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# *An improved form of petrological microscope: with some general notes on the illumination of microscopic objects.*

(*With Plate VIII.*)

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[Read March 15, 1910.]

## Introductory.

IT is more than twenty-one years since Mr. Allan B. Dick communicated a description of the microscope, now generally associated with his name, to this Society.[1] The instrument is familiar to all mineralogists, and it will suffice to say that the main feature consisted in having the polarizing and analysing prisms arranged so that they can be rotated simultaneously, instead of turning the object on the stage between them. The rotating stage is never very satisfactory, especially when it is desired to examine minute crystals in convergent light. In two pamphlets,[2] published later, Mr. Dick extended his description of the instrument and gave some methods of using it. He intended the microscope as a 'Student's instrument' suitable for work in all branches of science, and, with this view, he desired to fix its

[1] A. B. Dick, 'A new form of microscope.' Mineralogical Magazine, 1889, vol. viii, pp. 160–163.

[2] A. B. Dick, 'Notes on a new form of polarizing microscope,' London (J. Swift & Son), 1890. 'Additional notes on the polarizing microscope,' London (J. Swift & Son), 1894.

type in not too expensive a form. How well he succeeded in this may be judged from the fact that hardly any change has taken place during all the years that have elapsed. The most important improvement consists in fitting a condenser with an aperture suitable for use with immersion-lenses. The price of the small model, complete with lenses, amounts to close on £30, and would now appear to place it quite beyond the range of 'Student's instruments'.

The main defect of the instrument as placed on the market lies in the condenser fittings. The top lens of the system is fitted in a bar sliding in the stage, while the lower part is fixed to the top of the polarizer fitting, or placed in a mount that enables us to focus the condenser. The lens in the sliding bar is very liable to get scratched, while the other lenses are difficult to remove from the axis when it is desired to use parallel illumination. The use of immersion fluids is attended with a good deal of mess, and, unless the stage is carefully cleaned afterwards, the sliding bar may become clogged.

Another model embodying Mr. Dick's principle, but possessing different sub-stage arrangements, was brought out a few years ago by Messrs. R. & J. Beck under the name of 'The London petrological microscope'. The condensers could be focused by means of a rack and pinion, while the top lens of the system, instead of sliding in the stage, was pivoted so that it could be swung out of the axis when not required. The whole condenser could be removed, but the change from convergent to parallel illumination was not effected with the ease desirable in petrological studies. The arrangements were better suited for the use of immersion fluids; but practically no advantage was gained, as the aplanatic cone of the condenser was only 1·0 N.A. and consequently unable to fill the ordinary objective of about 1·3 N.A. when examining minerals in convergent polarized light. The stand was of the continental type and very heavy.

In one of his pamphlets on the microscope[1] Mr. Dick stated that more costly forms of the instrument had been made in which the stage rotates, the sub-stage can be centred and is moved up and down by rack and pinion, while the condenser and polarizer swing, separately or together, out of or into the axis of the instrument. For ordinary work he did not consider that there was any advantage in these appliances, though for special work they are desirable. No figure appears to have been given of this instrument and it was not placed on the market.

[1] A. B. Dick, 'Additional notes,' (1894), preface.

## The New Model.

When ordering a microscope for the Sudan Government, it occurred to me that the ordinary form of Dick's microscope was capable of improvement, and I desired an instrument in which the sub-stage permitted:—

(1) of an easy change from parallel to convergent illumination by having the condenser systems mounted so that they could be removed from or introduced into the axis of the instrument at will:

(2) the use of any condenser within the limits of the 'universal thread'.

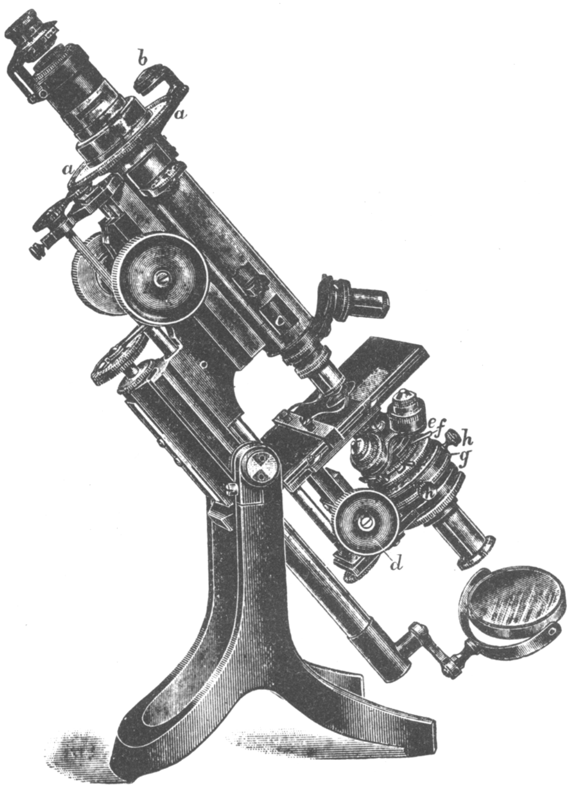



Fig. 1.[1]—Improved form of Mr. Dick's microscope with focusing sub-stage.

[1] The block for this figure has been kindly lent by Dr. A. E. H. Tutton, F.R.S., with the permission of Messrs. Macmillan & Co., Ltd., the publishers of his forthcoming book on crystallography.

These requirements were effected in a very simple way by placing the polarizer on a focusing sub-stage with a nose-piece to carry the condenser systems. The latter idea was taken from an instrument designed by Dr. J. S. Flett and built for the petrological department of H.M. Geological Survey. In the ordinary model means are provided in the shaft, which connects the analyser and polarizer, for taking up movements due to focusing of the objectives, and these means were adapted to take up those due to the focusing movements of the sub-stage as well.

Suggestions on these lines were put into the hands of Messrs. J. Swift and Son, who worked out the mechanical details and produced the instrument shown in fig. 1.

Mineralogists are generally familiar with the ordinary model, and it is therefore unnecessary to say more than a few words about the present instrument. The graduated circle (*a*) instead of being placed below the stage is now connected with the eye-piece and this obviates any play, due to cog-wheels, between the cross-wires and the graduations. The sub-stage is fitted with centring screws (*h*), an iris-diaphragm (*f*), and means of introducing coloured screens or stops for oblique illumination. A triple nose-piece is convenient, as this allows the use of high and low-power condensers, besides leaving an empty nozzle through which parallel light can pass freely along the axis of the microscope. The instrument is figured with a second analyser in a sliding fitting (*c*) just above the objective. This has been added for photographic purposes, but if the full advantage of it is to be gained there should be a rotating stage to enable the worker to orientate his section in the polarized light.

## Illumination of the Object.

A few remarks on the subject of illumination may not be out of place here, since the new model gives the worker a greater scope for variation than do some of the older forms of petrological instrument. There are numerous textbooks on the microscope that deal with the subject, but any that I have seen treat it merely from the standpoint of obtaining the finest definition and the greatest resolution. They do not, as a rule, consider the nature of the object and the rôle that differences in refractive index, either in the object itself or between it and the surrounding medium, may play in helping us to understand its constitution.[1] In mineralogical studies the microscope is used not merely as

[1] The matter, however, is referred to both by E. Weinschenk in his 'Anleitung zum Gebrauch des Polarisationsmikroskops' (2nd edit., Freiburg i. B., 1906), and by H. Rosenbusch and E. A. Wülfing in their 'Mikroskopische Physiographie der petrographisch wichtigen Mineralien' (Stuttgart, 1904).

a means of magnifying objects, but for the purpose of distinguishing between substances of different optical properties, and we generally have to make use of these differences to enable us to recognize the form of the various constituents of the object under examination.

Textbooks on microscopy tell us of the importance of seeing that the back lens of the objective is properly filled with light, and the evils attending the use of narrow cones are duly emphasized.[1] We are, however, left quite in the dark as to the defects of such illumination when used in the study of objects composed mainly of anisotropic substances. Good 1-inch and ⅔-inch objectives of 0·3 N.A., such as are commonly employed in the study of rock-sections, include an angular cone of light of about 20° in a mineral such as quartz, and it is obvious that if the birefringence of our object is at all marked, there may be considerable differences in the retardation and interference-colours produced in the various parts of even such a narrow cone.

If we place a section of fairly coarse-grained marble on the stage, focus it, and so adjust the illumination that the back lens of our 0·3 N.A. objective is filled with light, then examine this with the analyser in position, we see that the light transmitted by a single crystal is not uniform, but is variously coloured. The cone of illumination may, in fact, include one of the bars of the uniaxial figure, part of which may in consequence be observed by suitable methods. Such is the assortment of variously retarded rays that the eye-piece is presented with for the formation of the image when using the full aperture of our low-power objective, and it will be readily understood that the interference-tints are much paler in consequence. If we close the iris-diaphragm, and thus reduce the angle of the cone of light admitted to the objective, the interference-colours become very much brighter in the case of calcite, and there is a distinct difference in the case of a less strongly birefringent mineral such as olivine. The colours obtained as a result of using a cone of light often simulate those of a different order from that which would be

[1] The following quotation from Dr. E. J. Spitta's excellent book, 'Microscopy,' London, 1907, p. 177, will serve as an example: 'For example, bacteriologists seem mostly agreed that the bacillus tuberculosis is probably not an organism likely to have a capsule under ordinary conditions, and yet with a narrow cone, whether the specimen be stained or unstained, a very pronounced encircling capsule, as bright and clear as possible to the eye, appears in *every case*; yet, as the cone is steadily and slowly increased, so does this mysterious capsule disappear.' To the mineralogist, familiar with Becke's white-line effect, such a phenomenon offers no difficulty, and indeed is often sought for as a means of diagnosis. It is clear, however, from the sections dealing with polarized light that our author is not very familiar with the use of the microscope in petrology.

obtained with parallel light. The ordinary rock-slice, as now prepared, is about 0·015 mm. in thickness (olivine showing straw- to reddish-yellows) and the carbonates show colours of the third to fourth order in parallel light, but with a cone of 0·3 N.A. the tints become so pale that they might in some cases be mistaken for white light of the higher orders.

An experiment with oblique illumination may help to remove any remaining doubt as to the undesirability of filling the back lens of the objective with light if the interference-colours are to be examined. A suitable stop is placed in the fitting provided for the purpose so that only an oblique beam is admitted to the objective, forming a bright spot on the periphery of its back lens. Such a stop, in the form of a card-board disc with a hole about $\frac{1}{8}$-inch from the centre, can easily be prepared for the purpose; those provided by the makers may prove to be unsuitable when such a narrow cone of light is in use. Now, replacing the eye-piece and examining the slice of marble between crossed nicols, each grain of calcite shows different colours according to the direction in which the beam happens to be traversing the crystal. By rotating the stop we can alter the direction and, as we do so, the interference-colours are changed. In this way it is possible to produce an almost kaleidoscopic effect without turning the nicols or moving the specimen—simply by rotating a stop with an eccentric aperture beneath the condenser. These changes are due to the fact that we are using different portions of the optic figure, as seen in the back of the objective, for each particular grain, and this will vary according to the crystallographic direction in which it happens to be cut. If a section is chosen that gives a figure in the back lens of the objective such that the optic axis is just beyond its limits and the nicols are placed so that one of the bars lies across the field, it will be understood that our eccentric stop only admits a beam corresponding to a small portion of the periphery of the figure. As the direction of the beam alters, the colours may change from white of the first order to orange of the second order, and the section will actually extinguish in two directions of the beam, owing to the optic axial bar that crosses the field.

If convergent light is used, it is only possible to obtain good compensation by means of the quartz-wedge when the mineral has comparatively low double-refraction.

The study of pleochroism does not appear to be affected to the same extent as that of the interference-colours by the use of convergent light, and this, no doubt, is due to the fact that it depends on the direction of the vibrations and not so much on the path of the rays in the crystal. If, however, the optic axis of a strongly pleochroic mineral lies just within the angular field of the objective, a marked difference of colour can be seen, due to the plane-polarized light traversing the mineral as the extraordinary ray in one part of the cone and as the ordinary ray in another. The same sort of thing occurs in the case of sections almost perpendicular to the optic axis in a biaxial crystal, and there can be no doubt that it must be better to avoid the possibility of these effects by using parallel light for the examination of pleochroism. If we use convergent illumination, the image of the crystal is built up of a mixture of differently affected rays which drown the normal result.

### Refractive Index of the Object.

The necessity of using parallel illumination for the examination of refraction has always been realized, and in the ordinary model the nearest approach to this is obtained by lowering the condenser-lens and closing the iris-diaphragm. This involves some loss of light, and it is far better to be able to throw the condenser out of the axis, as we are able to do in the new model. To the practised eye refractive index is a most important guide in the distinction of minerals, and as convergent light tends to obliterate the effects due to it, workers using such illumination may be misled, unless they continually reduce the cone by means of the iris and so check their observations.

The expression 'parallel illumination' is used here, as elsewhere in this paper, in contradistinction to convergent illumination and not in the strict sense of the term. For ordinary purposes a cone of from 5° to 10°, only filling about half the back lens of the objective, is sufficiently narrow to give good results. This can be obtained either with a condenser or directly from a source of light, such as a window, which subtends about that angle. The latter always seems to me to be the most comfortable to work with; it appears to give more light, as well as rendering differences of refraction clearer, than a similar cone produced with the aid of the condenser.

### The White-Line Effect.

The ordinary explanation of Becke's white-line effect involves the use of convergent light, though it is explained [1] that too large a cone will

[1] H. Rosenbusch and E. A. Wülfing, 'Mikroskopische Physiographie der petrographisch wichtigen Mineralien,' Stuttgart, 1904, vol. i, pt. 1, p. 263. I have not been able to refer fully to the original papers, but a full account of them appears to be given in this textbook, which includes references to the work of other authors bearing on the white-line effect, notably W. Salomon and C. Viola.

drown it, and practically the only case considered is that in which the line of junction is normal to the plane of section, as shown in fig. 2.

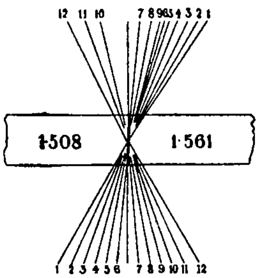



FIG. 2.—Old explanation of the white-line effect.

In practice, however, we make use of the nearest approach to parallel light that our instruments admit of, and as a line of junction normal to the plane of section must be extremely rare, we must seek some modification of the explanation usually given. Mr. E. M. Anderson, of H.M. Geological Survey, pointed this out to me some years ago, and I am very much indebted to him for permission to introduce the following explanation which is on the lines of the one he gave me.

If the junction of the minerals is inclined to the plane of section, we are at once presented with two cases according as the more highly refracting or the less highly refracting medium overlaps the other. In

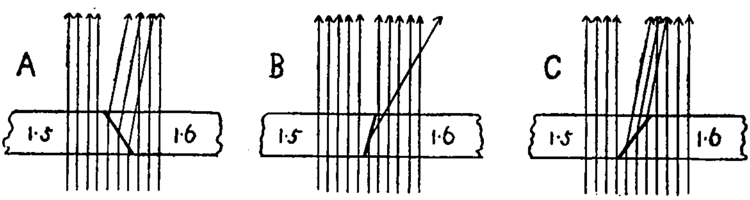



FIG. 3.—New explanation of the white-line effect.

the first case, shown diagramatically in fig. 3 A, rays normally incident on the section enter the denser medium at the inclined junction and are bent towards it. In the second case, the rays, on reaching the less dense medium, are either totally reflected back into the denser one, fig. 3 B, or they are refracted towards it on traversing the junction as shown in fig. 3 C. In whatever direction the junction happens to be inclined, a beam of light on traversing it is always bent towards the more highly refracting substance.

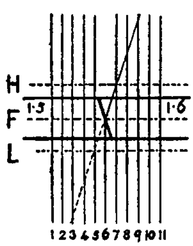



FIG. 4.—New explanation of the white-line effect.

This, however, does not entirely explain the white line seen parallel to the junction when the microscope-tube is either slightly raised or lowered, but it will be made clear on referring to the diagram, fig. 4, where rays of light, numbered 1–11, are shown traversing a section containing an inclined junction between two minerals of different refractive index. Ray 6 meets the junction and is bent towards the more highly refractive medium on the right, while the rest of the rays traverse the section without being bent. If the focal-plane of the objective lies in about the position of the dotted line *F*, the section appears in focus and no white line is seen at the junction. When the microscope-tube is raised, so that the focal-plane occupies the position *H*, a white line is seen on the side of the more highly refracting mineral; this is due to the fact that rays 6 and 7 are combined and brought to a focus as if they originated in their crossing point which lies on the focal-plane. If the tube is still farther raised, the point at which ray 6 meets the focal-plane moves on to the right and it is combined successively with rays 8 and 9, so the white-line effect becomes more remote from the junction. When, on the other hand, the microscope-tube is lowered, so that the focal-plane of the objective assumes the position *L*, the white line is produced by the combination of the deviated ray 6 with ray 5, as if they originated at a point in the focal plane. The position of this point is where the trace of the deviated ray would cross ray 5 if produced backwards as shown by the dotted line in the diagram. If we continue to lower the tube, the white line shifts to the left, as it is due to the successive combinations of 6 with 4 and 6 with 3 The inversion of the image by the microscope does not affect this explanation.

The case of a junction perfectly normal to the plane of section is probably very rare, but with ordinary methods of illumination a certain amount of light would meet it obliquely and be deviated towards the denser medium after the manner shown by Becke (fig. 2).

We may now apply these conclusions to a special case, and for the sake of simplicity choose contiguous sections of the mineral quartz, one cut normally to the optic axis and the other parallel to it. The light transmitted by one section is subjected to a retardation corresponding to the ordinary ray, while it may vary in the other section between limits corresponding to the refractive indices $\omega = 1{\cdot}5442$, and $\epsilon = 1{\cdot}5533$, according to the direction of vibration. If we set the polarizer so that the plane of vibration is parallel to the optic axis, we get the greatest difference between the retardations in the two sections, $\epsilon - \omega = 0{\cdot}0091$, since the beams transmitted by the two sections correspond to the ordinary and extraordinary rays respectively.

The effects of variously inclined junctions between two such sections are easily calculated and the results for a series ranging from an inclination of 60° towards the less dense to 60° towards the denser medium have been carefully plotted. In the diagram, fig. 5, the denser medium is always supposed to lie on the right-hand side of the junction and, in each individual case, the inclination of the junction and the deviation produced by it in a ray normally incident on the section are given. It is seen, beginning at the left of the diagram where the denser medium overlaps the less dense with the junction inclined at 60°, that the amount of deviation increases until the junction becomes normal to the plane of section. After passing the normal position, we have the less dense medium overlapping the other and the deviation, now due to total reflection, begins at zero and increases fast until the critical angle is reached at 83° 48′; it then falls immediately from over 12° to about 6°

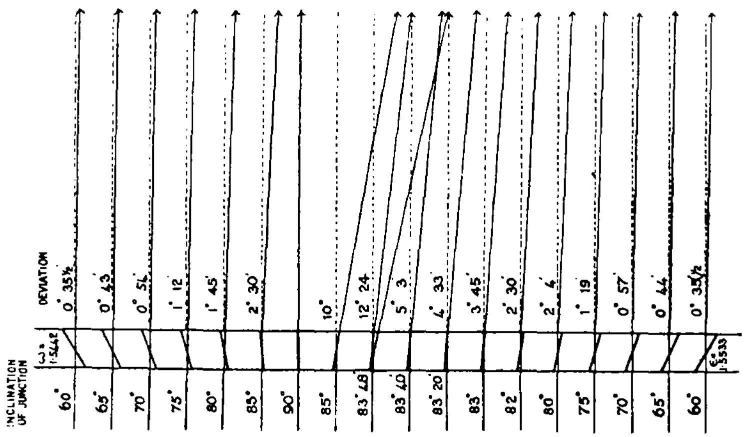



FIG. 5.—Deviations of rays at variously inclined junctions of quartz crystals.

and afterwards decreases rapidly, so that a junction inclined at 60° produces about the same amount of deviation whichever way it happens to lie.

In the case under consideration, the difference in retardation between the ordinary and extraordinary rays, though comparatively small, is enough to give a pronounced white-line effect; and it appears that a very small amount of deviation is sufficient to produce it, certainly less than half a degree in amount. We have seen that the deviation varies considerably, and with contiguous quartz crystals may amount to over 12°. This is sufficient to throw the beam outside the limits of an ordinary low-power objective and leave the junction dark, if it were illuminated by strictly parallel light. The best white-line effect is no doubt produced when the deviation is well marked.

A practical application of the principles involved can be made in the comparison of mediums of closely similar refractive index, or, where the junctions are few and bad, by the use of oblique illumination. It is obvious that, if we can make use of a beam incident in the vicinity of the critical angle, the delicacy of the test may be greatly increased. This can be done by using a condenser with a small movable stop beneath. It might be desirable to have a special fitting to enable the stop to be traversed across the condenser in every direction, but the expense of such a refinement is hardly justified by the amount of use likely to be made of it. With the aid of an eccentric stop in the rotating fitting beneath the stage we can obtain, without much trouble, any incidence of which the condenser is capable.

If, in addition to restricting the illuminating cone, a stop is introduced above the section, the reaction of the junction can be made very clear by cutting out either the direct light passing through the section alongside it or the deviated beam. A stop may be introduced for the purpose in any one of three positions. Either of the positions immediately above the eye-piece or below the objective is convenient, because the stop and section are seen in their proper relations to one another. The third position, just above the objective, is not so convenient, as the image of the object is reversed, while that of the stop is not, and consequently it appears to act in the reverse way to those introduced either below the objective or above the eye-piece. A piece of apparatus, known as a refractometer, designed in 1885 by Exner, may be used to stop out part of the emerging pupil above the eye-piece, but for ordinary purposes a piece of card or stout paper is quite serviceable. A stop placed just in front of the objective seems more effective, as the rays are spread farther apart in this position; but it is necessary to place it above the eye-piece in the case of high-power objectives, which do not admit of any stop being used between their front lens and the object.

The rays of light passing through the junction of two minerals are deviated towards the denser, and it may easily be remembered that the more highly refracting minerals stand out with a light margin towards the stop and a dark one away from it. In illustration of this the photographs in Plate VIII have been taken. They were done by an ordinary microscope fitted with an eye-piece and a 1-inch objective. The stop took the form of a wire, 0·74 mm. in diameter, placed just in front of the objective, and appears as a broad bar across the picture. The line at right angles to it is the image of one of the cross-wires of the eye-piece. The illumination was in the form of a cone as narrow as was compatible with a reasonable exposure and small enough to allow the stop to appear clearly. It was provided by focusing the image of a flame on a small hole in a diaphragm placed near the focus of a lens which projected the light along the axis of the microscope. The stop subtended an angle of about $3\frac{1}{2}°$ at a point in the focal-plane of the objective, for this had a working distance of 12·5 mm. and the wire was immediately in front of it. Knowing this angle, it appears that the cone of illumination had an even smaller one, for the stop would have been obliterated had the angle of the cone exceeded 2°. A polarizer was placed in the axis and the vibration-direction was adjusted in each case so as to show the differences of refractive index most clearly.

Photographs Nos. 1 and 2 show the junction of two quartz crystals: in the first, the direct light is cut off from its neighbourhood; while in the second the junction appears dark, owing to the deviated rays being intercepted while the direct light passes. The photographs are sufficiently sharp to show the varying inclinations of the junction by its differences in breadth. The next two photographs are of a quartz-mosaic. In No. 3 the section is in focus and the more highly refracting grains stand out along both sides of the stop; but in No. 4 the microscope-tube has been raised slightly and the white-line effect is seen just inside the margins of the more highly refracting grains all over the field of view. The actual boundaries appear as black lines because the deviation of the ray has left them in darkness. No. 5 is another view of a quartz-mosaic, and here, as in No. 3, the highly refracting grains are seen standing out along the sides of the stop. In both cases the varying inclinations of the junctions are indicated by the different breadths of the light and dark lines. The dark patches towards the margins are due to the presence of cloudy felspar.

No. 6 shows a plagioclase crystal cut nearly perpendicularly to the brachypinacoid, so that the conditions are favourable to the production of considerable deviations at the junctions of the twin-lamellae, and consequently some of their boundaries are clearly seen right across the bar.

If substances differ much in refractive index the rays passing through the junction may be deviated quite beyond the scope of an ordinary low-power objective, but they can often be caught by one of larger aperture. It is, therefore, an advantage to have objectives of large aperture even though the cone of illumination be restricted.

Becke[1] has pointed out the fact that the white-line effect is less distinct if the mineral section is embedded in a medium of markedly lower refractive index. The same may be said of a medium with a markedly

[1] H. Rosenbusch and E. A. Wülfing, loc. cit., p. 266.

higher refractive index, as in both cases a good deal of dispersion takes place at the surfaces of the section and this tends to mask the deviated rays. It is, therefore, important to have the section mounted in a substance of about the same index as those of the minerals it is desired to compare.

## Suggestions for Further Improvements in the Design of the Microscope.

The use of the instrument described in the first part of this paper shows that there is still something left to be desired.

The field of view, as in the older model, is small when compared with that of an ordinary microscope. This, I believe, is mainly due to the fact that the nicol is placed above the eye-piece instead of being as close as possible to the objective. There does not appear to be any practical difficulty in altering the position of the prism, and in fact it has already been done in an instrument made by Messrs. Voigt and Hochgesang of Göttingen. It would probably be best to enclose the nicol-carrier in a large body-tube, the whole of the inside of which would rotate with the eye-piece. Provision must, however, be made for the insertion of the quartz-wedge, &c., between the nicols.

The gearing which connects the analyser and polarizer is open to objection because the vertical shaft restricts the size of the stage, unless a train of cog-wheels larger in size than those generally provided is used at each end to connect with the nicols. It has been objected that, even with the best workmanship, there is sufficient back-lash to vitiate some observations between crossed nicols. Practically the whole of this back-lash can be made to compensate itself if the motion is imparted to the vertical shaft, when the lags in the trains of wheels equalize one another. It appears that a milled head has been provided in some instruments for this purpose. If a flexible shaft could be made use of to connect the nicols it would obviate the necessity for trains of cog-wheels and allow the use of a larger stage. Flexible shafts are composed of two spirals, wound in opposite directions one inside the other, and are only meant to be used in that direction of rotation which compresses them together by tending to unwind the inner and wind up the outer spiral. For our purpose it is necessary to have a fairly rigid shaft capable of rotation in either direction, and this might be attained by the use of three spirals, so that the central member would tend to press either against the inner or the outer one according to the direction of rotation. I do not know whether such a device would be sufficiently rigid to be of practical use, but no doubt it would be worth a trial.

A mechanical stage capable of rotation is very useful, and might be fitted to the instrument if the nicols were connected by means of a flexible shaft. It would be an additional advantage if the stage could be unshipped from the brackets, so as to admit of the use of a goniometer. If the stage does not rotate, it should be of the horse-shoe form, as this is convenient when using immersion liquids.

In conclusion, I do not apologize if ground has been traversed that has been dealt with by others before, as this paper has been written in Khartoum where no mineralogical library exists. If such investigations have been made, they do not appear to be referred to by the standard textbooks which I have at hand.

It is with pleasure that I record my indebtedness to Dr. J. S. Flett, of H.M. Geological Survey, for the way in which he superintended the construction of the instrument and helped me in the selection of lenses, &c. As a colleague I worked under his guidance at Jermyn Street in London, and learnt something of his practical improvements in the design of petrological microscopes. To Messrs. J. Swift and Son, the makers of the instrument, I am indebted for the skill with which the design was carried out and its details modified as necessity arose.

Finally, I take the opportunity of again recording my thanks to my former colleague, Mr. E. M. Anderson, in connexion with the explanation of the white-line effect which he has so kindly allowed me to introduce.

## EXPLANATION OF PLATE VIII.

(All the figures are magnified 30 diameters.)

FIG. 1. Junction of two quartz crystals. The direct light is cut off by the stop and the junction appears light on a dark ground. Rannoch Muir granite, ¾ mile south-south-west of Kingshouse, Glencoe, Argyllshire.

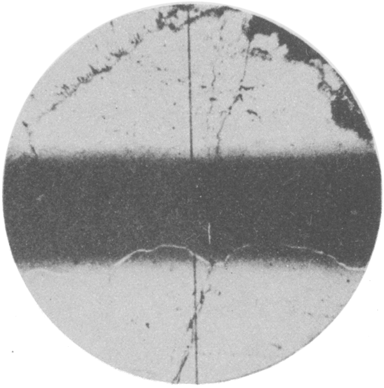
„ 2. The same junction as in fig. 1, but the deviated ray is cut off, so that the junction appears dark on a light ground.

„ 3. Quartz-mosaic, which shows the more highly refracting grains standing out along the margins of the stop, with light margins towards it and dark ones away from it. Pegmatite-vein in gneiss, Glen Mor, Glenelg, Inverness-shire.

FIG. 4. The same section, but as the microscope-tube has been raised it is not in focus. The white-line effect, just inside the margins of the more highly refracting grains, is seen all over the picture, while the actual junctions of the grains appear as dark lines.

,, 5. Quartz-mosaic, showing highly refracting grains standing out along margins of stop. The varying inclinations of the junctions are clearly indicated by the different widths of the light and dark margins. Different part of same slide as in fig. 3.

,, 6. Twinned felspar. The junctions of the albite-lamellae are shown. Tonalite, Coupall river, near Kingshouse, Glencoe, Argyllshire.



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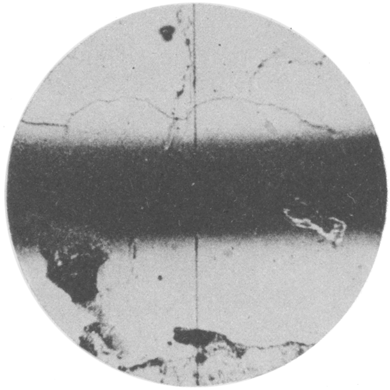
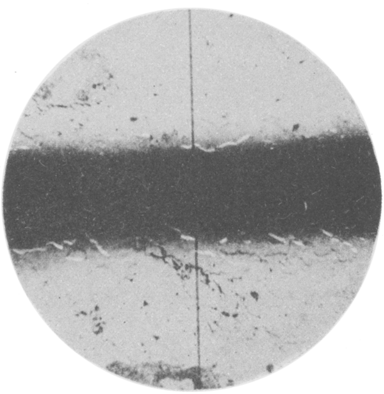


2



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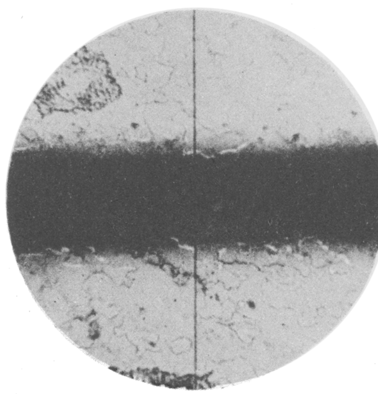

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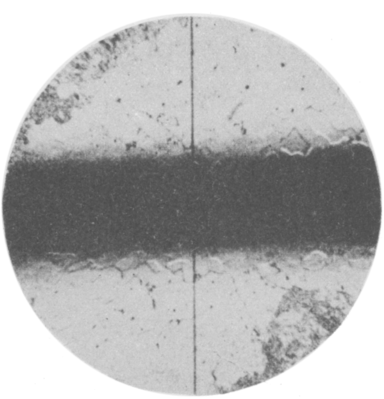

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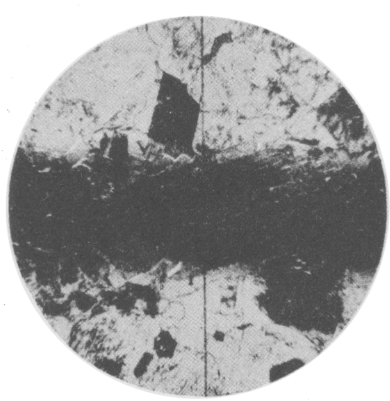

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G. W. GRABHAM: ILLUMINATION OF MICROSCOPIC OBJECTS.