Proc. Indian Acad. Sci. **A62** 125–132 (1965)

The new physiology of vision—Chapter XXII. The colours of flowers

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Received July 12, 1965

It is appropriate that we commence this chapter by giving some indication of the magnitude of Nature's creative work as also of man's efforts to improve upon Nature in the production of floral colours. The best known of all flowers is the rose. No less than 421 names varieties of that flower are portrayed in full colour in the *Encyclopaedia of Roses* (Blandford Press, London) which the enterprise of the publishers has made available to rose-lovers. It is no exaggeration to state that the varieties of rose developed of recent years and pictured in that book exhibit a surpassing loveliness of form and colour. Useful service has also been rendered by the Oxford University Press by the publication of their two books on Wild Flowers and Garden Flowers respectively. 887 species are described in the first book and 635 species in the second, accompanied in each case by 191 full-page plates in colour. Finally, mention may also be made of the volume entitled *Some Beautiful Indian Trees* published by the Bombay Natural History Society, describing and illustrating in colour the spectacular beauty of several of India's best-known flowering trees.

From the publications referred to above, it is evident that the colours exhibited by flowers are many and of varied nature. What we are concerned with here is the role played by human vision in the synthesis of the spectral components of the light diffused by the petals of flowers which gives rise to the colour sensation actually perceived. In many cases there is no obvious relationship or resemblance between the sensation that is actually perceived and the physical characters of the light which reaches the eyes of an observer. This situation reveals itself when the observer proceeds to study the colours of flowers with the aid of a direct-vision spectroscope. A wavelength scale in the eye piece of the instrument is extremely helpful for fixing the location of the observed features in the spectra.

The technique for a study of the kind indicated above is essentially the same as that explained in the preceding chapter on the green colour of vegetation. As in the case of foliage, the petals of flowers often exhibit a difference in the appearance of their two faces. The face that exhibits the more vivid colour is held and viewed in diffuse light of sufficient brightness to permit of the examination of the spectral character of the light that enters the petal and emerges again after internal diffusion. In the case of flowers there is usually no observable reflection of light by their petals which could interfere with the observations. But if such a reflection is noticeable in any case, it can be avoided by holding the petal at the proper angle to the light. The petal under observation has to be held at some little distance from the slit of the spectroscope which is directed towards it. It has, therefore, to be of adequate size and the observations are therefore made most easily with flowers having fairly large petals. However, even when the petals are small, if they are grouped together side by side in the flower, the spectroscope can be directed towards the aggregate, this being held facing the light at an appropriate distance from the instrument. Satisfactory observations are then possible.

There is an alternative procedure which can be adopted in all cases and is often found useful. The petal is held up against the light and close to the slit of the spectroscope, and the light that penetrates through it is viewed through the instrument. This is possible since in all cases, the flower petals are sufficiently thin to allow light to come through, though there is no regular transmission. A comparison between the characters of the spectra as observed with the two procedures is instructive. In many cases, there are differences in brightness and also noticeable differences in the spectral characters. These may arise in two different ways. Firstly, there is a difference in the absorption paths which are effective in the two cases. Secondly, in the observation of the light which has passed through the petal, both of its faces are effective in absorption and if there is any difference in the nature of the absorbing material present on the two sides, this would manifest itself in the spectrum of the light which emerges.

The fact that impresses itself forcibly on an observer who has made an extensive study of the material in the manner described above is the extremely important role played by the yellow sector of the spectrum, in other words, by the light included in the wavelength range from 560 to 600 mμ—in determining the perceived colours of flowers. In the preceding chapter, we have noticed that the foliage of plants does not exhibit its proper green colour unless the yellow of the spectrum has been more or less completely absorbed within the material of the leaves. The same phenomenon is even more conspicuously noticeable in respect of other colours. Indeed, it may be said that the presence or absence of the yellow sector in the light emerging from the petals of a flower makes all the difference in the colour which is perceived. No flower can exhibit a blue colour even feebly unless the yellow sector has been weakened by absorption and its place taken by a dark band crossing the spectrum. A vivid blue colour demands a complete extinction of the yellow sector and in addition a reduction in the intensity of the longer wavelengths in the spectrum. The removal of the yellow sector alone from the spectrum by absorption results in the colour of the flower being perceived as purple. But this may be modified so as more to resemble a red or a blue, if the red or the blue is stronger in relative intensity than in normally the case. Likewise, no flower can exhibit a proper red colour unless the yellow in its spectrum has been completely extinguished.

Classification of floral colours: The facts of observation set forth above suggest a basis for a classification of the whole range of observed floral colours. We proceed by specifying the part or parts of the spectrum in which the absorption by the pigments present in the flower-petals is effective. For this purpose, the spectrum is divided into four sectors, in the following order, viz., the blue, the green, the yellow and the red sectors, and their wavelength ranges are set respectively as from 400 to 500 mμ, from 500 to 560 mμ, from 560 to 600 mμ and from 600 to 700 mμ. It is possible, of course, that the absorption actually exercised in any of these sectors may be only partial, and that it may not extend over the whole of the sector. However, for developing a scheme of classification, the actual situation may be idealised by making the assumption that there is either no absorption, or else a complete absorption of any particular sector. Considering these two alternatives and combining them for the four sectors, we have in all 16 different possibilities which may be listed by writing down 1 as the symbol for complete transmission and 0 as the symbol for complete absorption of each of the four sectors. Thus the list would commence from (1111) which would be the symbol for a white flower and end with (0000) which would indicate a flower which is totally black. When the absorption of a particular sector in the spectrum is only partial, the case may be fitted into the general scheme by placing it in the category which it most nearly resembles and indicating the extent to which the observed colour differs from that noticeable in the ideal case.

We may illustrate the scheme of classification suggested above by some actual examples. Yellow is a colour very commonly exhibited by flowers. Amongst flowering trees, the Indian laburnum (*Cassia fistula*) may be mentioned and also the well-known Copper Pod (*Peltophorum ferrugineum*), both of which are magnificent spectacles when in flower. Amongst garden flowers we may single out for special mention the gorgeous *Allamanda cathartica* which has huge bell-shaped waxy-yellow flowers which bloom all the year round. Spectroscopic examination reveals a complete extinction of the blue sector of the spectrum by its flowers, while the green, yellow and red sectors appear in full strength. Accordingly, this flower (and yellow flowers generally) would fall under the classification (0111).

Perhaps the most familiar example of orange-hued flowers in India is furnished by the magnificent sprays of flowers with which the climbing shrub *Bignonia venusta* covers the walls or screens over which it is allowed to grow up. The well-known aloe-wood tree *Cordia sebestena* also bears clusters of brilliant bell-like flowers of orange hue verging towards scarlet. Spectroscopic examination reveals a cut-off of the blue and green sectors of the spectrum while the yellow and red sectors are in full strength. Accordingly, orange flowers appear in the classification under the symbol (0011).

Amongst red flowers, one of the best known is the China Rose (*Hibiscus rosa sinensis*) which has large single bell-shaped blooms from which long bunches of stamens hang out. The petals exhibit a rich red hue. Spectroscopic examination shows a complete extinction of the blue, green and yellow sectors in the spectrum, the red sector commencing from 600 mμ being in full strength. Accordingly, red flowers may be classified as (0001).

If the absorption extends also into the red sector and covers wavelengths greater than 600 mμ, the colour of the flower would change from a bright red to a dark red or crimson and finally black. It would then belong to the category (0000). Such flowers could be regarded as intermediates between the categories (0001) and (0000). Likewise, those flowers in which the blue sector is absorbed in part while the green, yellow and red sectors are in full strength would exhibit a pale yellow colour. Such flowers may be regarded as intermediates between the categories (1111) and (0111). It is evident from what has been stated that the five categories (1111), (0111), (0011), (0001) and (0000) together with their intermediates would form a regular colour sequence in which a great many flowers would find a place.

Having dealt with the cases in which the blue sector of the spectrum is totally absent, we turn our attention to those in which the blue sector is present in full strength. There are eight categories of this kind which form two subgroups of four each, viz., (1111), (1110), (1100), (1000) and (1001), (1101), (1011), (1010).

Two items in the second subgroup are of particular interest, viz., (1101) in which the yellow sector alone is absent and (1011) in which the green sector alone is absent, while all the other sectors are present in full strength. As has already been stated, the absence of the yellow sector alone would result in a purple sensation, while the absence of the green sector alone would result in the perception of a bright rose-red hue. Remarkably enough, illustrations of both of these categories are furnished by the flowers of two distinct varieties of *Lagerstroemia flos reginae*, which is one of the most spectacular of Indian flowering trees. Its flowers appear in the months of April and May and are borne in great profusion from the ends of branches in large erect sprays. The tree is one mass of flower when it is in bloom. The petals of the flowers are six or seven in number and quite thin and crinkly, but they are nevertheless very colourful. Spectroscopic examination reveals a nearly complete extinction of the yellow sector in the case of the purple flowers, and of the green sector in the case of the rose-red flowers.

Blue flowers and their spectra: We may now usefully consider the class of colours represented by the symbols (1111), (1110), (1100), (1000) and (0000) together with their intermediates. These colours would be perceived if an absorption which commences at the long-wave end advances through the spectrum towards shorter wavelengths, covering up in succession the red, orange, yellow, green and then the blue, indigo and violet. The observed result would begin as white and end up as black. It is the step from (1110) to (1100), in other words, the extinction of the yellow sector of the spectrum which would be particularly significant, for a change of the perceived colour from white to blue would occur at this stage. The preceding step, viz., the extinction of the red sector is, however, also important. For, the extinction of the yellow sector alone would give a purple sensation and not a blue.

All blue flowers exhibit in their spectra an absorption of the yellow sector. The more complete such absorption is, the more striking is the sensation of blue which results from its absence. In addition to the absorption of the yellow sector, the spectra of blue flowers also exhibit an absorption in the range of greater wavelengths. An absorption of the orange in the wavelength range between 600 and 630 mμ is particularly effective in this respect. This is to be expected, since the luminosity of the spectrum falls off rapidly at still greater wavelengths.

To illustrate how the perceived colour which arises from an absorption of the yellow and adjoining regions of the spectrum varies with the strength of such absorption, the flowers of the Morning Glory (*Ipomea learii*) and of the Heavenly Blue (*Thunbergia grandiflora*) may be compared with each other. Both are climbing plants which are great favourites as they produce large and showy flowers in striking colour contrast with the green foliage. The Morning Glory exhibits a saturated blue colour, whereas the Heavenly Blue presents a hue which is somewhat different and much less saturated. The spectra of the two flowers are strikingly different. The spectrum of the Morning Glory exhibits the entire visible spectrum from violet to red in full strength except in the wavelength range between 570 and 630 mμ which is strongly absorbed. The Heavenly Blue, on the other hand, exhibits rather weakly an absorption of the yellow between 570 and 590 mμ and also an absorption in the red around 630 mμ. But the orange of the spectrum is not absorbed and is seen as a bright band with darker regions on either side. A dimming of intensity is also noticeable in the spectrum around 540 mμ in the green sector. It is worthy of remark that a spectrum very similar to that of *Thunbergia grandiflora* is exhibited by the flowers of *Jacaranda mimosifolia*, which is a spectacular tree bearing during the months of March to May an immense canopy of flowers and buds of a beautiful blue-violet colour.

Bougainvilleas: We shall now proceed to consider some individual cases presenting features of special interest. The Bougainvilleas form one of the most conspicuous and colourful features in Eastern gardens. They are very ornamental, grow vigorously in any soil with very little attention and can be adapted to various purposes. There are several natural varieties and numerous others have also been developed by horticulturists which present attractive colours. What appear to be its blooms are really the trios of brightly-coloured bracts which surround the true flowers.

One of the familiar varieties known as *B. rosa catallina* has very large rose-coloured bracts. Spectroscopic examination shows it to belong to category (1011), the green being strongly absorbed. There are also numerous varieties which exhibit different shades of purple. One may recognise amongst them a typical purple belonging to the category (1101) in which the yellow sector is absent while the green is present in fair strength. Other varieties may be described as exhibiting a rose-purple colour and can be classed as intermediates between the categories (1011) and (1101). It is also possible to regard them as approximating to the category (1001) in which both the green and the yellow sectors have been extinguished by absorption. The varieties exhibiting a red colour show a complete extinction of the yellow sector which adjoins the red. But the spectroscope reveals that the green and the blue sectors are also present though with relatively low intensities.

The aster and its varied colours: The aster is well-known everywhere as one of the most showy of flowering shrubs. Each individual flower with its large feathery head and a gaily-coloured centre makes a most attractive picture. The asters commercially grown at Bangalore and exhibiting marked colour fall into two distinct classes. In each class one observes a progression of colour. In Class A the colour observed ranges from a bluish-purple to a deep violet. In Class B the colour observed ranges from a pale pink to a bright rose-red. A casual observer looking at the flowers might imagine that the asters of Class A absorb the longer wavelengths in the spectrum and therefore appear blue or violet, while the asters of the Class B absorb the shorter wavelengths and therefore appear red. Nothing could be further from the truth.

Spectroscopic examination reveals that the two classes are totally different in the nature of absorption which give rise to the perceived colours. The spectra in each class exhibit certain common features but there is a progressive change in the strength or intensity of the observed spectral features. The perceived colours of the asters in Class A have their origin in a readily observable extinction of the yellow sector in the spectrum. The absorption exhibits a well-defined edge at about 600 mμ, longer wavelengths having their normal intensities, while the absorption in the region of shorter wavelengths fall off progressively and becomes insensible at about 560 mμ. This absorption is moderately strong for the asters which appear purple-blue, quite strong for the asters which appear purple-violet and is total for those which appear of a violet colour. Apart from the strong absorption in the yellow, there are also indications of a minor absorption at 650 mμ which results in the red sector of the spectrum appearing bifurcated. This is a feature which is just noticeable in the purple-blue asters. But it is more clearly seen in the spectra of the asters of a deeper colour, viz., those which appear of a violet hue.

The asters in Class B show a spectrum in which the violet, blue, yellow, orange and red sectors in the spectrum appear with their usual intensities, while in the green sector, there is a sensible weakening, especially between 530 and 560 mμ, the maximum of absorption appearing at about 545 mμ. This absorption is noticeable with the pink asters; it is quite strong with those which appear as bright pink, and nearly complete with the rose-red asters. It is evident from these facts of observation that the asters of Class A fall in the colour category (1101) and the asters of Class B in the category (1011).