BRIGHTNESS DISCRIMINATION AS A FUNCTION OF THE DURATION OF THE INCREMENT IN INTENSITY

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Recent discussions of intensity discrimination in vision have focussed attention on initial events in the process. Hecht (1935), in particular, has proposed a theory which states that brightness discrimination is due to the photochemical processes which take place at the initial moment when the eye, already adapted to a given intensity, is exposed to a just discriminably higher intensity. Results of recent observations by Smith (1936) and Steinhardt (1936) lend support to the hypothesis.

An important question which arises when we consider a theory in terms of initial events is the problem of how such a formulation may be related to the Bunsen-Roscoe law. This law states that, for brief flashes of light, the product of intensity and duration is constant for the production of a constant photochemical effect. It has been found to apply within well marked limits of exposure to both the fovea and periphery of the human eye, for threshold (Graham and Margaria, 1935; Karn, 1936) and supraliminal excitation (McDougall, 1904; Blondel and Rey, 1911; Graham and Cook, 1937). Adrian and Matthews (1927) and Hartline (1928) have demonstrated the law for the eyes of lower organisms, and Hartline's findings for the single fiber of *Limulus* (1934) give adequate evidence on the nature and limitations of its application. The strict reciprocity relation fails for exposures longer than a "critical duration" beyond which, in the *Limulus* eye and probably in the human eye (Karn, 1936), the relation $I \cdot t = Constant$ is superseded by the relation $I = Constant$.

These considerations have led us to perform the experiments reported here. It has seemed important to us, because of the emphasis on initial events in brightness discrimination, to determine the effect of varying the duration of ΔI, the just discriminable increment of intensity. We have been particularly interested in results obtained for short flashes, where initial events [*e.g.*, a short burst of nerve impulses (Hartline, 1934)] might be expected to occur in relatively uncomplicated form and under conditions which will allow for an examination of a possible reciprocity effect of time and intensity. Data are presented on intensity discrimination for seven durations of ΔI, and the results are related theoretically to the Bunsen-Roscoe law and to Hecht's theory.

Apparatus and Procedure

The apparatus which was used in these experiments is a modification of one described by Smith (1936). The subject is seated in a cubicle which consists, in effect, of a small room within the larger, enclosing dark room. Only the back of the cubicle is open. During the experiment the subject noticed no appreciable amount of reflected light through the rear of the cubicle, and we are convinced that the shielding of the optical system precluded any possibility of anomalous results from stray light.

The optical system is constructed so as to provide two separate beams of light from the same source and equipped to permit gross variations in the intensity of both beams and fine variations in the intensity of one beam. Light from a 1000 watt lamp, after passing through a quartz cooling cell, a convex lens, and a holder for Wratten neutral tint filters, is divided by a system of four totally reflecting prisms into two beams. The two beams are centered by two pairs of matched convex lenses on semicircular apertures in a metal screen, this screen, in turn, being fastened to the front wall of the subject's cubicle. In one of the beams are a photographic wedge and balancing wedge. Manipulation of the wedge allows for an equation of the intensities on the two semicircles. The semicircles are covered with opal glass on the side toward the light source and are separated by a metal fin which projects perpendicularly from the screen in order to restrict the illumination of each semicircle to its single beam. The metal screen is attached to the front wall of the subject's cubicle in such a way that the two stimulus objects are directly in front of the subject and at the level of his eyes. Under these conditions they appear as two separate illuminated semicircles in a dark field. Viewed at a distance of 60 cm. each semicircle has a radius of 38 minutes, the separation between semicircles being 8 minutes. Thus, the total configuration subtends a visual angle of 84 minutes, and falls within the limits of the fovea. A stereoscope hood, from which the prisms have been removed, is used as a head-rest by the subject.

The apparatus, as described, makes it possible to equate (within approximately the limits of accuracy described by Smith) the intensities on the two semicircles. For the presentation of ΔI in the form of a flash we employed a third beam of light.

A mirror placed at one side of the light source reflects rays which pass through a holder for Wratten neutral tint filters, a condensing lens, and a Wratten neutral tint wedge with balancing wedge. The rays finally diverge from a focus to illuminate the opal glass patch situated on the subject's left. In the focal point of the third beam is placed a device for regulating the exposure of ΔI. For long durations (0.03 second to 0.5 second) we used a synchronous motor driven exposure device similar to one described by Graham and Granit (1931). This consists of two semicircular cardboard disks which may be caused to overlap by various degrees, thus giving different widths of exposure opening. The disks are attached by a shaft through reduction gears to a telechron synchronous motor. Pressure by the experimenter on a button releases a pin which holds the shaft in place and closes the switch which starts the motor. The shaft is stopped automatically at the end of one revolution by the pin and by the breaking of a mercury switch which is operated by a cam. The shaft turns at the rate of 1 revolution per second.

For durations of 0.03 second and shorter, we used a device which consists of a synchronous phonograph motor, to the axle of which is attached a large cardboard disk. A variable slit cut near the periphery of the disk allows for changes in the duration of exposure of the third beam. Since the motor is kept running all the time, the light, as it passes through the slit in the disk, flashes at the rate of once every 0.77 second. In order to restrict the illumination to single flashes, a hand-operated shutter is placed in the third beam between the opal glass and the disk of the exposure device. With practice it soon becomes possible for the experimenter to open the shutter at an interval before the slit of the disk passes through the focus of the third beam and to close it an interval after the emergence of the slit. In order to facilitate this procedure a small triangle of white paper is placed on the periphery of the disk at about a distance of 90° from the slit opening. This object can be seen rotating in the dim illumination provided by the apparatus and serves to mechanize the experimenter's timing of the hand-operated shutter. Thus, only when the hand-operated shutter is released is a flash let through to the milk glass surface, and the duration of this flash is determined by the size of the slit in the cardboard disk of the phonograph motor.

We feel that the error due to lack of "suddenness of onset" of the flash is small except for the shortest duration (0.002 second). The focus of the third beam consisted, in these experiments, of a small spot of light of about 1 mm. width, but a slight haze about the spot caused the total image to have a width of about 2 mm. Since the slit for the shortest exposure was 5 mm. in width, it is obvious that the waveform of distribution of light in time was by no means rectangular for this particular duration. For other durations, however, the error is slight.

The procedure on any day consisted in varying the photographic wedge in the second beam until the subject reported both beams as equal in intensity. This procedure was usually accomplished at a fairly high intensity of the two patches and always with the third beam occluded. Day to day variations in the equation point were relatively small and of about the same order of magnitude as those reported by Smith. After the equation point had been determined, determinations were made to find the necessary increment, ΔI. The wedge in the third beam was placed in such a position that a clearly visible flash of light was superimposed upon the left hand semicircle, and then the experimenter determined the threshold by decreasing the intensity of this beam. Single flashes of ΔI were allowed to stimulate the eye of the subject at approximately 10 second intervals. Since the subject was constantly adapted to the prevailing equated intensity on the two patches and since the intensity of the third beam was relatively small in comparison with the prevailing intensity, it may be accepted that a fairly constant level of adaptation was maintained at any intensity. Once the threshold for the given duration of flash had been determined for a given prevailing intensity, I, the filters in the third and in the divided beam were changed and determinations for ΔI were instituted at another intensity. This procedure was followed on any day for a given exposure time for eleven prevailing intensities (ten for the 0.002 second duration). In half of the series, determinations progressed from the lowest intensity level to the highest, and in the other half determinations were started at the highest intensity and progressed to the lowest. Because of the continued adaptation at any given intensity, the results for both series show a high degree of agreement. C. H. G. served as the subject throughout the determinations and E. H. K. was experimenter. Binocular observation was used in all the experiments.

RESULTS

The results of the experiment are presented in Table I and Fig. 1. In Fig. 1 log $\Delta I/I$ has been plotted against log I. Each value in Table I is the average of eight readings, except for the 0.03 second duration. The averages for this duration are based on fourteen readings of which eight were determined with the device used for shorter exposures and six with the device used for the longer exposures. Since a considerable change in apparatus took place when the exposure systems were changed, it was considered advisable to make determinations at the same duration by both devices. So far as we can see, the results obtained under the two conditions are quite similar. Two determinations were obtained in any single day's run at a particular duration of exposure.

The graph, as given in Fig. 1, indicates the general nature of the results obtained. Brightness discrimination at any given duration is represented by a high value of log $\Delta I/I$ at the lowest value of log I. From the highest value of log $\Delta I/I$ the curve drops in a continuous manner as intensity increases, until eventually at medium to high

TABLE I

ΔI/I As a Function of Intensity and Duration

Log I (millilamberts)	Log $\Delta I/I$						
	0.002 sec.	0.005 sec.	0.013 sec.	0.030 sec.	0.080 sec.	0.20 sec.	0.50 sec.
2.27		−0.65	−0.98	−1.33	−1.44	−1.30	−1.35
1.67	−0.22	−0.65	−0.99	−1.27	−1.34	−1.20	−1.40
1.27	−0.22	−0.60	−0.90	−1.20	−1.40	−1.22	−1.33
0.67	−0.23	−0.53	−0.93	−1.23	−1.37	−1.33	−1.30
0.27	−0.13	−0.53	−0.85	−1.09	−1.38	−1.37	−1.34
−0.33	0.08	−0.33	−0.69	−0.94	−1.26	−1.27	−1.25
−0.73	0.37	−0.09	−0.62	−0.81	−1.19	−1.23	−1.11
−1.33	0.65	0.21	−0.23	−0.57	−0.93	−0.99	−0.92
−1.73	0.89	0.45	0.01	−0.36	−0.92	−0.92	−0.83
−2.33	1.35	0.89	0.53	0.16	−0.26	−0.40	−0.34
−2.73	1.68	1.23	0.87	0.51	0.01	−0.08	−0.07

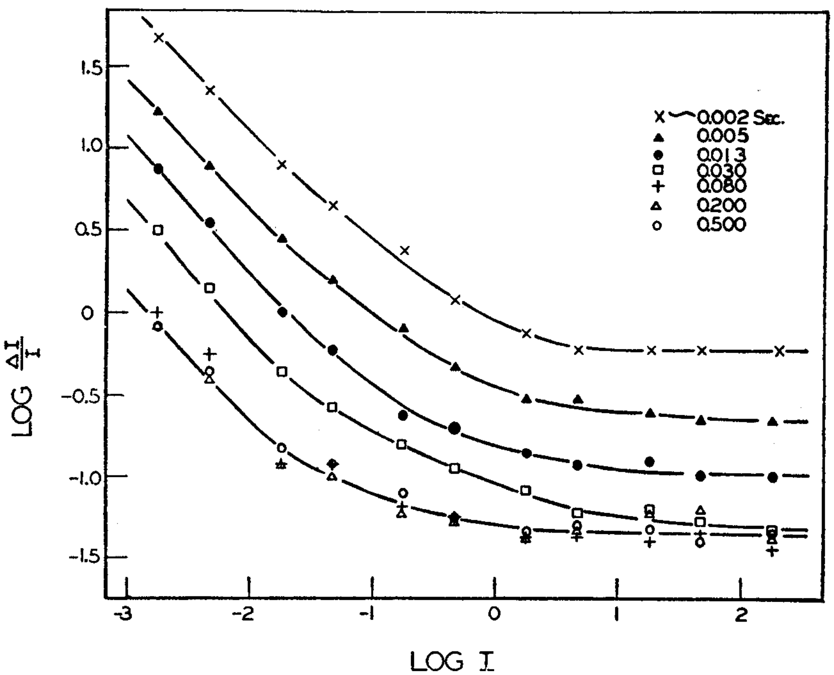

FIG. 1. The relation between $\Delta I/I$ and I for the different durations of ΔI used in these experiments.

intensities the logarithm of $\Delta I/I$ reaches a final steady minimum. The curve at any constant duration is similar in form to those that have been shown by Hecht (1935), Steinhardt (1936), and Smith (1936). Since our observations were restricted to a foveal region, there is no evidence of any rod portion of the curves. They are simple and continuous and exhibit no such breaks as have been shown to occur by Hecht and Steinhardt with larger fields and at lower values of intensity than we have used.

From the point of view of our interest, the important thing to note about the graphs is the position that they occupy upon the ordinate axis. The curve for the 0.002 second duration lies highest on the ordinate and the curves for the 0.005, 0.013, and 0.03 second durations are situated lower and lower in a progressive manner. At a duration of 0.08 second and beyond, the progressive downward displacement no longer takes place, and we find that the curves for 0.08, 0.2, and 0.5 second appear to be superimposed at the bottom of the graph. The curves for the three shortest exposure times, 0.002, 0.005, and 0.013 second, are parallel to one another, and the curve for 0.03 second may, within the limits of experimental error, be considered parallel to the other three. However, the superimposed curves for 0.08, 0.2, and 0.5 second cannot be considered, with all due allowance for error, to be parallel to the curves for the shorter durations.

An important characteristic to be noted in the curves for the shortest durations (with the possible inclusion of the 0.03 second curve) concerns the manner in which values of ΔI at common abscissa values of I vary with the duration of exposure. (Since the curves have common abscissa values of I we may just as readily note the variations in $\Delta I/I$.) When we regard Fig. 1 with this in mind we observe something of immediate significance: the increment in intensity, ΔI, required for brightness discrimination increases as the duration of exposure decreases. This generalization is demonstrated by the fact that the curve for the lowest duration (0.002 second) has the highest values of $\Delta I/I$ and the curves for successively higher durations (up to 0.03 second) have successively lower values of $\Delta I/I$. In general, it seems that an inverse relation exists between ΔI and exposure time, the exact form of which we shall discuss in a later section.

The progressive displacement in the values of $\Delta I/I$ does not occur for the three curves of longest duration, and so the ordinate values are independent of duration as a variable. In summary of these facts we may say that, within the limits of duration used, exposure time may influence the value of ΔI at a given intensity, I, for values of duration which include 0.03 second. For durations equal to and greater than 0.08 second, exposure time has no influence on the determination of ΔI, and the ratio $\Delta I/I$ at a given I is constant.

The Bunsen-Roscoe Law

The conditions of this experiment are such that after continued adaptation to a given intensity, I, the subject is required to discriminate a brief increase in the intensity of one of the semicircles. If we consider that the determinant of this discrimination is a given increase in the amount of photolysis above the level maintained by I, then for this new photolysis the Bunsen-Roscoe law should be valid and we should obtain the relation

$$\Delta I \cdot \tau = C = f(I) \tag{1}$$

where τ is the duration of the flash, and C a constant for a given value of I. With a change in I, C becomes a variable, since its magnitude depends upon the amount of photosensitive material present at the particular adaptation condition set up by I.

In studies such as this it is customary to test for this relationship by plotting the energy of the flash (intensity $\times$ duration) against duration. When this procedure is followed for the data of this experiment we obtain the family of curves presented in Fig. 2. In this figure we have plotted $\log \Delta I \cdot \tau$ (for seven exposure durations at each prevailing intensity, I) against $\log \tau$. This method is convenient for the reason that, with logarithmic plotting, a line having a slope of zero represents the relation $\Delta I \cdot \tau = C$. The number to the left of each curve in Fig. 2 is the logarithm of the intensity, I, for which the product $\Delta I \cdot \tau$ was calculated.

The graph demonstrates that the product of ΔI and τ is constant over the lower range of durations for all the levels of intensity used in these experiments. At longer durations, however, the curves show a clear-cut departure from the reciprocity relation. This is evidenced by the fact that the slope of each curve changes abruptly, beyond the horizontal region, to a slope which has been drawn with a value of unity. The resulting line in each case has an equation $\Delta I =$ *Constant.*

The critical duration, which sets a limit to the application of the Bunsen-Roscoe law, is the longest duration of stimulus which has an influence in determining a given aspect of the response. In the graphs of Fig. 2 the critical duration is determined by the intersection of the two lines having, respectively, the equations $\Delta I \cdot \tau = C$ (for short durations) and $\Delta I = Const.$ (for the longer durations). In Table II are entered the values of the critical durations as determined graphi-

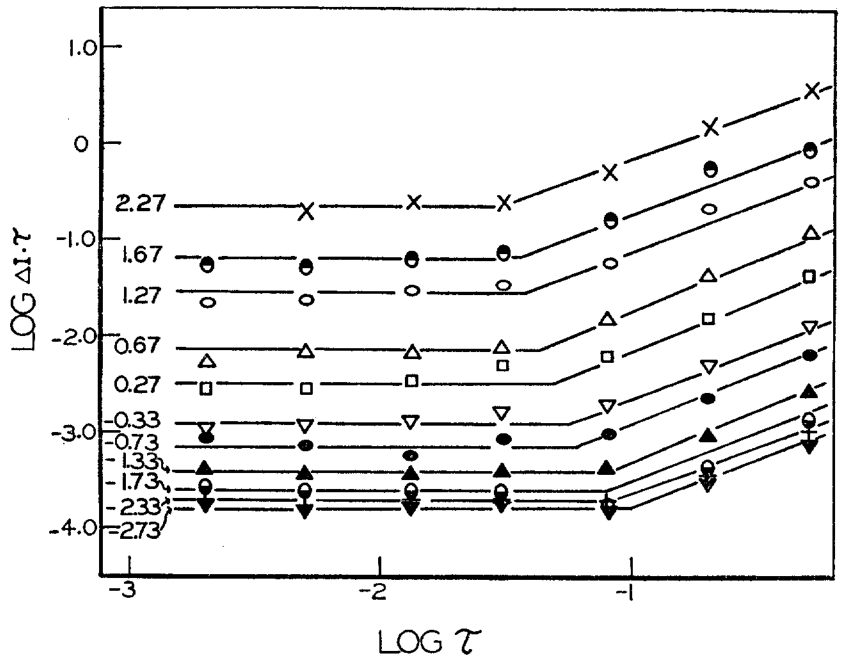

FIG. 2. The relation between ΔI and τ for the various levels of intensity used in these experiments. The horizontal lines represent the equation $\Delta I \cdot \tau$ = *Constant*, the inclined lines, ΔI = *Constant*.

cally in this manner for each value of prevailing intensity. Obviously, considerable deviations from these values might still result in good fits for Fig. 2, but the values are reliable enough for our purposes. Fig. 2 and Table II show that the value of the critical duration is a function of intensity. In line with observations by McDougall (1904) and Graham and Cook (1937) it is found that the critical duration decreases with an increase in intensity. This variable introduces a complicating factor into interpretations of intensity discrimination and will be discussed more fully in a later section.

The existence of a critical duration and its importance in limiting the reciprocity law have been discussed by McDougall (1904), Adrian and Matthews (1927), Hartline (1934), and Graham and Margaria (1935). Hartline found in the *Limulus* eye that for durations beyond the critical duration

$$I = \text{Const.} = C/\tau_c$$

where C is the product of I and τ below critical duration and τ_c is the critical duration. For the human eye this relation is not always

TABLE II

Critical Duration As a Function of Intensity

Log I	Log critical duration
2.27	−1.50
1.67	−1.45
1.27	−1.40
0.67	−1.35
0.27	−1.30
−0.33	−1.25
−0.73	−1.20
−1.33	−1.15
−1.73	−1.10
−2.33	−1.05
−2.73	−1.00

obvious (Graham and Margaria), but it is certain that the dependence on τ decreases with long durations. In the present experiment the result is clear and in accord with Hartline's finding. Beyond a critical duration the effect depends only on intensity, and

$$\Delta I = C/\tau_c = F(I). \tag{2}$$

This probably means that, as in the *Limulus* eye, where the action of the light is abruptly interrupted at the critical duration by the action of the sense cells, so in our experiment the action of ΔI is interaupted by the increase in sensory discharge which follows the flash. As Hartline points out, this deviation from strict reciprocity cannot be considered a failure of the Bunsen-Roscoe law in the photosensory process. When the restriction entailed by a consideration of the critical duration is recognized, we may conclude that the photochemical basis of the sensory process is a simple system to which the Bunsen-Roscoe law may be applied.

The Relation of the Results to Hecht's Theory

Equations (1) and (2) indicate that the values of C and C/τ_c are functions of intensity. This can be seen in Fig. 2 where the curve for the maximum intensity ($\log I = 2.27$) is highest on the ordinate and has the greatest values of C and C/τ_c. The curves for the other intensities are displaced downwards in a progressive manner as intensity decreases, the curve for the lowest intensity ($\log I = -2.73$) lying at the bottom of the graph. A consideration of the specific function involved in this progressive displacement leads us to a theoretical interpretation of brightness discrimination. Since Hecht's theory (1935) has been successful in accounting for brightness discrimination in a number of animals, it would seem important to examine our data with the intent of providing a further test of the hypothesis.

Hecht's fundamental equation is

$$\frac{dx}{dt} = k_1 \Delta I (a - x)^m$$

which states "that the initial rate of photochemical decomposition on the introduction of the higher intensity to the photochemical system at the stationary state is proportional to ΔI times the concentration of sensitive material at the stationary state" (1935). In this equation, x is the concentration of photoproducts broken down by the light, t is time, a is the total initial amount of photosensitive material, m is the order of the reaction, and k_1 the velocity constant of the "light" reaction. Without great modification this equation may be changed to read

$$\frac{\Delta x}{\Delta t} = k_1 \Delta I (a - x)^m \tag{3}$$

which says that the increase in x, through a small but finite interval of time, is proportional to ΔI times the concentration of sensitive material at the stationary state.

If Δt be accepted as equal to τ in our experiments, equation (3) becomes

$$\Delta x = k_1 \Delta I \cdot \tau (a - x)^m \tag{4}$$

and if it be assumed that, for the discrimination of $(I + \Delta I)$ from I, *the increment in* x, Δx, *is constant for any value of* I, equation (4) becomes

$$k_1 \Delta I \cdot \tau (a - x)^m = c \tag{5}$$

where c is a constant. This equation is similar to Hecht's equation (6) except that it involves τ, which for constant duration below critical duration may be considered as being contained in his k_1.

The steps involved in developing the relation between $\Delta I/I$ and I are similar, from this point on, to Hecht's. For the human eye, where both forward and back reactions are bimolecular, we finally derive the expression

$$\frac{\Delta I}{I} \cdot \tau = \frac{c}{a^2 k_2} \left(1 + \frac{1}{(KI)^{\frac{1}{2}}}\right)^2 \tag{6}$$

as a description of our experimental expectation for values of τ below critical duration.

For values of τ at and beyond critical duration the constant increment Δx must be considered as being determined within τ_c, and equation (4) is rewritten

$$\Delta x = k_1 \Delta I \cdot \tau_c (a - x)^m \tag{7}$$

for the case where τ equals or exceeds τ_c. For these conditions equation (6) becomes

$$\frac{\Delta I}{I} \cdot \tau_c = \frac{c}{a^2 k_2} \left(1 + \frac{1}{(KI)^{\frac{1}{2}}}\right)^2 \tag{8}$$

and the value of $\Delta I/I$ is independent of duration at a given value of I. This derivation of intensity discrimination is in accord with the implications of equations (1) and (2), as we can see if we consider the term $(a - x)^m$ of equation (5) to be constant for a given level of I. With this assumption equation (5) becomes $\Delta I \cdot \tau = C$, where $C = \frac{c}{k_1(a - x)^m}$. Similarly, if we substitute τ_c for τ in the same equation, the relationship is $\Delta I = C/\tau_c$. These are equations (1) and (2) of

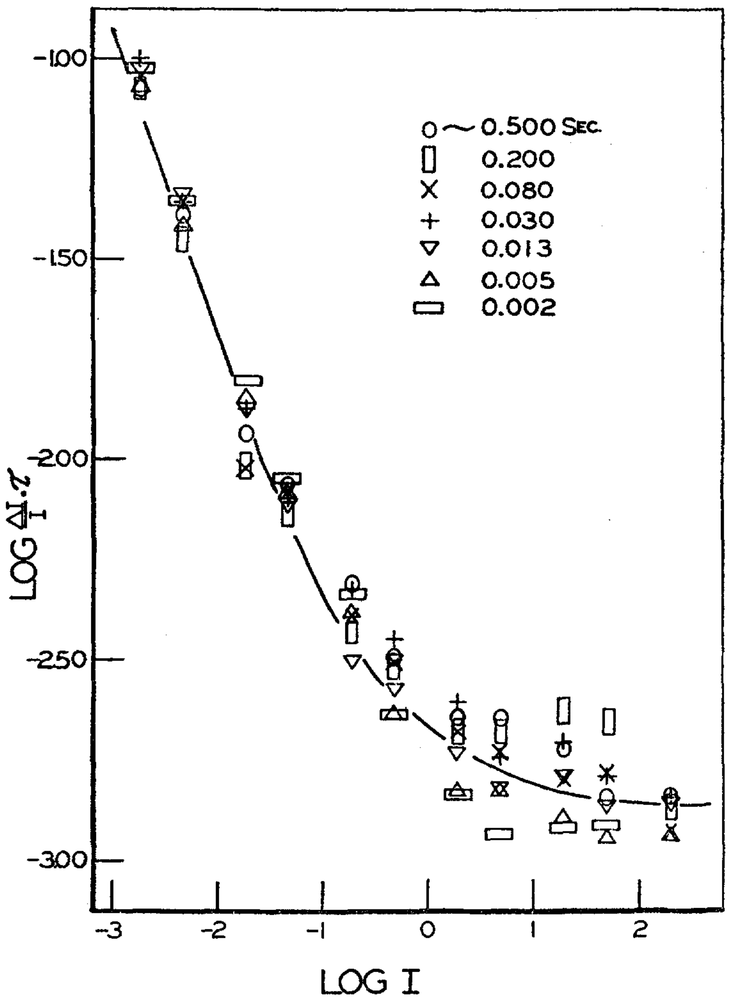

FIG. 3. The relation between $\frac{\Delta I}{I}\cdot\tau$ and I in terms of Hecht's theory. The curve is theoretical. For durations longer than the critical duration the ordinate is to be read as $\log\frac{\Delta I}{I}\cdot\tau_c$.

the earlier discussion, but it is significant that by these steps they are now related to Hecht's theory in a systematic manner.

The treatment of intensity discrimination given thus far would lead us to expect that, for durations below the critical, the product of $\Delta I/I$ and τ should be a function of intensity, and for durations of exposure at and beyond the critical duration, the product of $\Delta I/I$ and τ_c should be the same function. This is true because the right hand expressions of (6) and (8) are identical for the same values of I. Practically, this means that if we plot, on a graph with log I as abscissa, values of log $\Delta I/I \cdot \tau$ for all durations *below critical duration* and values of log $\Delta I/I \cdot \tau_c$ for all durations *at and above critical duration*, there should result a family of superimposed curves.

When the data of our experiment are treated in this way we obtain the graph of Fig. 3. In constructing this graph it was necessary to know the critical value of duration for each intensity level used. The values were obtained from Table II, and in making the graph, all values of $\Delta I/I$ for the 0.20 and 0.50 second exposures were multiplied by the appropriate values of τ_c as obtained from Table II. Only the values of $\Delta I/I$ for the eight highest intensities of the 0.08 second exposure could be considered as above critical duration and they, too, are multiplied by the corresponding τ_c values. All other values of $\Delta I/I$ are multiplied by the appropriate values of τ.

The graph of Fig. 3 is convincing evidence that our expectation is realized. Within the experimental error the seven curves of Fig. 3 may be considered a single curve. The line drawn through the data is the curve for equation (6) as applied to the data for the 0.013 second curve. Clearly the data for all the curves fit the theoretical line as adequately as could be desired for the conditions of the experiment.

DISCUSSION

Our results demonstrate that when ΔI is added to an already existing intensity, I, in the form of a flash, its intensity value must become greater as duration becomes less if a discrimination between intensities I and $I + \Delta I$ is to be accomplished by the subject. This is true only within certain limits of duration. Within this range of duration the requirement for brightness discrimination at a constant prevailing intensity, I, is fulfilled when the product of ΔI and time of exposure is a constant. This is the condition implied by the Bunsen-Roscoe law for the production of a constant photochemical effect, and our results show that the law holds for brightness discrimination in the human eye.

Beyond a critical duration the reciprocity relation appears to fail and the equation $\Delta I \cdot \tau = C$ is superseded by the relation $\Delta I = Constant$. Hartline (1934) has given the most adequate account of factors determining the critical duration and he points out that it is meaningless to discuss the influence of duration upon events in the nervous discharge which are over before the flash is complete. Only those durations which are shorter than the time of the appearance of the event may be considered logically. This type of reasoning must apply equally well to effects in the human eye, and it sets a logical restriction to the limits of duration within which one can adequately test for the validity of the Bunsen-Roscoe law. The change at the critical duration from the reciprocity relation to the expression $\Delta I = Constant$ does not necessarily, in the light of Hartline's discussion, mean a failure in the reciprocity law. It may mean, rather, that the action of the light is interrupted by the increase in activity of the sense cells which follows the presentation of ΔI. As applied to brightness discrimination, this interpretation implies that the photochemical effect of ΔI follows the Bunsen-Roscoe law rigorously. The apparent failure of the law is due to the interruption of the action of the light by the impulses which determine the discrimination.

The Bunsen-Roscoe law states conditions for the production of a constant amount of photolysis. In our experiments the validity of the law implies that brightness discrimination is determined, at any level of photolysis due to I, by a constant increment in the photoproducts which are broken down by the action of ΔI. This interpretation has been recognized by Hecht (1935) and his theory may be considered as accounting for brightness discrimination at constant values of duration. When duration varies, however, the theory requires a minor amplification. The change in theory is necessitated by the consideration that brightness discrimination is determined by a constant amount of photolysis rather than by its initial rate. When the theory is restated in these terms it adequately accounts for the findings of this experiment. Brightness discrimination is in accord with Hecht's theory and the Bunsen-Roscoe law for durations up to the critical duration. For durations greater than the critical duration the theory is written on the assumption that the necessary increment in photoproducts, Δx, is accomplished within the critical duration.

When due allowance is made in the theory for the complexities introduced by the critical duration, the hypothesis is valid for all conditions of exposure time. The steps involved in this verification have been discussed earlier.

The existence of a critical duration raises a practical problem in determinations of intensity discrimination thresholds. Where the duration of ΔI is shorter than the critical duration, τ in equation (6) may be thought of as being contained in the constant, $\frac{c}{a^2 k_2}$; but where ΔI has a duration longer than the critical duration, equation (8) applies, and τ_c cannot be contained in a constant because it is a function of intensity, as shown in Table II. Because of this it would seem that unequivocal results on brightness discrimination can only be obtained when we use durations of ΔI which are well below the critical exposure time for all values of intensity.

SUMMARY

1. This investigation has been concerned with an analysis of brightness discrimination as it is influenced by the duration of ΔI. The durations used extend from 0.002 second to 0.5 second.

2. $\Delta I/I$ values at constant intensity are highest for the shortest duration and decrease with an increase in duration up to the limits of a critical exposure time. At durations longer than the critical duration the ratio $\Delta I/I$ remains constant.

3. The Bunsen-Roscoe law holds for the photolysis due to ΔI. This is shown by the fact that, within the limits of a critical duration, the product of ΔI and exposure time is constant for any value of prevailing intensity, I.

4. At durations greater than the critical duration the Bunsen-Roscoe law is superseded by the relation $\Delta I = Constant$. This change of relation is considered in the light of Hartline's discussion (1934).

5. The critical duration is a function of intensity. As intensity increases the critical duration decreases.

6. Hecht's theory (1935) accounts for the data of this experiment if it be assumed that brightness discrimination is determined by a constant amount of photolysis.

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