VISUAL ACUITY AND ITS VARIATIONS

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1. INTRODUCTION

OUR visual organs are the principal gateways through which a knowledge of the external world finds its way into the realm of human consciousness and in consequence, they play a role of immense importance in human life and activity. Three distinct types of sensation are recognisable in the visual pictures of the outer world presented to us by our eyes, being respectively the binocular perception of space and form, the perception of colour and the perception of luminosity. These perceptions correspond respectively to the three physical characteristics of light considered as electromagnetic wave-motion in space which finds an entry into our eyes, *viz.*, its rectilinear propagation in free space, the length of the waves and the magnitude of the electric-vector in them. The value of the information conveyed by our visual impressions depends greatly on their accuracy. The precision reached in each of the three types of sensation is therefore a highly significant feature of our visual perceptions. They are respectively the acuity of vision, the power of colour discrimination and the photo-sensitivity. These definitive characteristics of our subjective sensations are of great importance in all considerations regarding the *modus operandi* of the physiological perception of light.

Reference was made above to the properties of light regarded as electromagnetic wave-motion in space. But in considering the sensory perception of light following its incidence on the retinæ of our eyes, these properties cease to be relevant, and we have, instead, to consider light in its quantum-theoretical aspects, in other words, as consisting of discrete quanta of energy. For, the absorption of light by the visual receptors is a necessary condition for its perception and such absorption takes place in complete quanta of energy. It follows that in seeking for an explanation of the various features characteristic of the visual perception of light, we have necessarily to proceed on the basis of the quantum theory. In particular, the acuity of vision, the power of colour discrimination and the sensitivity of our eyes to differences of intensity have all to be understood or interpreted on that basis. Though it is convenient to separate these three aspects of vision in describing and discussing the results of observation and experiment, they are, in reality, so closely interrelated that we have necessarily to adopt the same fundamental basis of approach for elucidation in all the three cases.

2. COLOUR AND THE QUANTUM THEORY

The intimate relationship between the theory of light-quanta and the physiological effects of light becomes evident when we consider the sensations excited by the monochromatic rays of the spectrum. As we proceed from the red to the violet end of the spectrum, the magnitude of the energy-quantum in light increases progressively and continuously. Likewise, we perceive a continuous progression of colour, and there is thus a one-to-one correspondence between the perceived colour and the magnitude of the energy-quantum. We are, therefore, justified in regarding every one of the numerous distinguishable colours in the spectrum—of which there are some 150 or more—as primary or fundamental physiological sensations. The so-called trichromatic hypothesis which assumes that there are only three fundamental colours or only three fundamental sensations has, therefore, no logical basis and is unsustainable. The explanation of the known facts regarding the perception of monochromatic light—namely the variations of the luminous efficiency and the variations of the power of colour discrimination noticed as we proceed along the spectrum from end to end—is to be found in the specific characteristics of the absorbing materials which function as the receptors in the retina. We shall not here pause to discuss these matters further, but will pass on to consider the subject of the acuity of vision on the basis of the quantum theory. This subject is, indeed, the principal topic to be dealt with in the present communication.

3. The Factors Influencing Visual Acuity

In any discussion of the subject of visual acuity, we have to assume that the functioning of the dioptrics of the organs of vision is perfect. This, of course, is not necessarily always the case. But since the various possible defects in such functioning can be corrected more or less perfectly after ophthalmoscopic examination, they need not trouble us here. Chromatic aberration in the eye and its elimination by the use of monochromatic light are, however, not unimportant in the present context. The two factors which most notably influence visual acuity are, firstly, the region of the retina which is made use of, and secondly, the intensity of the illumination employed. Other factors are the spectral nature of the illumination, the distribution of light in the object under view and the illumination of the surrounding field. We shall here briefly recall some well-established facts regarding these matters.

When we wish to observe any object closely, we turn our eyes and accommodate their focus so as to ensure that the image of the object falls precisely on the foveal region of the retinæ of both eyes. It is well known that the visual acuity is highest when the region under observation falls precisely at the centre of the fovea and that it falls off with extreme rapidity when the image moves away from that position. A movement of 10° in either direction is sufficient to reduce visual acuity to 20% of its maximum value, while a displacement of 20° brings it down to 10% of the maximum. Beyond this again, the acuity for daylight vision continues to fall off, but more slowly.

The influence of the intensity of illumination on visual acuity is a matter of familiar experience. The acuity is highest at high illuminations and falls off, at first slowly, and then much more quickly, and becomes a small fraction of its maximum value when the illumination is weak, even when it is well within the photopic range. These changes in the acuity of vision with diminishing illumination becomes evident, for example, when we seek to read the pages of a printed book by daylight in the late hours of the afternoon when the sun is about to set and before it has actually become dark. The smaller the print, the greater is the difficulty felt in recognising the letters on the page.

The influence of the spectral nature of the illumination on acuity is, speaking broadly, of the nature which might be anticipated from the consideration that the luminous efficiency of radiation varies enormously as between different parts of the spectrum. The acuity is, in fact, found to be greatest in the part of the spectrum which has the highest luminosity, the order being yellow, orange, green, red and blue. It is particularly low at and near the blue end of the spectrum which has a very low intrinsic luminosity.

Since visual acuity usually depends on the perception of differences in the luminosity of adjoining areas in the field of vision, it naturally falls off as these differences diminish. Likewise, it has been found that for a given brightness of the test-object, the acuity improves as the surround illumination is increased, until the brightness of surround and test-object are equal. A further increase of surround illumination then causes a rapid fall in acuity.

4. The Measurement of Visual Acuity

What precisely we mean by visual acuity depends on the nature of the object or objects under examination. It follows that there are several different ways in which the acuity may be defined and measured. One of the classic definitions is our ability to distinguish two stars in the night sky which are very close together as distinct objects. Amongst other tests may be mentioned, the discrimination of two parallel lines, the alignment of a vernier, the recognition of a break in a contour, the recognition of a localised thickening in the circumference of a circle, or the appearance of a crossed pair of gratings held together at various angles with respect to each other. Amongst other devices which have been employed may be mentioned the broken circle of Landolt where a circle with a gap is presented and the observer is asked to say in what segment the gap lies.

A commercially available test-object for the study of the variations of visual acuity is the chart regularly used by ophthalmologists for detecting and correcting defects in vision. These charts are sets of letters arranged in a descending order of size. The observer sits at a convenient distance away from the chart (say 6 metres) and his vision is expressed as a fraction of this distance and the theoretical distance at which the letters should be read on the basis of a minimum visual angle of one minute of arc. Using such a chart, the changes in visual acuity manifesting themselves in normal vision when the illumination is varied can be readily observed and measured. In such measurements, three different procedures may be adopted. Keeping the illumination constant, the observer may note the effect of his gradually approaching the chart in making the smaller letters appear distinct. Alternatively, the observer remaining in the same position with respect to the chart, the power of the light source may be varied. The third procedure is for the source and the observer to remain in the same position and to move the chart away from them so that both the illumination of the chart and the angular dimensions of the letters progressively diminish. All three procedures yield comparable results.

5. THE PHYSIOLOGICAL BASIS OF ACUITY

It is evident that for very fine detail of the object under observation to reveal itself to our perceptions, two conditions must be satisfied. Firstly, well-defined optical images of the object should be formed on the retinæ of our eyes. Secondly, there should be present on the area of the retina where such images are formed, a sufficiently close-packed mosaic of receptor-elements that can receive the incident light-image and transmit the details thereof to the visual cortex. But there is also a *third* and highly important condition to be satisfied which emerges as a consequence of the constitution of light itself, *viz.*, that it consists of discrete quanta of energy which must be absorbed as such by the visual receptors before the light can be perceived. We shall now consider each of these three conditions separately and comment on the influence exercised by them on visual acuity.

We have already referred to the first condition which should be satisfied for the highest acuity of vision to be possible. Even apart from any imperfections in the dioptric media of the eye, chromatic aberrations and the diffraction of light by reason of the limitation of aperture by the pupil of the eye have necessarily to be taken into account. The limitations set by these factors on visual acuity are well understood and we need not pause here to discuss them in detail. The fine structure of the retina, in other words, the size of the individual cones which are recognised as the receptors in daylight vision, and the manner which they are disposed relatively to each other determines the possibility of the details of the retinal image being conveyed to the visual cortex and thereby find a place in the perceived image of the object. The nature of the connections between the retina and the visual cortex is an important factor in this respect. The evidence that has been found that individual nerve-fibres carry the nerve-impulses from the receiving cones to the sensorium makes it easier to understand how the observed acuity of vision is attained.

It is with the *third* factor influencing the acuity of vision with which we are here specially concerned. The observed diminution of the visual acuity which accompanies a fall in the illumination of the objects under study finds a natural explanation on the basis of the principles of the quantum falling on each element of area of the retina to put forward a rational explanation of the observed facts on any other basis. If the optical image formed on the retina is to be transmitted without loss of detail to the visual cortex, the number of quanta of energy falling on each element of area of the retina and actually absorbed by it and passed on to the visual centres in the brain should be such that each cone in the area under consideration can function fully and effectively. This would obviously not be possible if the flux of illumination falling on the retina is too small, or if the absorbing power of the retinal pigments is inadequate to capture all the incident light-quanta, and make them available for visual perception. The fact that photopic vision can adjust itself to very high levels of illumination is an indication that the visual pigments present in the retina are not capable of absorbing more than a very small percentage of the incident light-quanta. If, in addition, the retinal illumination is itself of low intensity, not more than a small fraction of the cones in the retina can actually be functioning in any small interval of time—such as, say, one-hundredth part of the second—and a dropping off of the visual acuity to very low values is then inevitable. A simple calculation which takes account of the number of light-quanta incident on the retina during any such small interval of time and the number and spacing of the receptor-elements, *viz.*, the cones present in the area shows that this explanation is sustainable.

SQUALLS IN INDIA

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IN the design of buildings, bridges, chimneys, dams, light-houses, transmission poles, etc., the engineers have to take into account various aspects of destructive winds. The need for information on such winds in different parts of the country is on the increase.

From the point of engineering the destructive winds can be classified into two types—(*i*) winds associated with squalls which are transient local phenomena lasting for a couple of minutes and (*ii*) winds associated with large-scale phenomena like cyclones and depressions that last for a longer time affecting a wider area.

Here we shall consider only the squalls. Technically a squall is a sudden increase of wind speed by at least 3 stages on the Beaufort scale, the speed rising to force 6 (39 to 49 km.p.h.) or more, and lasting for at least one minute. In Assam and Kashmir there is no observatory equipped with anemograph to record squalls. The present study therefore refers to the rest of India for which 7 to 13 years data are readily available for a fairly good network of 25 stations given in Table I. It may be pointed out that the conclusions based on these short period data are tentative and intended to give only a very broad picture of the outstanding features of squalls.

Distribution of Squalls

From the distribution of mean annual number of squalls (Fig. 1), it is seen that a maximum of 50 to 70 squalls occur a year in S. Kanara and Kerala while a minimum is observed in Rajasthan and Gujarat and east of the Western Ghats over Deccan plateau. A large part of North India and the Coastal Andhra Pradesh also experience such small number of squalls, less than 20 per year.

In India squall is mainly a hot weather phenomenon. Over 60% of the annual squalls occur during the months March to September. It can be seen from Fig. 1 that certain regions experience practically all the squalls during a couple of months. For instance, the Punjab experiences as much as 80% of the total annual squalls during the period March to July. With the approach of the cold weather season the frequency of squalls rapidly decreases all over the country. During the months December and January, frequencies of squalls are negligibly small.

Directions of Squalls

Squalls may approach a place from any direction. On certain days they have been reported with directions diametrically opposite from two stations situated a few kilometres apart. Further