THE USE OF BECKE LINE COLORS IN REFRACTIVE INDEX DETERMINATION

R. C. EMMONS AND R. M. GATES, *University of Wisconsin, Madison, Wisconsin.*

ABSTRACT

The dispersion of immersion liquids is generally much greater than that of most minerals of the same refractive index. Colors appear in the Becke line when the liquid and mineral dispersion curves intersect. The colors produced offer a guide to the wave length for which the liquid and mineral have the same refractive index. From the Becke line colors the refractive index of the mineral for the *D* (589 mμ) line can be estimated with accuracy better than ±.002.

Immersion liquids customarily used are selected among other things for their low dispersion (1). The purpose of such a selection is to give the sharpest possible Becke line with white light, meaning one without a pronounced color fringe. Outlined here is a method employed for many years at the University of Wisconsin according to which the detailed appearance of the Becke line colors is used to extend the accuracy and applicability of the method. Specifically, not only do the colors of the Becke line close the gaps between liquids but they also serve to give an extrapolation which enables the operator to estimate the values of proximate indices in related extinction positions.

Becke line colors are explained by the difference in slope between the liquid and mineral dispersion curves and their point of intersection (Fig. 1). In this figure, the liquid and *Y*-ray of the mineral agree in refractive index for wave length 550 mμ. For the shorter wave lengths the liquid is higher in refractive index than the *Y*-ray and for the longer wave lengths the liquid is lower in refractive index than the *Y*-ray. Hence, for the wave lengths shorter than 550 mμ the Becke line will move toward the liquid and for the longer wave lengths the Becke line will move toward the mineral by the customary raising of the microscope tube. But the amount of apparent movement of the Becke line depends as always on the refractive index difference and the refractive index difference is greater for the extremes of wave length. This yields the spectral spread usually observed in the Becke line. If the slope of the dispersion curve of the liquid should agree with that of the mineral, there is, of course, no color in the Becke line. To the extent that the slope of the liquid dispersion curve is greater than that of the mineral a spread appears in the Becke line colors—the spread being greater with a greater slope difference. In general, the lower the mineral and liquid refractive indices, the more nearly the slopes of the dispersion curves empirically agree. And correspondingly, although the dispersion curve slope for minerals usually increases with an increase in refractive index, the slope increase for liquids is much greater. Hence, colors appear more clearly and more discretely in the Becke line in the study of minerals of high refractive index, when liquid immersion media are being used. Further, in the region of average refractive indices (1.55) the Becke line colors consist ordinarily of yellow and blue whereas in the higher values (1.70) an almost complete spectrum can usually be seen. This is to be explained by the principles outlined above. Namely, when the difference in the slopes of the two dispersion curves is sufficient, the spread in the spectral colors is strong enough to overcome blending of colors which takes place in the lower index range.

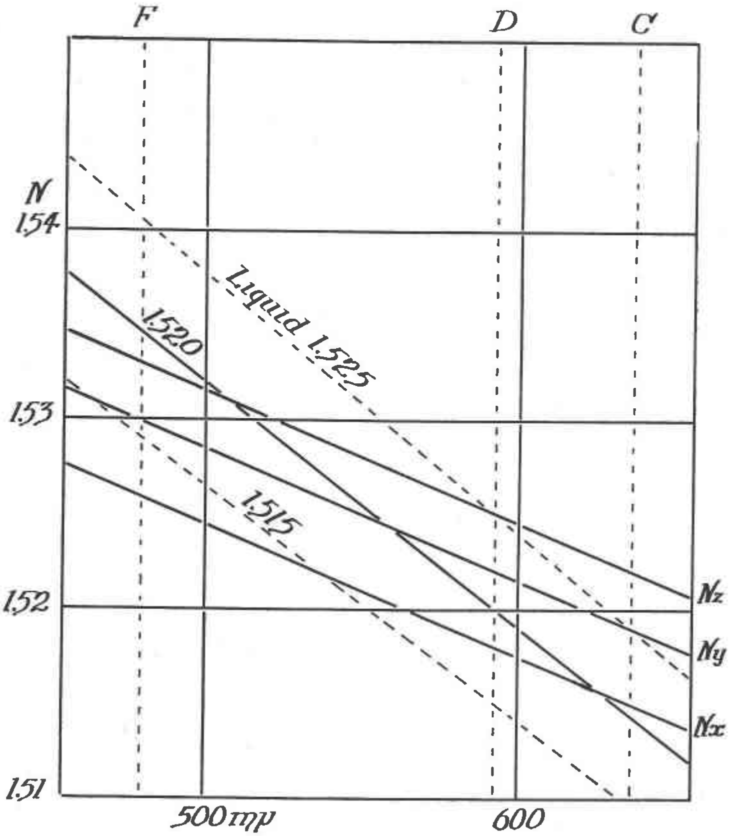

FIG. 1. THE RELATIONSHIP BETWEEN THE DISPERSION CURVES OF MICROCLINE AND APPROPRIATE IMMERSION MEDIA. The overlap in the range of visible light is sufficient to permit all three indices of the average mineral to be determined in one mount in white light.

The refractive index spread acquired by a liquid through its dispersion is also brought out in Fig. 1. The preferred liquid for the mineral would, of course, be liquid 1.520. Also plotted in Fig. 1 in dashed lines are liquids 1.525 and 1.515. Both of these adjacent liquids overlap the dispersion curves of this, an average mineral. For desirable accuracy the refractive index values for any such mineral curves can be satisfactorily estimated essentially without extrapolation through this dispersion curve overlap. The gaps between liquids are literally closed. In the lower refractive index ranges (±1.40) suitable liquids have not been found to accomplish this—the dispersion curve slopes of liquids and minerals are too nearly equal.

The accuracy of a given refractive index determination by this method depends mainly on two things, (1) how close to the chosen wave length (usually 589 mμ) is the point of intersection of the liquid and mineral dispersion curves, and (2) how effectively the operator can use the available colors of the Becke line. For best results, aiming toward accuracy, two determinations should be made in adjacent liquids on one mineral refractive index curve thereby establishing its slope. Knowing the slope and assuming the slope of other rays of the same mineral to be essentially the same, then any point of intersection at any wave length on another refractive index curve, such as X or Z in Fig. 1, makes it possible to estimate those indices for the D line by drawing their curves parallel to the one in which two determinations are made. That is, it is not necessary to make any determinations for the D line itself by mixing liquids. It is desirable, however, to plot results on some such graph as that of Fig. 1, though with practice and for routine work the experienced operator does not do it. Also, the refractive index values of the liquid for other reference wave lengths such as F and C should be given on the bottle, the value for the D line being the liquid reference or tag.

To illustrate the application of the method four cases may be described.

1. In the case of Fig. 1 in which the liquid and the Y-ray of microcline agree in refractive index near the middle (550 mμ) of the visible spectrum, the colors of the mid spectrum do not appear since they undergo little refraction at the solid-liquid interface. The colors for the extreme wave lengths are refracted and therefore appear as narrow fringes. Since the slopes of the two dispersion curves are not greatly different at this position on the refractive index scale, these colors are only modestly spread and are therefore blended with adjacent colors of the spectrum. The effect is that of medium yellow and medium blue appearing on opposite sides of the interface.

2. The liquid and the Z-ray of microcline (Fig. 1) agree in refractive index in the blue region of the spectrum. The colors of the Becke line here

are rich blue or violet on one side of the interface and a very pale yellow on the other. Since the dispersion curves intersect in the blue, all colors on the violet side are segregated and can produce only a rich blue or violet color. On the other hand, the colors composing the yellow fringe consist of a large part of the spectrum and yield therefore a very pale yellow line.

3. Similarly, the liquid and the *X*-ray of microcline agree in refractive index in the red region of the spectrum and yield for the same reasons a yellowish brown or even a red fringe on one side of the interface and a very pale blue on the other side.

Since the standard record in determinative tables is preferably given for the *D* line, the refractive index of the mineral and liquid may be said properly to agree when the color fringes are rich yellow and pale blue. A brown or red fringe indicates that the mineral is lower than the recorded (*D* line) refractive index of the liquid. Similarly, fringes of medium yellow and medium blue or still more, pale yellow and rich blue indicate that the refractive index of the mineral is higher than that of the liquid. With practice the approximate difference between the refractive indices of mineral and liquid can be well enough estimated that for minerals of average birefringence, such as the feldspars, the refractive indices of more than one ray can be determined from a single mount. In instructing beginning students especially, great emphasis should be placed on the proper recognition of shades of color of the Becke line and their use in the extrapolation of refractive index values.

4. When the dispersion curves differ more strongly in slope as has been pointed out for the minerals of higher refractive indices, the application of the method is both easier and more accurate (Fig. 2). Since for high refractive indices the Becke line may show an almost complete spectrum, it is usually possible to recognize the matching color by scanning the colors seen. A part of the spectrum appears always on one side of the interface and another part on the other side. Between these little or no color is seen but can be readily named. It is the matching color for which the mineral and liquid agree in refractive index. The matching color is best seen when the grain is well below focus. These ideal conditions are quite commonly met even in the very low refractive index range when the mineral dispersion curve has a lower relative slope than that illustrated in Fig. 1.

Should there be any doubt in the recognition of the matching color, a further observation may be made. On raising the focus according to standard Becke line procedure the colors on one side of the interface move toward the mineral and on the other side move toward the liquid. By observing the colors nearest the interface and on both sides of it, the match-

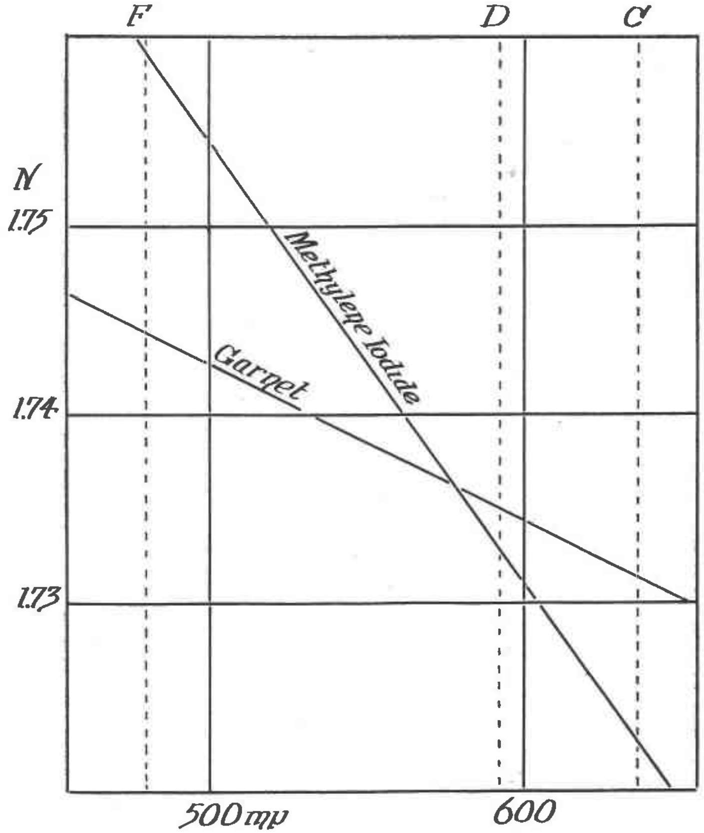

FIG. 2. THE RELATIONSHIP BETWEEN THE DISPERSION CURVES OF GARNET AND METHYLENE IODIDE. This shows the benefits which accrue to a mount in a liquid of relatively high dispersion.

ing color is revealed as lying between them. The greater the slope difference between liquid and mineral dispersion curves, the more accurate is this observation. It essentially fails below 1.50 as stated earlier.

The liquids of standard sets of immersion media ordinarily include α-chloronaphthalene, α-iodonaphthalene, and methylene iodide, all of which have highly satisfactory dispersion. Low dispersion is usually encountered in the liquids in the all important 1.50 to 1.60 range and below it. We have nothing to offer by way of improvement below 1.50. However, ethyl salicylate which is miscible in all proportions with both mineral oil and α-chloronaphthalene may be used to the exclusion of mineral oil above 1.521 and with mineral oil below 1.521. Its dispersion is .021 ($N_F - N_C$) and that of α-chloronaphthalene is .030. This gives liquids of excellent dispersion above 1.52 and a fair dispersion for 1.50. Fortunately, most work is done in the refractive index range above 1.50. The details are:

Liquid	R.I. (D, 24° C.)	N_F(486 mμ)–N_C(656 mμ)
Methylene iodide and sulfur	1.775±	.0369
Methylene iodide	1.738	.0369
α-iodonaphthalene	1.710	.0368
α-chloronaphthalene	1.633	.030
Ethyl salicylate	1.521	.021
Mineral oil	1.48	.0125

H. Winchell (2) recently published an ingenious diagram for the determination of 2V. The diagram is very helpful also in speeding up routine immersion work by the use of uncentered interference figures. When an optical symmetry plane is vertical (a straight and centered isogyre) and a recognized optical direction appears in the field in such a way that its angle with the microscope axis may be measured, the available refractive indices may be used to learn critical rays by calculations or graphical extrapolation. The calculation is covered elsewhere (3). This detail is most useful when the recognized direction (bisectrix or optic axis) is near the margin of the field making an angle with the microscope axis of about 25 degrees.

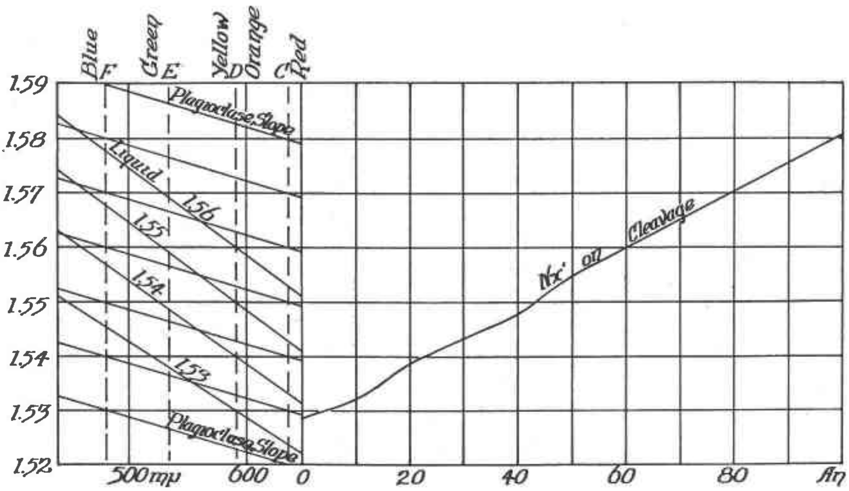

FIG. 3. TSUBOI'S PLAGIOCLASE DETERMINATION METHOD ADAPTED TO WHITE LIGHT. The Hartman scale is substituted for the uniform scale originally used by Tsuboi. The dispersion curves of the recommended immersion media are added. Tsuboi's two $N_{x'}$ curves for 001 and 010 have been averaged.

Another advantage accrues to the use of colors in the Becke line in the determination of feldspars by means of Tsuboi's curve (4)—probably the most used feldspar curve of all. As originally drawn, the curves are intended for data obtained from the use of monochromatic light but are quite amenable to use with white light. In Fig. 3 is one of Tsuboi's curves averaged and his feldspar dispersion curves to which have been added some dispersion curves of the liquids in a specific immersion set (ethyl salicylate and α-chloronaphthalene). The procedure is simple and rapid. As outlined above, determine the approximate wave length at which the Becke line colors are divided and locate this value on the abscissa scale. Follow vertically to the intersection of this value with the dispersion curve for the liquid being used. From this point follow the Tsuboi procedure, namely, follow the feldspar dispersion curve to the *D* line and from there horizontally to the mineral "index cleavage" curve in the right hand portion of the diagram. The abscissa gives the anorthite content as determined by Tsuboi. Although four liquids cover the plagioclase curves, actually two liquids, 1.540 and 1.550, cover all common plagioclases. The Hartman wave length scale has been substituted in the figure for the uniform scale of Tsuboi's original diagram.

Perhaps the greatest value to be offered by the detailed use of the Becke line colors in selected immersion media of high dispersion lies in the avoidance of extra mounts and the mixing of liquids to secure a better agreement.

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