Dichroscopes for microscope stage and ocular.

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THE optical accessories here described are two dichroscopes to facilitate microscopical comparisons by eye between the hues and intensities of axial absorption colours shown by thin slices, crushed fragments, or detrital grains of transparent coloured doubly-refracting crystals. Their chief applications lie in microscopic mineralogy and petrology, but they can be of service, also, in chemistry and allied subjects.

The aims of the accessories are two in number. They provide: (i) simple microscopic means for viewing simultaneously any pair of distinct hues, intensities of hue, or combinations of these variables, which result from differential absorption of white light; and (ii) a convenient method for detecting small differences between any pair of hues, intensities, or both, in terms of immediate ocular comparison between two sets of small symmetrically-shaped coloured images which alternate, and meet in straight boundaries. Neither advantage (i) nor (ii) above is afforded by the petrographic microscope when employing only the polarizer in the optical system (Tschermak's method, 1869) (1); while if the alternative is adopted of using only the analyser in the optical system the interpretation of such pleochroic tints as are seen can be complicated by effects due to a variable proportion of polarized light reflected at the surface of the microscope mirror (2).

Both the grating and chequer types of these accessories, composed of polaroid, are adapted for use either on the stage or in the ocular of a petrographic or other microscope.

The *grating type* (fig. 1 *a*) yields a field divided into a set of narrow parallel bands of equal width, alternate bands of which show one of the two absorption tints or intensities of tint concerned. The resulting subdivision and interdigitation of the two equal areas of distinct hue or intensity enables a considerably more accurate estimate of such differences to be made by eye than is possible when the areas are discrete, and the two halves of the field meet in a single straight boundary, as is the case with the image seen in the hand-dichroscope (dichroskopische Loupe of W. Haidinger) (3).

In the *chequer type* (fig. 1 *b*), on the other hand, the centre of the field is occupied by a small square subdivided into four smaller squares of which diagonally-opposed pairs show the same absorption hue or intensity, while adjacent pairs show the two different absorption hues or different intensities involved.

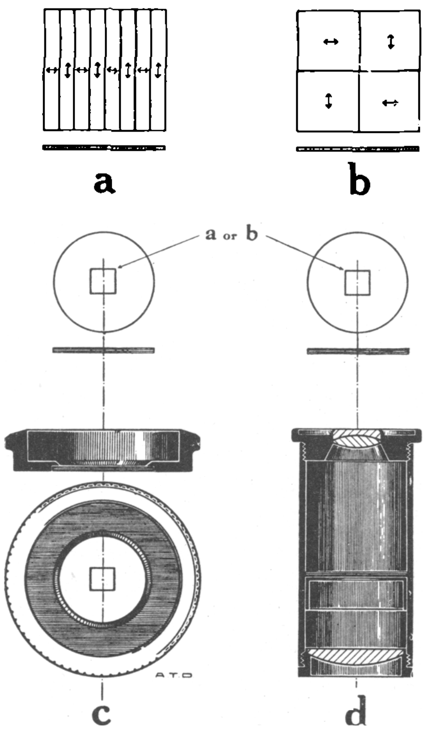

FIG. 1. Microscope dichroscope. *a*, grating type. *b*, chequer type. *c*, for stage. *d*, for ocular.

The *stage adaptation* of either the grating or chequer type (fig. 1 *c*) has the advantage that it can be introduced over a mounted pleochroic crystal without change in any adjustment of the microscope other than focus. Experience shows that these types function more efficiently on the microscope stage than in the accessory slot of the body tube.

The *eyepiece adaptation* of either type (fig. 1 *d*) has the advantage that: (i) it can be made to cover less than 4 % of the field, and thus does not interfere markedly with optical observations other than those of differential absorption; while (ii) it can be turned through any desired angle by rotating the eyepiece in the body tube, thereby enabling the accessory to be set in such a position relative to the crystal concerned that extreme differences of hue or intensity are visible for direct inter-comparison. This latter is the method appropriate to those microscopes with non-rotating stages, but when a rotating stage is fitted the same result can be obtained with equal ease by centring the crystal and then revolving it through the necessary angle on this stage, while leaving the eyepiece stationary.

The chief disadvantage of this adaptation is that it cannot be removed from the microscope ocular without unscrewing the eye-lens of the latter.

Generally the grating type of these accessories is better suited for studies of pleochroism in small elongated crystals than the chequer type, which serves for corresponding determinations on small but more nearly equidimensional crystals.

Functionally, both varieties of dichroscope behave in the same manner as the hand-instrument described by W. Haidinger in 1845 (3), but they differ from it in being (i) designed for microscopic rather than macroscopic use and in being (ii) constructed of small plates of polaroid in place of a prism of Iceland-spar. That the improved polaroid now available is a suitable substitute for Iceland-spar in this respect is evidenced by the investigations of Dr. A. F. Hallimond (4) into its efficiency as a polarizing medium and by those of Dr. J. McClelland (4) on its 'remarkably uniform' absorption over nearly the whole range of the visible spectrum, apart from a 'slight increase in absorption of the blue-green'. The latter is not a serious factor in practice.

The operation of the ocular adaptation of these accessories is comparable with that of the dichroscope ocular devised by C. Leiss in 1897 (5), but differs from it in being due to a group of small square plates of polaroid, as opposed to a prism of Iceland-spar. In employing polaroid plates, this latest dichroscope ocular resembles one suggested ten years ago by N. W. Thibault (6).

The polarizing medium.—The modern 'polaroid'[1] used as the light-polarizing medium in these two types of stage and ocular dichroscope is a development of an invention by the physicist E. H. Land (7). It is understood to be a thin sheet of a molecularly orientated linear polyvinyl oxy-compound (e.g. polyvinyl alcohol), or its equivalent, incorporating an iodine-bearing dichroic stain. Usually the linear molecular orientation of the plastic base would appear to be effected by appropriate stretching of the sheet, while the associated dichroic stain is protected from changes due to moisture, heat, or ultra-violet radiation by one of several special treatments of the surface of the sheet during production.

Since this latest kind of polaroid, patented in 1945 (8), differs from that patented during 1934, 1935, and subsequently (7) in being (i) more stable, both physically and chemically, and in (ii) transmitting light of a more nearly neutral tint, it is to be preferred in the dichroscopes described, but the efficiency of the earlier kind in these connexions is closely similar.

This earlier variety has been described as a uniformly distributed and flow-orientated suspension of elongate sub-microscopic crystals of the

[1] Manufactured by the International Polaroid Corporation, U.S.A.

strongly dichroic quinine sulphatoperiodide, 'herapathite'[1] (9), some allied alkaloid compound, or the inorganic compound purpureocobalt-chloride-sulphate-periodide (10), occupying the central layer of a thin cellulose nitrate or cellulose acetate sheet.

Optically, such a sheet behaves as a single thin crystal. Further, since the minute constituent crystals cannot be seen, even when magnified 1100 diameters, the sheet shows no structure under the microscope, though it is estimated there are about 10^{12} of them per square inch of sheet, and the uniformity of polarization throughout the sheet suggests they are distributed and alined with corresponding uniformity (11).

It has been shown that the degree of polarization of white light achieved by such a piece of polaroid varies between 95 and 98 % for the range 5000 to 6500 Å., i.e. for that part of the visible spectrum to which the human eye is most sensitive (12).

The faint neutral tint of the light transmitted by such a sheet has been described as 'similar to that of lightly smoked glass' (11). The amount of light so transmitted constitutes about 33 % of the incident light, as compared with nearly 50 % of the incident light passed by a nicol prism (4).

Practical importance attaches to the fact that both the earlier and later varieties of polaroid are stable up to temperatures in the neighbourhood of 120° C., for on this account they can be mounted permanently in 'cooked' Canada balsam without detriment to their polarizing properties.

Lastly, neither variety shows appreciable deterioration with age, as is evidenced particularly by the results of thermal and optical tests carried out recently by the author on pieces of the earlier types of polaroid which have been in his laboratory for the past nine years.

Construction.—To fulfil the optical requirements of the dichroscopes under discussion it is necessary to derive from polaroid: (i) rectangular plates $2 \times 0{\cdot}25 \times 0{\cdot}07$ mm.; or (ii) square plates $1 \times 1 \times 0{\cdot}07$ mm., which in either case can be mounted so that they fit together very closely, edge to edge, with the polarization axes in adjoining pairs of plates orientated at 90° to each other. Means were sought for cutting sets of parallel-sided strips 0·25 and 1 mm. wide respectively, in each set of which half the number had their polarization axes parallel to the *lengths* of the strips while the other half had their polarization axes parallel to the *widths* of the strips.

At first, experimental strips were cut and subdivided with sharp

[1] $4Qu.3H_2SO_4.2HI.I_4.6H_2O$.

surgical scissors, but while the resulting plates established the general efficacy of the dichroscopes so produced, when arranged and mounted appropriately, their edges were so burred, serrated, and chipped that an inadequate fit was obtained between them. Similar though slightly improved results were obtained with a large photographic print-trimmer and a printer's guillotine. Ultimately suitable strips, some 80 mm. in length, were cut by hand with a stiff mounted safety razor blade, using plate-glass as a base and a steel straight-edge as a guide.

From the resulting strips a careful selection was made by means of a petrographic microscope, employing an eyepiece micrometer for checking widths and parallelism between pairs of long edges of the strips, and the polarizer for checking the directions of their polarization axes.

In assembling the grating type of this dichroscope (fig. 1 *a*) eight strips 0·25 mm. in width, about 40 mm. in length, and 0·07 mm. in thickness were chosen, four of them with their polarization axes parallel to their lengths and four with their polarization axes perpendicular to their lengths. Strips were then placed alternately and laid approximately parallel to each other on a plate-glass sheet, slid with the finger tips into the closest possible contact, edge to edge, and then held thus, and to the glass, by small cakes of plasticine pressed down across their ends.

Next, a length of about 20 mm. in the centre of the resulting group of parallel strips was cemented into a continuous ribbon by a thin coat of 'D.P.X. balsam'[1] which was applied across and between the strips with a small soft brush. As soon as this coat had hardened the plasticine cakes were removed, the ribbon peeled from the glass, a length of 2 mm. cut from the centre of its cemented portion with a safety razor blade, and the resulting square mounted centrally between two circular cover-slips [22 mm. (⅞ inch) diameter] with 'cooked' Canada balsam. Thus by means of this 'D.P.X. balsam' both malalinement of the small plates of the grating and the development of bubbles between them was prevented, without introducing any optical disadvantage thereby.

Prepared in this way the grating can be cemented into the base of the brass ring shown in fig. 1 *c*, for use as a microscope-stage dichroscope, or placed on the diaphragm of a microscope eyepiece (fig. 1 *d*), when it constitutes an ocular dichroscope.

To assemble the chequer type of this dichroscope (fig. 1 *b*), four squares, each $1 \times 1 \times 0{\cdot}07$ mm., were cut with a safety razor blade from a strip of polaroid $1 \times 40 \times 0{\cdot}07$ mm., the polarization axis of which was parallel to its length. These four small square plates were then laid edge to edge

[1] 'Distrene 80', 10 gm.: butyl phthalate, 5 c.c.: xylol, 35 c.c.

in a thin tacky layer of 'D.P.X. balsam' on a plate-glass sheet to form a large square with the small squares so orientated relative to each other that the respective polarization axes of the two diagonally opposite pairs were parallel but the polarization axes of adjacent pairs were perpendicular.

After pressing the plates into intimate contact with each other by means of square-ended tweezers a thin layer of 'D.P.X. balsam' was brushed over the plates to fix their relative positions and prevent bubbles developing between their edges during subsequent mounting. When this balsam had hardened the resulting chequered unit, consisting of four polaroid plates embedded in it, was stripped from the glass, and then mounted centrally between two circular cover-slips [22 mm. ($\frac{7}{8}$ inch) diameter] in hot Canada balsam.

As with the grating type of this accessory, such a mount of the chequer type can be cemented into the base of the brass ring shown in fig. 1 *c*, for use as a microscope-stage dichroscope, or slid on to the diaphragm of a microscope eyepiece (fig. 1 *d*) to give an ocular dichroscope.

The form of the small metal holder for the stage adaptations of these accessories is illustrated in fig. 1 *c*. It consists of a rhodium-plated brass ring, 32 mm. in diameter, and 6·5 mm. in maximum depth, with a central circular aperture 13 mm. in diameter. A knurled outer rim 2 mm. in width facilitates the manipulation of the ring on the microscope stage. A recess 1·5 mm. in depth is cut in the base of the annulus, about the viewing aperture, to receive either a mounted grating or chequer dichroscope unit which is cemented in position by a convenient plastic varnish so that its lower surface is flush with that of the ring. The surface of the recess in the upper side of the ring is coated with matt black paint, to avoid unwanted reflections of light.

Operation.—Polarizer and analyser are withdrawn from the optical system of a petrographic microscope and a crystal grain is focused and centred under an objective of low or medium power, using unpolarized white light of the highest convenient intensity for illumination.

(*a*) *Stage adaptation.*—The base of the brass ring which contains the polaroid dichroscope unit (fig. 1 *c*) is held in contact with the cover-slip between finger and thumb; the dichroscope plates are centred over the crystal grain and the latter re-focused through this group of plates. Then, to observe and compare the absorption effects involved: either (i) the specimen is rotated beneath the dichroscope plates by revolving the stage; or (ii) the dichroscope unit is turned above the stationary crystal grain by revolving the brass ring between finger and thumb until either a maximum difference of hue or intensity of one hue is shown by adjacent pairs of rectangular or square plates, depending on whether the grating type or chequer type of the accessory is concerned.

When using the grating type, detection of the small differences of hue or intensity shown by pairs of adjacent plates can be facilitated by oscillating the group of plates across the specimen at a frequency of about four per second in a direction parallel to the widths of the plates.

Similarly, when employing the chequer type, improved perception of these small differences of hue or intensity can be obtained by giving such a bodily rotation of the brass ring, between finger and thumb, without turning it about its centre, that the centre of the square formed by the polaroid plates revolves in a small circle within the periphery of the image of the crystal grain. For this purpose a frequency of between two and four revolutions per second will suffice.

(*b*) *Ocular adaptation.*—An eyepiece bearing either type of polaroid dichroscope unit on its diaphragm (fig. 1 *d*), is inserted in the microscope, after which the crystal grain is focused and centred at the intersection of the cross-wires, i.e. the centre of either dichroscope unit.

Then, for comparison of the absorption effects: either (i) the dichroscope is rotated by revolving the ocular in the body tube, while leaving the stage and crystal stationary; or (ii) the crystal is rotated on the stage, while keeping the ocular stationary, until the maximum difference between two hues or intensities is seen.

It will be noticed that in this adaptation of the accessory the image of either the grating or chequer group of dichroscope plates and that of the crystal grain can be brought into focus simultaneously, whereas with the stage adaptation the image of either group of dichroscope plates is slightly out of focus when that of the crystal is in sharp focus.

To aid in the detection of small differences of hue or intensity by means of this form of the accessory, the glass slide carrying the specimen may be oscillated beneath the stationary grating dichroscope, or rotated bodily beneath the stationary chequer dichroscope, at a frequency of about four per second in either case.

(c) *Precautions.*—In using any one of these dichroscopes to the best advantage the light employed to illuminate the specimen should be: (i) white; (ii) not appreciably polarized before meeting the specimen; and (iii) of an intensity such that, at the ocular of the microscope, it gives rise to bright colour-images subtending suitable angles at the eye. Further, the observer should know the kind and degree of any colour defect of his eyes, considered individually, and in terms of this knowledge should use the more appropriate eye for sufficiently short periods of time to avoid errors due to retinal fatigue.

Of white light from natural sources, diffused sunlight from a sky entirely covered with white cloud is preferable to that from a partially-clouded or unclouded sky, particularly as regards degree of polarization (13). However, if the intensity of this light is insufficient to give the necessary bright images, then an artificial source will serve if used in conjunction with appropriate colour filters (14).

Inaccuracies in these studies can result from the use of partially-polarized light reflected by the microscope mirror. A. Johannsen would appear to regard this polarization as arising during reflection of the light at the mirror, and consequently recommends dispensing with the latter and so inclining the microscope as to receive light directly reflected from the sky or clouds (15). However, in this same connexion, T. Crook states that while such a microscope mirror is unable to produce any appreciable degree of polarization of incident light, it can and does reflect naturally polarized sky-light (16).

As early as 1809 Arago showed that light from a clear sky is partially polarized. It is now known that the maximum proportion of such polarized light (usually about two-thirds) is propagated from a region in the solar vertical and about 90° from the sun, except for three small neutral points in or near to the solar vertical, the light from which is unpolarized. For a solar altitude in excess of 20° the plane of polarization of light from this region departs little from that including the sun, the observer, and the observed point. The degree of polarization and the positions of the neutral points at any given moment depend upon the wave-length of the light concerned, the altitude of the sun, and the degree of turbidity of the atmosphere (17). Hence, when making such dichroscopic determinations as have been described, unqualified acceptance of the suggestion that 'at ordinary magnifications a good north light with a broad clear sky forms an excellent source of illumination for the polarizing microscope' (18) may introduce errors, especially if these determinations are made in the early forenoon or late afternoon.

When a calcite polarizer in a petrographic microscope is revolved as rapidly as possible the least intensity-fluctuation produced in the beam of light reflected through it from the mirror, as seen in the eyepiece, indicates a minimum polarization of about 20 % (19). A comparable result can be obtained by using either the grating or chequer type of dichroscope unit here described, or a single sheet of polaroid on the rotating stage, in place of the calcite polarizer mentioned above.

As the acuity of the human eye is practically the same for both red and blue light of medium intensity, but different when these are of low intensity—the 'Purkinje phenomenon'—it follows that the illumination of the specimen under the microscope should be of sufficient intensity to avoid this source of error (20). Also the coloured field should subtend not less than 2° at the eye if a restricted chromatic response of the retina is to be avoided (21).

Since not less than 8 % of males and about 0·5 % of females have grossly abnormal colour vision, and an additional percentage of each sex possesses the defect to a distinct though more limited extent, this factor should not be neglected in ocular studies of pleochroism, especially by male observers (22). Of such people the greater number show this abnormality in both eyes, but a few—possibly 3–4 % of the colour blind—possess it in one eye (23).

On account of the colours confused and the frequency with which it occurs, congenital red-green blindness is a most important type, affecting about 5·6 % of males (22). In mild cases the ability to distinguish between red and green fails when the intensity of illumination lies below a critical value, or the individual is fatigued, or both conditions apply (23).

Finally, apart from these congenital colour defects there are acquired types due to certain pathological conditions of the eye, or to such causes as excessive smoking (24), for example.

Utility.—With a suitable kind and intensity of illumination the two types of dichroscope described provide means for direct quantitative and qualitative ocular comparison between pairs of absorption tints of pleochroic crystals under either the polarizing or non-polarizing microscope by symmetrically subdividing and alternating the parts of two coloured images of equal size, which images can be compared in contact with each other across a number of straight boundaries. In this way either of these types of dichroscope enables small differences between two absorption tints, or between two intensities of one absorption tint, to be detected which could pass unnoticed when seen in succession.

On account of the very faint absorption tint shown by modern polaroid itself, this material is slightly more efficient as a means for detecting small differences of intensity of one absorption tint than it is of differentiating between two nearly identical absorption tints of the same intensity.

Either stage adaptation of these accessories can be introduced into, or withdrawn from, the optical system of the microscope without disturbing any previous adjustment except focus. On the other hand, either ocular adaptation can be brought into operation immediately by centring a crystal grain at the intersection of the cross-wires, whereas at other times the large area of the field not covered by the groups of polaroid plates allows of many optical determinations not involving differential absorption.

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