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The new physiology of vision—Chapter XXI. The green colour of vegetation

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In the present chapter and the following one, we shall concern ourselves with the products of the plant world which are available in great variety as materials for a study of the relationships between the sensory perception of colour and the spectral characteristics of the light which is perceived. The nature of these relationships has already been ascertained from the observations described in earlier chapters. But the illustrations of the same which are furnished by studies of floral colour are particularly striking and impressive.

The most familiar of all plant colours is the characteristic green colour of foliage. The immensely important role played by the green leaves of plants in photosynthetic activity is well-known. It is the absorption of light by the pigments present in the green leaves which enables them to play this role and it is the same pigments which determine the spectral character of the unabsorbed light emerging from the leaves on which depends their perceived colour. It is this relationship that invests the study of the colour of green leaves with special interest and importance.

Massed display of colour: We may appropriately begin with a reference to the circumstances which enable vegetation to display the colours with which we are all familiar. It is a characteristic feature of foliage that the two sides of each leaf present a different appearance, the difference in some cases being highly pronounced. One side of the leaf is smooth and exhibits vivid colour, while the other side has a rough surface and a dull colour. Invariably, however, the side which is smooth and vividly coloured is turned towards the light, thereby enabling the photosynthetic activity of the leaf to function. Further, the outermost leaves screen the interior of the plant or tree from observation. As the result, a mass of foliage from whatever direction it may be viewed exhibits the most brilliant display of colour which it is capable of. This feature of plant life contributes much to its attractiveness and explains why well-kept lawns, ivy-clad walls and trimmed hedges are much admired and extensively made use of around homes and in gardens. Indeed, the colour of vegetation is particularly impressive when seen from a distance where the individual leaves cannot be perceived. One may here recall the magnificent spectacle provided by a great stretch of rice-fields in deltaic areas. It is also worthy of mention that we can recognise even distant trees by the distinctive colour of their foliage.

The development of colour: A special feature of interest which calls for explanation is the changing colour of vegetation which accompanies the growth and development of the leaves to full maturity. This is particularly obvious in the case of trees which drop all their leaves at a particular season of the year and begin again with a fresh suit of leaves when the season is propitious for their appearance and growth. But the same phenomenon can also be observed when new leaves are put forth on the growing stems of plants and trees. In general, the new leaves exhibit a greenish-yellow hue and this later alters to green and then progressively to darker shades of green. In some cases, the early leaves show other colours, appearing pink or even red; but these hues soon give place to the colours normally exhibited by foliage. Some reference should also be made here to the colours exhibited by leaves when the time arrives for them to drop off from the tree. The change commonly observed is from a dark green to a bright golden-yellow. But there are cases in which the leaves put on a bright red hue before they fall off. The display of such vivid colours by the foliage of trees before the onset of winter is a regularly recurring event in the colder climates of the world.

Spectroscopic studies: Even the thinnest of leaves is opaque to light in the sense that it is not possible to view distant objects through it. This is a consequence of the scattering of light in its passage through the leaf. But sufficient light diffuses even through the thickest of leaves to permit of its spectral character being ascertained with the aid of a pocket spectroscope. For this purpose, the leaf may be held against the bright sky or if necessary in the path of a beam of sunlight, the slit of the instrument being placed close to the leaf so as to prevent entry of extraneous light. Alternatively, the smoother side of the leaf may be viewed through the spectroscope, the light being incident directly on the surface under observation and emerging from inside the leaf after internal diffusion. In this method of examination, it is necessary to hold the leaf and view its surface at such an angle that the glitter due to reflection at the smooth surface of the leaf does not appear and vitiate the observations.

Very interesting results emerge from a comparative study of the leaves in different stages of growth from the same tree. For example, the mature leaves of the Jack-fruit tree (*Artocarpus integrifolia*) exhibit a dark green colour, while the small tender leaves are greenish-yellow, and three or four intermediate stages can be recognised between these extremes. The comparisons are best made by viewing the surface of each such leaf under similar conditions of illumination through the spectroscope, the leaf being held to the light at such an angle that the glitter due to the reflection at the surface is avoided. It is then noticed that despite the enormous differences in the colour of the leaf in various cases, the spectral range covered by the light emerging from the leaf remains the same, viz., from 520 to 640 mμ, these limits being set by the strong absorptions of the carotenoids and the chlorophylls respectively. The brightness of the spectrum shows a progressive diminution as we pass from stage to stage in the development of the leaf. But this cannot possibly account for the remarkable changes in colour.

A feature noticeable in the spectrum of the light emerging from the thinnest leaf is a perceptible weakening of the yellow region as compared with the green and the orange on either side of it. This feature is more conspicuous in the spectra observed with the leaves in the later stages of development. With the thickest of the leaves which exhibits a dark green colour, this feature is highly pronounced and a dark band can be seen in the spectrum in the region where the yellow should have appeared. This band appears as a clear demarcation between the two parts of the spectrum on either side of it. From these observations, it is manifest that the extinction of the yellow part of the spectrum is a requisite for the dark green colour to be exhibited by the leaves. In other words, the progressive change of colour that accompanies the development of the leaves is produced by the enhanced absorption of the yellow region of the spectrum by the leaf pigment.

The absorption of the yellow by the leaf pigments covers the wavelength range between 570 and 586 mμ and appears between the green on one side and the orange and red of the spectrum on the other side. These colours may be observed in the spectrum when light falling on one side of the leaf and emerging on the other side of it is examined spectroscopically. They are equally well seen with the other method of observation described above. The green is definitely brighter than the orange and the red in all cases. But the difference is not great in the case of the thinnest leaves. The green gains in brightness relatively to the orange and the red as we proceed to the later stages of development of the leaf. But even in the case of the thickest leaves exhibiting a dark green colour, the orange and red regions continue to be observable and they are by no means of negligible brightness in comparison with the green. Since in these cases they make no perceivable contribution to the observed colour, we conclude that they are masked or prevented from being so observed by the more luminous green in the spectrum.

It is worthy of note that though these observations are as a matter of convenience best made using individual leaves, the same phenomena are also noticed when the spectroscope is directed by an observer towards any distant mass of foliage. Differences in the spectra of the same nature as those described above with individual leaves are noticeable in such cases as well.

Absorption spectra of the leaf pigments: Long ago, it was discovered by Sir George Stokes that the green pigment of leaves is a mixture of substances. Subsequent investigations have shown that the principal components are of two kinds, viz., the carotenoids and the chlorophylls. Here, we are only concerned with the absorption of light by the mixture of pigments. Both the carotenoids and the chlorophylls can be extracted from the green leaf by prolonged immersion in organic solvents, the most suitable and effective of them being acetone.

Placing the acetone extract of the leaf pigment in a flat glass cell, 2 cm thick, the colour as seen by transmitted light and its relation to the absorption spectrum of the solution can be readily ascertained. The colour can be seen by holding the cell against the sky or other extended source of light. To ascertain the nature of the absorption spectrum, the observer can hold the cell before his eyes together with a replica diffraction grating and view the first-order diffraction spectrum of the linear source of light provided by a tubular lamp with a straight tungsten filament stretched along its axis. Alternatively, the absorption spectrum can be viewed through a pocket spectroscope, and the positions of the absorption bands may be read on the wavelength scale provided in the eye-piece of the instrument.

A striking demonstration of colour changes entirely analogous to those exhibited by the leaves of plants in the course of their growth and development is possible with the acetone extracts of the leaf pigments. The glass cell is filled to about a third of its depth with acetone and then the acetone extract of the leaf pigments (which is itself of a deep green colour) is added a little at the time. The acetone in the cell first turns yellow in colour. Further additions alter the yellow to a greenish-yellow and then progressively to a clear green. These changes correspond to the alterations in the character of the absorption spectrum of the solution. A cut-off of the red beyond 640 mμ appears at the very outset, and this is soon followed by the total extinction of the blue up to 500 mμ. But not until the band of absorption in the yellow between 570 and 586 mμ appears and is fully developed does the solution exhibit a full green colour.

Some finer details observed with the green leaves themselves correspond to the features noticed in the absorption spectra of the leaf extracts. Particular mention may be made of the two *bright* bands noticed in the spectrum of the leaves, one in the green between 550 and 570 mμ and the other in the orange between 586 and 613 mμ. These bands are also noticeable in the spectrum of the transmitted light of the leaf-extracts.