# FLORAL COLOURS AND THEIR SPECTRAL COMPOSITION

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## 1. Introduction

THE leaves and flowers of plants are the most familiar objects manifesting colour met with in the organic world. It follows that the nature and origin of these colours is well worth a detailed study. The chemical constitution of the pigments present in plant products and capable of extraction therefrom by suitable solvents has been the subject of numerous investigations in the past. But there is another point of view from which the subject can be regarded. The colours exhibited by the leaves and flowers of plants are determined by the spectroscopic behaviour of the material *in vivo*, and this can be studied by quite simple methods. We have only to observe the changes in the spectral character of the light produced by its entry into the material and subsequent emergence from it, as a result of absorption and diffusion within the substance. The observation of these changes may be expected to throw some light on the nature of the material. Further, it should be remarked that the relationship between the spectral character of the emerging light and the observed colour of the leaves or flowers is of great interest from the standpoint of physiological optics.

The present communication is in the nature of a preliminary survey of the subject. It will be seen, however, that some highly significant results have emerged from it.

## 2. Origin of the Green Colour of Leaves

The most familiar of all plant colours is the characteristic green hue exhibited by the foliage of the great majority of trees, shrubs and other forms of vegetation. We shall therefore begin by considering the question how this colour originates. A very simple technique suffices to furnish the necessary information. We hold the leaf in a beam of sunlight and examine the light which emerges from it through a pocket-spectroscope of the direct-vision type. The instrument should be provided with a wavelength scale capable of being focused independently and also capable of being adjusted so that the wavelength readings check with those of the lines in the solar spectrum.

It is well known that the foliage of different species of plants is often noticeably different in colour. Further, fresh leaves which have just emerged and have not yet attained maturity often exhibit tints different from those of fully developed leaves of the same species. We are, however, here concerned with the features exhibited by green leaves in general. Hence, it is convenient to make observations with plants in which the colour of the leaves is a clear green at all stages of development and exhibits only the changes accompanying the increased thickness due to growth.

The spectrum of the light which emerges from the rear of a green leaf on the front face of which sunlight is incident may be divided into three parts: (*a*) the first between 400 m$\mu$ and 520 m$\mu$, (*b*) the second from 520 m$\mu$ to 640 m$\mu$ and (*c*) the third from 640 m$\mu$ to 700 m$\mu$. The transmission in the violet and blue regions of the spectrum becomes very weak with increasing thickness of the leaf, and the wavelengths less than 520 m$\mu$ are then effectively cut off. On the other hand, the region between 640 m$\mu$ and the extreme red end of the spectrum is itself intrinsically very weak to our perceptions. However, when the leaf is not very thick and it is held up in sunlight, this part of the spectrum can be seen coming through weakly, and the absorption bands due to chlorophyll in the (*a*) and (*b*) forms can be recognised in it. It is evident, however, that these bands appearing in a region of very low luminosity cannot influence the observed colour of the emerging light to any appreciable extent. We have, in fact, to consider only the spectral region between 520 m$\mu$ and 640 m$\mu$ covering the green, yellow and orange sectors and the brightest part of the red in the determination of the resultant effect.

A comparison of the light emerging through a green leaf and that which has passed through the petals of a flower having a golden-yellow colour is very instructive. Flowers of the latter variety are very numerous, and it does not much matter which particular one is chosen for the comparison. The brightness of the light emerging from the petal may, if necessary, be reduced by holding two of them together, so that the intensities observable in the spectrum of the flower may be comparable with those in the light transmitted by the green leaf under study. It will be found that the extension of the spectrum observable in the two cases is not appreciably different, being between 520 m$\mu$ and

640 mμ for the green leaf, and between 520 mμ and 650 mμ for the golden-yellow flower petal. It is evident that the slightly greater extension towards the red end observed in the spectrum of the flower petals cannot account for the enormous difference in colour between a golden yellow and a bright green. Indeed, the similarity of the two spectra is a most surprising and unexpected feature. Careful examination, however, reveals that the spectrum of the green leaf shows a low intensity in the spectral region between 560 mμ and 620 mμ as compared with the intensity in the same region of the yellow flower petals. It is clear from these observations that it is the absorption in the yellow and orange sectors of the spectrum and not the absorption in the red sector which is the operative factor resulting in the green colour of the leaves. The absorption by the two forms of chlorophyll in the wavelength range under reference, *viz.*, between 560 mμ and 620 mμ is weak compared with the principal absorptions by them appearing in the red sector of the spectrum. But it is nevertheless the former and not the latter that results in our perceiving the characteristic green colour of the foliage of plants.

### 3. The Spectrum of the "Morning Glory"

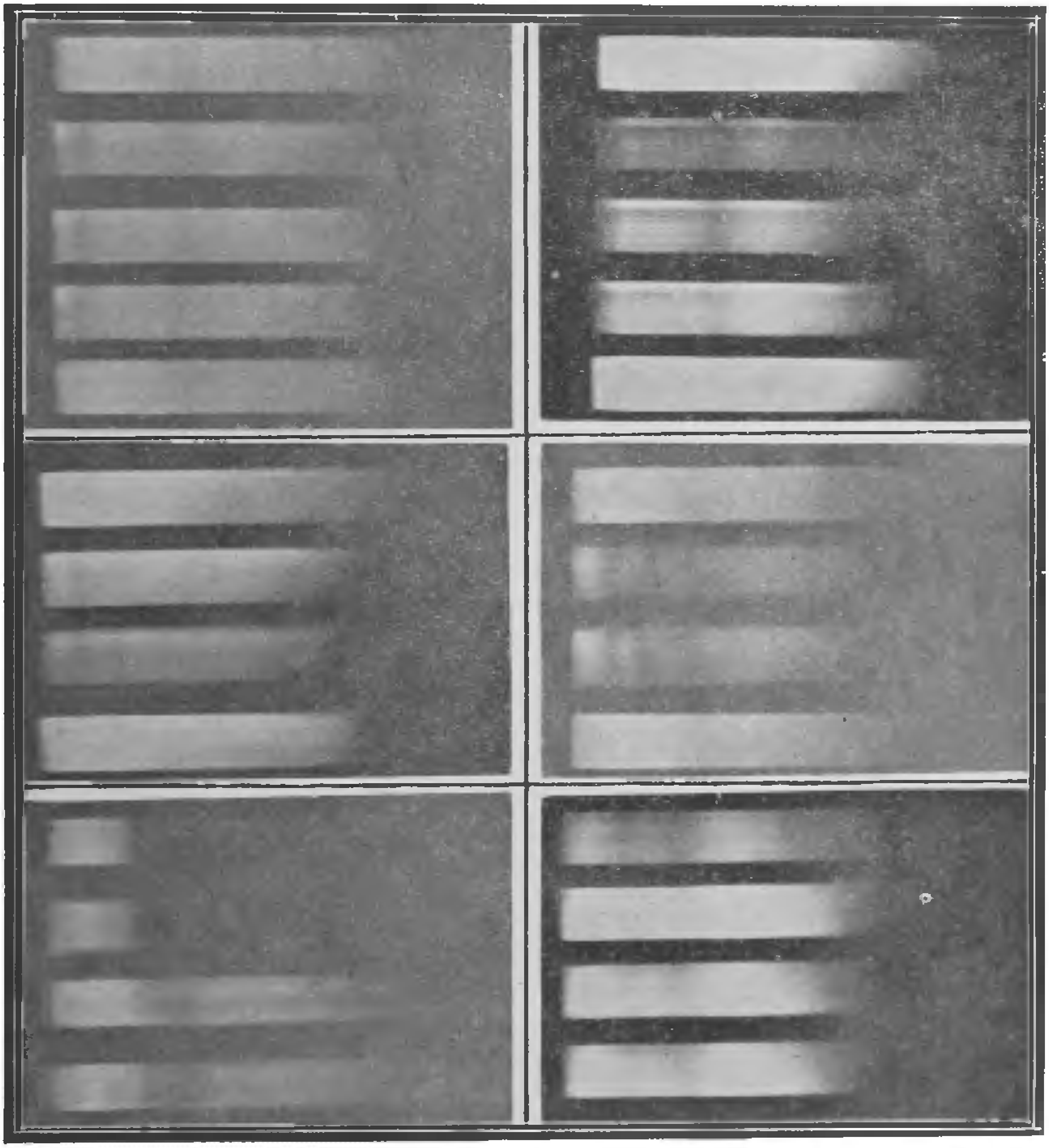
We shall next consider the remarkably interesting case of the flower known popularly as the "Morning Glory", the botanical name of the plant being "*Ipomea learii*". This plant is a creeper which when trained over a screen presents a magnificent sight in the early mornings with its green foliage studded over with large trumpet-shaped flowers of a deep blue colour. These show five divisions exhibiting the blue colour which are held together by narrow ribs of a purplish tint. The colour of the flowers is a highly saturated blue and may indeed be described as exhibiting spectral purity. It is distinctly more so when seen from the front by reflected light than as observed from the rear by transmitted light. That this difference is due to the extreme thinness of the petals is clear from the fact that when two of them are held together and the absorption path thereby doubled, the colour as seen by transmission is more highly saturated.

The spectrum of the "Morning Glory" may be observed either by the light reflected or by the light transmitted by the flower. In either case the entire spectrum extending from the extreme violet to the extreme red may be seen without any noticeable change in the relative intensities of its different parts as compared with the light reflected by a white sheet of paper, *except in the wavelength range between 570 mμ and 630 mμ*; this spectral region is much diminished in brightness and a practically complete cut-off appears between 600 mμ and 630 mμ. To exhibit this feature, the spectrum of the transmitted light was photographed with a Hilger constant-deviation spectrograph on an Agfa panchromatic film. A tungsten filament lamp was used as the source of light in conjunction with a filter of copper sulphate solution so as to reproduce daylight conditions as nearly as practicable. Spectrograms obtained with three different exposures are reproduced together in Fig. 1 below, the first and the last in the series of five spectrograms being the comparison spectra exhibiting the light of the source employed. A dark band is very clearly seen in the three spectrograms not far from the red end of the spectrum, but clearly separated from it.

The "Morning Glory" thus presents us with the surprising fact that the weakening or removal from the spectrum of white light of a narrow strip covering its yellow and orange sectors transforms the resulting visual sensation from a pure white to a highly saturated blue closely resembling a pure spectral colour. As observed visually and as also shown by the spectrograms reproduced, the light which produces this sensation has its red, green, blue and violet sectors present in full strength and yet it does not excite in any observable degree the achromatic sensation which should, accordingly to the generally accepted beliefs, result from their superposition. These facts are highly significant in relation to our fundamental notions regarding physiological optics and the theory of colour perception.

### 4. The Spectrum of the Blue Lotus

The lotus is one of the most famous and best-loved flowers of India. In the sunken garden attached to the author's residence at Bangalore, the floating leaves and blue flowers of a lotus make a most colourful exhibit in a large cistern of water. The petals of the lotus exhibit a purplish-blue colour which, though not so saturated as the blue of the "Morning Glory", nevertheless is very impressive by reason of the large number and geometric arrangement of the petals. The spectrum of the colour is readily observed either by reflection or by transmission. As in the case of the "Morning Glory", the violet, blue-green and red regions of the spectrum appear without any noticeable alteration of their relative intensities; but the spectral region between 550 mμ and 610 mμ appears much weakened in its intensity, and *two* dark bands clearly separated from each other are noticeable in it. One of the bands appears between 550 mμ and 570 mμ, and the other between 590 mμ and 610 mμ, the latter being the stronger and better defined absorption of the two. The differences in colour and the degree of its saturation in the case of the two flowers thus correspond to the differences in the spectral composition of the light in the two cases.



1 2 3 4 5 6

FIGS. 1–6. Spectra of Flower Petals by Transmitted Light.

Fig. 1. "Morning Glory" with comparison spectra. Fig. 2. Jacaranda with comparison spectra. Fig. 3. "Heavenly Blue" (two petals) with comparison spectra. Fig. 4. Ground-Orchid with comparison spectra. Fig. 5. "Cloth of Gold" two petals and one petal. Fig. 6. Aster with purple petals.

### 5. THE BLUE OF THE JACARANDA

Many flowering trees are known in India which in the appropriate seasons of the year array themselves in flower-mantles of spectacular beauty. The Jacaranda of which the full botanical name is *Jacaranda mimosifolia* is singled out here by reason of the unique character of its floral display. In the month of March each year, it bursts into flower and is then one of the most striking exhibitions of colour which could be imagined. The number of individual flowers on each tree is so enormous and they are so densely aggregated that each tree appears to carry a "blue mist" on its head. A whole avenue of such trees is an unforgettable sight.

The colour of the Jacaranda flowers is more nearly violet than blue. When freshly removed from the tree, they exhibit a vivid but not a saturated hue. But the colour becomes more vivid as the flower dries up. Its spectrum may be examined either by transmitted or by reflected light. Two absorption bands are noticeable, one between 580 mμ and 600 mμ covering the yellow region of the spectrum and another in the red beyond 630 mμ. The orange sector of the spectrum between 600 mμ and 630 mμ stands out as a bright strip between these two absorption bands. The third of the five spectrograms, reproduced in Fig. 2, shows this effect clearly, the first and the fifth in the group being the comparison spectra of the light source employed. Though the absorption in the yellow between 580 mμ and 600 mμ is not very conspicuous, it nevertheless plays the major role in determining the colourful appearance of the Jacaranda flowers, since the red end of the spectrum where the second absorption appears is intrinsically of low luminosity to our perceptions.

We may also refer here to two other plants which are well known and the spectral behaviour of whose flowers somewhat resemble those of the Jacaranda. One of them is the creeper known botanically as *Thunbergia grandiflora* which bears large five-lobed flowers popularly known as the "Heavenly Blue". The other is *Plumbago capensis* which is commonly planted out as hedges by reason of its bearing numerous clusters of small pale-blue flowers which make a fine show against the green foliage of the plant. Holding two of the lobes of the "Heavenly Blue" flower one behind the other, the transmitted light appears of a deeper blue than with one flower alone, and the absorption band in the yellow between 580 mμ and 600 mμ is then more conspicuous. A succession of fainter bands can also be seen in the region of smaller wave lengths. This effect is reproduced in Fig. 3. Very similar effects may also be observed with the *Plumbago capensis* flowers if they are bunched together, thereby increasing the absorption paths in the material.

### 6. Flowers Exhibiting Band Spectra

Of particular interest to the spectroscopist are those flowers which exhibit regularly-spaced band spectra in the light reflected by or transmitted through their petals. One such plant is a ground-orchid in the author's garden which bears elongated leaves like those of a palm and also carries long green stalks on which the flowers come out in succession, making a colourful show. The flowers have five petals of a reddish purple hue, and when viewed through a pocket spectroscope they exhibit a succession of bright and dark bands, as shown in the two spectrograms reproduced in Fig. 4 between the two comparison spectra of the light-source. The first dark band is very dark and sharp and appears at 590 mμ. The second dark band is somewhat broader but nearly as dark and appears at 545 mμ. The third dark band is rather diffuse and appears at about 505 mμ. The elimination of the yellow sector of the spectrum and the weakening of the green sector by the dark bands appearing in it are evidently responsible for the colour exhibited by the flower.

The flowers of the well-known garden shrub known as the *Cineraria* are also found to exhibit the band spectra in a conspicuous manner. Particularly striking in this respect are those varieties in which the petals exhibit a purplish-red hue. The band system in these cases resemble that observed with the ground-orchid described above and illustrated in Fig. 4. On the other hand, the varieties in which the petals are of a bluish-purple hue give a different type of spectra. The first bright band in the orange-red sector appears split into two, and the other bands also exhibit indications of such splitting. The blue flowers of the larkspur are also found to exhibit a set of rather closely-spaced bands in the red, orange and yellow sectors of the spectrum.

The question naturally arises why the absorption spectra exhibit a succession of dark and bright bands in the cases described. The suggestion may be ventured that we are perhaps concerned with a superposition of the vibrational and of the electronic absorption spectra of the molecules of the pigments present in the flowers.

### 7. The Spectrum of the "Cloth-of-Gold"

As has been remarked earlier, a great many flowers are known which exhibit a golden-yellow colour, and their spectra are usually very similar to each other. The faintest yellow indicates the presence of a sensible absorption in the region of shorter wavelengths in the spectrum. The deeper the colour, the further has the absorption advanced from the violet into the blue and then towards the green. A change from yellow to orange indicates that the absorption has entered well into the green sector of the spectrum. The further the absorption advances into the green, the deeper becomes the orange hue. It then passes over into orange-red and finally into a scarlet colour.

The absorption by yellow flowers in the violet and blue sectors of the spectrum is usually so strong as to result in a complete cut-off of those regions. When the petals are very thin, however, it is possible with longer exposures photographically to record a feeble transmission in the blue and the violet sectors. It is interesting to remark that the transmission then appears as a succession of bands clearly resolved from each other.

The four spectrograms reproduced as Fig. 5 were recorded with the petals of a flower which is grown extensively in South India and finds a large market. It is known as "Kanakambaram" which may be translated into English as the "Cloth-of-Gold". The flower is of a beautiful orange-yellow tint. The individual petals are so thin that there is a sensible transmission over the entire spectrum which however exhibits a succession of bands, as can be seen in the third and fourth of the spectrograms reproduced as Fig. 5. When two petals are held together, however, the shorter wavelengths are cut off and only three bands are recorded, as can be seen in the first two spectrograms in Fig. 5. It would be interesting to ascertain the chemical constitution of the colouring matter which gives these remarkable effects.

## A METHOD OF DEGRADATION OF HARD RESIN FROM LAC

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THE resin secreted by the insect *Laccifer lacca* Kerr has been the subject of extensive investigation over a number of decades. After the separation of the colouring matters and the waxes that accompany the resin it is generally divided into two parts on the basis of solubility : (1) ether-soluble soft resin and (2) ether-insoluble hard resin. The hard resin possesses the desirable resinous properties and consequently has been more widely investigated. It is apparent however that a rigorous separation of the soft and hard resin is often not made. This is the result of the following factors. The resin is a mixture of a number of polymeric acids with some free hydroxyl groups and its nature depends on storage and preliminary treatment. The remarkable property of the resin to form rubbery aggregates in contact with non-polar solvents, particularly ether, into which further penetration of the solvent becomes difficult, leaves the chemical separation often incomplete.

A fairly satisfactory and effective method of separation has now been attempted with a view to get a standard product. A concentrated alcoholic solution of the resin, free from wax and colouring matters obtained from palas (*Butea frondosa*) seedlac, was poured into ether with continuous vigorous stirring. The precipitated hard resin was treated similarly two or three times until all the ether-soluble material was removed. The hard resin, obtained as an amorphous powder, gave consistent results and was employed in all the reactions. The viscous residue obtained by evaporating the ether solution consists of soft resin along with some hard resin that has been carried over because of the presence of some alcohol in the mother liquors.

There seems to be a need to explore the possibility of using new methods of study of lac resin. The hard resin has so far been investigated by alkaline degradation. Two fission products, aleuritic acid[1] (I) and shellolic acid[2,3] (II) have been isolated and completely characterised. Recently Cookson and his co-workers[4] reported the isolation of epishellolic acid in small yield. The isolation of an aldehydo acid named jalaric acid[5] was reported from the jalari (*Shorea talura*) seedlac. However the yields of aleuritic acid and shellolic acid have always been a subject of uncertainty. Yields of aleuritic acid that have been reported vary from 20% to 40%,[6] that of shellolic acid 0-8%.[7] Most of the remaining portion of the fission products has not been fully characterised.