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The new physiology of vision—Chapter III. Corpuscles of light and the perception of luminosity

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In a communication published under the title "Fluctuations of Luminosity in Visual Fields" in the issue of *Current Science* on the 5th of February, 1964, a phenomenon discovered by the author was described, the general features of which indicated it to be a consequence of the corpuscular nature of light. The circumstances in which the phenomenon was observed and the nature of the effects seen were as follows. The observer views a uniformly illuminated surface situated at a sufficient distance from himself; it is noticed that its luminosity does not appear uniform or static, but exhibits fluctuations over its entire area. The nature and magnitude of the observed effects depend greatly on the strength of the illumination. A particularly noteworthy feature is that the fluctuations continue to be conspicuously noticeable even when the illumination of the screen is thousands of times more powerful than the absolute threshold at which the sensation of light itself vanishes.

The earliest observations of the phenomenon were made without any special arrangements. The illuminated surface was that of a wall in a darkened room on which the light of the sky entering through a ventilator near the roof was incident. The wall was itself distempered with a pale green wash and this greatly reduced the intensity of the light diffused by its surface. The observations were made in the early hours of the morning soon after dawn, so that the effect of the gradually increasing strength of illumination could be very conveniently followed, the observer being at a fixed distance from the wall. Subsequent observations under controlled conditions in a laboratory revealed the influence of varying the distance of the observer from the screen, as well as the highly important role played by the spectral character of the light in the observed phenomena. It was discovered that the effects were most conspicuous when the screen was illuminated with monochromatic light; the effects, though observable with light of all wavelengths, differed greatly in the measure of their conspicuousness for different parts of the spectrum.

Observations with monochromatic light: Definitive studies of the phenomenon were made in a fairly large laboratory room. This was ten metres square and could be completely darkened. The observations were made using as the screen a plastic sheet which was perfectly white and 150 cm × 100 cm in area. This was fixed vertically on a stand so that the distance of the screen from the source of light as well as the distance of the observer from the screen could be independently varied. The surface of the screen had a smooth polish, so much so that the image of the source of light reflected by it was seen sharply defined; but setting the screen suitably with reference to the position of the source and the observer, the reflection could be put out of sight, and only the light diffused by the material of the screen was visible. The screen was uniform and completely free from blemishes, so much so that its diffusing power showed no detectable variations over its entire area.

Monochromatic illumination of the screen could readily be achieved by using a sodium vapour lamp of modest size. This was enclosed in a box provided with an adequately large opening on one side and this was covered over by a diffusing screen of ground glass. The illumination of the distant screen could be varied over a wide range of values by covering the aperture through which the light issued with an iris diaphragm of which the opening could be varied from 10 cm diameter down to a mm, thereby enabling the illumination of the screen to be reduced by a ratio of 10000:1. As the distance of the screen from the source could be diminished from nearly ten metres down to about 10 cm, its illumination could be further altered over a ratio of about 10000:1. Thus, the intensity of the light falling on the screen could be varied from the maximum available in the immediate neighbourhood of the source to a value smaller than that maximum by a factor of about 10^{-8}. The strength of the illumination in the immediate neighbourhood of the aperture from which the light issued could be read with a light meter and was found (with the particular lamp under use) to be fifty foot-candles. When the diaphragm of the iris is closed down to the smallest value and the screen is at the maximum distance from the source, its illumination was found to be unobservable. Thus, the arrangements permit of the screen being viewed under a very wide range of intensities of illumination.

For obtaining monochromatic illumination other than that which could be provided by a sodium-vapour lamp, the most suitable arrangement was found to be the use of a mercury-vapour arc of the high pressure type enclosed in a quartz tube and to focus the image of the arc lamp upon the entrance slit of a double monochromator. An instrument of this kind obtained some years ago from Messrs Kipp and Zonen in Holland was available and was found to be well suited for the purpose. By adjusting the position of the central slit within the instrument, the radiation of any of the chief mercury-arc lines (λ4046, 4358, 4916, 5461, 5770–5790 and 6150) could be effectively isolated from the rest of the spectrum and used to illuminate the distant screen. By varying the width of the slit through which the light finds entry into the monochromator, as well as of the slit through which it finally emerges, the intensity of the issuing beam could be increased in a very considerable ratio without any noticeable loss either of the monochromatism of the emerging light or of the uniformity of illumination of the screen. With the arrangements indicated, the intensity of the emerging light is high in the immediate vicinity of the exit slit and can easily be read with a light-meter: it falls off rapidly in a calculable ratio as we move away from the slit.

Factors influencing the observed effects: As has already been indicated, three factors influence the nature of the observed phenomena. *Firstly*, the strength of the illumination of the screen; *secondly*, the distance of the observer from the screen; and *thirdly*, the spectral character of the illumination. With suitable arrangements, the effect of varying each of these factors could be separately studied. Before describing the observed results, a few remarks of a preliminary nature may be usefully made. It is desirable, though not absolutely essential, to make the observations in a room which has been completely darkened. The need for such darkening is obvious when we wish to make the observations at the lowest levels of illumination of the screen. But, even otherwise, it is desirable that the eyes of the observer are not distracted by light reaching them from other sources than the screen under observation. Especially if such sources are much brighter than the screen itself would be distracting effect be serious. For the same reason also, it is desirable that the observer should not proceed to view the screen immediately after entering the darkened room from a brightly illuminated exterior, but should allow a sufficient time for the visual after-images produced by exposure to strong light to disappear completely. The interval thus allowed would also serve for the adaptation of his vision to the level of illumination of the screen actually under study: the time-interval needed for such adaptation would be a few minutes if the level is high and would be much longer if the level is very low.

A further remark is here needed regarding the characteristics of vision of the observer. It is necessary, of course, that the screen should be seen distinctly by the observer from the position actually taken up by him. If his vision is good for both of his eyes for all distances, no further comment need be made. It is often the case, however, that vision of one eye is much better than that of the other; the observations can then be made with both eyes open, for the phenomena are effectively those seen by the eye of which the vision is good. If the vision of both eyes is equally good, it is found that the fluctuations are better seen when one eye or the other eye is covered up than with both eyes open. This is a clear indication that the fluctuations as seen by the two eyes are independent of each other and the binocular superposition tends to make them less conspicuous than otherwise. If both of the eyes are optically defective, it is necessary to wear correcting glasses. But this is not needful for observations made with screens held at a sufficient distance, if at least one eye of the observer has good vision for distant objects.

Effect of varying the luminosity: As has already been indicated, the strength of the illumination of the screen may be varied by one or another of two methods or by both together; firstly by altering the luminous flux issuing from the light source and secondly by varying the distance of the screen from the source. The former method has the advantage that the observer can remain at a fixed distance from the screen, and hence the effect of varying such distance does not arise. The change in the strength of the illumination can be effected in a quantitative fashion using the sodium-vapour lamp and varying the aperture of the iris diaphragm as already described. Using this technique, it is found that the fluctuations of luminosity of the screen are discernible over a great range of strength of its illumination. But the observable characters of the fluctuations differ greatly at different levels of illumination. The differences observed are of three kinds: firstly in respect of the degree of contrast observable as between the darker and brighter areas in the fluctuating illumination; secondly, in respect of the rapidity with which the changes occur; and thirdly, in respect of the sizes of the areas of brightness and darkness seen on the screen. We may describe the differences which are observed succinctly as follows. In the higher ranges of illumination, the contrasts between the areas of darkness and brightness are less, the areas themselves are distinctly smaller, and the changes with time are more rapid. At the lower levels of illumination, the contrasts are more striking, the areas are larger and the changes with time are slower. These differences in the characters of the fluctuations increase progressively with the decreasing strength of illumination.

Effect of varying the observer's position: When the observer alters his location and approaches an illuminated screen, the flux of illumination from any given area of the screen which finds entry into the pupils of his eyes increases in the inverse proportion of the square of his distance from the screen: but the image of that area formed on the retinae of his eyes increases in size in the same proportion, and hence it is not to be expected that the luminosity of the screen as actually perceived would alter sensibly. Actually, it is found that the fluctuating pattern of varying intensities visible on the screen progressively increases in the absolute scale of size of its details as the observer moves away from the screen; *per contra*, the details seen in the pattern visibly contract as he moves towards the screen. But other features of the pattern, viz., the contrasts between light and shade, and the rapidity of the fluctuations do not seem to alter. In the higher ranges of illumination of the screen, however, the patterns of fluctuation themselves are on a small scale and also change rapidly with time. Hence, it becomes more and more difficult to recognise the existence of the fluctuations when the observer approaches too closely to the screen under observation. For these reasons, it is desirable that he takes his stand at a reasonable distance from it, say, a metre or two from the screen. When, however, the illumination is very low, he can approach much closer and still have no difficulty in recognising the varying patterns of light and shade moving over the screen.

Influence of the spectral composition: As is well known, the intrinsic luminosity of the visible spectrum varies greatly over the range of wavelengths included in it as we pass from one end of the spectrum to the other. The absolute level of illumination and the particular region of the retina made use of for the observations are also known to influence the form of the spectral luminosity curve. In these circumstances, it is only to be expected that the character of the fluctuations of luminosity visible on an illuminated screen would depend greatly on the position in the spectrum of the light employed for the observations. The light of the sodium-vapour lamp is not far in its position from the point of maximum luminosity in the spectrum at high levels of illumination. Since the fluctuations of luminosity are conspicuous with sodium light over a great range of intensities of illumination, one may reasonably expect that monochromatic light from the parts of the spectrum of which the intrinsic brightness is lower should exhibit the phenomena even more conspicuously. This is indeed found to be the case. As we move from the yellow into the red, and also as we move from the yellow into the green and then into the blue and the violet the effects become more strikingly visible. Indeed, the fluctuations of luminosity on a screen illuminated by the λ 4358 radiations of the mercury lamp are conspicuous even at high levels of illumination; indeed more so, than could have been anticipated on the basis of the low intrinsic luminosity of the λ 4358 radiation as compared with the 5896 light of the sodium lamp.

The origin of the fluctuations: The energy carried by an individual corpuscle of light is an exceedingly small quantity, and the number of corpuscles corresponding to even a moderate light-flux incident on a screen is enormously large. As has already been noted in the preceding chapter, a lumen of illumination of wavelength 555 mμ falling on an area of one square metre is equivalent to the incidence on it of $4{\cdot}3 \times 10^{15}$ quanta per second of time. This number being enormous, it might seem incredible that observations of an illuminated screen should enable us to perceive any noticeable fluctuations in brightness. The paradox is resolved when we consider the situation more closely. We have to take note of two distinct features in the situation which conspire and give rise to the observed effects. The first is the corpuscular nature of light. The second is the discrete structure of the retina. For light to be perceived, a corpuscle of light has not merely to fall on the retina, but has actually to be trapped by one of the receptors forming the fine structure of the retina and be transformed into an electrical impulse transmitted along the associated nerve-fibres to the cerebral centres involved in the perception of light. Such absorption of the corpuscle and transformation of its energy is essentially a *chance event* as has already been remarked in the preceding chapter. It should be noted in this connection that the range of illumination in which our eyes can function is enormous. For instance, the illumination of a diffusing screen on which direct sunlight is incident is of the order of 25000 lumens per square metre. It is not pleasant to look at such a brightly illuminated surface, but we can certainly do so for a little while without any disastrous effect on our visual faculties. In the circumstances, we are justified in assuming that the chance of a light corpuscle falling on the retina being trapped and transformed into an impulse carried by the optic nerves is exceedingly small, not greater than one in a hundred, and perhaps even less.

Granting that the perception of light by our eyes is the resultant of the individual chances of absorption of a light corpuscle by one of the receptors in the retina, the way is open to an explanation of the flucutations of luminosity actually observed. Here, we have to take note of the fact that only an exceedingly small fraction of the number of light corpuscles which reach the surface of a screen and are diffused by it can find their way into the pupil of an eye of the observer. This fraction is the ratio of the area of the pupil to the area of the surface of a hemisphere drawn with an element of area of the illuminated screen as centre and having as its radius, the distance of the observer from the screen. If we take the diameter of the pupil as 5 mm and the screen to be two metres away from the observer, the chance of a light corpuscle from the element of area finding its way to the retina is reduced in the ratio of 1 to 1,300,000. This factor will be further reduced by the very small probability of a corpuscle reaching the retina being actually perceived as light. Further, *to enable the screen to be perceived by the eye as uniformly illuminated, it is necessary that everyone of the individual receptors in the retina should be fully engaged all the time in receiving light corpuscles, absorbing them and passing on the absorbed energy in the form of nervous impulses, and that this process is repeated once in every small fraction of a second of time.* When it is further remarked that in the foveal depression in the retina alone, there are 100,000 individual receptors, it will be realised that even when the illumination of the screen is as high as one lumen per square metre, it is extremely unlikely that the requirements stated above would be fully satisfied. Actually, it may be expected that only a fraction of the receptors (determined by the laws of chance) would be functioning at any given instant. That fluctuations of luminosity over the area of the screen would be observed follows as a natural consequence of these considerations.

Some further remarks: What has been stated above enables us to proceed a little further and to offer a reasonable explanation of the features observed in various circumstances and set forth above. The smaller is the luminous flux incident on the screen, the less would be the proportion of the receptors of vision actually functioning at any given instant of time. In consequence, the larger would be the areas in which variations of brightness would manifest themselves. In other words, the contrasting areas of light and shade would be larger in size, and the contrasts themselves would be more readily perceptible and the changes from greater or lesser brightness occur less rapidly. An increase of the luminous flux falling on the screen would produce the reverse effects. As the observer moves away from the illuminating screen, the actual number of light corpuscles reaching any particular region of the retina would not alter appreciably. But the image of the fluctuations in the activity of the retina as seen projected on the illuminated screen would be enlarged in proportion to its distance from the observer, and this is what is actually observed. Finally, the very striking nature of the fluctuations observed when the illuminating radiation is in the region of shorter wavelengths becomes intelligible when it is recalled that the corpuscles in this region represent larger quanta of energy and for the same energy are therefore fewer in number, and that, further, the chance of a corpuscle being actually absorbed and giving rise to a visual impulse, is necessarily much smaller in view of the very low luminosity of these regions of the spectrum.