

Optics of hexagonal pyrrhotine ($\sim \text{Fe}_9\text{S}_{10}$)

By KURT VON GEHLEN, Dr.rer.nat.

Mineralogisches Institut, University of Erlangen-Nürnberg, Erlangen,
Germany,

and HORST PILLER, Dr.rer.nat.

Laboratory of Microscopy, Firma Carl Zeiss, Oberkochen, Germany

[Read 23 April 1964]

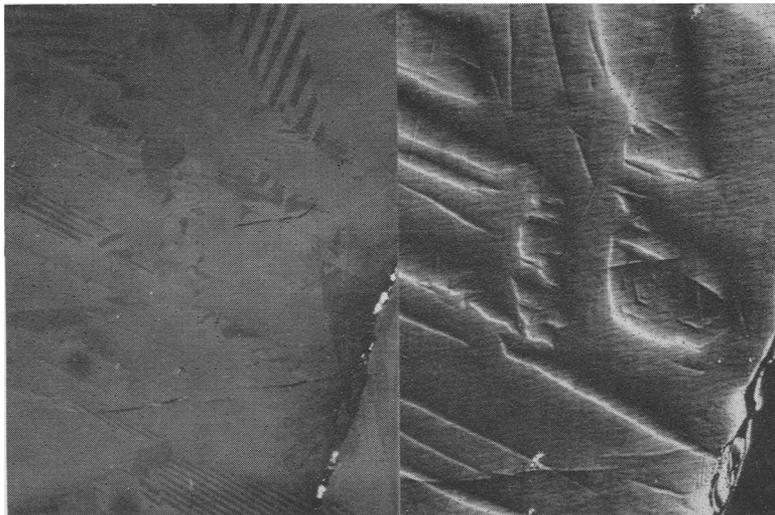
Summary. Reflectivities of a series of oriented polished sections through a single crystal of pyrrhotine (Fe_{1-x}S) from Trepča, Yugoslavia, were measured by means of a spectral photometer attached to a microscope. This pyrrhotine consists of two phases, namely intermediate pyrrhotine ($\sim \text{Fe}_9\text{S}_{10}$) and monoclinic pyrrhotine ($\sim \text{Fe}_7\text{S}_8$), which were probably formed by exsolution. The phase relations of pyrrhotine at low temperatures are discussed. Optical data are given for the intermediate pyrrhotine from 440 to 660 $\text{m}\mu$. From the reflectivities measured in air and oil against a carborundum standard, values of n , k , and κ were calculated for ω and ϵ and represented in dispersion curves. Also, sections through the various 'indicating surfaces' at 546 $\text{m}\mu$ are shown. The accuracy of the values, which should be approximately the same for other pyrrhotine phases, is discussed.

DURING the last years reflected-light microscopy appears to have finally entered its quantitative stage in routine measurements, about 50 years later than polarized-light microscopy in transmitted light, although the theoretical foundations for the treatment of the phenomena in reflected light have already been given much earlier.

Reflectivity is the most important property of a reflecting surface. The authors have recently discussed sources of error in reflectivity measurements as well as in calculations of refractive indices n and absorption coefficients $k = n \cdot \kappa$ ($\kappa =$ absorption index) therefrom (Piller and Gehlen, 1964). Although the errors of n and k vary widely, depending on their absolute values, it is often possible to calculate n and k with reasonable accuracy. This has already been demonstrated in the case of covelline (Gehlen and Piller, 1964).

Material studied. Oriented polished sections were prepared from a pyrrhotine single crystal of about 0.5 in. diameter from Trepča, Yugoslavia. An excellent polish was obtained using various methods including the improved Vanderwilt-Graton machine of Rehwald (1952),

with diamond abrasive and alumina for the final polish. Under oil immersion and crossed nicols, the crystal then appeared to consist of two pyrrhotine-like phases (beside some pyrite), which could only be distinguished under optimum conditions or using interference contrast after Nomarski and Weill (1954). One of the phases appeared to be



FIGS. 1 *a* and *b*: FIG. 1 *a* (left). Intergrowth of two pyrrhotine phases from Trepča, Yugoslavia. Reflected light, + nicols, oil immersion, exposure 15 minutes, extra hard copy. Magnification 80. FIG. 1 *b* (right). The same in interference contrast after Nomarski and Weill (1954). Reflected Light. Essentially homogeneous groundmass = intermediate hexagonal pyrrhotine; lamellar inclusions = monoclinic pyrrhotine.

essentially homogeneous in orientation while the other consisted of lamellae of different orientations (figs. 1 *a* and *b*).

The phase relations of pyrrhotine at low temperatures are still not known exactly (Gehlen, 1963). An attempt to interpret the data available so far is shown in fig. 2. At room temperature, four phases of Fe_{1-x}S composition (from FeS to Fe_7S_8) seem to be stable, namely, mackinawite = tetragonal FeS (field of stability unknown), troilite = hexagonal FeS, intermediate hexagonal pyrrhotine = approximately Fe_9S_{10} , and monoclinic pyrrhotine = approximately Fe_7S_8 , the last three of which have almost identical crystal structures.

The crystal from Trepča did not contain mackinawite. The pyrrhotine $10\bar{1}2$ peak (measured against $10\bar{1}1$ of quartz from Dörentrup,

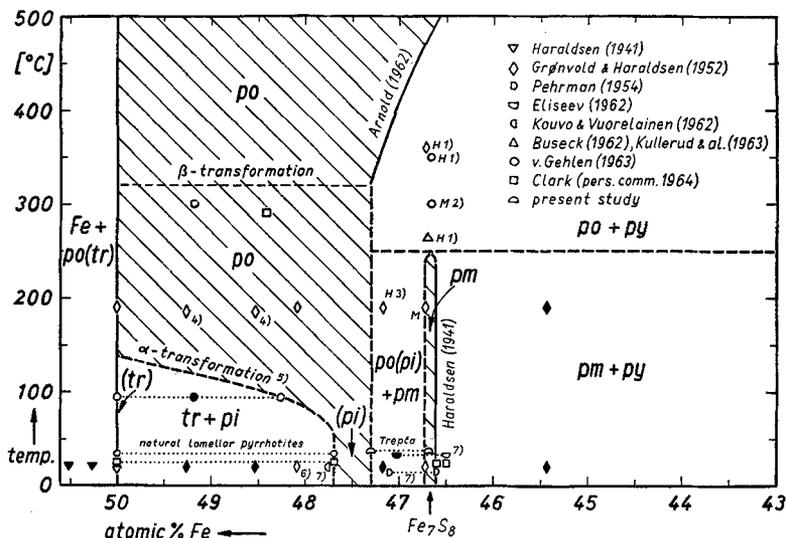


Fig. 2. Tentative phase diagram of the pyrrhotine region of the Fe-S system between 0° and 500° C, derived from selected data as indicated. (No stability fields can so far be given for mackinawite and smythite). Filled signatures = two phases; open signatures = single phase. Rows of points connect phases separated from the same specimen. Shaded areas = solid solutions.

po = hexagonal pyrrhotine solid solution (no important change of crystal lattice at 'β-transformation')

(tr) = troilite (stoichiometric FeS, hexagonal)

(pi) = 'intermediate pyrrhotine'

pm = monoclinic pyrrhotine (only slight deviation from hexagonal symmetry)

py = pyrite

H = hexagonal

Fe = metallic iron

M = monoclinic

(1) Assumed to be metastable (hexagonal).

(2) Quench effect? The transformation of monoclinic to (metastable?) hexagonal pyrrhotine on heating occurs below 260° C, see Buseck (1962) and Kullerud *et al.* (1963).

(3) Here assumed to have contained small amounts of the monoclinic phase also.

(4) Since in the high-temperature X-ray studies of Grnqvold and Haraldsen (1952) apparently exsolved (tr+pi) synthetic specimens have been re-homogenized at 185–190° C, the upper limit of the immiscibility gap should be below this temperature. So far the most reasonable solution is to take the 'α-transformation' as this limit.

(5) α-transformation according to data by Haraldsen (1941) and Hihara (1960).

(6) The most probable composition of intermediate pyrrhotine in natural lamellar pyrrhotines (together with troilite) was found both by Gehlen (1963) and Clark (1964) as 47.69 atomic % Fe.

(7) Chemically analysed, therefore composition not known as exactly as from X-rays or synthesis; partly samples separated magnetically, therefore not necessarily pure.

Germany) was split into a strong peak at $d\ 2.0648 \pm 0.0009 \text{ \AA}$ and a weaker one at $d\ 2.0505 \pm 0.0009 \text{ \AA}$. After magnetic separation of powdered pyrrhotine the weakly magnetic fraction showed a single peak at $d = 2.0658 \pm 0.0006 \text{ \AA}$ while the strongly magnetic one showed two peaks of similar intensity at $d = 2.0635$ and 2.0525 \AA (both $\pm 0.0014 \text{ \AA}$). This means that the first phase is an intermediate pyrrhotine containing 47.29 ± 0.06 atomic % Fe (after the curve of Arnold and Reichen, 1962). The values of the second one are close to those expected for the phase first described by Byström (1945) as monoclinic pyrrhotine (Gehlen, 1963).

An electron microprobe study kindly performed by Dr. J. V. P. Long (Cambridge) showed that the lamellar pyrrhotine contains about 0.5% less Fe than the homogeneous pyrrhotine. This difference agrees with that obtained from the X-ray data (see fig. 2) within the limits of error. Therefore, the lamellar phase must be monoclinic pyrrhotine while the homogeneous one is intermediate pyrrhotine.

The reflectivity measurements were made on the homogeneous phase and are therefore valid for a pyrrhotine composition of about 47.3 atomic % Fe (about Fe_9S_{10}). The results obtained on sections of different orientation proved that this phase has retained the orientation of the macrocrystal.

Apparently the two pyrrhotines were formed by exsolution of a high-temperature solid solution. The temperature of formation of the assumed original pyrrhotine (in presence of pyrite) would have been close to 400°C (after the curve of Arnold, 1962). If the pyrite found in the crystal is also an exsolution product of the same phase, the temperature would have been still higher. This would be compatible with other data from this important lead-zinc deposit, which is in several respects similar to Leadville, Colorado. The sphalerite analysis quoted by Schumacher (1950), giving 17.8 wt % FeS after recalculation, would indicate a temperature of (at least) 575°C after the sphalerite thermometer of Kullerud (1953).

Intergrowths of intermediate and monoclinic pyrrhotine as found in the present study can easily be overlooked and taken for a single phase. With the exception of a few observations (see fig. 2), so far mostly lamellar pyrrhotine intergrowths of type 'tr+pi' seem to have been described, which are easier to recognize (see Ramdohr, 1960, p. 550). Much more information on natural pyrrhotines is needed before it can be decided whether 'pi+pm' pyrrhotines are also common or not.

Equipment used. A highly stabilized single-beam photometer was combined with an ore microscope of Firma Carl Zeiss, Oberkochen. The equipment has already been characterized in an earlier paper on the optics of covelline (Gehlen and Piller, 1964). Nearly monochromatic light was obtained by using an interference filter of Firma Schott u. Gen., Mainz (cf. R. K. Harrison and G. Day, 1963). In some cases, the reflectivity values were not only read but also checked on a recorder while the microscope stage was rotated by a synchronous motor. The values were measured with polarizer only (vibration direction horizontally). Part of the measurements were made at low magnification (objective 4/0.1) where the measured area had a diameter of 0.1 mm. In this case, direct contact between immersion oil and objective was no longer possible. In order to keep the oil surface horizontal, the oil was covered with a small piece of cover glass (a procedure similar to that suggested by Cambon, 1947) and the measured reflectivity corrected for the additional reflection from the glass surface by

$$R_{\text{oil}} = \frac{R_{\text{ms.obj.}} + r(R_{\text{ms.obj.}} R_{\text{ms.std.}} - 2R_{\text{ms.obj.}} - 1)}{R_{\text{ms.std.}} + r(R_{\text{ms.obj.}} R_{\text{ms.std.}} - 2R_{\text{ms.std.}} - 1)} \cdot R_{\text{std.}}$$

(from Piller, in preparation). Here, r = reflectivity of cover glass; R_{oil} = real value of the reflectivity of the object in oil; $R_{\text{std.}}$ = real value of the reflectivity of the standard in oil; $R_{\text{ms.obj.}}$ and $R_{\text{ms.std.}}$ = measured values of the reflectivity of object and standard, respectively, under oil and cover glass. The reflection from the oil-glass interface can be neglected as long as the refractive indices of both media are similar. (Also, the r^2 terms have been neglected in the deduction.) All values are, of course, dependent on the wavelength of the light used.

Every measurement was compared with one taken on the standard under identical optical conditions immediately afterwards. As standard, a carborundum basal section (kindly supplied by Dr. N. F. M. Henry) was used. The reflectivities of this standard were calculated from the refractive indices of transparent synthetic carborundum given by Thibault (1944) (which are almost identical to those given by Weigel (1915)) and extrapolated as given in table I. The influence of absorption can be neglected. (In table I, the refractive indices of the cover glass and immersion oil are also given because they were needed in the calculations).

In determinations of reflectivity in oil at low magnification without direct contact between oil and objective and with a cover glass, the third column of table I corresponds to $R_{\text{std.}}$ and the fourth to $R_{\text{ms.std.}}$.

Reproducibility and accuracy of reflectivity values. To check the accuracy of single measurements, some reflectivity values of the standard covered with oil and cover glass at low magnification were compared with the reflectivities of a large oil surface the absolute data of which were accurately known. It appeared that even in this case relative errors of ± 2 to ± 5 % are possible when all other sources of error introduced by improper equipment and operation (see Piller and Gehlen, 1964) are excluded.

TABLE I. Reflectivity of basal plane of carborundum (calculated from refractive indices given by Thibault, 1944) and refractive indices of cover glass and immersion oil

wave-length λ	real reflectivity R_ω of carborundum in air	real reflectivity R_ω of carborundum in oil	reflectivity R_ω of carborundum under oil and cover glass*	refractive index of cover glass (Schott)	refractive index of immersion oil (21° C) (Zeiss)
440 m μ	0.2147	0.0794	0.1178	1.5398	1.5278
460	0.2126	0.0783	0.1166	1.5376	1.5251
480	0.2107	0.0774	0.1155	1.5356	1.5229
500	0.2091	0.0766	0.1146	1.5339	1.5210
520	0.2077	0.0759	0.1138	1.5325	1.5192
540	0.2065	0.0753	0.1131	1.5312	1.5176
560	0.2054	0.0748	0.1125	1.5300	1.5161
580	0.2044	0.0743	0.1119	1.5289	1.5147
600	0.2036	0.0739	0.1114	1.5280	1.5135
620	0.2028	0.0736	0.1111	1.5271	1.5124
640	0.2021	0.0733	0.1107	1.5263	1.5114
660	0.2015	0.0730	0.1103	1.5256	1.5106

$$* \text{ Calculated from } R_{\text{ms, std.}} = r + (1-r)^2 \cdot \frac{R_{\text{std.}}}{1-r \cdot R_{\text{std.}}}$$

Generally, our experience is that the relative errors of reflectivity measurements are much larger than normally accepted, even under favourable circumstances, although sometimes the 'reproducibility' of a single set-up may be rather good. But this does not give the real error. In our paper on covelline (Gehlen and Piller, 1964) we stated that our 'best' reflectivity values derived after several corrections and extrapolations still showed relative errors of 4 to 20 % (here, however, the largest errors correspond to the very low reflectivities of ω in oil).

Two series of reflectivities R_ω and R_ϵ in air and oil were measured on intermediate hexagonal pyrrhotine from Trepča at the wavelengths listed in table I, as well as several series of reflectivities on sections of various orientations at selected wavelengths and further check values. As an example of the 'reproducibility' of the measurements, selected R_ω values are listed in table II with their maximum deviations.

The reflectivities at the selected wavelengths were further improved through dispersion curves (constructed from the measurements 20 $m\mu$ apart between 440 and 660 $m\mu$) as well as through curves of the calculated n , k , and κ values (see below) where the best fit to smooth curves was used as the criterion for correction. For this reason, some of the 'best' reflectivity values given in table III differ slightly from those

TABLE II. Measured reflectivities R_ω of intermediate hexagonal pyrrhotine from Trepča at four standard wavelengths

immersion	λ	reflectivity	maximum deviation	number of determinations	relative error
air	486 $m\mu$	0.3167	± 0.0093	7	2.94 %
	546	0.3392	± 0.0058	9	1.71 %
	589	0.3582	± 0.0068	7	1.90 %
	656	0.3899	± 0.0045	7	1.15 %
oil	486	0.1883	± 0.0053	7	2.81 %
	546	0.2149	± 0.0059	6	2.75 %
	589	0.2348	± 0.0088	7	3.75 %
	656	0.2508	± 0.0136	6	5.42 %

given in table II although the deviations are always within the error limits. Some reflectivities and the final dispersion curves are shown graphically in fig. 3.

From the results obtained before and after re-polishing it appeared that pyrrhotine reflectivity values are sensitive to the quality of the polished surfaces. Therefore, several reflectivity values were discarded and only the highest sets of values used.

Calculations of n , k , and κ values. From the final reflectivities in air and oil, n , k , and κ values were calculated in the usual way from

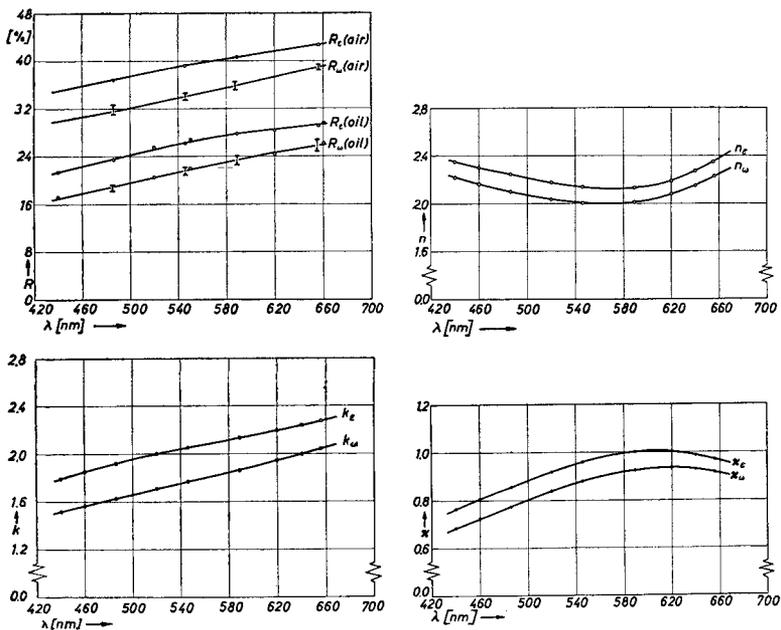
$$n = \frac{1}{2} \frac{(n_{\text{oil}}^2 - 1) \{ n_{\text{oil}}(1 + R_{\text{oil}}) / (1 - R_{\text{oil}}) - (1 + R_{\text{air}}) / (1 - R_{\text{air}}) \}}{\sqrt{\{(n+1)^2 R_{\text{air}} - (n-1)^2\} / (1 - R_{\text{air}})}}$$

$$k = k/n$$

The n values appeared to be very sensitive to slight changes in R while the k values were almost unaffected. This is easily explained by figs. 4 *a* and *b* of Piller and Gehlen (1964). With n near 2.5 and k near 2.0 as in pyrrhotine, the errors of n are rather high while those of k are small.

Table III gives the 'best' values obtained after correcting cross-wise to get smooth curves. The results are shown graphically in figs. 4, 5, and 6. Compared with covellite, pyrrhotine has no unusual optical

properties in the visible range (optically positive for all values). The reflectivity rises continuously from blue to red; the same is true for k , while n has a minimum in the green and yellow and κ a maximum around the orange.



FIGS. 3-6: FIG. 3 (top left). Reflectivities R_{ω} and R_{ϵ} of intermediate hexagonal pyrrhotine from Trepča. Error limits are those of table II. FIG. 4 (top right). Refractive indices n_{ω} and n_{ϵ} of intermediate hexagonal pyrrhotine from Trepča, calculated. FIG. 5 (bottom left). Absorption coefficients k_{ω} and k_{ϵ} of intermediate hexagonal pyrrhotine from Trepča, calculated. FIG. 6 (bottom right). Absorption indices κ_{ω} and κ_{ϵ} of intermediate hexagonal pyrrhotine from Trepča, calculated.

[The wavelength unit is the nanometre, nm; 1 nm = 10^{-9} m. = 1 $\mu\mu$ —Ed.]

The errors given in table III were (in the case of R) derived from the consideration that through the corrections the results should have been improved compared with the 'reproducibilities' given in table II. On the other hand, the errors introduced through the equipment or through improper operation were not included so far; therefore, the deviations of table II were taken as the approximate real errors in table III. The errors of n , k , and κ were derived from general considerations in Piller and Gehlen (1964) as well as from the scatter of values observed in the course of the calculations.

TABLE III. Most probable ('best') values of reflectivity and optical constants of intermediate hexagonal pyrrhotine from Trepča with probable errors, for six standard wavelengths (figures rounded to the first or second decimal)

ω	λ	R_{air}	relative error	R_{vill}	relative error	n	\tilde{k}	κ
ω	470 m μ	30.9 \pm 0.9 %	2.9 %	18.2 \pm 0.6 %	3.3 %	2.14 \pm 0.09	1.59 \pm 0.04	0.74 \pm 0.04
	486	31.5 \pm 0.9	2.9 %	18.9 \pm 0.6	3.2 %	2.10 \pm 0.09	1.63 \pm 0.04	0.78 \pm 0.04
	546	34.0 \pm 0.6	1.8 %	21.6 \pm 0.6	2.8 %	2.01 \pm 0.08	1.77 \pm 0.03	0.88 \pm 0.03
	589	35.8 \pm 0.7	2.0 %	23.4 \pm 0.9	3.8 %	2.01 \pm 0.08	1.86 \pm 0.03	0.93 \pm 0.04
	650	38.6 \pm 0.7	1.8 %	25.6 \pm 1.4	5.5 %	2.19 \pm 0.11	2.02 \pm 0.04	0.92 \pm 0.05
	656	38.9 \pm 0.7	1.8 %	25.8 \pm 1.4	5.4 %	2.23 \pm 0.11	2.04 \pm 0.04	0.92 \pm 0.05
ϵ	470	36.2 \pm 0.9	2.5 %	22.8 \pm 0.6	2.6 %	2.28 \pm 0.08	1.88 \pm 0.04	0.82 \pm 0.05
	486	36.9 \pm 0.9	2.4 %	23.6 \pm 0.6	2.5 %	2.25 \pm 0.08	1.92 \pm 0.04	0.86 \pm 0.05
	546	39.2 \pm 0.7	1.8 %	26.2 \pm 0.6	2.3 %	2.14 \pm 0.06	2.05 \pm 0.03	0.96 \pm 0.03
	589	40.7 \pm 0.7	1.7 %	27.7 \pm 0.6	2.2 %	2.13 \pm 0.07	2.14 \pm 0.03	1.00 \pm 0.04
	650	42.5 \pm 0.8	1.9 %	29.1 \pm 0.9	3.1 %	2.32 \pm 0.11	2.26 \pm 0.05	0.97 \pm 0.06
	656	42.7 \pm 0.8	1.9 %	29.4 \pm 0.9	3.1 %	2.35 \pm 0.11	2.28 \pm 0.05	0.97 \pm 0.06

The relative bireflection of pyrrhotine versus orientation at the four standard wavelengths of table II in air was already given by Gehlen (1960, fig. 23). Sections through 'indicating surfaces' of R_{air} , R_{oil} ,

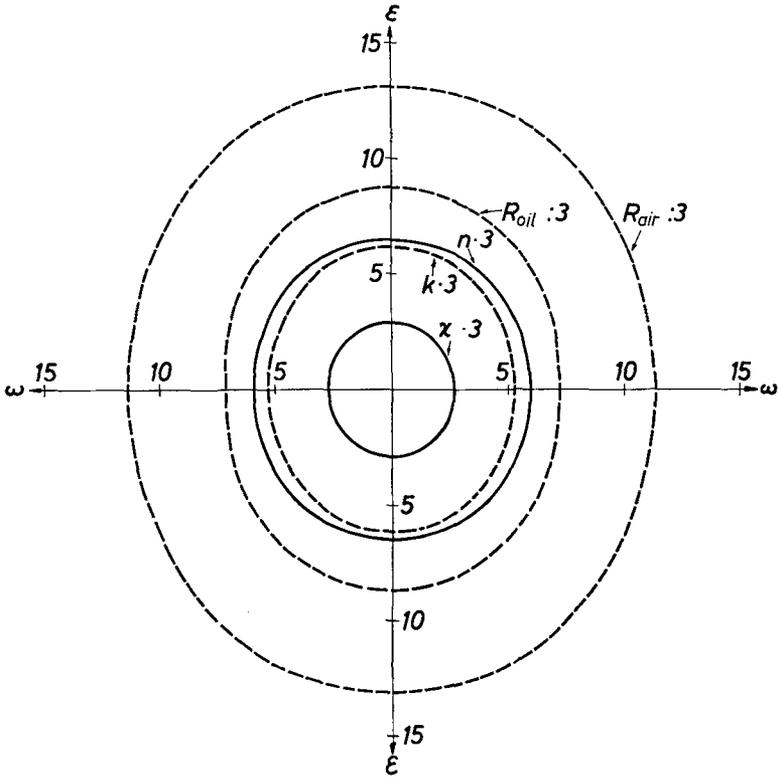


FIG. 7. 'Indicating surfaces' of R_{air} , R_{oil} , n , k , and κ of intermediate hexagonal pyrrhotine from Trepča. $\lambda = 546 \text{ m}\mu$.

n , k , and κ only show rather small deviations from circles (see fig. 7) as compared to the large deviations in covellite (Gehlen and Piller 1964, figs. 8 and 9).

General considerations regarding reflectivity measurements

The equipment should be checked thoroughly for possible sources of error (see, for example, Bowie, 1962; Ehrenberg, 1964; Bowie and Henry, 1964; Piller and Gehlen, 1964).

The quality of the specimen surface is important. It can be checked

under the microscope using interference contrast, phase contrast, or dark-field illumination.

As internal reflections in the microscope cannot be avoided completely, especially at high magnification, it is preferable to determine reflectivities in oil at low magnification with a cover glass without direct contact between oil and objective (Cambon, 1947; Piller, in preparation) if the surface condition of the specimen permits.

Reference reflectivity values should only be determined in light as monochromatic as possible (see, for example, recent discussions by Bowie, 1962, and Ramdohr, 1964). The sensitivity of the equipment, especially of the filter or monochromator, should be stated in every publication of this kind.

Single reflectivity values measured at selected wavelengths are normally not accurate enough; they should be checked through dispersion curves constructed from a series of different wavelengths and measured several times.

An error discussion of reflectivity values is absolutely necessary.

General considerations regarding calculations of n , k , and κ

An error discussion is also necessary in all calculations of this kind. A general outline was given by Piller and Gehlen (1964).

It is sometimes important to take the dispersion of the refractive index of the immersion oil into account (Gehlen and Piller, 1964).

Also n , k , and κ values should be checked through dispersion curves drawn from calculations at several different wavelengths. When a correction has to be made, R_{air} and R_{oil} have to be re-calculated. Sometimes even checking through curves of R (or n , k , κ) versus orientation may be necessary as in the case of covellite (Gehlen and Piller, 1964).

Acknowledgements. The authors are grateful to Mr. S. H. U. Bowie and Dr. N. F. M. Henry for the invitation to present this paper and for kindly checking the manuscript and to Dr. J. V. P. Long for his electron microprobe study of the specimen.

References

- ARNOLD (R. G.), 1962. *Econ. Geol.*, vol. 57, p. 72.
 — and REICHEN (L. E.), 1962. *Amer. Min.*, vol. 47, p. 105.
 BEREK (M.), 1953. In RINNE-BEREK, *Anleitung zu optischen Untersuchungen mit dem Polarisationsmikroskop*. 2nd edn, Stuttgart (Schweizerbart), p. 331.
 BOWIE (S. H. U.), 1962. *Econ. Geol.*, vol. 57, p. 983.
 — and HENRY (N. F. M.), 1964. *Trans. Inst. Mining Met.*, vol. 73, p. 467.
 BUSECK (P. R.), 1962. *Carnegie Inst. Washington Year Book*, vol. 61, p. 161.
 BYSTRÖM (A.), 1945. *Arkiv Kemi, Min. Geol.*, vol. 19 B, no. 8, p. 1.

- CAMBON (Th.), 1947. Contribution à l'emploi des méthodes optiques en métallographie microscopique. Thesis, University of Toulouse, p. 68.
- CLARK (A. H.), 1964. Studies on the mineralogy and geochemistry of the Ylöjärvi copper deposit, south-west Finland. Unpublished Ph.D. thesis, University of Manchester.
- EHRENBERG (H.), 1964. Zeits. wiss. Mikroskopie, vol. 66, p. 32.
- [ELISEEV (E. N.)] Елисеев (Э. И.), 1962. Вестник Ленинград. Унив., Сер. геол. геогр. [Vestnik Leningrad Univ., Ser. geol. geogr.], no. 6, p. 16.
- GEHLEN (K. v.), 1960. Beitr. Min. Petr., vol. 7, p. 340.
- 1963. Carnegie Inst. Washington Year Book, vol. 62, p. 213.
- and PILLER (H.), 1964. Beitr. Min. Petr., vol. 10, p. 94.
- GRØNVOLD (F.) and HARALDSEN (H.), 1952. Acta Chem. Scand., vol. 6, p. 1452.
- HARALDSEN (H.), 1941. Zeits. anorg. Chem., vol. 231, pp. 169, 195.
- HARRISON (R. K.) and DAY (G.), 1963. Min. Mag., vol. 33, p. 517.
- HIHARA (T.), 1960. Journ. Sci. Hiroshima Univ., vol. 24 A, p. 31.
- KOUVO (O.) and VUORELAINEN (Y.), 1962. Geologi, no. 6, p. 79.
- KULLERUD (G.), 1953. Norsk geol. Tidsskr., vol. 32, p. 61.
- , DOE (B. R.), BUSECK (P. R.), and TRÖFTEN (P. F.), 1963. Carnegie Inst. Washington Year Book, vol. 62, p. 210.
- NOMARSKI (G.) and WEILL (A. R.), 1954. Bull. Soc. franç. Min. Crist., vol. 77, p. 840.
- PEHRMAN (G.), 1954. Acta Acad. Aboensis, Math. Phys., vol. 19, no. 10.
- PILLER (H.), 1965. In preparation.
- and GEHLEN (K. v.), 1964. Amer. Min., vol. 49, p. 867.
- RAMDOHR (P.), 1960. Die Erzminerale und ihre Verwachsungen. 3rd edn, Akademie-Verlag, Berlin.
- 1964. Econ. Geol., vol. 59, p. 502.
- REHWALD (G.), 1952. Fortschr. Min., vol. 31, p. 17.
- SCHUMACHER (F.), 1950. Die Lagerstätte der Trepča und ihre Umgebung. Beograd.
- THIBAUT (N. W.), 1944. Amer. Min., vol. 29, p. 327.
- WEIGEL (O.), 1915. Nachr. kgl. Ges. Wiss. Göttingen, Math.-Phys., p. 264.

[Manuscript received 11 November 1964]
