THE NEW PHYSIOLOGY OF VISION

Chapter VIII. The Perception of Polarised Light

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ONE of the most remarkable of our visual faculties is the ability to recognise polarised light and to locate its plane of polarisation. It is the foveal region of the retina that exhibits this power which, it may be remarked, is limited to light appearing in the wavelength range between 400 mμ and 500 mμ. The fovea is the most useful part of the retina and the blue-violet sector in the spectrum covering this range of wavelengths stands in a category by itself as the most colourful and yet the least luminous part of it. Clearly, therefore, the process by which the fovea is enabled to recognise the presence of polarisation in light appearing in this restricted range within the spectrum and is unable to achieve the same result in other parts of it, merits scientific investigation. Indeed, one may well expect that such an investigation would throw much-needed light on the fundamental aspects of the physiology of vision. The studies of which the results are described in this chapter were undertaken with that object.

Haidinger's Brushes.—The blue colour of the sunlit sky has its origin in the scattering of sunlight by the molecules of the earth's atmosphere. Skylight accordingly exhibits a high degree of polarisation when observed in a direction transverse to the rays of the sun. As a consequence, observation of the parts of the sky which exhibit the maximum degree of polarisation should enable us to demonstrate the ability of our eyes to perceive and determine the state of such polarisation. The effects thus arising are best looked for in the forenoon of any bright clear morning when the sun is well up above the horizon. The observer should stand with his back to the sun and view the regions of the sky where the maximum of polarisation is to be expected. These regions would evidently lie along the arc of a great circle which runs at a slant across the sky. Scanning this circle rapidly with his eyes, the observer will notice a band along the circle which appears bluer than the rest of the sky and which is bordered on both sides by bands of the same width exhibiting a distinctly yellowish hue. On fixing his attention at a particular part of the circle to his left, it will be found that the colours seen in that region soon fade away from sight. The observer should then turn quickly and fix his attention on the part of the great circle to his right which is ninety degrees away from the original point of fixation on the left. He will then notice in this region a very striking phenomenon, *viz.*, a dumbell-shaped blue brush of light having its axis on the great circle of maximum polarisation of skylight and crossing this brush a yellow brush of light of similar shape with its axis transverse to that circle. These brushes are conspicuous when first seen, but when the observer continues to gaze at them, they fade away from sight. He should then again turn quickly to the region on the circle previously viewed. He will then notice in that region a similar conspicuous manifestation of the blue and yellow brushes crossing each other. This alternation between the left and the right can be repeated as often as desired.

Studied in the manner described, the nature and origin of the phenomena become clear. What the observer perceives is an enormously enlarged picture of the foveal region in the retinæ of his own eyes projected on the sky and manifesting itself by reason of the visual response of the fovea to the light incident on it. The spectral character of that light, its state of polarisation and the orientation of the plane of polarisation in relation to the fovea are the factors which determine the nature of the picture perceived. The circumstances in which it is observed indicate that the conditioning of the eye by an earlier exposure to polarised light also plays a highly important role. The entire light of the spectrum is polarised, but the part of the spectrum not included in the range of wavelengths between 400 mμ and 500 mμ behaves quite differently from the part which is included in that range. It is the latter part of the spectrum that evokes a powerful visual sensation in the two sectors of the fovea of which the axis is parallel to the direction of vibration in the incident light. The two other sectors of which the axis is perpendicular to that direction are not thus excited. Since these differences appear only in the blue-violet sector of the spectrum, the visual sensation in the former case manifests itself as a brush of a bright blue colour. In the latter case, the absence of any sensation in the blue region of the spectrum results in only the rest of the spectrum being perceived. The manifestation of a yellow brush crossing the blue brush is thus accounted for.

The blue and yellow brushes and the regions in the fovea which they represent interchange positions when the observer shifts his vision from the part of the sky on his left to another on his right located ninety degrees away from it. The regions of the fovea which are not excited in one case are those excited in the second case and *vice versa*. The sectors are thus conditioned by the first exposure respectively to respond and not to respond to the second exposure. Accordingly, the blue brush and the yellow brush both turn round through a right angle and manifest themselves conspicuously to the observer's vision.

The Spectral Characteristics.—As stated above, the ability of the fovea to perceive polarisation is restricted to the blue-violet part of the spectrum. In other words, polarisation is detectable throughout the spectral range between 400 mμ and 500 mμ but is unobservable in the region of greater wavelengths. A simple technique by which these facts can be demonstrated has been devised by the author. A brilliantly illuminated part of the sky (close to the sun) is viewed through the long slit-shaped opening between the two shutters of a window by the observer who takes up a position at a suitable distance from the opening. Holding a diffraction grating before his eye, the observer can view the first-order spectrum produced by it and can direct his vision to any particular part of the spectrum and scan the entire spectrum from end to end. Insertion of a polaroid before the grating results in polarising the light appearing in the spectrum. Two brushes are then seen crossing each other, one of them being a bright brush and the other a dark brush. When the polaroid is rotated, both the brushes rotate together in the same direction as the polaroid. The brushes can be very clearly seen in the blue-violet sector of the spectrum. But they are not observed in other parts of the spectrum.

That the polarisation of light is undetectable by the unaided vision if the wavelength of the light exceeds 500 mμ also becomes evident when the observer makes use of a colour filter which completely cuts off all wavelengths less than 500 mμ while freely transmitting greater wavelengths. Glass filters having such a spectral behaviour are commercially available and they appear of a golden-yellow colour by transmitted light. Viewing an extended source of light through such a filter with a polaroid placed in front which can be turned round in its own plane, critical examination fails to reveal any observable brushes in the field of view. *Per contra*, the use of a colour filter that cuts out all wavelengths greater than 500 mμ and transmits shorter wavelengths enormously facilitates the observation of the brushes. Instead of a blue brush crossed by an yellow brush, we have then a bright brush crossed by a dark brush, both appearing in a field exhibiting the colour of the transmitted light. The contrasts in respect of luminosity then manifested make the whole phenomenon very conspicuous. The axis of the bright brush is parallel to the direction of vibration in the polarised light, while the axis of the dark brush is transverse to that direction.

Techniques of Observation.—The use of a colour filter to eliminate the unwanted parts of the spectrum and of a polaroid to secure complete polarisation of the light in any desired azimuth makes further critical studies possible. Observations can then be made under controlled laboratory conditions and artificial light sources having the desired spectral characters can also be utilized. By such studies, it can be established that, though restricted to the blue-violet sector of the spectrum, the ability to detect polarisation belongs to the same category of visual phenomena as the perception of light, form and colour and that it stands in the closest relationship with these perceptions. The difficulty which presents itself in the evanescent character of the phenomenon can be overcome by the adoption of a suitable technique. Holding the colour filter together with the polaroid in front of his eye, the observer should view an extended source of light. The polaroid should be held at first in particular orientation and then smartly turned round in its own plane through a right angle. It should then be held in the new position for a little while and later turned back again to the original position. These movements may be repeated as often as desired. Immediately after the polaroid is turned into a new orientation, the brushes are seen at their best, a bright brush along the direction of vibration in the transmitted light and a dark brush in the transverse direction. The brushes fade away soon, but they reappear in full strength in the new position when the polaroid is turned again through a right angle.

The extended sources of light needed for the study are most conveniently accessible out-of-doors, sunlit clouds being the most luminous. Next in order comes skylight, the brightness of which varies enormously with the part of the sky under observation, as also with the time of the day. In the vicinity of the sun, especially when it is covered by a thin haze, skylight can be extremely brilliant. Further away from the sun, the luminosity falls off rapidly. It also becomes very weak in the twilight hours. Indoor observations may also be made using screens which receive their light from open windows. If the screen employed is of the type used for projection work, consisting of a great number of tiny glass-balls embedded in a plastic sheet, a fairly high luminosity may be achieved. Other screens are, of course, less satisfactory. It should be remembered that the combination of a blue-filter with a polaroid transmits only a very small part of white light. The need for a high intrinsic luminosity when an extended source of light is viewed through such a combination is obvious.

For observations indoors with monochromatic light, the most suitable source is a powerful mercury arc lamp of the type used in street lighting. This should be enclosed in a box of suitable size which is provided with an exit window of sufficient area for the emergence of the light. A glass cell containing cuprammonium solution which covers the exit aperture makes an effective filter. It transmits the λ 4358 radiations and cuts out all longer wavelengths. The light emerging through the filter may be received on a ground-glass screen, the observations being made on the light emerging through it. Alternatively, the light may be received on an opaque diffusing screen, the surface of the latter being viewed by the observer at any convenient angle. This, of course, is a much less efficient source of light than the ground-glass screen which operates by transmission. No colour filter is necessary in either case, only the polaroid being held by the observer before his eye. By varying the distance of the ground-glass sheet or of the diffusing screen from the exit-aperture of the source, a very wide range of strength of the illumination may be obtained.

Results of the Investigation.—When the techniques of observation described above are made use of, it becomes immediately apparent that the perception of polarisation is only possible when the source under observation has a fairly high luminosity and that it becomes more and more difficult as the luminosity of the source is progressively diminished. Finally, a limit is reached below which the phenomenon cannot be observed at all. The progressive deterioration in visibility is the result of a diminishing contrast between the luminosities of the dark and the bright brushes seen in the field of view of the polaroid. A stage is reached when by reason of such diminishing contrast, the brushes are barely perceptible and finally become altogether invisible.

The observations made using the λ 4358 light of the mercury arc in the manner described above make it clear that the falling off in the visibility of the brushes as seen through the polaroid takes place in the same range of luminosities of the field as the progressive weakening of the chromaticity and the diminution in visual acuity described and discussed in the earlier chapters of this work. The parallelism between these phenomena is close and may indeed be described as a semi-quantitative relationship. That the perception of polarisation belongs to the same category as the perception of form and the perception of colour is thereby clearly established.

We may now sum up the observations described above and the conclusions which have resulted in the following series of propositions: I. The perception of the polarisation of light in a luminous field is limited to the blue-violet sector of the spectrum, *viz.*, the wavelength range between 400 mμ and 500 mμ. II. The perception takes the form of two crossed brushes which are bright and dark respectively, the bright brush running parallel to the direction of vibration in the polarised light, and the dark brush transverse to that direction. III. The brushes appear in the field of view which corresponds to the location of the fovea in the retina. They rotate with the plane of polarisation when the latter is rotated. IV. The contrast in luminosity between the bright and dark brushes diminishes till they finally become invisible when the luminosity of the field is diminished progressively to a low level. V. There is a complete parallelism between the behaviour just described and the weakening in chromaticity and the fall of visual acuity in the blue-violet region of the spectrum which accompanies a diminishing strength of illumination. VI. The perception of polarisation thus emerges as an integral part of the same visual process which makes the perceptions of light, form and colour possible in the blue-violet sector of the spectrum. VII. The materials present in the fovea which activate the perception of light in the blue-violet part of the spectrum are disposed with a high degree of radial symmetry around the centre of the fovea.

In the succeeding chapter, we shall return to a more detailed consideration of the results stated in these propositions.