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Note on the van der Kolk method of determining refractive indices.

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IT is well known that in the Schroeder van der Kolk[1] method of comparing the refractive index of a crystal grain with that of the material in which it is mounted, the effect can be reversed by moving the microscope sub-stage condenser, and that the position of this condenser must therefore be carefully controlled if ambiguities in the interpretation of the observations are to be avoided. This fact is mentioned in the majority of text-books and is referred to in a general manner by Wright[2] and by Winchell.[3] No clear explanation of the reversal is offered, however, and students are consequently inclined to forget this important limitation in the method or, alternatively, to forget in which sense the movement of the condenser influences the effect: unless a control experiment is invariably performed errors may therefore result. A simple application of elementary optical principles to the effect is an instructive exercise, serving to fix in mind the phenomena which will occur under any set of conditions and at the same time to make clear the conditions most favourable for the success of the method.

The effects observed when a crystal grain is viewed in light incident obliquely are conveniently explained by assuming the grain to be roughly lens-shaped. The grain then acts as a converging or as a diverging lens accordingly as it is immersed in a medium of lower or of higher refractive index than itself, and a parallel beam of light is deflected in the two cases as shown in figs. 1*a* and 1*b* respectively. In either case the ray *BP* is roughly parallel to the axis of the microscope and emerges from the eyepiece, while *AQ* is travelling so obliquely that it either does not enter the objective or is absorbed by the walls of the tube before reaching the eyepiece. The edge *B* therefore appears illuminated while *A* is in darkness. The optical train of the microscope forms an image which is, of course, reversed relative to the object on the stage, so that the *image* appears illuminated on the side from which the light is incident or on the opposite side according as the refractive index of the grain is higher or lower than that of the mounting medium.

Although the above argument has been developed in terms of the whole grain it is clear that it could be applied equally well to each boundary separately, the

[1] J. L. C. Schroeder van der Kolk, Tabellen zur mikroskopischen Bestimmung der Mineralien nach ihrem Brechungsindex. 2nd edit., Wiesbaden, 1906.

[2] F. E. Wright, The methods of petrographic-microscopic research. 1911, p. 94.

[3] A. N. Winchell, Elements of optical mineralogy. 5th edit., pt. 1, 1937, p. 79.

only necessary assumption being that the grain boundaries are tapering. This point is of importance in considering the case of a microscope fitted with condenser, for then the conditions of illumination may differ in different parts of the field of view, so that opposite boundaries of an extended grain may not show equally marked effects.

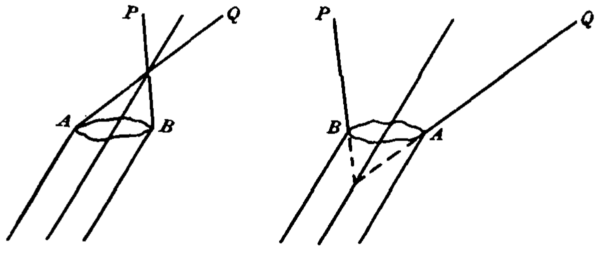


FIG. 1. Path of light rays through a lenticular grain: (*a*) in a lighter medium; (*b*) in a denser medium.

Microscope without condenser.

Let us consider first the case of a microscope having no sub-stage condenser. In this case conditions approximating closely to those shown in fig. 1 can be realized by removing the polarizer and swinging the mirror to one side. The effect is then very pronounced and will be the same and equally pronounced at all points in the field of view, especially if a small source of illumination is employed. If an extended source is used the oblique light can be obtained alternatively by retaining the mirror in its central position and covering part of it with an opaque screen. It should be noted, however, that this method is rarely satisfactory, since the mirror subtends at the stage only a relatively small angle and the obliquity of rays even from the edges of the mirror is not very marked. Especially is this the case when the polarizer is in position and the mirror is necessarily at some distance from the stage. Under these conditions the introduction of a screen will only have the effect of obscuring the sensibly parallel light reaching part of the field without greatly influencing the obliquity of that reaching the part which remains illuminated. It is not therefore in general satisfactory to use the Schroeder van der Kolk method on a microscope without sub-stage condenser unless the polarizer can be removed and the mirror swung some distance to one side; and this limitation should be clearly recognized. If observations in polarized light are required the analyser can, of course, be used.

Microscope with condenser.

When a sub-stage condenser is employed conditions are completely changed. It is now only necessary to remember that all light reaching a single point X on the stage will, before refraction by the condenser, have passed through a second point Y, X and Y being conjugate points with respect to the lens system of the condenser. If the condenser is accurately focused on the slide, Y is at infinity and a beam of initially parallel rays is condensed to X (fig. 2*a*). If the object lies within the focus of the condenser the point Y is virtual and the illumination at X is derived from an initially convergent beam (fig. 2*b*). If now a screen is inserted at S_1, S_2, or S_3 it will clearly intercept the light reaching X from the right so that the conditions of illumination of the grain are now similar to those illustrated in fig. 1 obtained by using parallel light and an inclined mirror. Which side of the grain appears to be illuminated is then determined as before by the relative refractive indices of crystal and mounting medium.

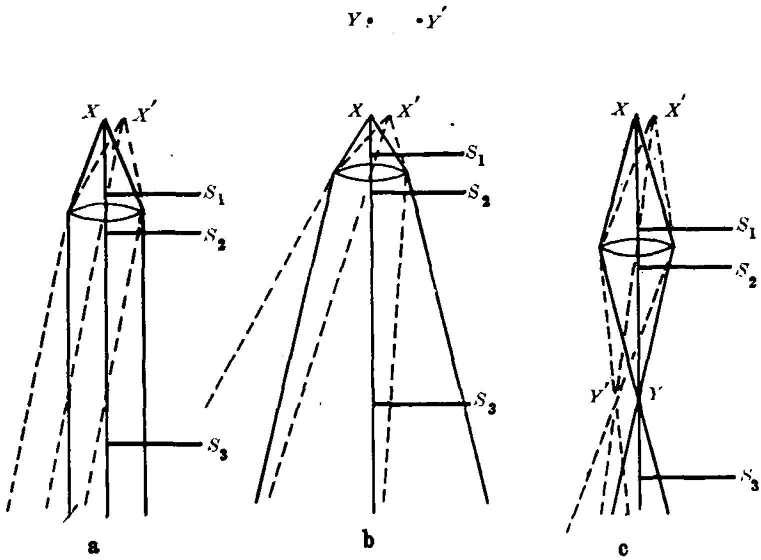


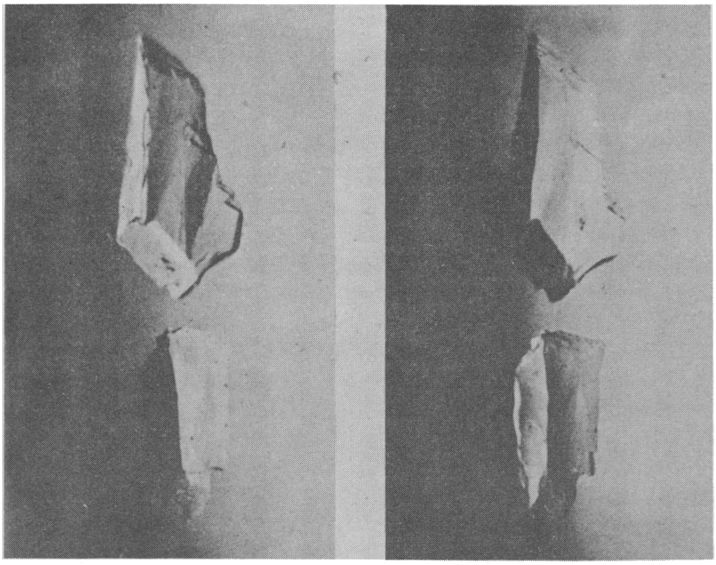
FIG. 2. Illumination of points on the stage with the condenser: (*a*) in focus on the stage; (*b*) raised; (*c*) lowered.

Let us now consider the effect of lowering the condenser so that the object X is considerably above its focus (fig. 2*c*). A screen placed at S_1 or S_2 will, as before, cut off light reaching X from the right, but if the screen is placed at S_3 conditions are precisely reversed and light from the left will be intercepted. It is clear that the transition between these two conditions will take place when the screen occupies the position Y, and that in this position a sharp image of the edge of the screen will be visible in the microscope.

If the distance through which the condenser is lowered be carefully regulated, Y can be adjusted to be at a convenient distance of, say, a few centimetres below the condenser, and the reversal of the effect obtained by placing the screen first above and then below Y, the condenser remaining unmoved, can then be clearly observed. Alternatively, if the screen is inserted at S_3 and the condenser is then lowered, a position will be found in which the image of the screen is sharply focused and on further lowering of the condenser the reversal will again be obtained.

The photographs shown in fig. 3 were obtained in the latter manner. The upper grain is fluorite and the lower quartz, with refractive indices of 1·43 and 1·55 respectively, and the mounting medium is an oil of refractive index 1·50.

For fig. 3*a* the condenser was raised as high as possible and a screen was introduced from the right in a position corresponding roughly to S_3 of fig. 2*b*. Light is therefore falling on the left-hand side of each grain and accordingly the quartz



(*a*) (*b*)

FIG. 3. Fragments of fluorite (upper) (n 1·43) and quartz (n 1·55) in oil (n 1·50). Screen inserted below condenser from right. (*a*) Condenser raised; (*b*) condenser lowered.

appears illuminated on the right, the fluorite on the left. (The optical train of the camera produces an image reversed compared with that observed in the microscope, and therefore of the same sense as that which would be seen if the slide was viewed directly with the naked eye.) For fig. 3*b* the screen occupied the same position, but the condenser was lowered to correspond to the condition shown in fig. 2*c*. It will be seen that the illumination of the two grains is now reversed.

Some further points calling for attention arise when several crystal grains in different parts of the field of view are considered simultaneously. We have seen above that for the Schroeder van der Kolk effect to be observed it is necessary that the screen should eclipse part, but not all, of the light reaching the grain considered. This may be expressed alternatively by saying that the grain must lie within the penumbra of the image of the edge of the screen as seen in the microscope. The breadth of this penumbral region under different conditions may be determined by considering the light reaching a point X' close to X on the stage. The rays reaching such a point are shown as dashed lines in fig. 2 and it is clear that in the cases shown in figs. 2*a* and 2*c* these rays are partially eclipsed only when the screen is at S_1 or S_2. In other words X' lies within the penumbra when the screen is at S_1 or S_2 but not when it is at S_3. In practice it is rarely convenient to insert the screen either at S_1 (because the condenser is normally very close to the stage), or at S_2 (because of the space occupied by the polarizer), so that conditions necessarily approximate to those obtaining with the screen at S_3 and the effect is confined to grains in a narrow penumbral region. Under the conditions shown in fig. 2*b*, however, i.e. when the condenser is raised, it is clear that X' lies within the penumbra even with the screen at S_3 so that the penumbral region is of considerable width in this case: it can, in fact, be made to cover the whole field of view if the condenser is sufficiently close to the stage. It is best, therefore, to raise the condenser as high as possible when studying the effects on grains in different parts of the field, e.g. when distinguishing between orthoclase and untwinned basic plagioclase in a section or in grains mounted in balsam.

A further point which appears from fig. 2*c* is that, no matter whether the screen is placed at S_2 or S_3, X' lies in a region of greater illumination than X. In other words, although individual grains are illuminated from opposite sides in the two cases, the dark and light sides of the field of view are not reversed, as is clearly seen in fig. 3. It is therefore manifest that the light does not necessarily reach the grains from that side of the field which appears illuminated.

It is also to be remarked from fig. 2 that the rays reaching the different points X, X', &c., are derived from bundles of rays initially incident on the condenser in widely different directions. If it is desired to make observations at more than one point in the field of view it is therefore imperative that an extended source of illumination be employed, and this can be achieved by the use either of the sky or of a microscope lamp of conventional type placed as close to the mirror as possible. If the lamp is situated at any considerable distance it will not subtend a sufficiently large angle at the condenser and only a small region in the centre of the field will be illuminated. It is clear that when the condenser is in use inclining the mirror cannot influence the obliquity of the rays reaching any given grain and can only determine the part of the field which is illuminated.

We may summarize our conclusions by saying that if the Schroeder van der Kolk method is employed on a microscope without condenser the oblique illumination should be obtained by removing the polarizer and swinging the mirror some distance to one side. This can be most effectively done if the mirror is fitted on a knuckle joint. If a condenser is fitted to the microscope it should be raised as high as possible and an extended source of light should be used. If a screen is then inserted into the path of the light at any convenient point below the condenser, but preferably as close to the condenser as possible, unambiguous results will be obtained. It is easy to remember that with the condenser raised, a crystal of higher refractive index than the medium appears light on the light side of the field. If, however, the condenser is lowered, ambiguities may arise and care in interpreting the observations is necessary. In the case of microscopes of the Dick type, a screen inserted between the polarizer and the mirror is well above the conjugate focus whether the fixed condenser is used alone or with the addition of the upper part. The reversal of the phenomenon which occurs when the condenser is lowered cannot, therefore, take place with these microscopes.