Brit. J. Ophthal. (1955) **39**, 170.

CLINICAL STUDY OF COLOUR VISION*

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THE analysis of colour defects and individual differences in normal colour vision requires an apparatus in which spectral stimuli are used. It should be possible to determine the following:

(1) Relative luminous efficiency of spectral light (luminosity curve).
(2) Threshold of wavelength discrimination in spectrum (hue discrimination curve).
(3) Threshold of saturation discrimination in spectrum (purity discrimination curve).
(4) Trichromatic coefficients of spectral colours (colour mixture curves).

In clinical practice these tests are too time-consuming, and the examination has therefore to be limited to the determination of a few points on every curve at various wavelengths, but it is desirable that in some special cases the analysis should be carried out more completely with the same apparatus.

The Nagel anomaloscope, the only apparatus in general use for detecting defective colour vision, was designed to make one colour match: between monochromatic yellow and a mixture of red and green in the spectrum. It is a direct vision spectroscope with a circular field of about 2 degrees diameter, divided into two halves. The lower half of the field is illuminated by monochromatic yellow light from a slit of variable width, which can be controlled by the right-hand screw. The upper half of the field is illuminated by a mixture of monochromatic red and green. How the beams are made monochromatic will be clear from the diagram of the optical system of the anomaloscope (Fig. 1). The ratio between the widths of the slits for red

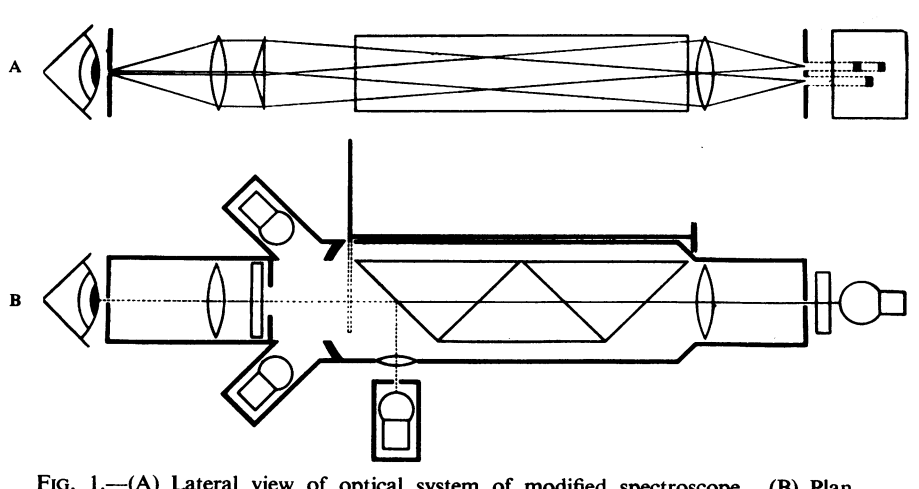

FIG. 1.—(A) Lateral view of optical system of modified spectroscope. (B) Plan.

*Received for publication May 17, 1954.

and green is controlled by the left-hand screw. The observer has to adjust both fields to equal hue by operating the left control and to equal brightness by operating the right control.

The anomaloscope is easy to handle and satisfactory for distinguishing the well-known defects of red-green discrimination, but cannot be used for more extensive investigations.

The instrument-maker of the Amsterdam Eye Clinic, Mr. C. van den Bosch, has therefore reconstructed a Nagel anomaloscope at my directions (Fig. 2).

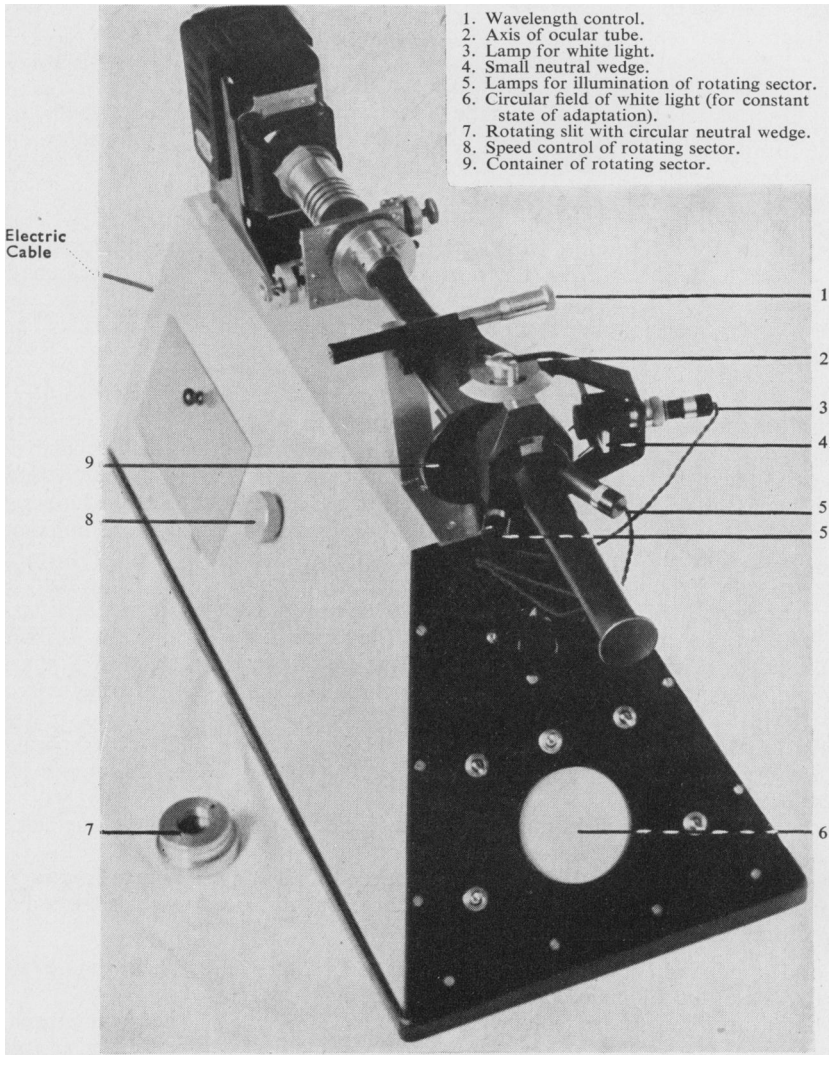

FIG. 2.—General view of apparatus.

To make a more universal apparatus the following changes have been made:

(A) The light source has been replaced by a Leitz projector, the intensity of light being thus increased thirty times. The intensity can be lowered by neutral filters.

(B) The ocular tube can be rotated around a vertical axis through the observing end of the prism (anomaloscope, type II). Any monochromatic light can now be matched with a mixture of two colours of the spectrum, the wavelengths of which are determined by the choice of the monochromatic stimulus. With this device we are still far from the determination of colour mixture curves mentioned above, because it is not possible to compare a light of variable wavelength with a mixture of matching stimuli of constant wavelength. But at least we can perform a colour equation in the short wave half of the spectrum which is analogous to the Raleigh equation in the other half of the spectrum.

When a blue light of wavelength 0,480μ is chosen as monochromatic stimulus, the matching stimuli available are blue-violet (0,455μ) and green (0,513μ).

For an exact match the monochromatic blue has to be desaturated by white light. How this is achieved is described below. A small neutral filter must be put before the "red" slit of the original anomaloscope to make the blue-violet and green of approximately equal brightness.

An equation for tritanomaly has been advocated by Trendelenburg (1941). An anomalous match is not a proof of tritanomaly, as abnormal ocular pigmentation is likely to yield the same deviation from the normal match. The wavelength discrimination curve, however, will be abnormal in the case of tritanomaly and normal in the case of abnormally heavy ocular pigmentation. I have already found instances of both possibilities.

(C) The double prism in the ocular tube, which divides the colorimeter field into two halves, has been mounted so that it can be replaced by a single prism. This prism has the same angle as both halves of the biprism, and is placed base up. The circular field will now be illuminated homogeneously by any monochromatic light from the "yellow" slit, according to the position of the ocular tube. For the determination of the luminosity curve, a flicker photometer has been included. A whitened rotating sector, illuminated at the observer's side by a lamp situated at each side of the ocular tube, intercepts the pencil of monochromatic light. Flicker is observed but disappears when the white light and the monochromatic light are of equal brightness. From the slit widths at each wavelength the luminosity curve can be computed. The range of measurement of the slit is much enlarged by neutral filters. The speed of the sector can be mechanically adjusted to the minimal frequency when white and monochromatic light of equal brightness are fused.

The brightness measurements are carried out at a brightness level of about 100 photons, but at the short wave end of the spectrum (between 0,460μ and 0,425μ) the brightness is inevitably lower.

Brightness measurements yield important data in cases of unclassified colour defects, and are of value in detecting heterozygous carriers.

Among other atypical cases the author has recorded the luminosity curve in a case of cone monochromatism. The maximum of the curve was displaced towards the red end of the spectrum, as in deuteranopia.

(D) For determination of the threshold of saturation a source of light has been mounted at the right side of the anomaloscope (Vierling, 1928).

The white light of this source (colour temperature 5,000° K) is reflected by the back of the prism into the ocular tube. By a diaphragm the white light can be shut off from the upper colorimeter field, while in the lower field the brightness can be adjusted by a small neutral wedge.

For the determination of purity discrimination, white light is admitted into both fields. In addition, the lower field is illuminated by monochromatic light (from the " yellow " slit). When a difference in colour between the two fields can just be detected, the amount of monochromatic light needed is measured. Meanwhile, the fields have to be adjusted to equal brightness by the neutral wedge. From these data, combined with the luminosity curve, a purity discrimination curve can be computed.

To determine the neutral point in a case of dichromatism, the white light can be shut off from the lower field; thus, monochromatic light in the lower field can be compared with white light in the upper field.

(E) For the measurement of the threshold of wavelength discrimination in the spectrum of equal brightness, the Nagel slit system is replaced by one slit 0·2 mm. in width, which can be rotated around the axis of the collimator tube. When the slit is placed perpendicularly, both colorimeter fields are illuminated by light of the same wavelength, but when the slit is slightly rotated the wavelengths differ.

At each setting a difference in brightness must be compensated by a circular neutral wedge before the slit. This wedge can be rotated around the same axis as the rotating slit. The brightness level in the different parts of the spectrum is roughly equalized by neutral filters in front of the projector.

Calibration of the Apparatus.—The wavelength scale has been calibrated by placing the " yellow " slit of the apparatus before the slit of a commercial spectrophotometer.

The impurity of the monochromatic light is principally determined by the width of the exit pupil and to a lesser extent by the (variable) width of the slits. At a wavelength of 0,600μ, the width of the spectrum at the exit pupil is 0,007μ; at a wavelength of 0,500μ, it is 0,004μ. The slits are opened from one side only, which causes a slight shift in the spectral composition of the light. The maximal shift of the dominating wavelength, between light from a very narrow slit and from a widely opened slit, is less than 0,003μ at a wavelength of 0,600μ.

The " neutral " filters have been calibrated for each wavelength in a spectrophotometer. The energy of the spectrum used has not been measured. The luminosity data, therefore, cannot be corrected for an equal energy spectrum, but have to be compared to a mean curve of a number of normal trichromats.

It has thus been possible to construct a modified Nagel anomaloscope providing a simple universal apparatus for the clinical investigation of colour vision.

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