CHAPTER X

Visual acuity and its variations

We may begin by briefly recalling the facts of observation set out in Chapter V under the heading "Fluctuations of luminosity in visual fields". It was there stated that a diffusing screen which is uniform and is uniformly illuminated nevertheless appears to the observer viewing it from a distance to exhibit variations of luminosity over its area which alter from instant to instant and are seen to move about in a chaotic fashion. These variations of luminosity, however, exhibit certain recognisable characteristics which are different in different circumstances. They depend on the strength of the illumination and also on the distance of the observer from the screen. The spectral character of the light which illuminates the screen is also observed to play an important role in determining the characters of the observed phenomena.

It is evident that such fluctuations of luminosity would interfere with our perception of the details of any objects depicted on the screen which are recognisable by reason of differences in brightness or colour exhibited over their area. The extent of such interference with the visibility of the objects may also be expected to be influenced by the same circumstances as those which determine the characters of the fluctuations of luminosity. Observations show that these anticipations are completely in accord with the actual facts of the case.

For the study of visual acuity and its variations, the well-known Snellen test-charts of the type used by oculists are very convenient. Letters of various sizes printed in black on white card and arranged in rows and columns appear in these charts. The letters are of large size and few in number in the top rows and progressively diminish in size and increase in their number in the following rows. The sizes of the letters in the chart are such that when it is placed at a distance of 8 m from an observer with normal vision in a well-lighted room, he can read all the letters without difficulty or hesitation.

To exhibit the dependence of visual acuity on luminosity, the observations may be made in a chamber the admission of light into which can be controlled and varied over a great range with the aid of an iris-diaphragm covering a circular opening in a window which faces the sky. The test-chart should be placed as far away as possible from this opening, but facing it so that it is uniformly illuminated. The observer should also face the chart and can view it from any desired distance, commencing from the maximum permitted by the size of the room.

When the iris is fully open and the chart is therefore brightly illuminated, all the eight rows of letters on the chart can be read by the observer provided that he is not too far away from it. If the observer remains in a fixed position and the iris is then progressively closed down, the successive rows of letters disappear from sight one after another, commencing from the last row containing the smallest letters and proceeding upwards. Finally, when the opening of the iris is a minimum and the illumination of the chart is very feeble, even the rows at the top containing letters of large size are scarcely visible or recognisable. If at this stage, the observer moves towards the chart and comes closer to it, the sequence of changes is again observed, but in the reverse order. In other words, the rows of letters become visible one after another commencing from the rows of the larger letters at the top and moving downwards to the rows of smaller letters. Finally, when the observer is close to the chart, he can read all the letters, despite the weakness of the illumination.

Fluctuations and visual acuity: Attentive observation of the individual letters at various stages of the foregoing experiment reveals a phenomenon which may be described as a disintegration or break-up of the lines or curves which together make up a complete letter. In other words, only a part of the complete letter is visible and the other parts are not. At intervals, even the complete letter vanishes from sight and later reappears. These changes make it difficult to recognise and read the letters, and when they have proceeded far enough result in their obliteration. The lower the level of the illumination, the larger are the areas which pass out of sight. It is readily understood why in these circumstances, it is the smallest letters which first cease to be legible as the illumination is diminished and that they are followed later by the larger letters. Likewise, it is noticeable that the distance of the observer from the chart determines the size of the regions of disturbance. The closer he approaches to the chart, the smaller they become. When the regions are small enough, even the smallest letters on the chart become legible.

These facts are intelligible in the light of the opening remarks in this chapter. The ability to observe and recognise the details of any object under view depends on the existence of visible differences between the contiguous areas of the object in respect of brightness or other features, as also a reasonable measure of constancy in time of these differences. The observations set forth above demonstrate that the falling away of visual acuity with diminishing illumination is a consequence of the lack of such constancy. In other words, the perception of light is not continuous but is a fluctuating phenomenon, the magnitude and character of these fluctuations varying with the strength of the illumination and the distance of the observer from the object under view.

That the fluctuations of luminosity of the same nature as those described in Chapter V are the effective cause of the diminishing acuity of vision with decreasing illumination becomes even more clearly evident when we set the test-chart side by side with a simple white screen so that they are illuminated similarly and observed from the same distance. It is then noticed that the parts of the chart in which the letters cannot be recognised exhibit the fluctuations of brightness much in the same manner as the smooth white screen. Further, even in the part of the chart where the letters can be read, local variations of brightness of the same nature and of the same magnitude as in the white screen are noticeable. In every case, the size of the patches of varying luminosity is comparable with the size of the letters which are just on the limit of visibility.

Instead of the Snellen charts, a white card on which rows of letters of different sizes following each other are printed may be used. The card may be held in the hand by the observer and read from the usual distance of distinct vision. We may, for example, have a card with ten rows in each of which all letters of the alphabet appear, the first row being 15 cm in length and the last only 3 cm long, the types being of correspondingly smaller sizes. In a brightly lit room, all the letters on the card are legible. But as the illumination is progressively reduced, the successive rows of letters commencing from the last go out of sight one after another, until finally even the first row becomes illegible. Simultaneously, it will be noticed that in the blank white spaces on either side of the region occupied by the letters, the card exhibits a fluctuating luminosity, the character of these fluctuations altering progressively as the illumination is reduced.

It is easy to demonstrate that the finer the detail which we wish to observe and recognise by our unaided vision, the stronger should be the illumination of the object under view. If, for example, we endeavour to read a page of ordinary print which has been miniaturised and reduced in size to a third or one-fourth of its normal dimensions, the lines of print on it will be found to be illegible even in a brightly-lighted room, But it is found that such a page when held in bright sunlight can be read easily enough.

Visual acuity and brightness contrast: The visibility of details in any object viewed by an observer is a consequence of the brightness or the colour of the object being different at different points in his field of view. The greater these differences are, the easier it is to recognise their existence, and it is a familiar experience that the closeness of the observer to the object and an increase in the strength of its illumination are both favourable to such recognition. Here again, we have another illustration of the role played by fluctuations of luminosity in the functioning of our visual perceptions. The effect of these fluctuations on the visibility of detail in the objects under view would evidently be greater, if the contrasts which permit of such visibility are relatively feeble. By increasing the strength of the illumination or by the observer approaching closer to the object, the fluctuations are rendered less effective and the visibility of the detail is thereby improved.

By way of illustrating the foregoing remarks and to reinforce them by actual observations, a Snellen test-chart was specially prepared which was similar to those ordinarily made use of, but the letters, instead of being printed in black type, were filled up by hand using an ordinary graphite pencil. The letters then appear of a grey colour, the contrast between them and the white surface of the card being then much less than that exhibited by letters printed in black on white ground. When a Snellen chart thus prepared is set side by side with one of the usual kind, and the illumination of both is progressively reduced, they display a strikingly different behaviour. The chart with the grey lines becomes totally illegible at a level of illumination at which the black lines on the other chart can all be seen and the letters of the first four or five rows are, quite distinctly readable. The fluctuations of luminosity are visible on both charts and their effectiveness in suppressing the visibility of the grey letters is recognisably the result of the low contrast between them and the background on which they have been placed.

Colour and the acuity of vision: A remarkable and highly significant relationship between the ability to perceive colour and the ability to perceive fine detail in a visual field emerges when the observations set out in the preceding paragraphs are made with monochromatic light instead of with ordinary daylight. Such observations demonstrate that, as in the case of white light, so also with monochromatic light, the fluctuations of luminosity in the visual field are effectively the origin of the observed dependence of visual acuity on the strength of the illumination. But they also show that *pari passu* with the fall in visual acuity as the strength of the illumination diminishes, there is a progressive falling off of the colour sensation excited by monochromatic light. The latter effect and its explanation have already been set out in Chapter IV on "The basic visual sensations". But what now emerges is that the perception of colour and visual acuity stand in the closest relationship to each other. As the sensation of colour becomes more pronounced, the acuity of vision is enhanced. *Vice-versa*, when the perception of colour becomes weaker, visual acuity also falls off. Finally, when the colour sensation ceases to be perceived, the visual acuity has also vanished.

An impressive demonstration of the statements made above may be given, using appropriate arrangements of the nature already described. A test-chart containing a series of rows of printed letters of progressively diminishing size is held by the observer in his hand and moved away from an area strongly illuminated by monochromatic light to a region in which the chart is much less strongly lit up. Viewing the chart in these circumstances, it is noticed that the successive rows of letters become illegible, commencing from those of smallest size and followed by those of larger size. Simultaneously, the colour of the illuminated chart exhibits a rapid change, beginning from a rich hue resembling that of the light-source as viewed directly and falling off to a much paler hue and progressively approaching an achromatic sensation. The experiment may be made with monochromatic light of various colours, viz., the yellow light of a sodium vapour-lamp, the green and the blue radiations of mercury-vapour isolated by appropriate colour-filters, and also with the light from a tungsten filament lamp covered by a deep red filter. The rapid weakening of the colour sensation which accompanies the rapid diminution of visual acuity is noticeable in all cases. But the effect is particularly striking as exhibited by the blue-violet λ 4358 radiations of the mercury vapour-lamp.

That the variations of visual acuity with the strength of illumination over its entire range have their origin in the fluctuations of luminosity observed in the field of vision is readily established with the aid of monochromatic light-sources. The fluctuations are then distinctly more conspicuous than those observed with white light and are noticeable even at fairly high levels of intensity. The regions of the spectrum for which the visual acuity is low, including especially the blue, exhibit the fluctuations more conspicuously than those for which the visual acuity is high.

Binocular vision: The fluctuations of luminosity on a uniformly illuminated screen are more conspicuous when viewed with only one eye of the observer open (the other being closed), or *vice-versa*. This observation indicates that the fluctuations of luminosity as seen by the retinae of the two eyes are independent and the effect of binocular superposition is therefore to diminish their visibility. In the circumstances, it is not surprising to find that when a test-chart is viewed under reduced illumination, the visibility of the letters is noticeably improved by using both eyes instead of only one or the other.

Scintillating charts: Instead of letters of various sizes printed in black on a white background, we may employ charts in which the objects depicted are all similar and are arranged in regular geometric order. We may, for example, use charts exhibiting a pattern of white squares arranged in parallel rows and columns on a black background. It is useful to have a set of such charts in which the squares are of different sizes. They may be viewed by the observer from various distances and illuminated at different levels of brightness, and the visibility of the squares on the different charts may be compared with each other, and some quantitative results may be obtained. Some particularly interesting effects are noticed with the charts containing squares of rather small size, e.g., 5 mm, when they are illuminated with the light of a sodium vapour lamp at a fairly low level of brightness and viewed from such a distance that the squares can still be distinguished as separate entities. They are then observed to scintillate, showing large variations in intensity, the patterns of such luminosity moving over the chart from instant to instant. The charts containing the larger squares exhibit in similar circumstances some very curious phenomena, the individual squares changing their shape from instant to instant and showing irregular patterns of light and shade within their respective areas.

Visibility of fine detail: Of particular interest is the question, what is it that sets a limit to the ability of our eyes to perceive fine detail in any object? In considering this question, we have also to take into account the nature of the object. Earlier in this chapter, we have already dealt with some particular cases, e.g., small letters in black type printed on white paper. The observations showed that an adequate strength of illumination is essential for their legibility. A somewhat similar case presents itself when we examine half-tone illustrations printed in black and white. It is the intention that the illustrations should present only gradations of light and shade to the eye of the observer. But when adequately illuminated, e.g., by direct sunlight, the mesh of even the finest half-tone screens is readily visible in the printed illustrations.

A slightly different situation arises when the object under examination is a transparency. We may take the typical example of screens woven with fine metallic wires interlacing each other. Such screens are commercially available and exhibit a remarkable uniformity in the diameters of the wires and in their spacing. Five such screens have been examined by the author, the spacing of the wire-mesh being respectively 0·85, 0·52, 0·26, 0·22 and 0·18 mm. When held at the usual distance of distinct vision and viewed against the bright sky, the two most widely spaced meshes are quite clearly visible. But the visibility is much less with the other three, the last of the series being particularly difficult. In every case, the visibility falls off as the screen is moved further away from the observer, the maximum distance beyond which the visibility vanishes being the greatest for the first of the series and progressively less for the others. It is found also that the visibility depends notably on the illumination of the background against which the mesh is viewed, the minimum necessary increasing as the spacing of the wires is smaller. Even the coarsest mesh of the five ceases to be visible when held at the usual distance of distinct vision, if the background illumination is below a certain limit.

A rather searching test of visual acuity is provided by the "BMC Fine mesh" made by the firm Buckbee Mears of Saint Paul, Minnesota. This is a thin film which exhibits under a magnifying lens a network of dark lines spaced a tenth of a mm apart and crossing each other at right angles. For the mesh to be visible to the unaided eye, it is found necessary to hold it against a brilliantly illuminated background.

CHAPTER XI

Vision in dim light

There is an immense disparity between the illumination which reaches the Earth in daytime from the Sun and the light received from various sources in the sky on a clear but moonless night. The former is roughly about a thousand million times brighter than the latter. Between these extremes is the light of the full moon which may be put as roughly half-a-millionth part of the light of the noonday sun. Twilight, the duration of which in the tropics is about an hour, permits of a comfortable transition from the brilliance of sunlight to the dimness of starlight, in other words allows human vision to adjust itself naturally to the enormously reduced intensity. It also permits of a leisurely observation of the changes in the characters of the visual perception of light which accompany this reduction.

Very readily noticeable changes appear in our visual perceptions in dim light; firstly, the very low visual acuity and secondly, the weakness or even total disappearance of the sense of colour. These changes are essentially progressive in their nature, becoming more and more obvious as the level of illumination falls off. In the earlier chapters of this book, it has been shown that such changes are necessary consequences of the corpuscular nature of light. No special hypotheses or assumptions are needed to account for them.

The idea that human vision is of two kinds designated respectively as photopic vision and scotopic vision arose originally as an explanation of the disease or abnormal condition known as night-blindness. It gained strength from the anatomical finding that there are two kinds of structures in the retina, now known familiarly as the rods and the cones which were identified as the visual receptors. It was an easy step to recognise the rods as the receptors for dim light and the cones as the receptors for bright light. A further step was to assume that the rods enable us to perceive light but without colour, whereas the cones enable us to perceive both light and colour.

We shall later in this book have occasion to comment on these and other aspects of the duplicity theory of vision. In the present chapter, we shall confine ourselves to setting out the observational evidence that points to the conclusion that human vision is of one kind only at all levels of illumination.

As has been remarked above, the differences between vision in bright light and vision in dim light are of a progressive nature and it is not possible to set definite limits which would require us to recognise two different categories of perception. This is particularly evident from the studies of visual acuity and its variations described in the preceding chapter. The strength of illumination needed for any particular visual task is determined by the nature of the task. If the task is particularly difficult, brilliant light is needed. If the task is easy, much less illumination is sufficient. Hence, the differences in visual acuity cannot possibly furnish any support for the idea that vision is of two different kinds.

The position is very similar in regard to the perception of colour. We have indeed remarked upon the remarkable parallelism which exists between the variations in visual acuity and in colour perception produced by lowering or raising the level of illumination. Colour is vividly perceived in bright light and it fades away quite gradually as the light becomes feebler. Here again, there is no basis for the assumption that we have two kinds of vision, one in which we have both light and colour and another in which we have light but no colour.

The credence which the duplicity theory of vision obtained is largely based on the supposition that the rods and cones correspond to two different kinds of perception. As against this, we have only to point out that in the foveal region of the retina, the anatomist finds only cones and no rods. Nevertheless, the characteristic differences between vision in bright light and vision in dim light, viz., the lowered visual acuity and the enfeebled perception of colour are very clearly manifested in foveal vision. From this, it may properly be inferred that the rod-cone dualism is altogether irrelevant in this context.

The clearest proof that we are concerned with only one kind of vision at all levels of illumination is forthcoming from a study of the spectrum of white light commencing from ordinary or daylight levels and carried down to the lowest levels of illumination at which it is possible for vision to function. There are indeed noteworthy changes in the observed features of the spectrum as has already been remarked in Chapter VI. But there is a feature common to all levels, namely the role played by the green sector of the spectrum, the limits of which may be put as between 500 and 560 mμ in wavelength. This sector may properly be described as the principal feature in the spectrum of white light. It is a region in which the luminous efficiency is high. As we pass from bright light to dim light, the parts of the spectrum which are of both greater and lesser wavelengths, viz., the red, orange and yellow on one side and the violet, indigo and blue on the other fall off in their luminous efficiency and ultimately disappear from sight. But the green sector survives even in the dimmest light and is indeed the only part of the spectrum which then functions in vision. It is thereby made evident that a differentiation between photopic and scotopic vision is wholly unjustified.

There are several different techniques which may be adopted to enable us to observe the changes in the spectrum of white light as the level of its brightness is progressively reduced to the minimum. They all yield the same result. We shall describe them in the order of their simplicity, beginning with that which is the least sophisticated and ending up with that which makes use of instruments and artificial light sources.