THE BRITISH JOURNAL OF OPHTHALMOLOGY

JANUARY, 1940

COMMUNICATIONS

THE RESPONSE OF THE EYE TO LIGHT IN RELATION TO THE MEASUREMENT OF SUBJECTIVE BRIGHTNESS AND CONTRAST

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(This paper was first published in a slightly more extended form in the Transactions of the Illuminating Engineering Society, Vol. IV, January, 1939, and is reproduced here by kind permission of the Society.)

Introduction

In recent years it has become increasingly recognised¹ that a satisfactory analysis of certain lighting problems can only be arrived at by evaluating the subjective effects of light. Some method of measuring the magnitude of the visual response is required for various conditions of stimulation and adaptation of the eye. Further, since contrast plays an all-important part in vision, that, too, should be measured, and the factors tending either to increase or decrease it, understood. The object of this paper has therefore been to summarise the information available about those processes which govern the magnitude of the visual response, to indicate how they come into play under normal conditions of seeing, and to put forward suggestions regarding

suitable methods for measuring subjective brightness and contrast.

For the sake of brevity, at certain points in the paper, data are given in note form.

SECTION I

THE RESPONSE OF THE EYE TO LIGHT

A. Objective Data

RESPONSE IN SINGLE FIBRES OF THE OPTIC NERVE.

During the last few years a technique has been developed by which, when a beam of light stimulates the retina, the impulses from a single element in the retina of certain eyes have been recorded as they travel down the associated nerve fibre in the optic nerve. The methods used vary from one eye to another, but in general an eye is excised from the animal with a portion of the optic nerve attached. The nerve sheath is then removed and the nerve itself frayed out into small bundles. These bundles may then be split into still finer strands if necessary until, as shown by the nerve record, a response from a single fibre has been obtained. The response which is measured is the potential that develops between the cut end of the nerve strand and an uninjured portion of the nerve. Electrical contact is made with suitable electrodes, *e.g.*, silk threads soaked in sea-water, the potential changes are amplified, and the result recorded in an oscillograph. In some cases it is necessary to obtain the impulses from fibres on the anterior surface of the retina before they have reached the optic nerve, in which case the anterior half of the excised eye is removed and the potential between the dissected nerve fibre and the surface of the retina is recorded.

Results.—Typical response obtained from eye of horseshoe crab shown in Fig. 1.

Response consists of series of impulses all of same magnitude. Magnitude varies from fibre to fibre. Short latent period before discharge commences. Initial discharge consists of rapid burst of impulses; frequency falls rapidly at first, approaching steady

FIG. 1.

Impulses in single nerve fibre from eye of horseshoe crab.
(Hartline and Graham².)
Line A B shows duration of stimulation Time in fifth of
seconds shown below record.

value. With increased intensity of light, latent period shorter, frequency of discharge greater. Range of intensity to which single unit responds may be as great as 1 to 1,000,000.²

For short duration of exposure to light stimulus, change in time of exposure is equivalent to change in intensity of stimulus.³

Results from cold-blooded vertebrate eyes (*e.g.*, bull-frog) show different types of response: 20 per cent. show response of type in Fig. 1; 50 per cent. show burst of impulses at onset of illumination and another at cessation, but no impulses during steady illumination; 30 per cent. show no impulses at onset or during illumination, but give marked discharge when light cut off.⁴

With the scallop, two kinds of sense cell observed; one responds at the onset and during illumination, the other to cessation of illumination.⁵

RETINAL ACTION POTENTIAL.

Instead of obtaining records from individual fibres, an alternative technique has been developed from which a composite curve can be obtained showing the potential that is developed over a more extended area of the retina. Again various methods are available

FIG. 2.

Analysis of retinal action potential of dark-adapted cat's eye. (Granit⁶.)

Line A B shows duration of stimulation of intensity 14 ml. Resultant response shown by continuous line. Individual components of response, P I, P II, and P III, shown by dotted curves.

of deriving this so-called retinal action potential, but a typical way is to place an excised eye in a holder in which contacts can be made to the cornea and the back of the eye by means of suitable electrodes. The potentials which develop when light enters the eye are amplified as before and recorded in an oscillograph. An alternative process is to use a decerebrate animal, in which case contact is made with the cornea and the decerebration wound.

Results.—Typical record is shown in Fig. 2.

Electroretinogram analysed by Granit⁶ into three components, P I, P II, P III. P III is negative; on stimulation, commences

before positive PII to produce negative notch a. Potential rises rapidly to maximum, b, and then falls. Steady positive rise c, follows. At cessation of stimulation, off-effect, d, occurs, explained as interference construction between positive and negative components. Components PI, PII, PIII can be isolated by suitable treatment, *e.g.*, PII removed from retinogram of cat by asphyxia.

PI not known to be connected with discharge in optic nerve. PII corresponds to excitation, PIII to inhibition.

Light adaptation increases inhibitory component PIII'. Light adapted eye shows brisk response, dark adapted eye is sluggish.

Interaction between separated areas of retina demonstrated by effect on latent period of stimulating retina in separated areas.^{6, 8}

Stimulation of retina by bright light can amplify difference between responses of two test lights viewed after primary stimulation.⁹

Prolonged light adaptation reduces size of b-wave obtained from test light. During subsequent dark adaptation, size of b-wave returns gradually to normal.¹⁰

Rod retina (*e.g.*, albino rat) has maximum of sensitivity for equal energy spectrum between 0.50 and 0.51 μ . When eye exposed to bright sunshine, no response at all. With dark-adapted frog's eye (rods and cones), maximum sensitivity between 0.50 and 0.51 μ . When light adapted, maximum about 0.56 μ . Frog's eye exposed to bright sunshine still responds to stimulation. Conclusion that rod-visual purple mechanism put out of action by high intensities, but cone mechanism continues to react.¹¹

PHOTOCHEMICAL REACTIONS.

The light sensitive substance, visual purple, can be extracted from various retinæ by the appropriate chemical treatment (see, *e.g.*, Lythgoe¹²). Measurement of the spectral absorption curve of bleached and unbleached visual purple can be made, the bleaching process can be followed, and although no appreciable regeneration of the substance after bleaching can be observed once it has been extracted from the eye, the regeneration has been determined by measuring the concentration of visual purple extracted from the eyes of rats at intervals after complete bleaching.

Results.—After allowance for impurities, maximum absorption of unbleached visual purple at about 0.50 μ . Intermediate product is formed in course of bleaching; orange colour of this product depends on temperature and pH of solution. Not certain whether this substance sensitive to light.¹³

Regeneration of visual purple in rat eye (rods) slow process continuing for several hours.¹³

Amount of bleaching governed by intensity of incident light.

No certain information available of photochemical substances in cone retina.

IRIS.

As is well known, the rapid enlargement and contraction of the iris serves to compensate for sudden changes in the illumination level. A given diameter of iris is not uniquely related to one level of illumination. An illumination that appears bright to a dark-adapted eye, and therefore, produces a contraction of the iris, may appear dark to a light-adapted eye, thus causing the iris to expand. The average range in the diameter of the iris is from 2 mm. to 8 mm. The speed of reaction of the iris, a completely reflex action, varies from one person to another, but the adjustment is usually complete in $\frac{1}{2}$ sec. or thereabouts.

ANATOMY OF THE EYE.

Since the response from rods and cones is very different, their distribution in the retina is a relevant factor in an analysis of the subjective effects of light. Histological examination of the retina reveals two types of neurone, the rod and cone. The anatomical distinction is frequently not very marked, but the rods, which are held responsible for vision at low illumination (scotopic mechanism), can be defined as the neurones secreting visual purple.¹¹ In the human retina, some 120,000,000 rods are found and 6,500,000 cones. In the fovea, the seat of distinct vision, only cones are present, and these are believed to show a 1:1 relation between receptors and nerve fibres. In outer parts of the retina the rods predominate, and many rods may converge on to one nerve fibre.

B. Subjective Data

THRESHOLDS.

Subjective measurements of the visual response are difficult. The inherent obstacle is the impossibility of measuring sensations, and the method most commonly employed to avoid this difficulty has been to measure the intensity of a patch of light when it just becomes visible. On the assumption that the threshold sensation always requires the same visual response to elicit it, measurement of the threshold intensity does provide a means of recording the state of sensitivity of the eye under various conditions of adaptation, etc. This assumption is reasonable, at least for restricted conditions of observation, *e.g.*, given angular size of threshold patch. On the other hand, to derive anything about the magnitude of response that would result from a stimulus well above the threshold intensity necessitates assumptions concerning the retinal processes that are difficult to justify. For this reason extensive deductions from threshold measurements for conditions above the threshold must be accepted with reserve.

Results.—Dark adaptation: process observed by measuring threshold intensity at various times after observer placed in dark following pre-stimulation to definite intensity. Curve obtained depends on intensity of initial stimulus, area of retina used to view threshold patch. Typical result, Fig. 3.¹⁴ Where curve has cusp, initial part presumably represents regeneration of cone photochemical substance, later part regeneration of visual purple. Where no cusp, only visual purple involved.

Retinal variation of sensitivity: for light-adapted eye, maximum sensitivity at fovea and rapid falling off in periphery;¹⁵ for dark adapted eye, minimum sensitivity at fovea, maximum 10° or 15° from fovea.

Glare: measurements of threshold intensity viewed simultaneously with glare source provide record of loss of sensitivity due to glare. Sensitivity, β , shown experimentally^{17, 18} to obey law of type:—

$$\beta = \kappa \frac{E}{\Theta^2}$$

where κ is a constant, E illumination produced by glare source in plane of observer's eye, and Θ is angle between test patch and glare source. Formula as given applies when test patch viewed against black background.

FIG. 3.

Dark adaptation process for various intensities of previous stimulation. (Winsor and Clark¹⁴.)
Initial intensity of light adaptation shown in diagram.

Light adaptation: threshold measurements for various intensities of light adaptation show lowering of sensitivity as intensity increased, Fig. 4.¹⁹

Brightness discrimination: sensitivity to brightness differences recorded by measurement of just noticeable brightness difference, ΔB , at various intensities, B .

Relation between B and ΔB shown in Fig. 5.²⁰

Result affected if eye maintained at given adaptation level instead of adapting to test field. Relation between B and ΔB for constant adaptation shown in Fig. 6.²⁰

FIG. 4.

Threshold brightness for various degrees of light adaptation. (Nutting¹⁹.)

DEVELOPMENT OF RESPONSE.

The visual response takes a finite, but very short, time to develop, and having reached a maximum value, the response diminishes. Broca and Sulzer²¹ and others have measured the apparent brightness of a flashing light for various short exposures by comparison with a fixed light. The development of the response is shown in Fig. 7, as obtained recently by Schouten,²² by the method of binocular matching.

LIGHT ADAPTATION.

Apart from measurements of threshold intensities at various adaptation levels, little has been recorded of the light adaptation process except for the results obtained recently by the binocular matching method.^{22, 23, 24} In this method the right eye views a test patch and the left eye a comparison patch, and the two may be equated both for colour and intensity. The right eye is then subjected to various degrees of light adaptation, and the changes induced are measured by comparison and equation with the patch

FIG. 5.

Brightness discrimination curve. (Atribat²⁰.)
 $\Delta B/B$ shown in relation to $\log B$, where ΔB is the just noticeable brightness difference observed at different values of the brightness B .

viewed in the left eye. On removal of the adapting field, the eye returns gradually to its original sensitivity; by making a rapid series of matches, the course of this recovery can be derived. The author's results have been confined to the fovea and presumably record the photochemical reaction that takes place there; Schouten has included the effect of extra-foveal adaptation, and has also investigated a more rapid action of the adapting light.

Results.—Within limits, depression of sensitivity approximately proportional to adaptation intensity. For adaptation of 6,000 photons. mean result for 85 observers gave reduction of sensitivity by factor 12.5. (A photon is the unit of retinal illumination. An illumination of one photon is obtained when a surface having a brightness of 1 cdl. per sq. metre is viewed through a pupil

area of 1 sq. mm.) Direct linear recovery for some observers after white adaptation, delayed recovery for others, Fig. 8.²⁵ Recovery effectively complete after two or three minutes. Irregular recovery curves obtained after very high intensity adaptations.²³ Variety of effects obtained after coloured adaptations, which cannot conveniently be summarised here.^{23, 24} Depression of sensitivity for

FIG. 6.

Brightness discrimination curve for eye maintained at constant state of adaptation to field of brightness 3.8 cdl. per sq. ft. (Abriat²⁰.)

given adaptation increases with time of exposure until approximately steady state reached after about one minute, Fig. 9.

When sensitivity tested after very short exposure to adapting light²² some depression of sensitivity found already, which increases with longer (but still very short) exposures until steady state reached, Fig. 10. Prolonged exposure caused the further depression already illustrated in Fig. 9. Rapid adaptation called α -adaptation, slower process β -adaptation (Schouten). Exposure to glare source (viewed 6° from fovea) giving illumination at

FIG. 7

Development of visual response immediately eye is stimulated. (Schouten²².)

FIG. 8.

Recovery of sensitivity of fovea after adaptation to intensity of 6,000 photons. Two types of recovery curve. (Wright²⁵.)

observer's eye of 17 ft. c. lowered sensitivity of retina at fovea to one-eighth initial value. Increase of adaptation intensity causes increased α -effect. α -adaptation affects adjoining parts of retina in addition to area actually stimulated.²² β -adaptation local adaptation confined to illuminated portion of retina.²⁴ Time of recovery from α -adaptation uncertain. If electrical effect as believed, recovery likely to be very rapid, although Schouten's results tend to show slower recovery process.

STILES AND CRAWFORD EFFECT.

By comparing the brightness of two patches formed by narrow pencils of light which had passed through different parts of the lens of the eye, Stiles and Crawford found that a pencil passing centrally through the lens gave a markedly greater visual response than in the case of a pencil passing through the periphery of the

FIG. 9.

Reduction of sensitivity of fovea during process of light adaptation. (Wright²³.)
This records photo-chemical or β -adaptation process.

FIG. 10.

Reduction of sensitivity of fovea immediately eye is stimulated.
(Schouten²².)
This records electrical or α -adaptation process.

lens.^{26, 27} This effect must almost certainly be due to the different angle at which the light strikes the retina in the two cases. The phenomenon has a bearing on the subject of this paper inasmuch as it modifies the action of the iris and in instruments in which artificial pupils are necessary, it may mean that they must be centred relative to the eye pupils, and this, in turn, may mean fixing the observer's head relative to the apparatus.

GENERAL DISCUSSION OF OBJECTIVE AND SUBJECTIVE DATA.

From the data quoted above it may be deduced with some certainty that the following processes operate when the eye is stimulated. A large initial response is produced almost instantaneously, but is rapidly reduced to a lower value. The rapid reduction is apparent in Hartline's record of nerve impulses, in Granit's inhibitory component, in Broca and Sulzer's observations, and in Schouten's α -adaptation. It seems likely also, as suggested by Schouten, that this rapid reaction is identical with the effect of simultaneous contrast by which, as is well known, a surround

field or a glare source may produce a profound effect on the apparent brightness and colour of a test field. The diameter of the iris will also rapidly change when the stimulus is introduced. On continued exposure to the stimulus, a photo-chemical decomposition occurs and continues until a balance between decomposition and regeneration is reached within a minute or so. If the intensity is high, the visual purple system in the rods will be put out of action, but cone vision will continue to operate, although at a low sensitivity level. These facts follow from the subjective adaptation phenomena, Granit's measurements on frog's eyes, and experiments with visual purple. Removal of the stimulus causes a partial rapid recovery of sensitivity due to the removal of the inhibitory component or *a*-adaptation, and also sets in motion a more gradual recovery due to photochemical regeneration taking place. In the cones this regeneration is more or less complete in two or three minutes, in the rods at least half an hour is required before recovery approaches completion. These facts follow, as before, from subjective adaptation phenomena, from retinal action potential measurements, and from visual purple experiments. Schouten's experiments do not suggest a rapid recovery from the *a*-adaptation, but it is easy to demonstrate that some recovery from the effects of simultaneous contrast takes place almost instantaneously, and for the purpose of this paper we will assume that the *a*-process is essentially a rapid process.

These changes in sensitivity may be represented qualitatively in a diagram such as Fig. 11. No emphasis need be laid on the shape of the different components of the diagram, but it can be

FIG. 11.

Diagram to illustrate change of sensitivity of fovea during and after stimulation.

Line A B shows duration of stimulation.

Dotted part of curve represents rapid, electrical process.

Continuous part of curve represents photo-chemical process.

regarded as giving a general indication of what is taking place. The visual response, which is assumed to be proportional to the sensitivity, will follow a curve similar to that of Fig. 11.

Consider next what happens when one patch of light is viewed at the fovea and a second patch is thrown on a neighbouring part of the retina. The second patch will tend to inhibit or suppress the response from the first patch; the sensitivity curve will then

FIG. 12.

Diagram to illustrate change of sensitivity of fovea during and after stimulation, including effect of glare source imaged on neighbouring part of retina.

Line A B shows duration of stimulation at fovea.

Line C D shows duration of stimulation from glare source.

Dotted part electrical process.

Continuous part ——— photo-chemical process.

be as in Fig. 12, for the particular timing of the two patches given in the diagram.

Finally, what happens to the sensitivity when the eye views a scene, as it normally does, by scanning it rapidly from point to point, each element of the scene being of a different intensity from its neighbour? Since the eye moves rapidly over the scene there will be no time for any local variations of photo-chemical concentration to develop in the retina; in others words, the state of the β -adaptation will be governed by the integrated value of the light entering the eye. To some extent this will also be true of the α -adaptation; for the contrasting action between one light and another is greater the nearer they are to one another, and to that extent the α -process is a local process. At the same time it is clear, especially from Schouten's work, that the reaction taking place on one retinal area may spread over a considerable fraction of the retina. It is therefore

desirable to separate the a -adaptation into two parts, one a local and the other a general effect. This division is not essential and the boundary between the two effects cannot be clearly demarcated. For our purpose we may regard the general a -effect as governed by an integrated value of the light from the scene and assume that it will have a roughly constant value for any given scene, while the local effect will vary rapidly as the eye darts about over the scene.

Summarising, we can say that the sensitivity of any point of the retina is governed by

- (1) the β -adaptation, which will be a function of the integrated light from the scene;
- (2) the general component of the a -adaptation, which will also be a function of the integrated light from the scene;
- (3) the local component of the a -adaptation, which will be a function of the illumination at, and surrounding, the point of the retina being considered.

The visual response will then be derived as the product of the sensitivity as defined above and the stimulus acting at the point of the retina concerned.

SECTION II

THE MEASUREMENT OF SUBJECTIVE BRIGHTNESS

Introduction

True measurement of subjective brightness implies the measurement of sensations. This is an impossible process for reasons which the author has discussed elsewhere,²⁸ and into which it is not proposed to enter here. Yet it is obviously possible to compare the apparent brightness of an object seen under one set of adaptation conditions with another object seen under a different adaptation level; for instance, an approximate comparison or match might be made by memory, or by the method of binocular matching to be described. This comparison does not really measure subjective brightness, but it does make it possible to erect a reference scale of brightnesses. For many purposes this may be all that is required; thus, if we had a standard level of adaptation, we might be able to say that an object in some scene had the same apparent brightness as intensity Y viewed at the standard level. The value Y would then define the brightness of the object, and from previous investigations we might know that such a value was too low for the task in hand. Further, the measurement of brightness is an intermediate stage in the measurement of contrast, since from the reference scale of brightnesses at the standard level, a scale of contrasts can be derived (see Section III); hence a knowledge of the "standard brightness"

of two objects will lead to a determination of the contrast between them.

It is with the measurement of subjective brightness in this sense that this section deals. The problem can be divided into two fairly well-defined parts: (1) To devise a means of viewing various intensities at a standard level of adaptation; and (2) to develop a method of comparing the standard brightness with the unknown brightness that we wish to measure. Superficially, the former appears an easy problem to solve, but this is not altogether true.

Maintenance of a Standard State of Adaptation

The most obvious method would be to adapt the eye to a standard illumination for a definite time, then remove the adapting field rapidly and substitute whatever matching intensity was required. This intensity is then, it seems, being viewed at a standard level

FIG. 13.

Sensitivity changes of fovea when viewing test patch after adaptation to standard intensity.

Line A B shows duration of exposure to standard adaptation.

Line E F shows duration of exposure of test patch.

Dotted part electrical process.

Continuous part ——— photo-chemical process.

of adaptation. The error in this assumption can be shown by reference to Fig. 13. Just before the adapting light is removed the sensitivity reaches a standard level, but as soon as it is removed the α -component recovers. On introducing the matching intensity, a new α -component will immediately be introduced, and, if viewed for any time, a new β -process would also come into operation. The instant at which the match is made will

determine the actual sensitivity level of the eye, but it will be seen that, to some extent at least, this level will be governed by the value of the matching intensity required. When measuring a high value of subjective brightness, a high matching intensity will be needed, producing a greater adapting action. Hence strictly it is impossible to view a range of matching intensities all at one standard adaptation level.

Fortunately, although it is a point that requires thorough examination, it is more of academic than practical importance. What is required is a standard technique for reproducing any apparent brightness rather than a standardised state of adaptation. This can be achieved by standardising the following quantities:

- (1) The intensity of the preliminary adaptation.
- (2) The size of field of this adaptation.
- (3) The duration of the adaptation.
- (4) The period to elapse between the end of the adaptation and the comparison between the matching intensity and the unknown intensity.
- (5) The size of field of the matching intensity.

Method of Comparing Apparent Brightnesses

Assuming that there is available a method of producing any apparent brightness under the appropriate specified conditions, what method is to be used to equate that brightness to the one that has to be measured? Two possible methods seem to be open. The first is that of a memory match in which the test object is viewed first and then matched as nearly as can be remembered against the standard field viewed subsequently; but it will immediately be obvious that any measurement of this sort must be of a low order of accuracy. Even so, it would be a mistake to despise the value of a memory match, and it should undoubtedly be given a thorough trial.

The second method is that of binocular matching in which one eye views the road surface while the other views a comparison patch under standard conditions. A direct match between the two would then be made. This method has been employed successfully during the past few years^{22, 23, 24} in the investigation of visual processes, and the author is satisfied as to the validity of the principles involved. These have been discussed in detail in another paper,²⁵ and space need not be taken here in repeating that discussion. It is easy, however, to visualise a number of fresh difficulties that would follow any attempt to transform the apparatus and method from a laboratory process into an engineering device suitable for use in the field.

One obstacle to measuring subjective brightness that applies to whatever method is contemplated is peculiarly subtle. In Section I

the factors that govern the magnitude of the visual response have been discussed, and reference was made to the fact that, in looking at any scene, the photo-chemical adaptation level will be governed by the integrated light from the scene. But this does not apply when the eye, instead of scanning rapidly across the scene, gazes steadily at a given area for any length of time. Under these conditions local adaptation levels develop on the retina, and in consequence the sensitivity, and hence the visual response, is modified.

From this it follows that any attempt to measure the subjective brightness of part of a scene will be successful provided it is glanced at only intermittently. If the observer looks continuously at what he is trying to measure, his measurement will be erroneous. For faint objects, the error is not likely to be great provided it is not viewed steadily for too long. For bright objects, the error may be considerable.

SECTION III

THE SPECIFICATION OF CONTRAST

Introduction

Although the measurement of sensations is impossible, it is possible to erect a scale of sensation intervals or contrast steps; thus, if two intensities A and B are selected, a third intermediate intensity, C, can be found such that the contrast between A and C is equal to that between C and B. Extending the process over the whole gamut of intensities, it is at least theoretically possible to divide the complete sensation interval from subjective black to blinding white into a large number of equal contrast steps. Supposing, then, that it was required to find the contrast between an object in a road and the background against which it is viewed, it would be necessary to determine the number of contrast steps covered by the interval between the brightnesses of the object and its background. This section, therefore, deals with the method to be followed to derive the contrast scale and the means to adopt to equate an unknown contrast to the appropriate interval on that scale.

The Contrast Scale

From what has already been said earlier, it is obvious that the specification of two intensities A and B is not sufficient to define the subjective contrast between them. This will vary according to the state of adaptation of the eye, and a standard scale must therefore be erected under properly defined conditions of viewing. The obvious choice of conditions would be the same as those

adopted for measuring subjective brightness, and for those conditions, as wide a range of test intensities as possible should be divided into equal contrast steps.

This is not likely to be easy, but it should be possible. Difficulties similar to those referred to in connection with subjective brightness would be encountered, and no doubt others would also arise.

The only data available, as far as the author is aware, which aim at deriving a contrast scale under properly controlled adaptation conditions, are those of Abribat.²⁰ The one objection to Abribat's work is that the scale is derived from observations of just noticeable differences, a process that may not be identical with the derivation of equal steps of contrast. Space will not

FIG. 14.

Effect of variation of field size on contrast.

permit any detailed discussion of this question (see²⁸ for a further analysis), but one illustration may serve to indicate the dilemma that might arise from the use of threshold steps.

Suppose the field of view is circular and is divided into two equal parts as in Fig. 14 (a), one half being appreciably darker than the other. An observer is conscious of a certain amount of contrast between the two halves. Now suppose the field is reduced in size, Fig. 14 (b), without any change in intensity of the patches; the contrast between them will remain practically the same, at least until the field is made very small. This is precisely as expected if contrast were to be evaluated from values of the subjective brightness of the two fields, since these will be practically unaffected by the reduction in size of field. But if the contrast had been calculated from the number of just noticeable steps, the value would have been greater with the large field than with the small field, since the eye is more sensitive to small differences the larger the field of view. How is this discrepancy to be resolved? Is it right to assume that the contrast between the two parts of the field when set for a just noticeable difference is smaller for

the large field than for the small field? Or is the summation of small differences to give a measure of a finite degree of contrast not a legitimate process? In either case the validity of a contrast scale based on just noticeable differences is very uncertain. It must, on the other hand, be admitted that, inversely, the scale derived from finite steps is equally uncertain when applied to very small intensity differences.

A similar discrepancy would probably arise if the time of viewing were reduced to a very short interval. However, as a problem in illuminating engineering, the measurement of contrast is most frequently related to the evaluation of visibility; the specification of contrast would form one element in the specification of visibility, while area and time of exposure could be regarded as separate elements. Regarded in this way, contrast could then be safely measured in terms of the subjective brightness of the contrasting areas.

The Measurement of Contrast

If the view expressed in the last sentence is accepted, the measurement of contrast reduces to the measurement of subjective brightness on the lines suggested in Section II. The measurements would have to be made under the working conditions in which the contrasting objects were normally seen, and recorded, presumably by the binocular method, in terms of the brightness of test patches viewed under standard conditions of adaptation. Interpolation on the standard contrast scale would then give the required value of the contrast.

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THE MECHANISM OF DARK ADAPTATION

A Critical Resumé

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It is a familiar experience that the eyes take some minutes or even hours to accustom themselves to a very low illumination after having been exposed to a high one. Few realise that the increase in sensitivity may be 10,000 fold. If, for example, an illumination of 0.1 metre candle (m.c.) is just visible immediately after switching off a very bright light, an hour or so later in the dark the necessary illumination may have fallen to 0.00001 m.c. Not all scientists working on this and related subjects realize that the process continues for at least an hour, and, according to Achmatov (1927) for at least 24 hours. To measure the least visible illumination of a test surface at various times after going into the dark seems a simple problem, but there are many complicating factors (Phillips, 1939) which have served as traps for the unwary. In this paper, however, we shall not criticize the technique of measurements, but test the adequacy of the physiological theories used to explain the results. The subject now concerns not only a few specialists but also workers from other fields, since it has become generally realized that deficiency of vitamin A may produce faulty dark adaptation.

In times of peace town dwellers never need to use their eyes at the low illuminations encountered in the country at night. Owing to the "black-outs" and the increase in night operations in the services it will not be possible to delay for very much longer a serious study of the problems.

Dual mechanism of dark adaptation.—The curve in Fig. 1 shows the change in visual threshold with time in the dark measured from the time when the observer had been plunged into darkness. He had previously looked at a brightly illuminated