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The new physiology of vision—Chapter XXVII. The colours of interference

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The characteristic features and properties of human vision are exhibited in a very striking manner in the phenomena which will occupy our attention in the present chapter. The results here described have emerged from the author's own investigations. Strangely enough, though the experiments themselves have been familiar for three centuries, the phenomena which they exhibit have not till now been correctly observed and described and hence their real nature has been misunderstood.

A thin film of air enclosed between two flat or nearly flat plates of glass exhibits colours when it is viewed by the light reflected at the surfaces enclosing the film. The colours owe their origin to the interference of the beams of light reflected at the two surfaces which differ in their optical paths, such difference being itself determined by the thickness of the film. If, therefore, the thickness of the film varies over its area, the colours exhibited also vary and the pattern of colours follows the variations of thickness and serves to indicate their geometric configuration.

In the classical form of the experiment, the air-film is that enclosed between two surfaces, of which one is plane and the other spherical with a large radius of curvature. In these circumstances, the interferences take the form of rings which are concentric around the region of actual contact of the two surfaces where the film has zero thickness. This central region appears black in the pattern. Sir Isaac Newton devoted the second book of his classical treatise on optics to a description of these rings and hence they are usually known by his name. But neither Newton nor any of the numerous other observers who have described and discussed the effects observed in the experiment make any reference to the major feature of the phenomenon, viz., the manifestation of a series of maxima and minima of luminosity in the field covered by the pattern. These alternations of luminosity determine the characters of the interference pattern, and the alternations of colour observed are related to the alternations of luminosity in a manner which clearly indicates that the latter constitute the basic phenomenon and that the colour differences are only incidental consequences.

Newton's rings in white light: The area over which the interferences as seen by white light are recognisable depends on the radius of curvature of one surface, the other surface being assumed to be plane. In the apparatus employed, the surface which is spherical has a radius of curvature of 3·6 metres and the pattern as seen by reflected light extends over a circle of about 1 cm diameter. Holding the plates at the usual distance of distinct vision and viewing the pattern by reflected light without any optical aid, it exhibits a black centre around which can be seen a succession of bright and dark rings, but no colours are noticeable. The spacings of the rings progressively diminish. Six rings are readily distinguishable, while a few others beyond can be glimpsed, the difficulty in seeing and counting them being a consequence of the closeness of the outer rings as well as the diminishing contrast in brightness of the successive maxima and minima of illumination. While the first few bright rings are definitely more luminous than the outer field of illumination, this difference progressively diminishes as we proceed from ring to ring till finally the rings melt into a background of uniform illumination.

The observations described above make the real nature of Newton's rings evident, viz., that they represent fluctuations of visual brightness or luminosity in the field of view. To observe colours, it is necessary to examine the interference pattern more closely, using a magnifying lens of adequate power. The maxima and minima of brightness remain conspicuously visible but are then accompanied by manifestations of colour in a fashion closely related to the variations of luminosity in the field. What we actually observe with white light may appropriately be compared with the nature of the interferences which would be seen if monochromatic light in the yellow part of the spectrum were used to observe them. In the latter case, as is well-known, the entire field would be covered with a succession of maxima and minima of luminosity in great numbers, all the maxima being equally bright and all the minima being perfectly dark, the successive rings coming closer and closer together as we proceed outwards from the centre of the pattern. The differences between this case and the interferences as observed with white light may be stated as follows:

Firstly, with white light, the contrast between the maxima and the minima of luminosity diminishes progressively instead of remaining the same everywhere. The maxima themselves progressively diminish in brightness until they merge with the uniform field of brightness at a sufficient distance from the centre of the pattern. The character of the minima of illumination also alters progressively. The first minimum of illumination is highly pronounced, being almost perfectly dark. The second minimum of illumination is also conspicuous, indeed only slightly less so than the first. The third minimum of illumination is also quite pronounced, though much less so than the first or the second. The fourth minimum of illumination is clearly recognisable as such, while the fifth is only just noticeable.

Secondly, the manifestations of colour are very clearly related to the variations of luminosity in the field. What we may describe as a cycle of colours begins at each minimum of luminosity and ends at the next minimum, where a fresh cycle commences and proceeds to the next and so on. At least six such cycles are clearly recognisable, beyond which a few more can be glimpsed. The characters of the cycle of colours show a rapid change as we proceed from the first to the second and then to the third, the subsequent cycles resembling each other pretty closely. In the first three cycles, the yellow colour of the circle of maximum luminosity is evident, but in the later cycles it is not to be seen, and we observe instead a rapid change of colour from green to red. In the earlier cycles, the progression of colour is more gradual. At each minimum, we begin with a blue or bluish-green and pass on to the yellow, and then through orange to red at the next minimum where the cycle terminates.

Measurement of the white light patterns: The comparisons made above between the nature of the interferences as observed with white light and those seen with a monochromatic yellow are significant. Since the minima of luminosity are conspicuously visible, their positions can be determined accurately and compared with those of the minima observed with monochromatic light of various wavelengths. For this purpose, the apparatus is placed on the stage of a Hilger micrometer of the kind commonly used for the measurement of spectra and a slip of glass held at an angle of 45° is attached to it. A horizontal beam of light from the source of light employed is reflected downwards by this slip and the interference pattern is then seen by the reflected light coming back through the slip. The spiderlines in the field of view can then be set on the minima of illumination one after another, tangentially to the circles seen in the field of view. The observations are first made with a small brilliant tungsten-filament source, and they are then repeated using monochromatic light of different wavelengths. The green 5461 Å light of a mercury lamp, the yellow 5770–5790 Å light of a mercury lamp—in each case isolated by suitable colour filters—and the 5890–5896 Å orange-yellow of a sodium lamp are suitable for such comparisons. The measurements thus made show that the green line of mercury has a wavelength much less than the correct value, while the orange-yellow line of sodium has a wavelength definitely too large. On the other hand, the minima seen with the yellow lines of the mercury lamp agree excellently in their positions with all the minima of illumination observed with the tungsten lamp illumination. In other words, the minima of luminosity in the pattern observed with white light appear in the same positions as those produced with the yellow 579 mμ radiation of a mercury lamp.

The origin of the white light fringes: The foregoing observations establish that the wavelength 579 mμ has a special significance in relation to the visual perception of light and colour. The colour of light of that wavelength is a pure yellow; observations indicate that the yellow sector (in the spectrum of which the limits may be put as 560 and 600 mμ and) of which it is the centre which plays a dominant role in human vision. In those regions of the interference pattern where this sector is weak or absent, the other colours of the spectrum can make an appearance. The region of wavelengths between 500 and 560 mμ may be designated as the "green" sector, and the region between 600 and 700 mμ as the "red" sector. The observed distribution of colour in the interference pattern becomes intelligible when it is remarked that the light in the red sector and light in the green sector would manifest themselves with adequate intensity on *opposite* sides of the region where the yellow sector has the minimum intensity. *Per contra*, in the regions where the yellow sector has the maximum intensity, the red and green sectors would have a negligible effect.

The picture of the nature of human vision which emerges from the present investigations is thus radically different from that envisaged in the so-called trichromatic hypothesis which assigns to the "green" and "red" sensations major roles in vision and regards "yellow" as a secondary or derived sensation, thus assigning to it a minor position in the perception of light and colour. Actually, we find that it is the yellow sector of the spectrum which plays the major role in vision, while the green and the red sectors play relatively minor roles, serving to supplement and extend the range of human vision respectively towards lesser and greater wavelengths beyond those covered by the yellow sector.

Other methods of observations: The fundamental importance of the results set forth above indicates the desirability of enabling the colours of interference to be exhibited in a more vivid fashion than is possible with the usual form of Newton's rings apparatus. Indeed, there is no necessity for any special apparatus for observing the interference colours of thin films of air. If two square plates of ordinary glass, each about half a mm thick and 5 cm in length and breadth are carefully cleaned and pressed into contact, they may be caused to adhere firmly all along their edges, leaving enclosed between them a thin film of air of varying thickness due to the plates not being absolutely plane. This film exhibits brilliant colours by reflected light and they may be made more impressive by blackening the rear surface of one of the plates. The interference patterns thus obtained usually appear as a set of closed curves. The edges where the plates are in contact appear perfectly black. The fringes running parallel to the edges exhibit maxima and minima of luminosity and cycles of colour, these being completely similar to the effects observed with Newton's rings except that they are on a larger scale and are manifest to the unaided vision.

Very striking effects can also be obtained with thicker plate-glass of the kind used for covering large windows. The methods of manufacture of such glasses ensure both smoothness of surface and a reasonably uniform thickness. Nevertheless, the residual deviations from planeness are sufficient to enable beautiful exhibits of interference colours on a large scale to be prepared from them. For this purpose, small square or oblong strips, a few cm in length and breadth, should be cut out using a diamond and the cut edges ground and bevelled to remove the resulting strains. If two such strips are carefully cleaned and put together, beautiful interferences are obtained, the configuration of which may be altered by rotating the strips with respect to one another. Perfectly circular ring-patterns may be obtained, and also elliptic-ring patterns of various eccentricities but quite regular in shape. Putting the two plates together in a light frame of aluminium, they can be held together in an appropriate orientation so as to exhibit an interference pattern of the desired nature on a large scale (see figure 1 in plate I).

Another type of interference pattern may be obtained using two plates held together by metal clamps so as to be actually in contact all around their edges, so that the area enclosed by them shows interferences. In such cases, the interferences of zero order form a closed curve following the edges, while the interferences of higher orders are enclosed within the area. The number of closed curves seen is determined by the thickness of the air-film at the centre of the pattern (see figure 2 in plate I).

Another way of exhibiting interferences in a striking fashion is to use two disks of optical glass, one face of each plate being carefully worked as to make it as nearly plane as possible. If the two disks are held clamped together with these two faces adjacent, the pressure of the clamps being exerted near the end of one diameter, the wedge-shaped air-film then formed will exhibit a nearly straight series of fringes. The characteristic alternations of luminosity and the accompanying cycles of colour are very well shown by this arrangement (see figure 3 in plate I).

Explanation of Plate I

The pictures reproduced in Plate exhibit interference patterns obtained with the arrangements described above which were photographed using panchromatic plates.

Figures 1–3. **1.** Reproduces circular-rings similar to the familiar rings of Newton but on a much larger scale. The figure on the left was recorded with the light of a sodium lamp and that on the right with white light from a tungsten-filament lamp. **2.** Reproduces the interferences due to an air-film with zero thickness all round its edges and a maximum thickness at the centre. The photograph was recorded with white light. **3.** Shows the interferences of a wedge-shaped film recorded with white light.

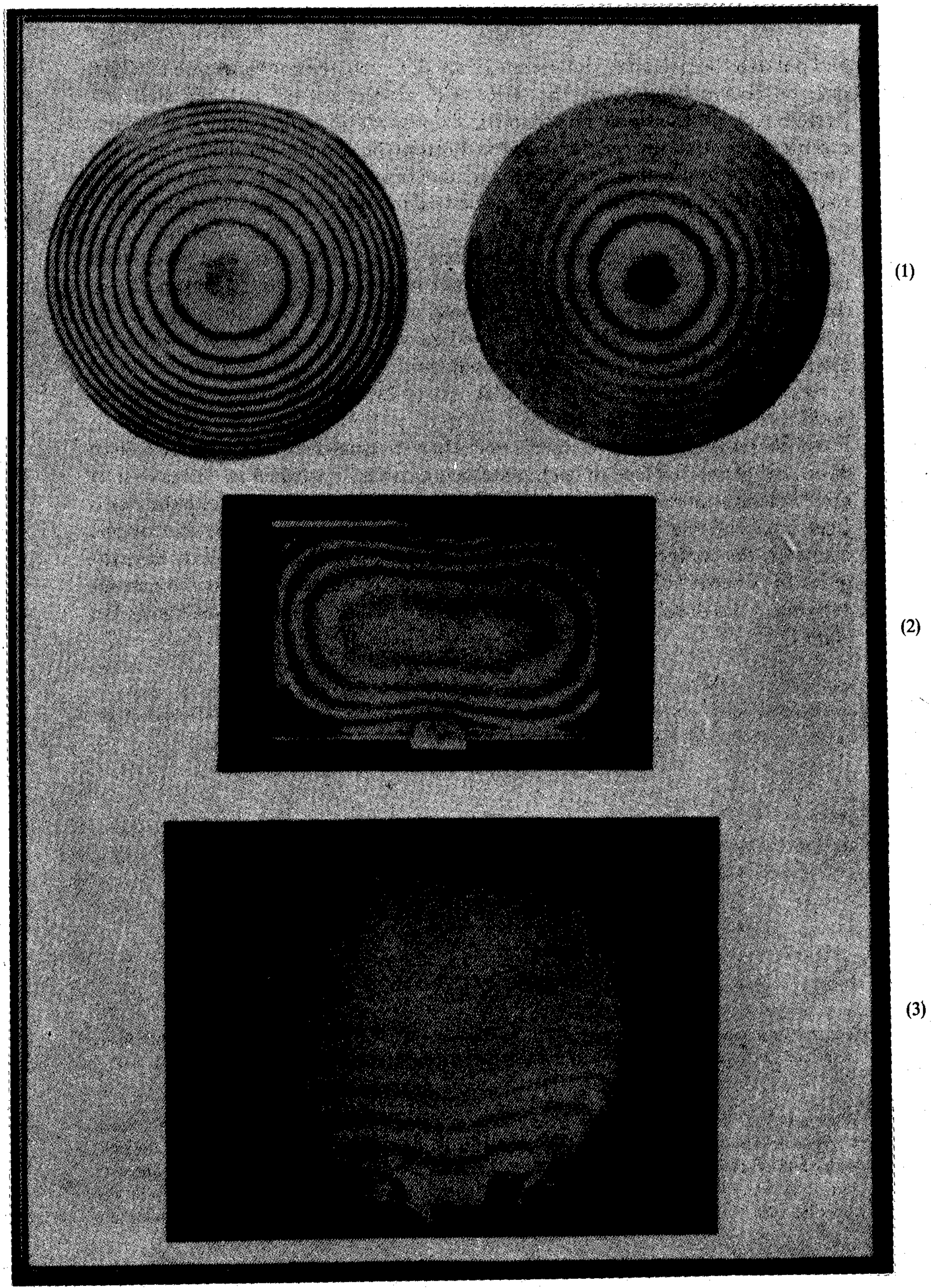

Figure 1–3
Plate I (see p. 363 for captions)