Comparing the two sets of apparatus, that by Emmons and that by Lindley, it is clear that each in light of the other has certain advantages and disadvantages. Only the Emmons apparatus in combination with the modified Fedorow universal stage is here considered, as with the ordinary stage this method is greatly limited. The more important advantages of the Emmons method consist in the provision to *rapidly cool* the specimen, even somewhat below the normal laboratory temperature; the very exact temperature control; and moreover, because of the numerous possible movements of the modified universal stage, the ability not only to turn a grain so that its principal optical directions lie parallel to the vibration directions of the nicols, but even to rotate the oriented grain in these two planes. From the point of view of the teacher who wishes to train his students with a certain theory and technique, the writer agrees with Reinhard[7] that crystal study on the universal stage is of great value in leading to a clear conception of crystal optics.

On the other hand with the Lindley apparatus much higher indices can be measured; also it is expected that much higher temperatures can be obtained, which among other obvious advantages permit the use of high-index melts which at lower temperatures solidify to non-isotropic media. Moreover, one is not limited to certain definite embedding fluids, but may use almost any miscible mixture prepared on the stage to suit the particular grain being studied; even if the fluids used have considerably different boiling points, this is of little importance since almost the very instant the grain is matched the index of the liquid is measured.

Until one has had an opportunity to work at leisure with both instruments, it will be impossible to be certain that it is not desirable to have both. The advantage of the greater simplicity of the Lindley apparatus may be offset by its not being so universally applicable as the Emmons modified stage. This would certainly be true were it less accurate; the relative accuracy of the two instruments is at present unknown to the writer. Emmons[8] estimates an accuracy of $\pm.0002$ at best, and more commonly $\pm.0005$. The difficulty of learning the technique of preventing a mineral grain from sliding around on a tilting universal stage may be no greater than keeping it glued to the pin. The mineralogist is generally not interested in obtaining the dispersion curves for a specimen, but wishes to determine α, β, and γ accurately for sodium light. These values are read from dispersion curves in the Emmons method. Whether the Lindley apparatus would lead to these results direct with no loss in accuracy and at a saving of time as compared to the method of the preparation of dispersion curves (perhaps substituting dilution of the n-fluid for change in temperature) is unknown, but in case it would, possibly a cheaper source of illumination could be substituted for the arc and monochromator.

ADDITIONAL COMMENTS ON THE DOUBLE VARIATION APPARATUS

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Professor Fisher very kindly sent me a copy of the manuscript of his accompanying description of the Scheumann-Lindley microscope refractometer. Through his

[7] Reinhard, M., *Universal Drehtischmethoden*, p. 5, Basel, **1931**. In this connection the model of a universal stage as figured on page 14 (with index ellipsoids as shown, or with rubber balls on which skiodromes are painted) is of great value.

[8] Letter dated August 14, 1931.

courtesy and that of the editor these supplementary remarks appear with Fisher's paper. Since Fisher informs me that he has not yet received his own double variation apparatus from Bausch & Lomb he has not had an opportunity to use the equipment except once in the University of Wisconsin Mineralogical Laboratories. There are, accordingly, a few points which I feel should be added descriptive of the double variation apparatus. I myself am quite unacquainted with the Fuess instrument which at the time of writing has not yet reached this country.

The requirements for a suitable determinative technique are becoming more pressing and more clearly defined; especially so as our knowledge increases in the field of correlation of optical constants and chemical composition of crystalline materials. Workers in the allied sciences who are beginning to show interest in determinative technique with a view to using it in their own work commonly find that the lack of accuracy of the routine procedure renders the results somewhat ntangible. They are not satisfied with an indefinite statement corresponding with our "olivine," "scapolite," or "epidote," or, to name one of our best, "plagioclase $(ab_{70}an_{30} \pm 5\%$ ab)" as an example. Nor are mineralogists remaining satisfied with this type of determination. Our requirements are including more specific information, particularly in the chemistry of the materials we are handling. Although suitable data for our newer needs are not yet available they are accumulating. To use such data necessitates the accurate determination *with confidence* and comparative speed not only of the three indices n_g, n_m, and n_p but of any other constants which are conveniently available. In order to determine the three indices accurately it is necessary to go through most of the steps which are necessary to secure other data of important critical value such as dispersion and crystallographic orientation. It seems fair to assume that as index data of accuracy $\pm .003$ and $\pm .001$ have accumulated in the past, so also will data of accuracy $\pm .0004$ and $\pm .0002$ be accumulated in the future.[1] The value to the research worker of suitably accurate data can scarcely be over-estimated. Although we are not yet able by optical means to determine with satisfactory accuracy the three main constituents (ab, an, or) of feldspar, our most common mineral, yet it appears from preliminary calculations that index data correct to $\pm .0002$ will meet this limitation when properly correlated with analyzed material. It is highly probable, however, that stereographic projections such as those of Duparc and Reinhard[2] will be an essential accessory, serving to indicate changes in the relative orientation of elements of optical symmetry with respect to crystallographic directions. Other minerals than feldspar will in turn doubtless demand an equally rigorous procedure for their complete understanding. The successful attainment of these worthy objectives will be realized only through the cooperative research efforts of a large number of members of the profession actively interested in the detailed study of mineral and crystalline materials.

[1] Reference is made to V. E. Barnes, Changes in Hornblende at about 800° C. *Am. Mineralogist*, Vol. 15, 1930, p. 393. In this paper Dr. Barnes records 369 mineral index determinations of which 63 are $\pm .0002$, $27 \pm .0003$, $81 \pm .0004$, $144 \pm .0005$ and 54 are of greater error, the maximum being $\pm .0012$; the size of the error is closely related to the color of the material in this case. Some of the material was so strongly absorptive as to be almost opaque except in very minute grains indeed.

[2] *Mem. Soc. Phys. Hist. Nat. Genève*, XL, 1924. Based on the work of Fedorov and Nikitin.

The development of the double variation principle[3] was intended as one step toward a more detailed understanding of minerals. The Bausch & Lomb Optical Co. is manufacturing the equipment as a complete unit (without royalty). A laboratory source of hot and cold water and a waste are necessary in addition. Fuess is offering an entirely different piece of apparatus designed by Professors Scheumann and Lindley, to serve a similar purpose and using some of the same principles. Each equipment must stand on its own merits. A satisfactory comparison cannot be made until both have had considerable use, but there are certain features of each which recommend them, as Fisher has brought out. It is my purpose to add to Fisher's comments, emphasis on some features of the double variation equipment of Bausch & Lomb which seem to recommend it. It would be of interest to have the further comments of Professor Scheumann, also.

1. The refractometer feature of the Scheumann-Lindley apparatus is said by Fisher to be capable of an accuracy of $\pm.0003$ to $\pm.0010$. The standard Abbé refractometer used in the Bausch & Lomb apparatus is capable of an accuracy throughout its range of $\pm.0002$. Index readings on crystalline materials studied by either method discussed here must necessarily be less accurate than the refractometer in the system.

2. I am unable to state the lower limit of size of grain which the Scheumann-Lindley apparatus will accommodate. I should anticipate difficulty in gluing grains smaller than .5 mm. to the end of a needle. The universal stage conveniently handles material one tenth this size.

3. A large proportion of the material in which the petrographer is interested is unavailable or unsuitable in grains larger than .1 mm. in diameter. Colored material such as hornblende must be still smaller to be transparent. Thin edges of large grains, which are opaque inside the edges, normally do not give satisfactory results in Becke line tests if accuracy is desired.[4] Using a 16 mm. or #3 objective, material .03 mm. in diameter can be worked very nicely with the universal stage. For this purpose Bausch & Lomb carries a smaller hemisphere as a stock item.

4. In the field of higher indices progress has recently been made. Spencer offers a high index Abbé refractometer, to read to 1.84. This is essentially the limit of immersion liquids and it includes all ordinary needs.

5. All known media of high refractive index are considerably colored and are transparent only in thin films, introducing a serious limitation to any method which requires an amount of liquid in excess of that needed to immerse the grain.

6. Fisher mentions that the Scheumann-Lindley instrument gives interference figures. Although I have never been interested in the use of interference figures with the universal stage, since the information they give is so easily available by other routine procedures, yet after reading Fisher's paper I have tested this possibility, thinking that others might agree with him in considering interference figures advantageous. Using topaz (birefringence .009) I find that grains as small as .3 mm.

[3] R. C. Emmons, *Am. Mineralogist*, vol. **13**, p. 504; vol. **14**, p. 414, p. 441.

[4] This is an empirical fact of observation. The explanation may be that the Becke line in immersion work is due to the lens effect of the grain. In large grains of low transparency the lens effect is greatly reduced.

yield excellent figures. The numerous rotations of the universal stage make it possible to change from one figure to another very easily. These figures were obtained with both low and medium power objectives by removing the ocular.

7. In using the double variation procedure one is limited to certain definite embedding fluids only when the highest degree of accuracy is desired.

To my mind there are two features of the Scheumann-Lindley apparatus which highly commend it. First, the ability to mix liquids on the stage affords still another means of varying the index of the immersion medium. I am eager to test the convenience and especially the effect on the accuracy of this detail of their procedure. Second, Fisher states that Lindley is now working on a heating stage. For moderate temperatures this has already been accomplished, but Fisher expresses the hope that high index melts may be kept molten. If the attendant difficulties do not prove too great (i.e., the problem of gluing the grain, cleaning the lenses between melts, heat damage to the lenses, effect of higher temperatures on the optical and physical properties of minerals) this brilliant idea should lead to an interesting and useful technique which could be applied very widely.

BOOK REVIEW

MICROSCOPIC DETERMINATION OF THE ORE MINERALS, M. N. SHORT, U. S. Geol. Survey, *Bulletin* **825**, 1931, 204 pages, 11 plates, 16 figures.

This very comprehensive treatise on the microscopic characteristics of the ore minerals is based on surer foundations than any previous publication of the same kind. The genuineness of each mineral species is given a very critical review and, while the reviewer disagrees with some of the author's conclusions as in the cases of galenobismutite and kallilite, accurate and reliable data are for the first time available on a great majority of the ore minerals. Approximately one-fourth of the bulletin is devoted to a discussion of microscopic technique and physical properties. As earlier text-books have included a considerable proportion of this information, it would seem that this introductory part might have been considerably abbreviated without impairing its value.

A step in the right direction has been taken in eliminating the intermediate grade of hardness. Since there is sufficient range in the hardness of certain mineral species to cause overlapping in the three-class system of soft, intermediate, and hard, it seems inadvisable to attempt anything more than a simple classification into soft and hard minerals as outlined in this bulletin.

Part 3, which makes up the second quarter of the volume, is taken up with an admirably brief discussion of etch reactions followed by a set of determinative tables based on isotropic or anisotropic character, and on etch reactions with the four standard and two supplementary reagents of Davy-Farnham. The use of aqua regia in differentiating such groups as pyrite and sperrylite on the one hand and braunite, chromite, cobaltite, franklinite, hematite, and magnetite on the other, would seem of doubtful value since the first two can be differentiated quite easily from the remainder by other means. Apart from such minor details these tables seem to be well adapted to the use of microscopic investigators of this special class.