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The colours of gemstones

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Colour is the sensation experienced by an observer when he views the material under study. It is, therefore, essentially a subjective phenomenon. While the optical properties of the material alter the spectral character of the light falling thereon and emerging therefrom which reaches the eye of the observer, the visual impression which such light produces is determined by the physiological characteristics of the sensory apparatus. These characteristics accordingly play the leading role in the perception of colour and must necessarily take precedence in all considerations regarding the subject.

In a memoir by the writer which has been recently published (reference 1), the results of systematic studies on floral colours have been described and discussed. The products of the plant world, including especially the leaves and flowers of living plants, constitute a very large class of materials exhibiting colour which invite study. Being products of biological activity, they conform to set patterns and are therefore exceptionally well suited for precise scientific investigations. The number of species of flowering plants is enormous, and the colours displayed by their flowers are of the most varied nature. Further, not merely is the material available in abundance, but it is also available in forms and sizes exceptionally well suited for a spectroscopic examination. It is only to be expected in these circumstances that the studies would be richly rewarding and this has indeed proved to be the case. The observational data which the studies have yielded are of a comprehensive nature and have been obtained by methods which do not involve any particular assumptions or hypotheses regarding the visual mechanism and what it is or is not capable of achieving. In other words, they represent the results of an unbiassed study of the facts and therefore give us a true picture of the reality.

It emerges clearly from the studies on floral colours that the ideas regarding colour composition and colour perception based on the so-called trichromatic hypothesis are inadmissible and have of necessity to be totally rejected as being inconsistent with or contradicted by the real facts of the case. As an example of such inconsistencies and contradictions, we may mention here the circumstances in which the well-known sensation of "purple" is actually perceived. Numerous flowers exhibit that colour, and spectroscopic examination reveals that it arises from the more or less complete extinction of the narrow range of wavelengths between 560 and 590 mμ which constitutes the yellow sector of the spectrum, all other parts of the spectrum remaining unaffected. This result, even taken by itself, is a complete refutation of the entire framework of ideas embodied in the so-called trichromatic hypothesis.

Another class of objects which exhibit colour and are worthy of study form the subject of the present communication, namely gemstones. In several respects, they are an antithesis to the products of the plant world when considered from the present point of view. For a material to be classed as a gemstone, it must be a rarity or at least so scarce as to be an expensive commodity, usually available only in small pieces and generally only after it has been converted by lapidaries into a form calculated to exhibit its lustre and beauty to the maximum extent and for that same reason wholly unsuitable for any precise scientific investigation of its spectroscopic behaviour. It is the rarity and costliness of the gems which are natural products which motivated the efforts made to produce them synthetically, thereby creating for buyers and sellers alike, the acute problem of distinguishing between the natural and synthetic gemstones. Nevertheless, such questions, as for example, why is emerald green, why is ruby red and why is sapphire blue, possess both a human and a scientific interest. One can, of course, escape the difficulty of obtaining material suitable for the studies by employing the synthetic instead of the natural gems. But, then, the interest of the investigation and of its results would be materially diminished.

To the reader interested in gemstones and the practical problems arising in the identification of gemstones and of distinguishing between natural and the synthetic gems, Mr B W Anderson's book on gem-testing (6th Edition, Heywood and Co., London) may be heartily recommended. The following remarks made by him which are pertinent to the subject may usefully be quoted here: "Minerals can be classified into the idiochromatic ('self-coloured') type which owes its colour to an element which is an essential part of its composition—e.g., the iron in almandine garnet or peridot, the copper in malachite—and the allochromatic type, in which the colouring element is present in quite small quantity as an 'accidental' impurity. The majority of gem minerals are allochromatic: that is, the mineral itself has no distinctive colour, and is in fact colourless when pure, but exhibits a range of coloured varieties according to the presence of traces of different colouring elements. Quartz, beryl, corundum, tourmaline, topaz, spinel, zircon, and many others are in this category."

Anderson's book also contains a chapter on the use of the spectroscope in gem-testing which contains material relevant to the present topic, viz., the colours of gemstones. In that chapter are reproduced four charts which contain drawings made from visual observations of the spectra of 35 different gemstones, grouped together under the four headings of red, yellow, green and blue stones. The spectra exhibit very varied features, and this fact is of considerable assistance in the identification of the gemstones. The usefulness of the charts from this point of view should not however be allowed to obscure the fact that they cannot serve as a basis for the explanation of the colours of the gemstones. It is not merely the positions of the absorptions noticeable in the spectrum of the gemstones, but also the strength of such absorptions that has to be considered in relation to the intensity of the unabsorbed parts. In other words, we need a complete picture of the energy distribution or at least of the visual luminosities in the spectrum of the light emerging through the gemstone before we can proceed to consider the explanation of its visually observed colour.

It is naturally to be expected that the results which have emerged from the studies on floral colours would be found to be equally well applicable to the case of gemstones and enable us to give a satisfactory interpretation or explanation of their colours. The interest of the subject and the fact that a considerable collection of gem minerals was available in the museum of the Raman Research Institute induced the author to undertake some preliminary studies in this field with a view to find whether this is actually the case. The present communication is a brief report on the results.

We may first consider the case of emerald. The rich green colour characteristic of this gem is exhibited by numerous pieces of beryl purchased by the author some years ago at Jaipur in Rajputana and included in the collection of beryl specimens of various sorts deposited in his museum. Unfortunately, however, none of these specimens is transparent enough to permit of light transmitted in the regular fashion through it being observed or examined. However, the author was presented by Sri Chand Golecha, a leading jeweller of Jaipur, when he recently visited Bangalore, with a hexagonal crystal of beryl from the Colombian mines about one centimetre thick. The two faces of the plate facing each other were ground down and polished, and the material was then found to be fairly transparent and the transmitted light also exhibited the characteristic green colour of emerald. Visual spectroscopic examination, confirmed by photographically recorded spectra, showed that in the passage of light through the plate, the violet and blue sectors of the spectrum were noticeably weakened, especially the former. But there was a readily observable transmission in the wavelength range between 450 and 500 mμ. The green and the red sectors of the spectrum were also visibly diminished in their intensities in the light emerging through the plate. But such diminution was not more than could reasonably be ascribed to the loss by reflection at the two surfaces of the plate as well as the imperfect transparency of the material. On the basis of these facts, we should have expected the colour of the light emerging through the emerald to be a bright yellow, while actually it was a clear green.

We have now to consider the explanation of this striking discrepancy. There is indeed a weakening of intensity (including a narrow band of absorption) noticeable at and near the red end of the spectrum. But the visual luminosity of this part of the spectrum is so small that such absorption is incapable of explaining the fact that the observed colour of the gem is green and not yellow. A careful examination of the spectrum shows, however, that the part of the spectrum between 570 and 600 mμ, in other words, the yellow sector of the spectrum is greatly weakened. It is clear that it is this extinction of the yellow that is responsible for the observed colour of emerald.

The results obtained with the hexagonal beryl crystal were confirmed with a fine piece of emerald of gem quality which was purchased from a jeweller at Bangalore. It is of much smaller thickness (about 2 mm), but exhibits a deep green colour. The yellow of the spectrum is found to be greatly weakened in the passage of the light through the gem. The aggregate intensity of the red sector relatively to the green sector is distinctly less than it is before entry into the gem, but it is far from being negligible. The observed vivid green hue of the emerald indicates that in the circumstances of the case, the visual sensation excited by the red sector is more or less completely masked by that of the more luminous green sector, in other words, prevented from influencing the perceived colour of the gem.

We shall next consider the case of the ruby. The author's collection of corundum from Ceylon includes numerous individual specimens exhibiting varied colours. Placing them under the ultra-violet lamp and picking out those which exhibit the characteristic red glow enables us to separate the rubies from other species of corundum. Such separation resulted in the interesting discovery that some rubies exhibit a purple colour. They show a strong absorption in the region of wavelengths between 560 and 590 mμ, in other words, of the yellow sector in the spectrum. Their spectral behaviour thus closely resembles that of the purple flowers mentioned earlier.

Rubies which appear red owe their colour to the existence of an absorption covering both the yellow and green sectors of the spectrum. It is a remarkable fact that the blue of the spectrum is transmitted more or less freely by such rubies. But it does not appear to influence the observed colour. We are led to infer that in the particular circumstances of the case, the weaker sensation due to the blue part of the spectrum is masked or prevented from being perceived by the more luminous red sector.

Flowers which appear of a blue colour invariably exhibit a strong absorption of the yellow of the spectrum. A very similar behaviour is found to be exhibited by blue sapphire.

We may sum up all that has been said above in a few words, viz., that the colours of gemstones exhibit features which are in complete accord with those met with in the realm of flowers (reference in footnote).

Raman, Sir C V, "Floral Colours and the Physiology of Vision," *Memoir No.* 137 *of the Raman Research Institute*, pp. 57 to 108.