from table 2 that there is a good indication that the same factor exists for all these different Porter graphs. Experimental verification is required with better controlled adaptation of the eye and using a number of different wave lengths, but there is good ground for believing that the elementary factor c is invariable with adaptation. If this be true then a change of adaptation changes perhaps two things only, first, the position of some or all of the thresholds, second, the number of the elementary reactions giving rise to the Porter effect along any branch.

It will be noticed in the table that the second branch of (b) is parallel to the fourth branch. There is some indication here that the threshold of the fourth branch would move lower on further dark adaptation, and give the usual Porter graph of dark adaptation with two branches only. It will be noticed also that the threshold of the second branch of (b) is lower than that of the normal (d) but that the branch has changed its' slope in such a way as to make it parallel to the fourth branch. This suggests there may exist a relation between the thresholds of some of the branches and their slopes. If this be true, then since the slopes can only change by quanta, then must also these thresholds change by quanta as well.

If 1/D be, as it usually is considered, a measure of sensation it is evident from the way that the graphs due to different degrees of adaptation cross over each other that a great many varieties of Purkinje effects, perhaps many of them too small to be evident without measurement, are possible, because, since the Porter graphs of different colors are so different in shape it is very unlikely that they could change their shape and position with adaptation as much as did the graph in fig. 4 without intersecting at many different places with different degrees of adaptation. Ives (1) has shown that the lower branches intersect with complete dark adaptation but the intermediate conditions of adaptation have not been investigated in this regard. However, it is evident that the Purkinje effect is probably due to a very complex set of relations, i.e., the relations

(1) Ives, Phil. Mag., 24 p. 352; 1912.
Peddie Color Vision, p. 164; 1922.

of the threshold changes and the changes of the number of elementary reactions making up the Porter effect with adaptation, and also perhaps of similar changesdue to reflex enhancement and depression,as,if the Porter effect for the eye is similar to that in touch the changes due to fatigue and enhancement are of the same nature as those due to adaptation, i.e., they are changes of thresholds along with changes of the number of elements making up the branches. Indeed the mechanism of adaptation may be the same mechanism as the mechanism of depression and enhancement. It is significant in this regard that in dark adaptation the reflex effects have been found to be very small if not absent, and the state of dark adaptation is perhaps the condition of rest of the mechanism of adaptation.

SECTION 3.

CRITICAL FREQUENCY MEASUREMENTS ON THE PERIPHERY OF THE EYE.

CRITICAL FREQUENCY MEASUREMENTS ON THE PERIPHERY OF THE EYE

The measurements plotted in Fig. 1 were made to find the variation of the critical frequency of flicker as a stimulus was directed to points further and further from the central part of the retina, the object being to find a suitable part of the periphery on which to make measurements of the luminosity of the spectrum by the critical frequency method.

The same apparatus was used as when the luminosities of the spectra of different intensities were measured for the central part of the eye. To the right of the slit of the instrument was fixed a millimetre scale with a slider. By means of the slider, a bright piece of platinum wire could be moved to any desired position. There was sufficient illumination from the room got in between the eye-piece of the instrument and the slit so that the platinum wire could be distinguished. When the readings were being made the platinum wire was looked at directly with the fovea, so that the light from the spectrometer was falling on the temporal periphery at a position determined by the distance of the platinum wire from the slit.

In Table 1 are given the values of the critical durations for three different wave lengths, and for several positions of the wire. $\underline{O}$ is the angular distance from the centre of the eye of the portion of the periphery being stimulated. $\underline{d}$ is the horizontal distance of the object fixated from the slit. $\underline{L}$ is the vertical distance from the slit to the lens of the eye; its' value in all cases was 61 cms. Thus O is the arc tangent of d divided by L (d/L).

As will be readily seen the plotted values fall in three distinct curves. The curves on the left have a sudden downward fluctuation when O is little greater than 30 minutes. This means that the critical duration increases in this partiular fashion until a visual angle of about 60 minutes is subtended. The fovea centralis measures from 0.24-0.3 mm., and subtends an angle of from 55-70 minutes (1). Thus it would appear that this fluctuation occurs at the edge of the fovea centralis, and with the usual assumption that 1/D is a measure of the sensation, it may be concluded that the sensation diminishes regularly out to the edge of the fovea centralis, then suddenly increases.

The second set of curves is of the readings taken in the area subtending from about 94 minutes up to 06 degrees 16 minutes. There seems to be no sudden change at the edge of the rod free area subtending 03 degrees 03 minutes, but it may be that the second fluctuation takes place at the edge of the macula lutea, which subtends 4-12 degrees (1).

(1) Parsons Color Vision 1924, Page 13.

Wave length	d	θ	D	d	θ	D
.57	.0	00°00'	.0123	.133	00°07'	.0129
.58	.0	00.00	.0122	.133	00.07	.0128
.59	.0	00.00	.0123	.133	00.07	.0129
.57	.533	00.30	.0148	.833	00.47	.0137
.58	.533	00.30	.0146	.833	00.47	.0132
.59	.533	00.30	.0148	.833	00.47	.0144
.57	1.33	01.15	.0142	2.33	02.08	.0154
.58	1.33	01.15	.0140	2.33	02.08	.0156
.59	1.33	01.15	.0145	2.33	02.08	.0159
.57	3.33	03.08	.0168	4.00	03.45	.0150
.58	3.33	03.08	.0177	4.00	03.45	.0144
.59	3.33	03.08	.0175	4.00	03.45	.0149
.57	4.33	04.04	.0155	5.33	05.00	.0155
.58	4.33	04.04	.0158	5.33	05.00	.0161
.59	4.33	04.04	.0162	5.33	05.00	.0157
.57	6.33	05.05	.0155	7.33	06.50	.0149
.58	6.33	05.05	.0155	7.33	06.50	.0156
.59	6.33	05.05	.0157	7.33	06.50	.0158
.57	8.33	07.40	.0157	9.00	08.40	.0136
.58	8.33	07.40	.0151	9.00	08.40	.0140
.59	8.33	07.40	.0153	9.00	08.40	.0151

TABLE 1

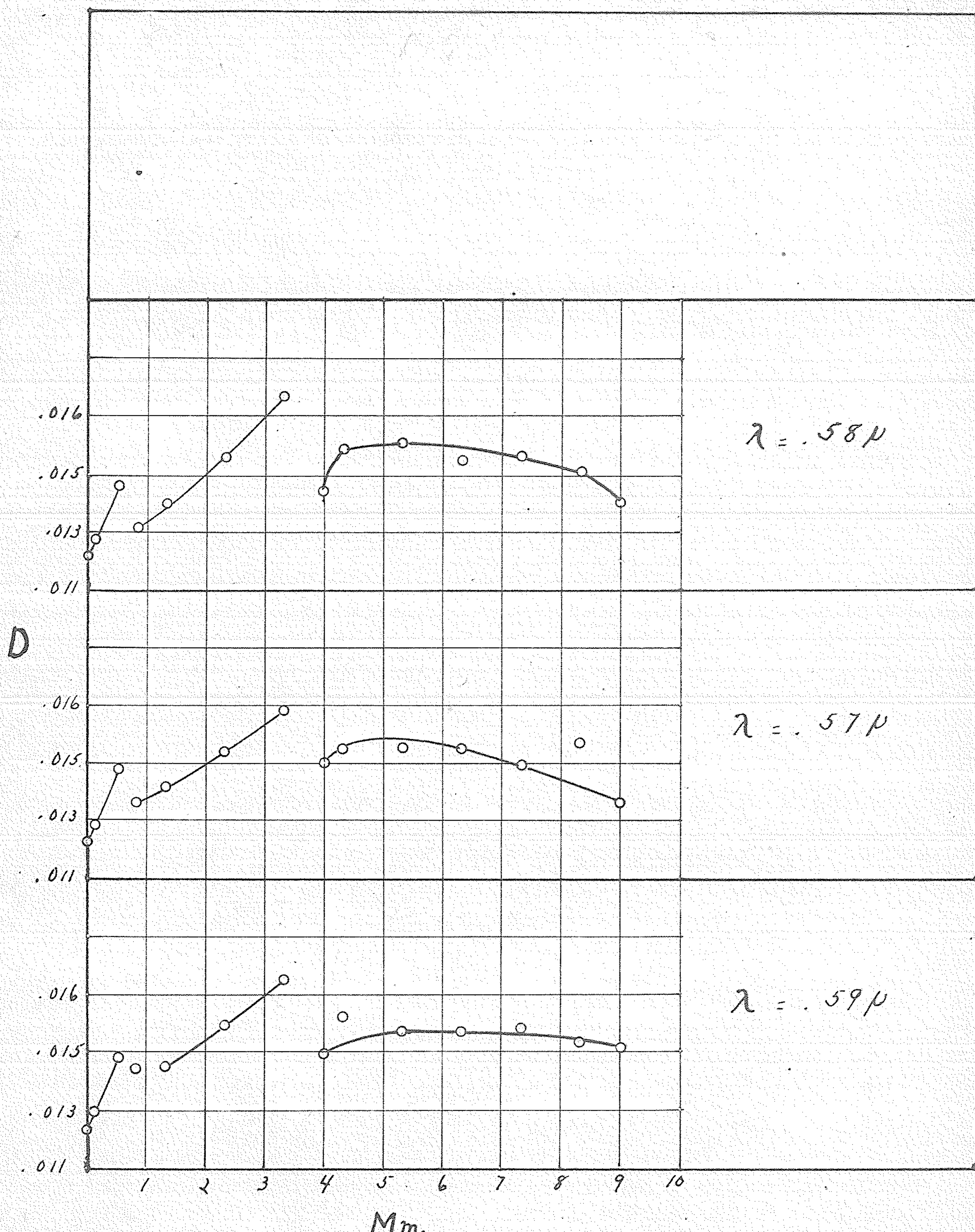


FIGURE 1.

It may be concluded, if these quoted values are valid for the author's eye, that the presence of the rods among the cones does not have any marked effect on vision. The rise in the curve could scarcely be attributed to the presence of the rods since it does not continue to rise when the rods become even more numerous.

Beyond the fluctuation, which has been considered to mark the boundary of the macula lutea, the critical duration D appears to rise to a maximum about five degrees from the centre of the eye, and then to decrease. Since these measurements were made only to find the general behavior no repetitions were made to eliminate errors, so that the points that lie off the curves probably have no significance.

The construction of the eye-piece of the instrument was such that it did not allow of any readings being taken at a greater angular distance from the centre of the eye than eight degrees and forty minutes, but it may be predicted from the shape of the curves that the critical frequency would shortly become greater on the periphery than on the centre of the eye. This is in agreement with Allen's measurements (1). He found that at ten degrees on the temporal side of the retina the critical frequency was greater than at the fovea centralis, and that at twenty degrees it was still greater. Allen worked with darkness adaptation.

(1) Frank Allen, Physical Review, Vol.28, No.1, January 1909.

Since but three different wave lengths were used, and these all in the yellow, it cannot be concluded from this data that all the colors will give effects similar to those obtained. On the contrary it is perhaps to be expected, since the macular pigmentation is yellow, that the second curve would gradually merge into the third as the wave length was changed toward either end of the spectrum. There is, however, evidence from subsequent measurements that there may be other fluctuations in the graph with other colors. These measurements will now be discussed.

As was stated previously the data plotted in fig. 1 was obtained in order to find a suitable part of the periphery on which to take a set of normal curves of spectra of varying intensities. The object of doing this was to see if the Purkinje effect could be connected with rod vision. Since at the middle of the third curve in fig. 1 the value of D did not change very rapidly with the angle, this portion of the periphery was considered to be the most suitable, and was, therefore, used.

The data for the normal peripheral curves is given in Table 2. The measurements were taken under the same conditions and with the same instrument as were those for the normal foveal curves (1) with which they are plotted. (Fig. 2 et seqq.) The readings were taken on the temporal

(1) Copied from Sec . 2.

Wave Length	α 00°	15°	20°	39°	50°	60°
	D	D	D	D	D	D
.74 μ	.0352					
.72	.0284	.0298	.0303	.0329		
.70	.0220	.0235	.0245	.0252	.0274	.0326
.68	.0192	.0191	.0216	.0208	.0205	.0242
.66	.0183	.0194 .0170	.0192	.0185	.0187	.0207
.64	.0161	.0180 .0164	.0177	.0170	.0164	.0180
.62	.0157 .0188	.0168 .0151	.0163 .0191	.0156	.0156	.0186
.61	.0171	.0168	.0174	.0156	.0152	.0176
.59	.0157	.0154	.0165	.0156	.0158	.0160
.58	.0160	.0153	.0156	.0153	.0156	.0158
.57	.0162	.0149	.0155	.0155	.0161	.0153
.55	.0152	.0152	.0162	.0155	.0154	.0158
.53	.0153	.0159	.0165	.0154	.0164	.0164
.50	.0169	.0167	.0173	.0180	.0191	.0189
.48	.0197	.0181	.0184	.0194	.0203	.0224
.46	.0227	.0220	.0246	.0225	.0261	.0283
.44	.0302	.0297	.0327	.0329	.0342	.0353
.42	.0409	.0370				

TABLE 2.

Wave Length	α 60° D	83° 05' D	85° D
.69 μ	.0261		
.67	.0242		
.66		.0398	
.65	.0191		
.64		.0287	.0364
.63	.0190 .0170		
.62		.0253	.0297
.61		.0254	
.60	.0162		
.59		.0218	
.58		.0233	
.57		.0237	
.56	.0161		
.55		.0222	.0286
.54	.0169		
.53		.0295	.0346
.52	.0172		
.51	.0183		
.50		.0295	.0388
.49	.0202		
.48		.0345	
.47	.0259		
.45	.0332		

TABLE 2 (a)

periphery at $06^{\circ}05'$ from the centre of the eye. D as before is the value in seconds of the critical duration and 1/D is the corresponding critical frequency. The angles α are the angles between the Nicol prisms so that the cosine squared of α is a measure of the intensity of each spectrum. The same intensity was used for each peripheral curve as was used for the corresponding foveal curve so that each pair of curves in figs. 2 et seqq. is for the same spectrum exactly. They differ only in that the measurements were made on different parts of the eye. The interval between readings was, as for the corresponding foveal measurements, four minutes. After a little practise it was found that these readings could be repeated so that a second reading would agree with the first, frequently exactly, and with seldom a greater difference than .004 or .005 seconds, except with dim lights and in the particular cases which are shown on the graphs by discontinuities, and which will be discussed later. There was never the same satisfaction felt that the just sufficient frequency had been reached in this case as when the measurements were made on the fovea, but nevertheless the judgment seems to be almost as good.

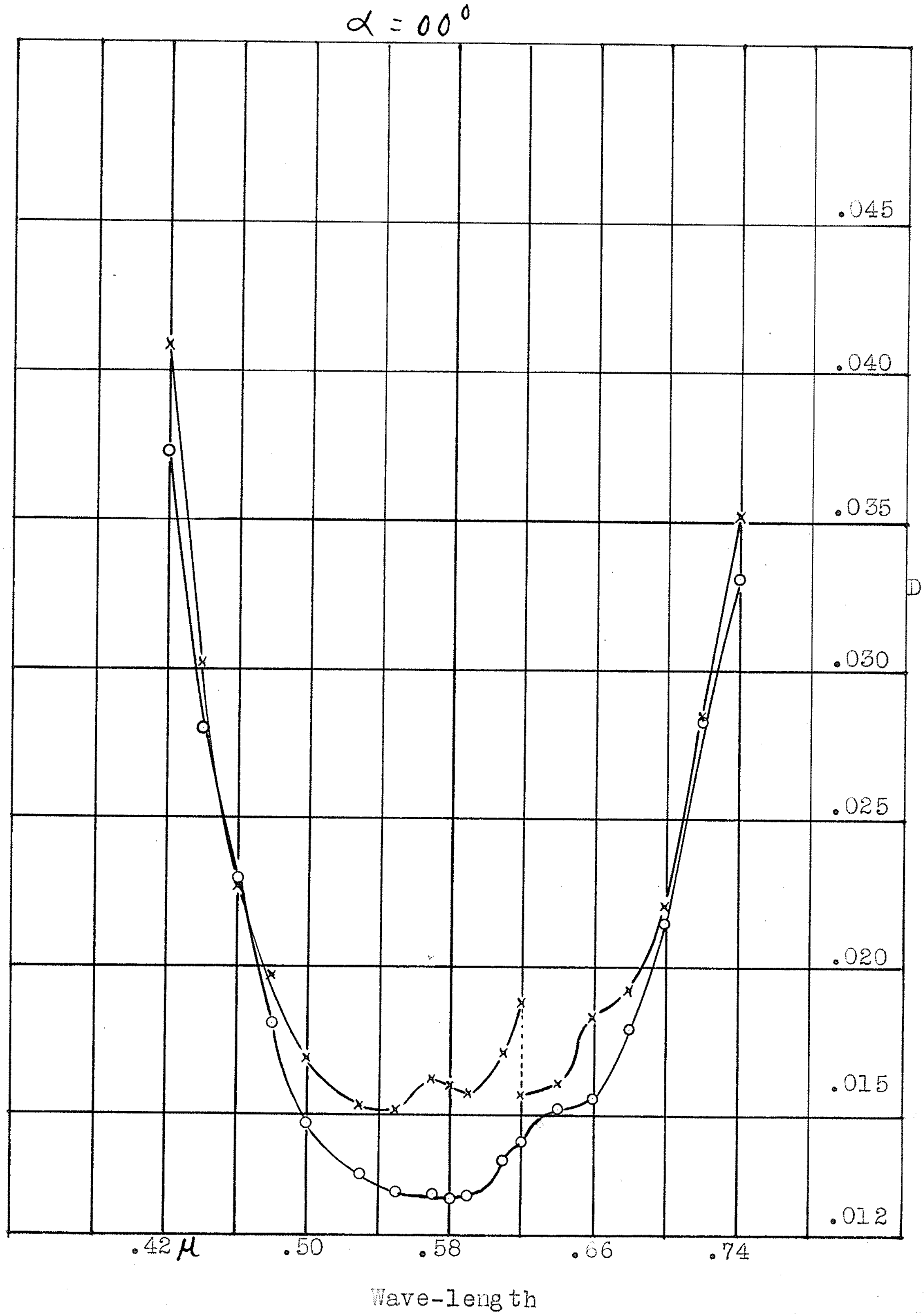


FIGURE 2.

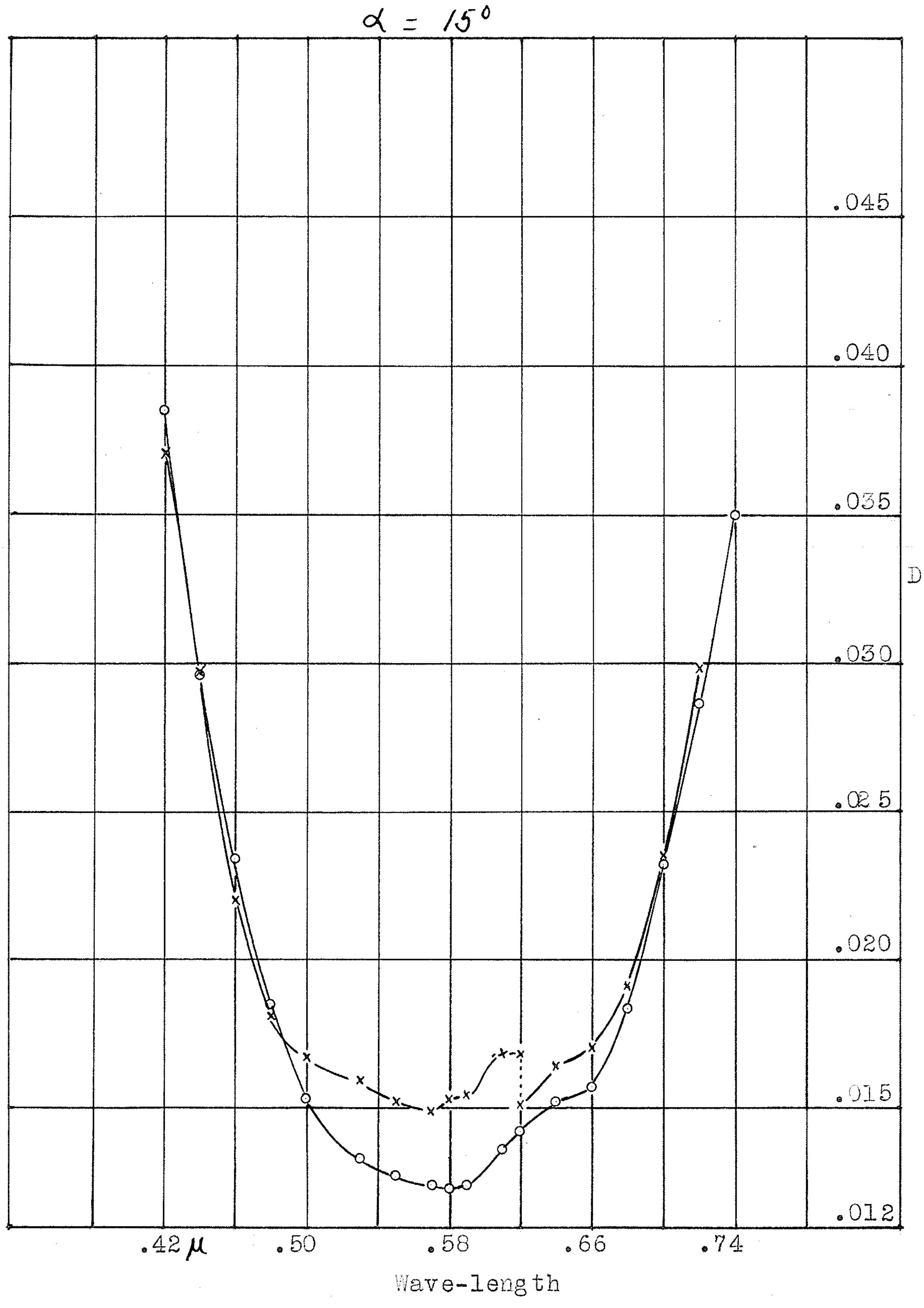
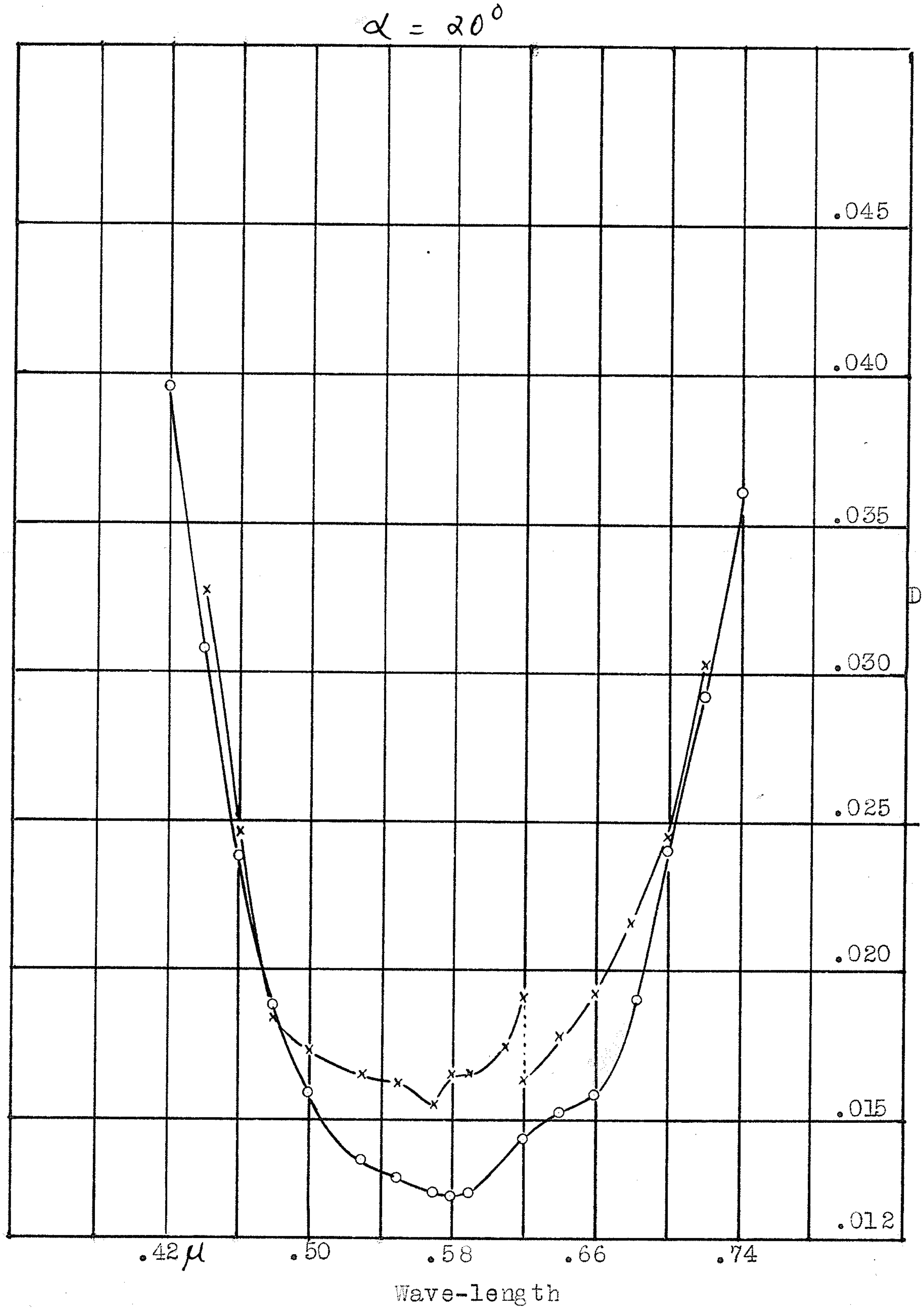


FIGURE 3.



$\alpha = 20^0$
.045
.040
.035
D
.030
.025
.020
.015
.012
.42μ
.50
.58
.66
.74
Wave-length

FIGURE 4.

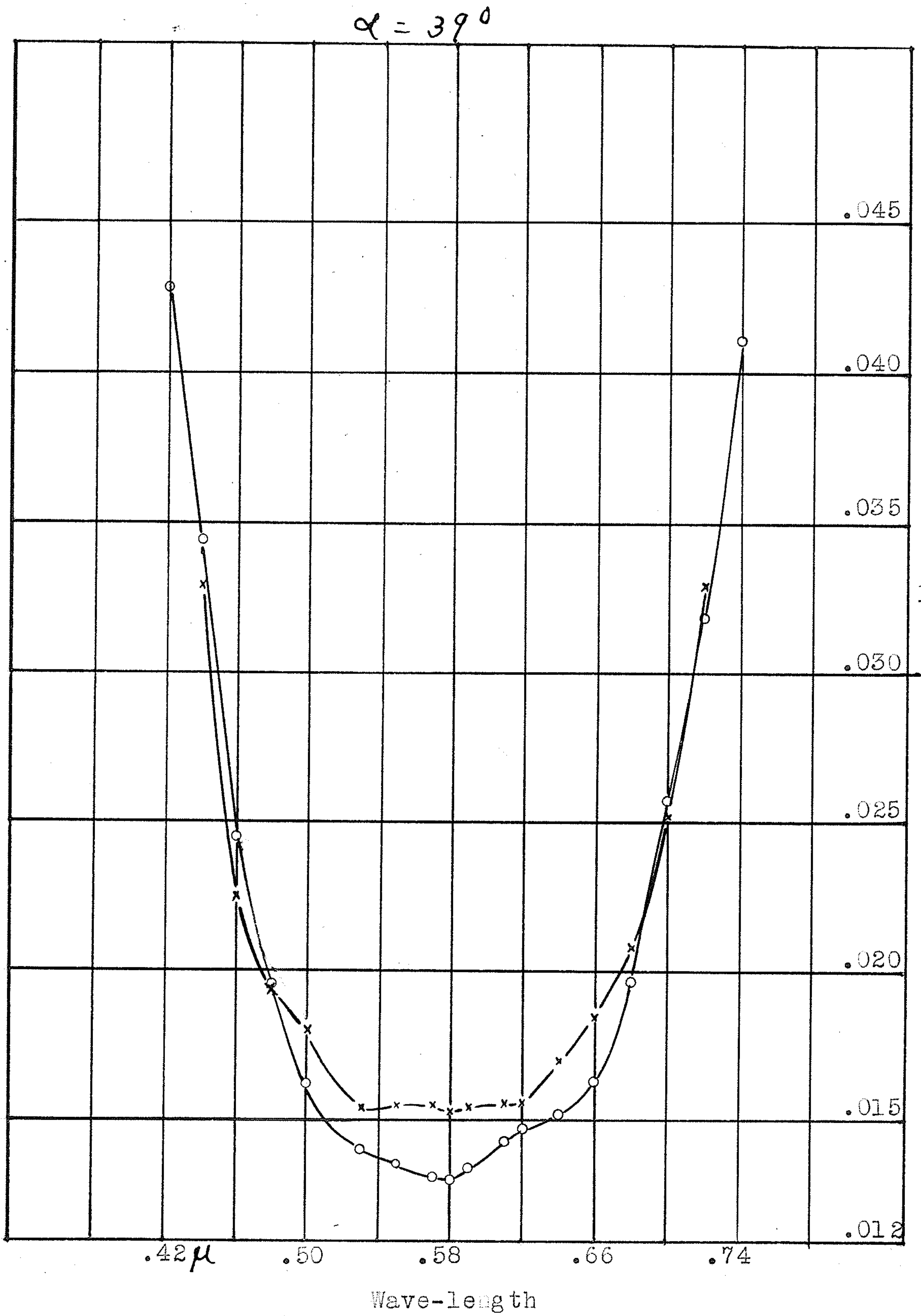
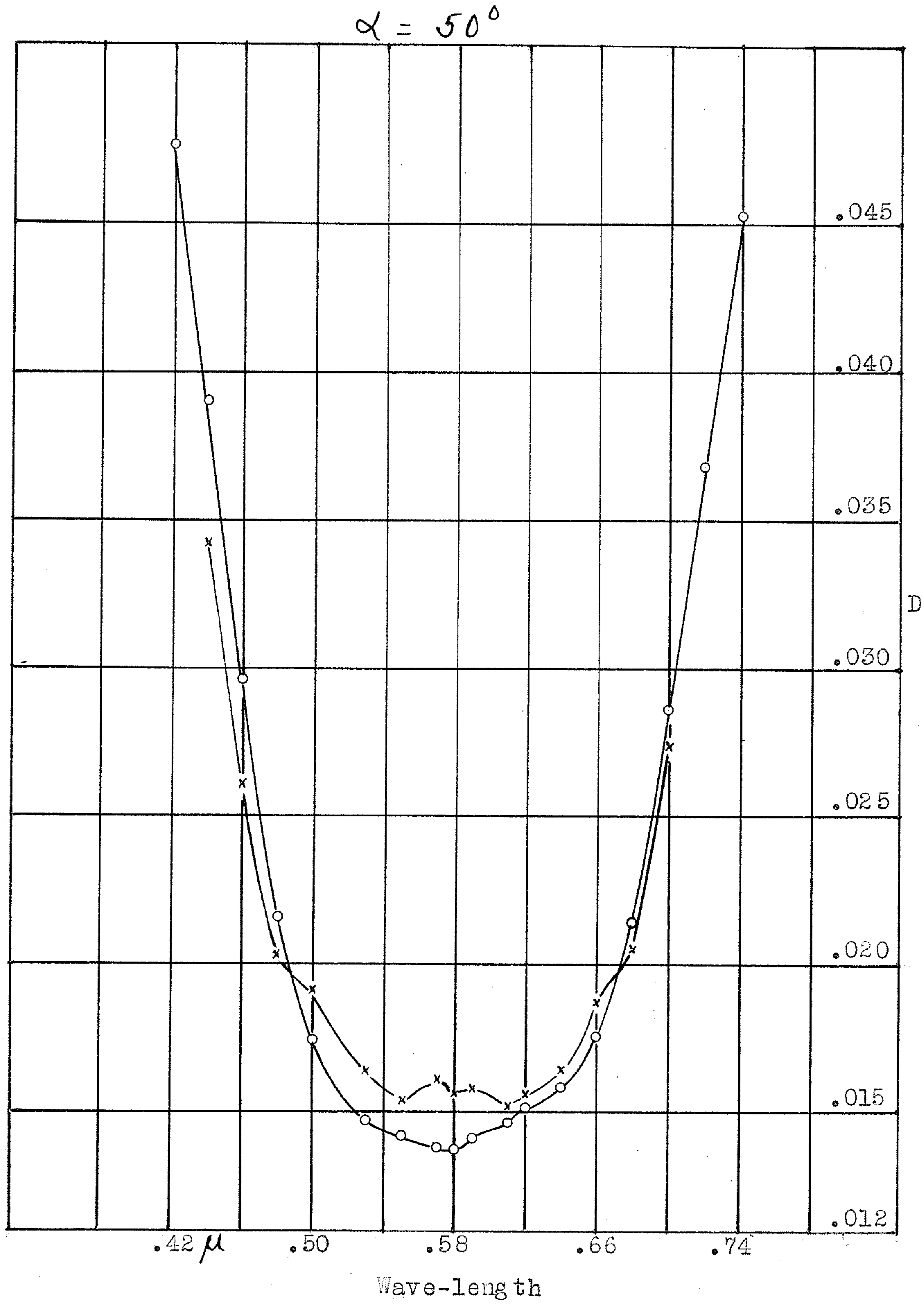
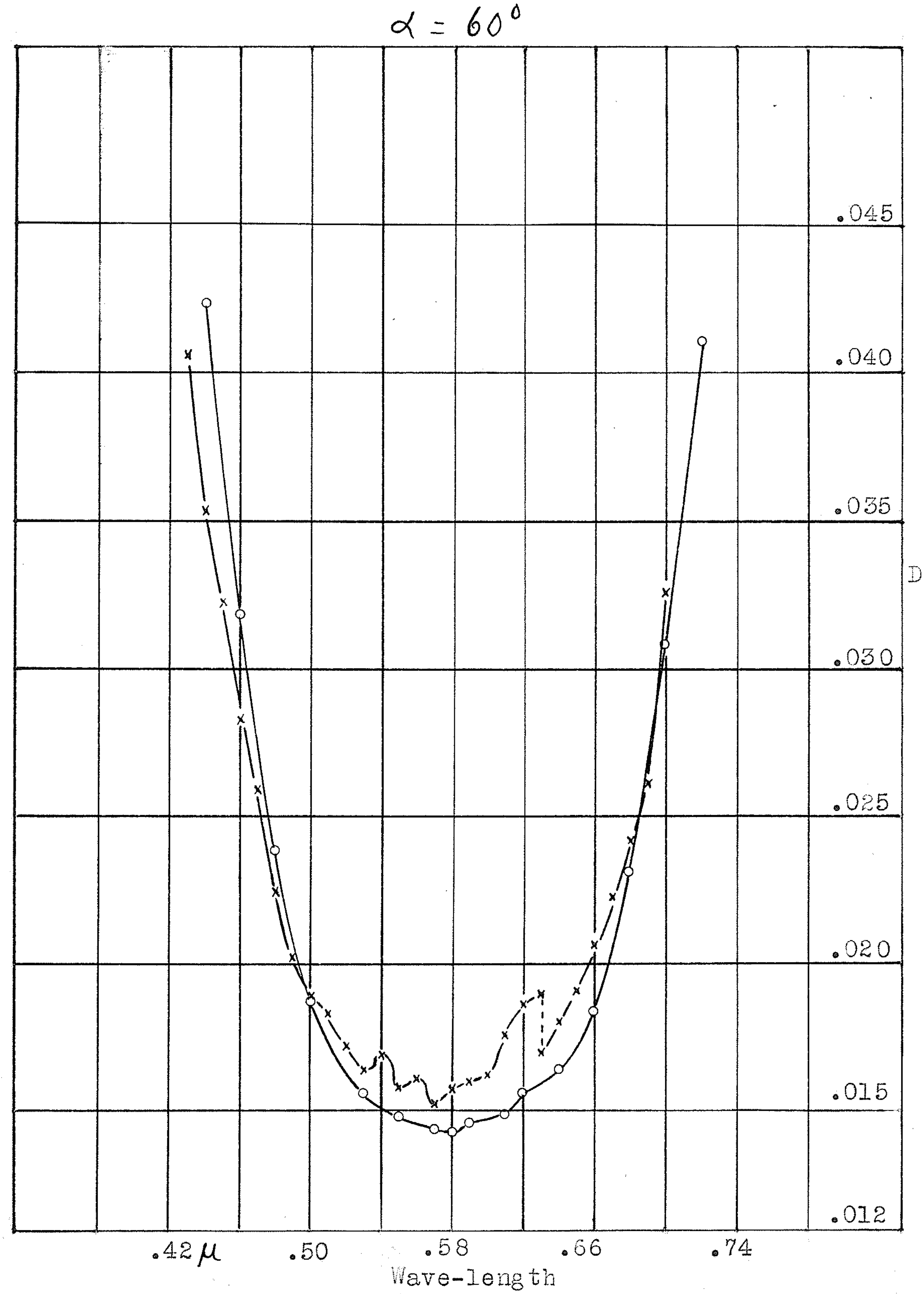


FIGURE 5.



$\alpha = 50^\circ$
.045
.040
.035
D
.030
.025
.020
.015
.012
.42 μ
.50
.58
.66
.74
Wave-length

FIGURE 6.



$\alpha = 60^\circ$
.045
.040
.035
D
.030
.025
.020
.015
.012
.42 μ
.50
.58
.66
.74
Wave-length

FIGURE 7.

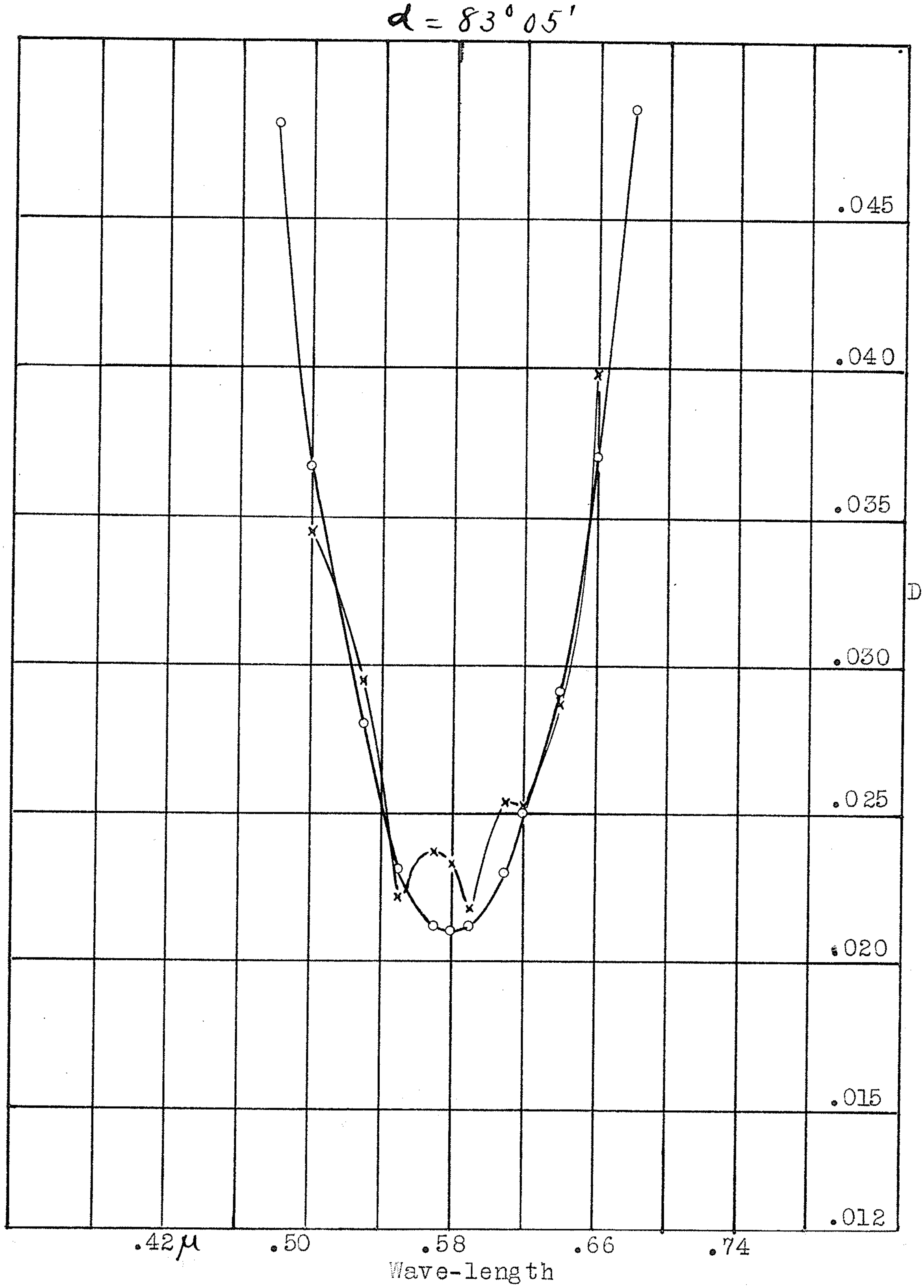

α = 83° 05'
.045
.040
.035
D
.030
.025
.020
.015
.012
.42μ
.50
.58
.66
.74
Wave-length

FIGURE 8.

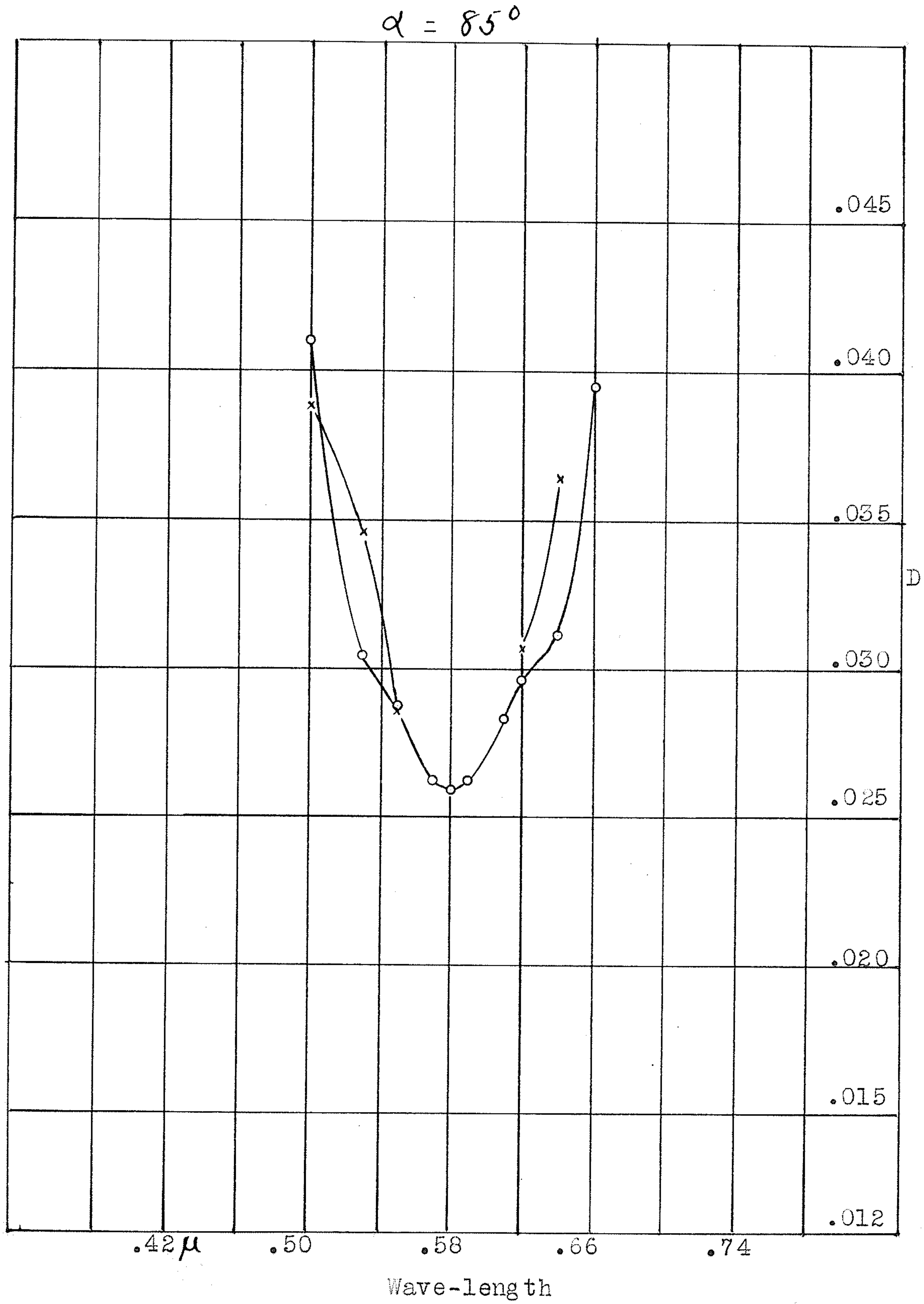


FIGURE 9.

With the lowest intensities it was found much more difficult to get readings with the middle part of the spectrum than the ends, and with the least intensity ($\alpha = 85^\circ$) the middle had to be omitted altogether.

According to the results of other observers, the fovea is more sensitive to red flicker, and the periphery to blue, especially at low intensities. (1). In this case at the highest intensity, Fig. 2, the fovea is more sensitive to the flicker of all colors, but in Figs. 3, 4, 5, 6 and 7 the peripheral curves cross the foveal curves at Wave Length .49 μ approximately, the junction of the blue and green, showing that the fovea is less sensitive to blue flicker for these intensities. The fovea in every case is more sensitive to flicker for the bright reds, but with the reds towards the end of the spectrum there is usually little difference between the foveal and peripheral values.

These results indicate that the graphs in Fig. 1 will not have the same form for all Wave Lengths, as they show the particular part of the periphery used here to be less sensitive to flicker than the fovea, while these show the reverse to be true for the blue end of the spectrum.

These results were also tested by plotting 1/D with log I to see if they conformed to the Ferry-Porter law. The relation did not appear to exist. If it does, the

(1) Parsons Color Vision, p. 108, 1924.

branches of the Porter graph must be very short, and their slope relations very complex. Since no data of this kind has been obtained by a normal trichromat it cannot be ascertained whether the lack of conformity to the Ferry-Porter law is due to the anomaly, or whether this is the general property of the periphery. An experimental determination of this matter might be important as an indication of the function of the rods, since with all the other senses either the critical frequency or the duration varies as the logarithm of the stimulus.

It will be evident from an examination of the curves that they give no such results as might be expected to be obtained if the Purkinje effect were connected with the rod mechanism. In fact there is more indication of a shift of the maximum toward the blue with the high intensities than with the low, since the lowest point of the peripheral curve in Fig. 2 for the highest intensity is at Wave Length .55 μ, while in Figs. 3 and 4 it is at Wave Length .58 μ, and in Fig. 5 all the Wave Lengths from .55 μ to .66 μ are of almost equal brightness. On the whole it may be concluded that the cause of the Purkinje effect is more clearly indicated in Section 2 where the changes in the Porter effect for Wave Length .55 μ with adaptation were considered. If the rods have any part in giving the Purkinje effect, it is perhaps more likely that they accomplish it through some functional dependence of the cones upon them.

There is, of course, a possibility that the peripheral curves of an anomalous trichromat will differ in general character to those of the normal trichromat, and there is evidence that the breaks shown in the peripheral curves are due to some anomaly. It was found that at about Wave Length .62 μ is most cases a consistent reading could not be obtained, and in each case the highest reading and the lowest reading were both plotted. This break is of a similar nature to the breaks in the curves of Fig. 1, and it may be due to some change in the retina such as was supposed to give the breaks there. However, it is very significant that these breaks are at the same region of Wave Length as the bumps in the foveal curves. This co-incidence indicates either a similarity of function of the rods and cones, or a dependence of the cone mechanism on the rod mechanism for its' general tone.

If this latter be true, the cause of the anomaly will perhaps be likely to be found in the rods. It is interesting to note in this regard that if the conclusions in Section 1 in regard to the Porter effect are assumed to be true the results here give some ground for believing the thresholds as well as the number of elementary reactions starting from each threshold to be under control of the rod mechanism, as the distinguishing feature of the anomalous Porter graphs is the greater number of thresholds.

SECTION 4.

VISION THROUGH TUBES.

VISION THROUGH TUBES

There is the familiar phenomenon of contrast (1) which is perhaps best exemplified by regarding an illuminated surface with the two eyes, one of which is looking through an internally blackened tube. In this case the part of the surface seen through the tube appears brighter than the part seen by the other eye.

The opposite effect, which is also frequently met with, was brought to the attention of the author by looking in a similar way through an illuminated tube, e. g., a tube of white paper illuminated by direct sunlight or otherwise from the outside. In this case the part seen through the tube looks darker than the part seen by the other eye. This latter effect is probably the same as that experienced on looking through a white net such as a curtain, which is brightly illuminated. If that which is being regarded beyond is less bright than the net it is seen only with difficulty.

Abney (2) dealt with an effect which is essentially

(1) Parsons Color Vision,1924, Sec.Vl,Chap.ll, also Page 26.

(2) On the Extinction of Light by an Illuminated Retina, Roy. Soc. Proc. A, Vol. 87, p. 147.

the same when by surrounding with white light a patch of spectral light he measured the relation between the intensity of the surrounding field and the intensity of the spectral patch when the patch was just extinguished. He regarded the raise of threshold, as he considered it, to be due to light adaptation.

Ives,(1) Cobb and Geissler (2) and Emerson and Martin (3) have investigated the relation of a bright surrounding field to precision in photometric measurements.

Emerson and Martin concluded that the differences in central vision were chiefly due to reflex action, and they considered the rods to be the, "organs chiefly concerned in the reflex actions producing enhancement of vision." It was found difficult to follow the discussion as they appear to have considered the "self light" to be a negative sensation.

The general conditions regarding vision through tubes seem to be these:-

(a) If the tube is darker than the surface viewed the

(1) H.E.Ives, "Phil.Mag"., Vol.24, p.747, 1912.

(2) Trans.Illuminating Eng.Soc., U.S.A., Sept.1912 & Sept.1915.

(3) The Photometric Matching Field - 11. Roy.Soc.Proc. A. Vol. 108, 1925.

part seen through the tube appears brighter than the part seen by the other eye.

(b) If the tube is brighter than the surface viewed the part seen through the tube appears darker than the part seen by the other eye.

(c) If the tube has the same brightness as the surface viewed both eyes will see the same.

It is at once evident especially from a consideration of condition (c) that these conditions will apply, probably, only when the quality of the light is the same on both the tube and the surface viewed. Most of the observations made were with tubes illuminated with white light so the investigation has been very incomplete; however, conditions (a) and (b) seem to be at least roughly true.

With one illuminated tube or with an illuminated tube on each eye, providing the illumination of the tube was sufficiently in excess of that of the field being viewed, it was found that all fields appeared black through the tubes. If the illumination of the tube were not sufficiently in excess to produce blackness, greyness resulted on looking at a white matte surface and colored surfaces appeared correspondingly darker.

It was also found that if a rotating sectored disc were used to obtain intermittent stimuli through the tube that the field became particularly black just at the critical frequency of flicker. As this critical frequency has been shown to give a measure of luminosity, a series of measurements was made using different colored fields and different arrangements of light and dark tubes in order to ascertain what changes, if any, were made in the value of the critical frequency when the peripheral parts of the eye were in different conditions.

The apparatus used was as shown in Fig. 1. The tube or tubes were placed in the position B so that the observer might regard through them the field D. At C was a motor driven, blackened, sectored disc with two sectors of 90 degrees each by means of which the stimulus from D was interrupted. On the motor was a revolution counter and the movement of the disc was registered on a chronograph along with the corresponding time. It was thus possible to obtain the durations of the intermittent stimuli when they were of just sufficient length to give a continuous sensation.

The white tubes used were 75 cms. long and 2.40 cms. in diameter. They were constructed by placing sheets of thin white paper into clear glass tubes so that the tube proper consisted of a single thickness of white paper. The dark tubes were made by wrapping black paper around the white tubes so they were not as black inside as the usual dark tube.

The size of the tubes was such that the angle subtended at the lens of the eye by the further end was approx-

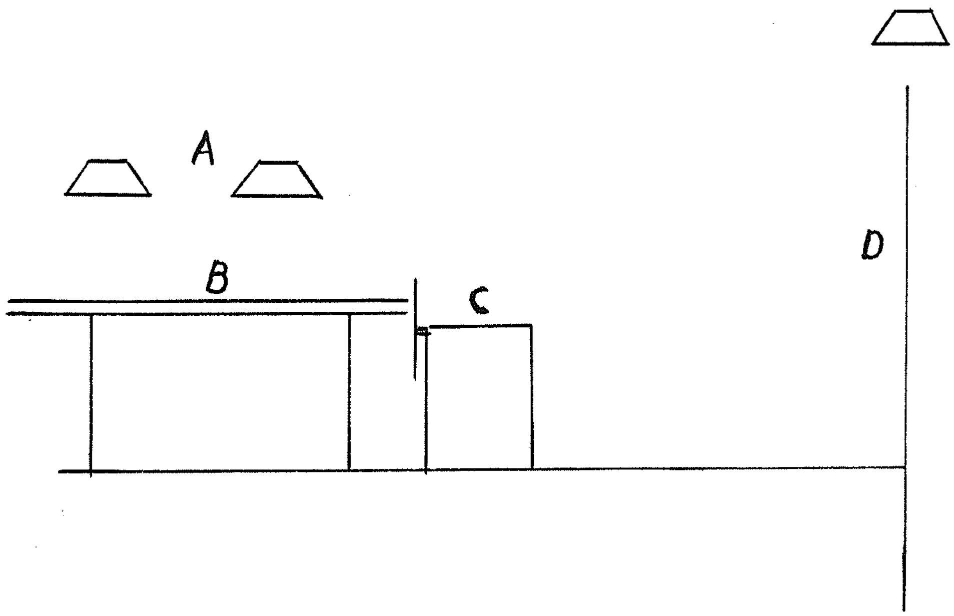


Fig. 1

imately equal to the angle subtended at the lens by the fovea centralis. The difference in the effect of using different sizes of tubes was not investigated except roughly, but the particular size used here is at least not essential.

The tubes were illuminated chiefly by two 150 W. Mazda lamps at A fig. 1 and partly by three 200 W. Mazda lamps above D. This arrangement was chosen because the relative illuminations of the white tube in the field was such that the field in each case appeared black through the white tube at the critical frequency. These were the only lights in the room and since the lights above D did not shine directly on the field, the field was much more dimly illuminated than were the tubes. The current flowing in the lamps was kept constant in all cases at 6.5 amperes, so that the illumination of the white tubes was the same throughout. The luminosities of the colored fields were, of course, different as cards were used but the illumination of each particular field was kept constant while measurements were being taken.

The normal reading in each case was taken with both eyes looking through the disc and the number recorded measures in seconds the durations of the intermittent stimuli when they were just frequent enough to give the impressions of continuous visibility. If this number be called D, then 1/D will be a measure of the luminosity of the field following the Ferry-Porter law.

imately equal to the angle subtended at the lens by the fovea centralis. There is apparently no difference with different sizes of tubes except perhaps in the magnitude of the effect, i.e., the effect does not seem to consist essentially in the mutual relations of rod and cone stimuli so that the particular size of tube used has perhaps no particular virtue.

The tubes were illuminated chiefly by two 150 W. Mazda lamps at A fig. 1 and partly by three 200 W. Mazda lamps above D. These were the only lights in the room and since the lights above D did not shine directly on the field, the field was much more dimly illuminated than were the tubes. The current flowing in the lamps was kept constant in all cases at 6.5 amperes, so that the illumination of the white tubes was the same throughout. The luminosities of the colored fields were, of course, different as cards were used but the illumination of each particular field was kept constant while measurements were being taken upon it.

The normal reading in each case was taken with both eyes looking through the disc and the number recorded measures in seconds the durations of the intermittent stimuli when they were just frequent enough to give the impressions of continuous visibility. If this number be called D, then 1/D will be a measure of the luminosity of the field following the Ferry-Porter law.

The first field used was white and it will be seen from the table that the normal reading gives the smallest D. With two white tubes the field appeared black but D was very little greater or 1/D was not much smaller.

When the value of D was obtained with the two black tubes the field looked brighter than when viewed without tubes at all but this value of D which might have been expected to be smaller than the normal D was even greater than the D obtained with the white tubes. Hence 1/D gives neither a measure of the physical intensity, for it was the same in each case, nor of the luminosity for the luminosity was almost zero with the white tubes, while 1/D was very little smaller than the normal 1/D. And with the dark tubes when the luminosity was even greater than the normal, 1/D was smaller than even the white tube 1/D at whose taking the luminosity was almost zero.

Hence it must be suspected that 1/D gives a comparable measure of luminosity only when the periphery of the eye is in one particular condition, and that luminosities can not be compared by comparison of values of 1/D unless these values have been obtained under the same conditions of peripheral illumination.

It is interesting to note in connection with these readings that the effect of an illuminated white card on the left eye is the same as the effect of a white

WHITE FIELD

Right Eye	Left Eye	D
W. T.	W. T.	.0130
B. T.	B. T.	.0133
W. T.	W. Card	.0130
B. T.	W. Card	.0144
B. T.	W. T.	.0143
W. T.	B. T.	.0137
NORMAL		.0119

GREEN FIELD

W. T.	W. T.	.0170
B. T.	B. T.	.0170
B. T.	Disc.	.0163
W. T.	Do.	.0163
NORMAL		.0159

RED FIELD

W. T.	W. T.	.0186
B. T.	B. T.	.0155
W. T.	Red Card	.0175
B. T.	Do.	.0168
W. T.	Green Card	.0358
B. T.	Do.	.0179
W. T.	Blue Card	.03 26
B. T.	Do.	.0164
W. T.	Violet Card	.0183
B. T.	Do.	.0160
W. T.	Yellow Card	.0183
B. T.	Do.	.0161
W. T.	Orange Card	.0179
B. T.	Do.	.0165
NORMAL		.0143

BLUE FIELD

Right Eye	Left Eye	D
W. T.	W. T.	.0169
B. T.	B. T.	.0189
W. T.	Red Card	.0190
B. T.	Do.	.0217
W. T.	Green Card	.0197
B. T.	Do.	.0228
W. T.	Blue Card	.0178
B. T.	Do.	.0215
NORMAL		.0138

YELLOW FIELD

W. T.	W. T.	.0137
B. T.	B. T.	.0143
W. T.	Disc.	.0144
B. T.	Do.	.0152
W. T.	Red Card	.0147
B. T.	Do.	.0145
W. T.	Green Card	.0156
B. T.	Do.	.0149
W. T.	Blue Card	.0143
B. T.	Do.	.0147
W. T.	Violet Card	.0150
B. T.	Do.	.0153
W. T.	Yellow Card	.0147
B. T.	Do.	.0151
NORMAL		.0117

tube, i.e., the reading with the right eye looking through a white tube was the same whether there was a white tube on the left eye or whether the left eye was directed at a white card 30 cms. distant. Also when the reading was taken with the right eye through a dark tube it was the same under either of these two conditions. Since the white tube illuminated the periphery of the eye chiefly while the white card illuminated the whole of it, it would appear to be true that when the right eye is affected by the stimulation of the left that the principal effect is from the stimulation of the periphery of the left eye and that stimulation of the left fovea does not affect the right eye appreciably, in comparison.

If the readings on the green card are considered it will be seen that D had the same value through both kinds of tubes, although this value was much greater than the normal. When the left eye instead of looking through a tube was directed through the disc, again D had the same value for both kinds of tubes but it was again much higher than the normal, and higher than in the case in which two tubes were used. It may be concluded from these readings that with a green of this particular quality and intensity at any rate the value of D is not changed by changing the amount of illumination of the periphery of the eye within a considerable range at least.

With the red field the normal reading was again the smallest but this time the white tube D instead of being less than the black tube D, as the case with the white field, is much greater. When an illuminated red card of the same color as the field was placed in front of the left eye at a distance of 30 cms., and the readings made with the right eye, W.T. D was reduced while when the same thing was done and the readings taken through a black tube D was increased. When a green card was used in front of the left eye in the same way, the W.T. reading was increased very much while the B.T. reading was increased a comparatively small amount. Curiously in this case it will be observed that the W.T. D is equal to 2B.T. exactly and that when a blue card was used in front of the left eye in the same way the same relation held approximately although the D's differed greatly.

With violet or yellow cards in front of the left eye in the same way the readings are the same through the W.T., and these differ little with the reading using the two W.T's., but are smaller. A similar thing is true with the B.T., except that D in this case is somewhat greater than with the two black tubes.

The orange card on the left eye transferred about the same effect from the left eye to the right as the red card did previously since the readings are nearly the same.

Inconclusion in regard to these measurements on the red field, is it not remarkable how great an increase

The normal D with the blue field was the lowest reading as usual but these readings differed from the red and were similar to the white in that the W.T. D was less than the B.T. D. This means that using white tubes decreases the value of D much more when a red field is being viewed than when a blue field is being viewed but that the black tubes decrease the value of D much more when a blue field is being viewed than when a red field is being viewed - an opposite effect. When a red card was used in front of the left eye and the readings were made with the right both the W.T. D and the B.T. D were greatly increased, the B.T. D more than the W.T. D, and the same thing was true when the left eye regarded a green card. It will be noticed that when the readings were made on the red field that the effect of putting a green or a blue card in front of the left eye was to increase the W.T. D more than the B.T. D - again an opposite effect.

When a blue card was placed in front of the left eye the readings on the blue field both increased, the B.T. D more than the W.T. D, while when a red card was placed in front of the left eye when the readings were being made on the red field, a corresponding case, the W.T. D was decreased while the B.T. D was increased - a different effect altogether.

An examination of the yellow field measurements shows these to be similar to those obtained on the white from the normal 2 W.T. reading, is the D obtained by the right eye in W.T. due to stimulating the left eye by the other two fundamentals green and blue; while the effect due to stimulating with the compound colors orange, yellow and violet is, if it exists at all, slight and in the opposite direction. This fact may be stated thus:- If the measuring eye have its' periphery stimulated with the white light while the other eye is being stimulated with either of the other fundamental colors the value of the critical frequency is very much decreased while if the other eye be stimulated with a compound color about the same value of the critical frequency is obtained as if a white tube were on the other eye instead.

It will be noted that when the right eye is reading through a black tube that all the colors have a similar but small effect, i.e., the critical frequency is somewhat smaller in each case than the normal 2 B.T. reading. This is in agreement with Allen's finding (1) that reflex effects are large only with the light adapted eye, since the eye will probably become somewhat dark adapted on looking through a dark tube. The reflex effects are apparently unusually large when the periphery is stimulated in excess of the fovea.

(1) Americal Journal of Physiological Optics Vol.5, No. 3.

field.

These measurements are not systematic enough nor complete enough to draw any definite conclusions from. They, however, show very clearly that the effects transferred from one eye to the other may be very large judging from the changes in value of the critical frequency for one eye which may be obtained by stimulating the other in various ways. It is particularly significant that the transferred effect due to a fundamental color acting alone is very large, e.g., the W.T. readings with the right eye on the red field when the left eye was stimulated with blue and with green; also the B.T. readings with the right eye on the blue field when the left eye was stimulated with red and with green. These results are in excellent agreement with Allen's visual reflex theory. Since D is undoubtedly the measure of some physiological reaction or condition it is difficult to imagine such large changes in D being caused by the stimulation of the other eye unless the effects are conveyed by the nervous system.

Since frequently almost the same or a smaller value was obtained for D on looking through a white tube at a black appearing field, as was obtained on looking through the black tube at the same field which then appeared bright and colored, it seems that it must be admitted in the case of the white tubes at least that 1/D does not give a measure of the sensation. The physiological reaction of which 1/D is a measure, and which normally gives rise to the sensation appears to be still proceeding even though it gives rise to no sensation, so the difficulty cannot be explained away by assuming that the illumination of the periphery of the eye arests the ability of the central part to respond to stimulus. That the stimulus of the black appearing color is still effective is further indicated by the following:- If through a white tube sufficiently illuminated to give the appearance of blackness a red field be viewed and then a well illuminated black card be passed in front of the tube a very strong green sensation is experienced. However, it has been observed by Burch that colors of intensity below their threshold values may give after images when the periphery is not being stimulated, so the above effect cannot be adduced as evidence that the blackness of the field seen through a white tube is not due solely to raising of the threshold. On the other hand, it is not conceded that the threshold value of a light will give a value of 1/D other than zero.

The "error of judgment" explanation of the phenomenon may receive support because of the following:- If a light colored surface be regarded through a white tube which is sufficiently illuminated to give a very dark patch, and something dark be moved into the field of vision through the tube so as to partly cover it, the dark patch immediately becomes much brighter.

The phenomenon may also be taken as a very striking means of experiencing the black sensation of Hering. Parsons (1) speaks of Hering as follows:- "According to him "black" occurs only as the result of external stimulation, i.e., under the influence of simultaneous or successive contrast. The "black" of a black patch seen on a white background, or of the after image of a white patch, is blacker than the intrinsic light of the eye and is regarded by Hering as the true black sensation."

It is evident that the phenomenon might well have been predicted from Hering's theory, and that its' existence may be considered as confirmatory evidence in support of Hering's ideas in regard to the black sensation, this, "white tube black", being the black due to simultaneous contrast.

Hering's theory is perhaps inadequate to embrace the following:- If a part red and part green field is regarded with the right eye through a white tube of sufficiently high illumination to give blackness with a homogeneous field the colors are not extinguished, but if a red card and a green card are held in front of the left eye at convenient distance blackness is again obtained

(1) Color Vision, p.267, 1924.

through the tube whether the red and green parts of the two fields are in the same relative positions or not. In the light of Sherrington's (1) investigations on binocular summation this effect is perhaps likely to be found due to reflex action in part at least, i.e., it is to be expected that the right eye or its' nerve system has been effected rather than that there is a difference of interpretation in the brain.

Another effect of interest in conjunction with the last is the following:- If the right eye be looking through a white tube at a yellow field which appears black, while the left eye be looking at an illuminated violet card 10 cms. distant, and then the gaze be shifted so that the right eye is directed at the interior wall of the tube, the wall of the tube will appear yellow. This would indicate a reflex enhancement in the right eye of the complementary of the light stimulating the left. If the same thing occurred in the previous experiment, does it not seem likely that the field through the tube would be at least as highly colored as before?

The measurements discussed here along with the different effects which may be obtained while looking through white tubes indicate that a matter of considerable complexity is being dealt with; a complexity, however, which may be due to a lack of knowledge of the intensities of the various stimuli. The measurements suggest that the reflex

(1) The Integrative Action of the Nervous System.

effects are considerably larger than those usually obtained although they cannot be considered to give any evidence that the black appearance through the tubes is due to reflex action.

An attempt to explain the phenomenon may well be left until the physical relations have been more fully obtained. Using the critical frequency method this may perhaps be easily done by using an apparatus similar to that used by Abney (1) to measure the change of threshold with adaptation. With this kind of apparatus measurements may be made varying the peripheral white stimulation while keeping the central field constant, and also the central field may be varied while the peripheral field is kept constant. When spectral light is used for the central field it will also be possible to interrupt the stimulus in such a way that the disc is invisible. The critical frequency measurements using this method may give results which are not so contrary to the accepted theory that 1/D is a measure of sensation, as an objection may be used to the method used here on account of the visibility of the disc.

The results of Section 1 indicate a possibility that reflex effects may modify the Porter effect according to definite laws, and that their magnitude may be obtainable

(1) Roy.Soc. Proc.A. Vol. 87, p. 147.

from the changes in slope and perhaps thresholds of the Porter graphs. If so, the measurements suggested above should indicate reflex action by these relations if the tube effects are due to reflex action; if they are not, the lack of relation will lead to seeking an explanation in other terms.

<u>SECTION 5.</u>

THE PORTER EFFECT IN PHOTOMETRIC MEASUREMENTS.

THE PORTER EFFECT IN PHOTOMETRIC MEASUREMENTS

It is in general the function of photometry to compare the brightness of a given light with that of a certain standard light, the object being to obtain the luminous sensation value of the one light in terms of the other rather than to obtain the value of the physical intensity of the one light in terms of the other.

It is usual to consider in photometric measurements that the luminosity or brightness of a given light is directly proportional to the physical intensity of the light, i.e., the brightness due to a light at a given point is considered to vary inversely as the square of the distance between the light and the given point.

The method of making the measurements is as follows:- A standard light B, fig. 1, is placed at the end of a graduated scale M, and at the other end of the scale is placed the light A which is to be compared with the standard.

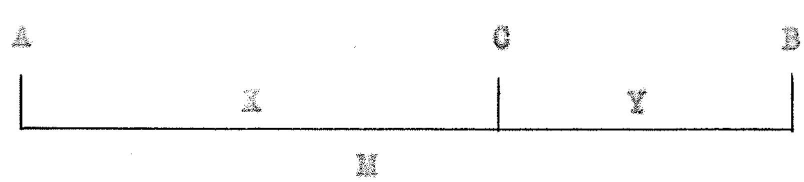


Fig. 1.

Between the two lights is a device C, which is moveable along the graduated scale. The device C is of such a nature that upon it may be seen side by side two patches of light, the one due to B, and the other due to A. In making the measurements C is adjusted until the two patches are equally bright and appear to give a single field of homogeneous luminosity. Let the position of C when this is true be such that C is X units distant from A and Y units distant from B. It is now usual to say that since the luminosity or brightness at C due to each light is the same then the brightness of A is to the brightness of B as X^2 is to Y^2 according to the universe square law. It is quite true that the physical intensity of the light A is to the physical intensity of the light B as X^2 is to Y^2, depending only on the assumption that equal intensities of the same kind of light applied simultaneously to adjoining parts of the central part of the eye arouse the same sensations, which is admitted, (Equation 1 following). That is in this case it may be said that providing B and A are lights of the same quality, then will the intensity of A be to the intensity of B as X^2 is to Y^2. This relation, however, is not one which deals with the relative luminosities of the lights.

According to Fechner's law in its' simplest form,-

$$S = K \log I.$$

where S is the sensation value due to a physical stimulus of intensity I, and K is a constant depending on the quality of the stimulus, and on the particular receptor organ being affected. In the case under consideration S will be the brightness or luminous sensation due to a given physical intensity of light.

When the device C is adjusted so that the patches of light due to A and to B are equally bright, then the brightness due to A on the one patch may be written,-

$$L_A = K \log \frac{A}{X^2}$$

where A is the physical intensity of A. Similarly the brightness due to B on the other patch is,

$$L_B = K \log \frac{B}{Y^2}$$

where B is the physical intensity of B. But these are equal:

$$\therefore \quad K \log \frac{A}{X^2} = K \log \frac{B}{Y^2}$$

or

$$\frac{A}{B} = \frac{X^2}{Y^2} \quad \text{..............................} \quad (1)$$

That is since A and B are physical intensities it may be said that the physical intensities are in the ratio of X^2 to Y^2. That is ~~it~~ is proper to measure physical intensities in this way.

However, by Fechner's law the brightness of the standard B is,

$$L_B = K \log B.$$

when B is right at the eye.

And the brightness of the light A is,

$$L_A = K \log A$$

when A is right at the eye.

$$\therefore \quad \frac{L_A}{L_B} = \frac{K \log A}{K \log B}$$

But $\quad A = \frac{B\, X^2}{Y^2} \quad$ From (1).

$$\therefore \quad \frac{L_A}{L_B} = \frac{\log \frac{B\, X^2}{Y^2}}{\log B} \quad \text{.................... (2).}$$

Which is the relation between the brightnesses or luminosities of the lights, if Fechner's law be true, and if the lights may be considered to be points and if their quality is the same.

In a similar way may the case be considered in which it is desired to determine the luminosity of a lighted patch in terms of the luminosity of a given standard light. Let the standard light give a parallel beam which forms a patch of light adjacent to the patch to be compared. Let there be a device in the patch of the standard beam by means of which the intensity of the beam may be reduced until the two patches appear to be of equal brightness. Now will

$$K \log I_u = K \log I_s$$

where I_u and I_s are the intensities of the unknown patch and the standard patch respectively. But if I_s is $\frac{1}{X}$ of the intensity of the standard light, then the intensity of the standard light,

$$I = I_s . X$$

and its' luminosity,

$$K \log I = K \log (I_s . X)$$

Thus the luminosity of the unknown L_u is to the luminosity of the standard L as, $K \log I_s$ is to $K \log(I_s . X)$

i. e.,
$$L_u = L . \frac{\log I_s}{\log (I_s . X)}$$

or
$$L_u = K \log \frac{I}{X}$$

The above results will, however, be only approximations if Fechner's law and the Ferry-Porter law are equivalent, for then the simple form of Fechner's law used above will not be adequate. Since the Ferry-Porter law,

$$L = K \log I + K'$$

applies only to a particular range of intensities of a light of particular quality without change of constants, it is to be expected that the general relations will be very complex. If, however, the general Porter law may be written as suggested in Section 1, i.e.,

$$L = c . i. \log (I . K)$$

where i and K only change comparative simplicity may arise through a knowledge of the values of the integers i and the threshold factor K for different colors. Apart from this a simple relation can be expected only when the two lights are of the same quality and of the same intensity range as regards the Porter effect. In this case if the lights are designated A and B as are those in Fig. 1 then the luminosity of A may be written,

$$L_A = K \log I_A / I_0$$

and

$$L_B = K \log I_B / I_0$$

And if the lights are compared as they were before,

$$L_A / L_B = \frac{\log (B \cdot X^2) / (I_0 \cdot Y^2)}{\log (B / I_0)} \quad \ldots\ldots\ (4)$$

where B is the physical intensity of the light B.

Since the relation of equation 4 is the simplest of all there seems to be little doubt that heterochromatic photemetry will attain practicable simplicity using the critical frequency or flicker method rather than the comparison method. It is also evident that the comparison method gives only approximate results even comparing physical intensities as well as sensations when the calculations are made in the usual way.