CLASSICS OF SCIENCE:

Young on Color Vision

Physics

Make a color top and try the effects of combining the spectral colors in different ways. Also, hold a prism close to your eyes and see whether you can see the dark "Fraunhofer lines" crossing the bright solar spectrum.

A COURSE OF LECTURES ON NATURAL PHILOSOPHY AND THE MECHANICAL ARTS, by Thomas Young, M. D., London, 1907.

Colours in White Light

The separation of colours by refraction is one of the most striking of all optical phenomena. It was discovered by Newton that white light is a compound of rays of different kinds, mixed in a certain proportion, that these rays differ in colour and in refrangibility, that they constitute a series, which proceeds by gradual changes from red to violet, and that those substances which appear coloured when placed in white light, derive their colours only from the property reflecting some kind of rays most abundantly, and of transmitting or extinguishing the rest. Dr. Herschel has added to this series rays of heat less refrangible than the red, and Ritter and Dr. Wollaston have discovered, beyond the violet, other still more refrangible rays, which blacken the salts of silver.

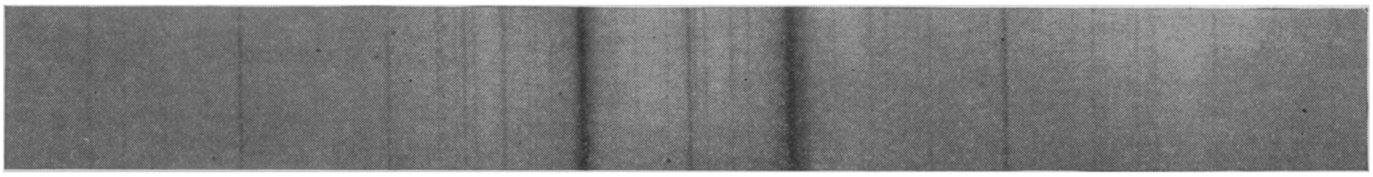
It has generally been supposed, since the time of Newton, that when the rays of light are separated as completely as possible by means of refraction, they exhibit seven varieties of colour, related to each other with respect to the extent that they occupy, in ratios nearly analogous to those of the ascending scale of the minor mode in music. The observations were, however, imperfect, and the analogy was wholly imaginary. Dr. Wollaston has determined the division of the coloured image or spectrum, in a much more accurate manner than had been done before: by looking through a prism, at a narrow line of light, he produces a more effectual separation of the colours, than can be obtained by the common method of throwing the sun's image on a wall. The spectrum formed in this manner consists of four colours only, red, green, blue, and violet, which occupy spaces in the proportion of 16, 23, 36, and 25 respectively, making together 100 for the whole length; the red being nearly one-sixth, the green and the violet each about one-fourth, and the blue more than one-third of the length. The colours differ scarcely at all in quality within their respective limits, but they vary in brightness; the greatest intensity of light being in that part of the green which is nearest to the red. A narrow line of yellow is generally visible at the limit of the red and green, but its breadth scarcely exceeds that of the aperture by which the light is admitted, and Dr. Wollaston attributes it to the mixture of the red with the green light. There are also several dark lines crossing the spectrum within the blue portion and its neighbourhood, in which the continuity of the light seems to be interrupted. This distribution of the spectrum Dr. Wollaston has found to be the same, whatever refracting substance may have been employed for its formation; and he attributes the difference which has sometimes been observed in the proportions, to accidental variations of the obliquity of the rays. The angular extent of the spectrum formed by a prism of crown glass is one-twenty-seventh of the deviation of the red rays; by a prism of flint glass, one-nineteenth.

In light produced by the combustion of terrestrial substances, the spectrum is sometimes still more interrupted; thus, the bluish light of the lower part of a flame of a candle is separated by refraction into five parcels of various colours; the light of burning spirits, which appears perfectly blue, is chiefly composed of green and violet rays; and the light of a candle into which salt is thrown abounds with a pure yellow, inclining to green, but not separable by refraction. The electrical spark furnished also a light which is differently divided in different circumstances.

If the breadth of the aperature viewed through a prism is somewhat increased, the space occupied by each variety of light in the spectrum is augmented in the same proportion, and each portion encroaches on the neighbouring colours, and is mixed with them; so that the red is succeeded by orange, yellow, and yellowish green, and the blue is mixed on the one side with the green, and on the other with the violet; and it is in this state that the prismatic spectrum is commonly exhibited.

When the beam of light is so much enlarged as to exceed the angular magnitude of the spectrum, it retains its whiteness in the centre, and is terminated by two different series of colours at the different ends. These series are still divided by well-marked lines: on the one hand the red remains unmixed; the space belonging to the green and blue becomes a greenish yellow, nearly uniform throughout, and here the appearance of colour ends, the place of the violet being scarcely distinguishable from the neighbouring white light: on the other hand, the space belonging to the red, green, and blue of the simple spectrum, appears of a bluish green, becoming more and more blue till it meets the violet, which retains its place without alteration. This second series is also the same that accompanies the limit of total reflection at the posterior surface of a prism.

Sir Isaac Newton observed that the effect of white light on the sense of sight might be imitated by a mixture of colours taken from different parts



FRAUNHOFER LINES, dicovered by Wollaston and here described by Young, were at first thought to mark the divisions between the colors in the solar spectrum. Since Fraunhofer discovered their true significance, they have been the means of chemical analysis of glowing matter throughout space. The spectrum here shown (full size) was photographed recently at Mt. Wilson observatory with the largest spectrograph in the world, of 75-foot focus. The two heavy lines are the "double line" of sodium, with many faint lines between them, including the heavier one of nickel

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of the spectrum, notwithstanding the omission of some of the rays naturally belonging to white light. Thus, if we intercept one-half of each of the four principal portions into which the spectrum is divided, the remaining halves will still preserve, when mixed together, the appearance of whiteness; so that it is probable that the different parts of those portions of the spectrum, which appear of one colour, have precisely the same effect on the eye. It is certain that the perfect sensations of yellow and of blue are produced respectively, by mixtures of red and green and of green and violet light, and there is reason to suspect that those sensations are always compounded of the separate sensations combined; at least, this supposition simplifies the theory of colours: it may, therefore, be adopted with advantage, until it be found inconsistent with any of the phenomena; and we may consider white light as composed of a mixture of red, green, and violet only, in the proportion of about two parts red, four green, and one violet, with respect to the quantity or intensity of the sensations produced.

Mixtures of Colours

If we mix together, in proper proportions, any substances exhibiting these colours in their greatest purity, and place the mixture in a light sufficiently strong, we obtain the appearance of perfect whiteness; but in a fainter light the mixture is grey, or of that hue which arises from a combination of white and black; black bodies being such as reflect white light but in a very scanty proportion. For the same reason, green and red substances mixed together usually make rather a brown than a yellow colour, and many yellow colours, when laid on very thickly, or mixed with black, become brown. The sensations of various kinds of light may also be combined in a still more satisfactory manner, by painting the surface of a circle with different colours, in any way that may be desired, and causing it to revolve with such rapidity that the whole may assume the appearance of a single tint, or of a combination of tints, resulting from the mixture of the colours.

From three simple sensations, with their combinations, we obtain seven primitive distinctions of colours; but the different proportions in which they may be combined afford a variety of tints beyond all calculation. The three simple sensations being red, green, and violet, the three binary combinations are yellow, consisting of red and green; crimson, of red and violet; and blue, of green and violet; and the seventh in order is white light, composed by all the three united. But the blue thus produced, by combining the whole of the green and violet rays, is not the blue of the spectrum, for four parts of green and one of violet make a blue, differing very little from green; while the blue of the spectrum appears to contain as much violet as green: and it is for this reason that red and blue usually make a purple, deriving its hue from the predominance of the violet.

It would be possible to exhibit at once to the eye the combinations of any three colours in all imaginable varieties. Two of them might be laid down on a revolving surface, in the form of triangles, placed in opposite directions, and the third on projections perpendicular to the surface, which, while the eye remained at rest in any one point, obliquely situated, would exhibit more or less of their painted sides, as they passed through their different angular positions; and the only further alteration, that could be produced in any of the tints, would be derived from the different degrees of light only. The same effect may also be exhibited by mixing the colours in different proportions, by means of the pencil, beginning from three equidistant points as the centres of the respective colours. . . .

Rainbows and Halos

The atmospherical phenomena of rainbows and halos present us with examples of the spontaneous separation of colours by refraction. The rainbow is universally attributed to the refraction and reflection of the sun's rays in the minute drops of falling rain or dew, and the halos, usually appearing in frosty atmospheres, are in all probability produced by the refraction of small triangular or hexagonal crystals of snow. It is only necessary, for the formation of a rainbow, that the sun should shine on a dense cloud or a shower of rain, in a proper situation, or even on a number of minute drops of water, scattered by a brush or by a syringe, so that the light may reach the eye after having undergone a certain angular deviation, by means of various refractions and reflections; and the drops so situated must necessarily be found somewhere in a conical surface, of which the eye is the vertex, and must present the appearance of an arch. The light, which is reflected by the external surface of a sphere, is scattered almost equally in all directions, setting aside the difference arising from the greater efficacy of oblique reflection; but when it first enters the drop, and is there reflected by its posterior surface, its deviation never exceeds a certain angle, which depends on the degree of refrangibility, and is, therefore, different for light of different colours; and the density of the light being the greatest at the angle of greatest deviation, the appearance of a luminous arch is produced by the rays of each colour at its appropriate distance. The rays which never enter the drops produce no other effect than to cause a brightness or haziness round the sun, where the reflection is the most oblique; those which are once reflected within the drop exhibit the common internal or primary rainbow, at the distance of about 41 degrees from the point opposite to the sun; those which are twice reflected, the external or secondary rainbow, of 52°; and if the effect of the light, three times reflected, were sufficiently powerful, it would appear at the distance of about 42 degrees from the sun. The colours of both rainbows encroach considerably on each other; for each point of the sun may be considered as affording a distinct arch of each colour, and the whole disc as producing an arch about half a degree in breadth for each kind of light; so that the arrangement nearly resembles that of the common mixed spectrum.

Thomas Young was born in Somerset, England, June 13, 1773, and died in London, May 10, 1829. At the age of 14 he knew 7 languages, including Persian and Arabic. He began to study medicine in England at the age of 19, and took his doctor's degree at 23 from the University of Göttingen. Three years later he established a practice in London. The following year he was appointed professor at the Royal Institution, where he gave the course of lectures from which the above extract is taken. At the age of 29 he was appointed foreign secretary of the Royal Society of London. He had become a Fellow at the age of 21. In later years he served as secretary of committees on a variety of subjects, from the length of the seconds pendulum to the dangers of gas lighting in London. He was made a Foreign Associate of the French Academy of Sciences in 1827.

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