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PREFACE

The polarizing light microscope (PLM) remains the premier tool for rapidly identifying the minerals and mineral reactions that occur in petrographic thin sections of rocks. This present text, like its predecessor (*An Introduction to the Methods of Optical Crystallography*, 1961, Holt, Rinehart and Winston), is intended to supply a firm foundation for such petrographic studies. Thus it includes much of the material from the 1961 text, particularly the marvelous illustrations, drawn by Mark Klopp, that students found so helpful. An innovation is the brief overview that precedes each chapter. These may be sufficient to allow the reader to skip to the next chapter.

The PLM has also been quintessential for determination of the properties of single crystals or fragments thereof. In recent years, however, the precision and ease of such determinations has undergone a quantum leap, thanks to (1) the increased availability, speed, and power of personal computers and (2) an inexpensive device called a spindle stage, which permits remarkably precise optical measurements to be made on single crystals, particularly biaxial ones (see *The Microscope*, 1992, vol. 40, no. 1). Even the simplest spindle stage, if mounted on the stage of a PLM, allows a crystal to be rotated about two axes: The M -axis, the vertical axis of rotation routinely supplied by a PLM's rotatable stage, and the S -axis, the horizontal axis of rotation that a spindle stage supplies. These two rotational capabilities permit the principal refractive indices of any anisotropic, transparent crystal to be determined by the immersion method *without appreciable error from misorientation*. The procedures are so simple that beginning students, once they've learned the immersion method of determining refractive indices, can employ them almost immediately. The basic procedure involves rotating the crystal about axis S to each of the set positions — $S = 0^\circ, S = 10^\circ \dots S = 180^\circ$ — and, at each such position, rotating the microscope stage to the position — $M_0, M_{10} \dots M_{180}$ — that causes crystal extinction. The resultant crystal extinction data, entered into a personal computer and solved by the computer program EXCALIBR (Bartelmehs, et al., 1992), will yield $2V$, the optic axial angle. It also computes $S_x, M_x; S_y, M_y$; and S_z, M_z —the settings of the spindle axis (S) and of the microscope stage (M) that respectively orient the crystal so that its principal indices (α, β, γ) can be measured as easily as if the crystal were isotropic.

EXCALIBR locates the five significant biaxial vectors—namely, the two optic axes plus X, Y , and Z —with unprecedented precision and calculates $2V$ to within a fraction of a degree. If crystal extinctions for up to five different wavelengths are submitted, EXCALIBR calculates the angular shifts in position (with wavelength) for each of the five significant vectors. It then estimates statistically whether these shifts can be ascribed to dispersion or to chance.

The ease and precision with which $2V$ can be determined at several different wavelengths for biaxial crystals suggests many practical uses for spindle stage data. For example, during the manufacture of biaxial pharmaceuticals, the angle $2V$, which is highly sensitive to compositional change and to changes in the crystal's atomic structure, could well prove to be a sensitive monitor for quality control. And in forensic studies, the finding that $2V$ for feldspar, amphibole, or pyroxene crystals occurring in soil or sand at the crime site agree to within one degree with similar crystals from soil or sand samples associated with the suspect should be compelling evidence.

It is a pleasure to acknowledge my debt to the many people who have been so helpful. I'll start with Ray E. Wilcox, now retired from the U. S. Geological Survey. I learned a lot under your gentle tutelage, Ray. And then there are the students that taught me. From 1951 to 1957 at the University of Tennessee, I learned from Louis S. Walter,

Robert Milici, and G.V. Gibbs, the latter also my colleague for over 30 years. At Southern Illinois University (1957-1967) I learned from Paul Robinson, Ray Kerns, and from my colleague there, Jen-Ho Fang. At Virginia Tech (1957-1991) I have had the pleasure of collaborating with many students, from undergraduates to postdoctorals. For example, Ed Wolfe helped me to get the ball rolling relative to precise optical studies of crystals at elevated temperatures and at wavelengths beyond the visible. As did the late John Louisnathan who went from my lab to Corning's and in 1996-97 won their Stookey Award for his development of a new technique to determine the core geometry in optical fibers with unprecedented precision. And during his master's study, Kevin Selkregg used combined X-ray and spindle stage studies of cordierites to explode the myth that the distortion index was a measure of structural state. Around 1979, a postdoctoral student from Germany, Thomas Armbruster, carried out many brilliant experiments on the optics and crystal structure of cordierite. Thomas successfully demonstrated why cordierite was sometimes optically positive instead of negative (CO_2 was occupying its channels). This also explained why, in one locality, all the cordierites on one side of a fault were (+) and on the other (-). Another student, Mickey Gunter, now at the University of Idaho, practically became a colleague while doing a master's and Ph.D. with me. During his X-ray/spindle stage study of the solid solution series between andalusite and kanonaite, Mickey found that the plots of principal refractive indices versus manganese content actually crossed so that, at one particular composition, an isotropic andalusite existed. In 1981 its existence was observed in a thin section by the late Jeff Grambling of the University of New Mexico. Also in 1981, Shu-Chun Su began a doctoral study (with Paul Ribbe and me) that showed how the optical properties of the K-feldspars *did* vary with structural state. The resultant paper, in which David Stewart of the U.S. Geological Survey joined us, showed that the optic axial angle $2V$, so easily and precisely determined by spindle stage methods, offered a ready measure of K-feldspar's structural state. Around this time, Laura Davis (now DeLoach) showed how the principal refractive indices of mica flakes could be precisely measured using an Abbé refractometer. Soon thereafter, Daniel Greiner showed that $2V$, as measured for members of the ambygonite-montebasite series, allowed their fluorine contents to be estimated to within 2 mole per cent.

Looking beyond the scope of my own university, I thank Dr. Walter McCrone for his many kindnesses to me and my students. He has, with enthusiasm, taught the world about the practical use of optics in asbestos identification, in checking the authenticity of oil paintings, and in forensic studies.

Prof. Ann G. Wylie of the University of Maryland contributed to the initial draft of the section on dispersion staining (Chapter 5). Subsequently, Dr. Shu-Chun Su of the Research Center of Hercules Incorporated added greatly to this section. Moreover, Chapter 13 (Rapid Determination of Asbestos...) is largely based on *Rapidly and Accurately Determining Refractive Indices of Asbestos Fibers by Using Dispersion Staining*. This latter is the standard operating procedure for identifying asbestos fibers by polarized light microscopy which Dr. Su wrote in his capacity as a technical expert for NVLAP (the National Voluntary Laboratory Accreditation Program) currently administered by the National Institute of Standards and Technology (NIST). I thank Dr. Olaf Medenbach of the Institute for Mineralogy at Bochum for providing the illustration (see Fig. 12-8) of his outstandingly versatile spindle stage. I also thank Bob Sacher of R. P. Cargille Laboratories for supplying the refractive index data for the Cargille refractive index liquids.

Jan Hinsch of Leica, a friend for 30 years and always a source of bubbling enthusiasm relative to microscopy, kindly read (and improved) Chapter 4. He was also so kind as to advise me relative to Köhler illumination. I also thank Dr. Walter J. Patzelt

of Leica Microsystems for allowing use of Leica's Michel-Levy charts and for assisting in the modifications which increase the chart's usefulness for identifying minerals in petrographic thin sections.

Jodi Rosso performed, in a remarkably short time, the task of optical scanning of the 1961 text and getting it on disk so that large portions of it could be integrated into this present text. Margie Sentelle added to it the bulk of the new material I wrote. Amy Braford Peterson did yeoman's work in putting finishing touches on the manuscript. My grandson, Andrew Kensler, used his considerable expertise in computer graphics to generate some remarkable new illustrations for this book.

I thank my colleague of over 30 years, Paul H. Ribbe, for editing this text and reading it critically. Other critical readers to whom I am grateful include Edward F. Lener, Dr. Mickey E. Gunter, Dr. Shu-Chun Su, and Dr. J. Alexander Speer.

Last but by no means least, I thank my wife Louise, to whom this book is dedicated, for giving the right answer to the question I asked her 55 years ago.

F. D. Bloss
Blacksburg, VA
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