Curr. Sci. **33** 97–101 (1964)

The visual synthesis of colour

SIR C V RAMAN

1. Introduction

Our visual organs possess in a high degree the faculty of distinguishing between the colours exhibited by the spectral components into which polychromatic radiation has been resolved by a dispersing apparatus such as a prism or a diffraction grating. On the other hand, without the aid of such apparatus, our eyes fail to recognise the presence of distinct spectral components in composite radiation. What they do perceive is the resultant sensation excited by it which is also (rather loosely) termed as the colour of the light. The number of such composite colours which can be distinguished from each other in appropriate circumstances is enormously larger than the number of monochromatic radiations which can be recognised as different in colour in a perfectly resolved spectrum. This is not surprising, since the nature of the polychromatic radiation, in other words, the distribution of energy in its spectrum admits of an infinite number of possible variations.

A knowledge of the relationship between the spectral nature of composite light and the character of the visual sensation which it excites is of great technical importance in various arts and industries. But it is no less important in relation to our understanding of the basic aspects of the physiology of vision. The only procedure for obtaining such knowledge which is not biased or invalidated by the prior acceptance of *ad hoc* hypotheses and can therefore be trusted to lead us to the real truth of the matter is the study of the relationship which actually exists between colour and spectral composition in a very large number of actual cases and the deduction from the results of such study of general principles which are found to be valid in all cases. These considerations led the present writer to undertake the systematic examination of floral colours in relation to their spectral composition. The results of the investigation of numerous individual cases were described and the inferences to which they pointed were set down in a recently published memoir by the author.[1] Since then, many more examples have been studied and satisfactory spectrograms illustrating the observed relationships in various cases have been recorded. The investigation has

1. "Floral Colours and the Physiology of Vision." Memoir No. 137 of the Raman Research Institute, *Proc. Indian Acad. Sci.* **A58**, 57, 1963.

also been extended to other classes of objects exhibiting colour, viz., gemstones (both natural and synthetic) and various technical products including especially dyed textiles. The results emerging from all these studies are in complete agreement with each other, as also with the conclusions arrived at in the memoir cited above. They make it evident that the geometric representations of the results of colour synthesis which have found favour for over a century, viz., the Maxwellian colour-triangle and the more recently adopted XYZ system, are based on a totally misconceived ideology and that the results indicated by these diagrammatic representations of colour are contradicted by the facts of observation.

2. The African violet and other flowers

The spectral composition of the colours of some hundreds of different floral species and varieties have been examined by the author. Amongst those more recently studied, three examples have been chosen as meriting special description in the columns of *Current Science*. The first example is that of the flowers of the plant known botanically as *Saintpaulia ionantha*, and more popularly as the African or Usambara violet. It is a small herbaceous perennial plant of great beauty which is almost stemless with a rosette of long stalked hairy leaves. The flowers are coloured deep purplish violet and resemble violets in shape though in size they are much larger (*see* figure 1). Throughout the year, the plant flowers freely. The second example belongs to the very interesting class of plants known as the Iris which bear curiously constructed flowers of attractive and gorgeous

Figure 1. Leaves and flowers of the African violet.

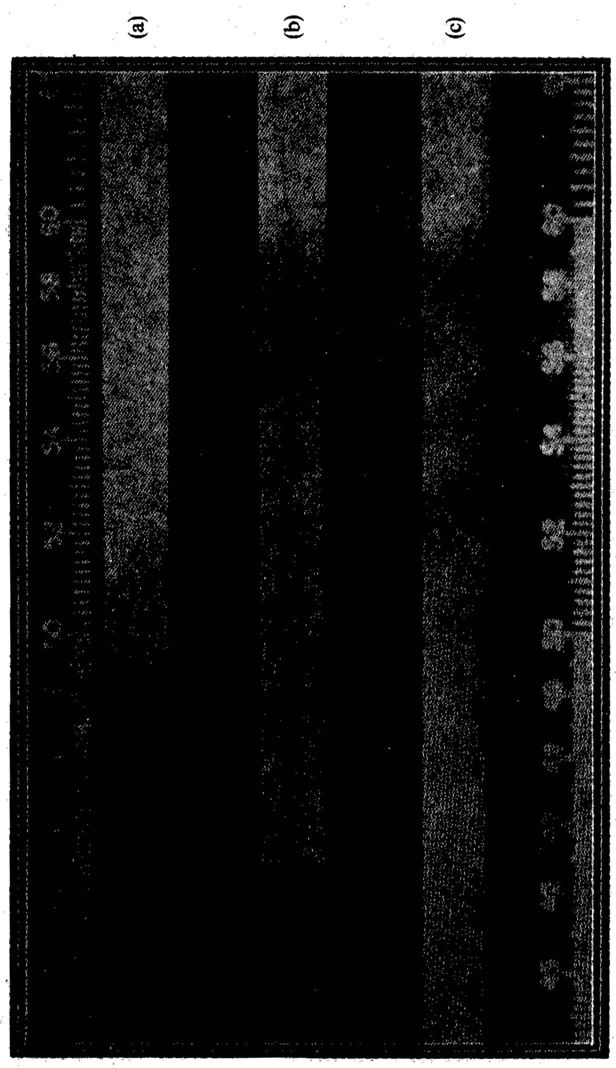

Figure 2. Spectrum of the African violet. (b) by transmission; (c) by reflection.

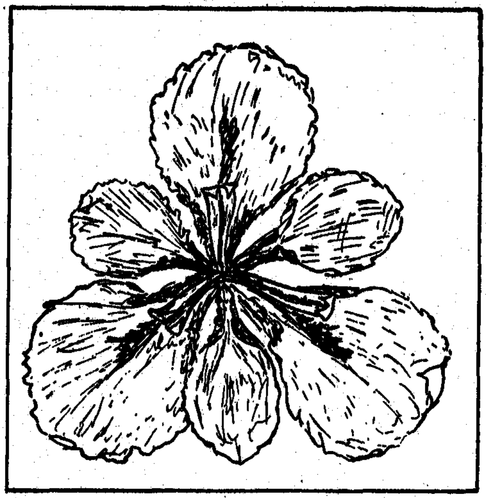

Figure 3. Petals of the Iris flower, spread flat.

colours. The particular plant whose flowers have been examined is *Iris germonica* which has sword-like leaves and bears flowers on erect stalks. They have a beautiful purplish-blue colour, a drawing of one such flower spread out flat on a sheet being reproduced as figure 3. The third example studied is a ground orchid which bears flowers on long spikes which may be 2 to 3 feet long. A group of such flowers appearing at the end of a stalk is illustrated in figure 5. The plant has been identified from the published descriptions and illustrations as the orchid *Spathoglottis plicata.* The most attractive of its varieties is one which bears flowers having a colour which may be described as a purplish-red. Spectrograms obtained with these three flowers are reproduced as figures 2, 4 and 6 respectively. We shall proceed to describe the features exhibited in these spectrograms and comment on their significance in relation to the theory of colour perception and the visual synthesis of colour, the latter being the special subject of the present communication.

3. The spectroscopic observations

The spectral composition of the colours of flowers may be studied either by transmission through their petals or by reflection at their surfaces. In the case of the African violet, the upper and lower surfaces of the petals present a slightly different appearance, the upper being of a deeper and more saturated violet hue. The colour as seen by reflection at the upper surface is likewise deeper and of a more saturated hue than that seen by transmission. The most striking feature observed in the spectrum of either the transmitted or the reflected light is an

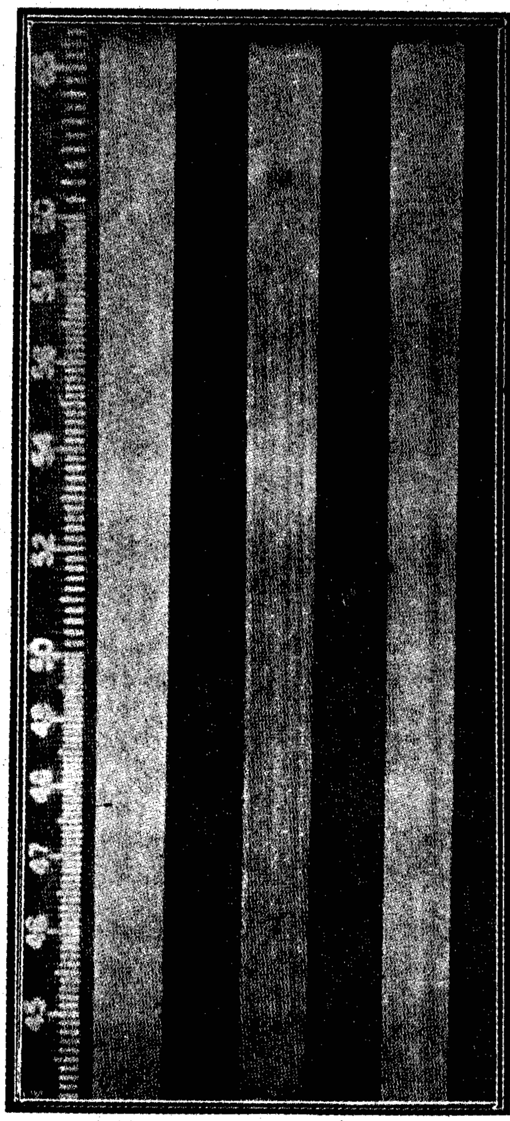

Figure 4. Spectrum of the Iris. (b) by transmission; (c) by reflection.

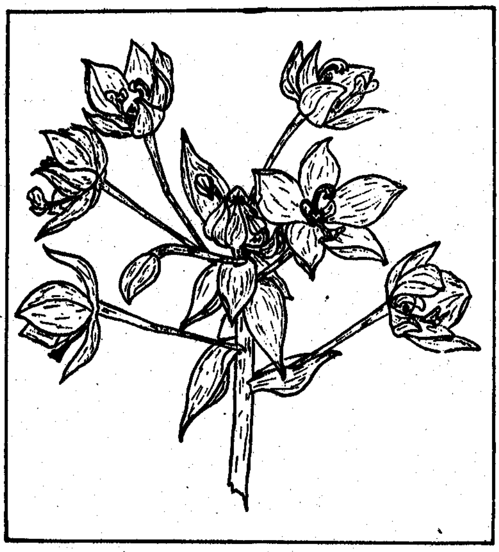

Figure 5. Bunch of flowers of the orchid.

intense absorption in the yellow region of the spectrum. This covers the region between 560 and 590 mμ and is very clearly exhibited in the two spectrograms reproduced as figure 2(b) and (c) respectively. Figure 2(a) is a comparison spectrum of the light source employed, viz., a tungsten-filament lamp. Remarkably enough, the red of the spectrum is conspicuous both in the transmitted and in the reflected light. It is evident, however, that considered in relation to the rest of the spectrum and especially the blue and violet, it has suffered a weakening. Further, it is noticed visually that in the spectrum of the reflected light, the red of the spectrum is split into two parts by a darker region located at 640 mμ. The spectrum also reveals a weak absorption in the green located at about 530 mμ. But these are relatively minor features. As is clear from the reproduced spectra, the major feature is the suppression of the relatively narrow yellow sector of the spectrum.

As stated earlier, the petals of the Iris exhibit a beautiful purplish-blue colour. The spectra of the light transmitted and reflected by its petals are reproduced in figure 4(b) and (c) respectively, figure 4(a) being the comparison spectrum of the light source. It will be noticed that the spectra exhibit an absorption in the yellow sector between 560 and 580 mμ, but this is not so strong as in the case of the African violet.

The spectrum of the light transmitted by the petals of the orchid *Spathoglottis plicata* is reproduced in figure 6(b), alongside of the comparison spectrum of the light source, figure 6(a).

Two strong absorption bands are noticed, one between 580 and 590 mμ in the

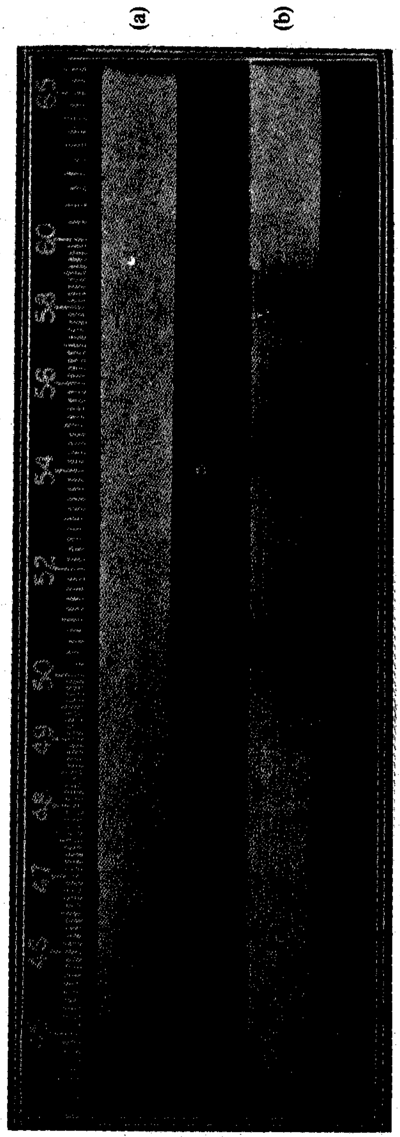

Figure 6. Transmission spectrum of the orchid with comparison spectrum.

yellow sector and another between 540 and 550 mμ in the greenish-yellow part of the spectrum. A third and much weaker absorption is also noticed at 510 mμ, but the rest of the green between 510 and 540 mμ is transmitted freely. Neither the violet and blue sectors between 400 and 500 mμ nor the red sector show any noticeable weakening or extinction.

4. The significance of the results

We may sum up the foregoing by the statement that the absorption of the yellow is the major common feature in the spectra of the flowers in all the three cases, and that the large differences in their observed colours arise from certain relatively minor differences in the character of their spectra.

The highly important role played by the yellow region of the spectrum in determining the observed colour of composite light by reason of its presence or of its absence as the case may be, emerged very clearly from the studies described in the author's memoir on floral colours cited earlier. It was there shown that the removal of the yellow from the spectrum, other parts of the latter remaining the same, results in the observed sensation being the colour familiarly known as *purple*. Numerous illustrations of this fact were noted in the study of floral colours. The same result is demonstrated in a very striking fashion by technical products of various sorts, as for example, by silks which have been dyed a purple colour. In the author's collection of doctor's gowns acquired at various times, there are three examples of this, which may be referred to respectively as Calcutta-1922, Glasgow-1930 and Delhi-1964. The Calcutta gown is made entirely of purple silk. The Glasgow gown is of wool dyed scarlet, but it has purple silk facings and the hood is also lined with purple silk. The Delhi gown is of scarlet-coloured silk, but the cap is of purple velvet with edgings and an inside lining of purple silk. The three examples of purple silk exhibit three different shades of colour. But the spectral composition of the colour is essentially the same in all three cases, viz., a complete or nearly complete extinction of the yellow sector of the spectrum in the 560 to 590 mμ region, while the violet, blue, green and red sectors of the spectrum are present with their normal relative intensities as visually observed.

In the Maxwellian colour triangle, as also in the well-known XYZ representation of the results of colour synthesis, the purples appear on a straight line joining the two extremities of the spectrum, viz., red and violet. The purples appear in the diagram opposite to the bend in the curve representing the green part of the spectrum extending from 500 to 550 mμ, the purple and the green being complementary colours. In other words, the diagram contemplates that the purple sensation results from the removal of the green from the spectrum. Actually, as we have seen, the purple sensation results from the yellow sector of the spectrum being removed, and it is experienced in a fully saturated form even though the green part of the spectrum is present in full strength. Then, again, as has already been set out in the author's monograph, there are numerous flowers in which the green part of the spectrum is partly or wholly extinguished by absorption, while the rest of the spectrum is not weakened or absorbed. In all such cases, the colour exhibited is *not a purple*, but is a colour which ranges from a pale to a deep rose-red depending on the degree of completeness of the extinction of the green sector.

Thus, quite apart from any question of theory or logic, the actual facts of experience show that the ideology on which the Maxwellian colour-triangle and its more recent modifications are based is false and totally misconceived.