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A new miniphotometer for teaching and routine work in ore microscopy

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SUMMARY. A simple and easy-to-use miniphotometer has been designed; the expense involved amounts to only a fraction of that required for large commercially available microphotometers.

The instrument can be employed for routine investigations and for teaching reflected light microscopy in conjunction with standard reflected light microscopes.

The reflectance of grains down to 50 μm size can be measured in white and monochromatic light employing continuous band and line interference filters. The systematic error does not exceed 1·5 % of the values measured. The only aspect that distinguishes the miniphotometer from larger instruments is the limitation of spot size. A comprehensive test programme including comparative sets of measurements on a Zeiss MPM spectral microphotometer has shown that the results obtained by both instruments coincide well.

PHOTO-ELECTRIC reflectance measurements were first performed by Orcel (1927, 1930). The method was further developed by, amongst others, Ehrenberg and Ramdohr (1934), Moses (1936), Bowie (1957), Piller (1964, 1966), and Gavrilovic (1970). A comprehensive survey of the methods of quantitative ore microscopy is given by Galopin and Henry (1972). Today, reflectance measurements constitute an integral and important aspect of ore microscopy; in combination with microhardness determination there emerges a system of speedy and reliable diagnosis of ore minerals (Tarkian, 1974).

Many common ore minerals differ but slightly in their qualitative microscopic features such as colour, bireflectance, and anisotropy. The use of quantitative data in conjunction with qualitative observations assists significantly in avoiding misidentification and ambiguous diagnosis.

The past ten years saw the development of sophisticated microphotometers, giving reproducible data, and internationally calibrated standards. Quantitative ore microscopy has thus moved into a new era. Every department dealing with reflected light microscopy, be it in economic geology, glass technology, metallurgy, or refractories, should have available a well-equipped microphotometer with photomultiplier. Because of financial limitations, such instruments will mostly be used for research purposes only.

There is still a lack of microphotometers that are simple, portable, and cheap, while maintaining a high degree of quantitative precision. We have attempted to design such an instrument for use in teaching and in routine mineral diagnosis. The results are presented in this note. The primary consideration has been to fill the gap that still

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exists as regards inexpensive, simple instruments, which the average Earth Science department could afford to acquire in sets of 10 or 20. Each student in an ore microscopy class could thus be given one photometer. Similarly, the average mine geological office is unlikely to obtain funds for the acquisition of a £4000 microphotometer. Sums of less than £500, however, might easily be available to provide the mine geologist with an accessory aid for ore mineral identification. Test series have shown that the miniphotometer performs to full satisfaction.

The instrument

All makes of reflected light microscopes may be used in conjunction with the miniphotometer as long as they embody the following parts:

Light source. The standard light source is replaced by a compact and fully adjustable illumination system, which has been specially developed for the miniphotometer. This consists of a lamp (60 watt, 12 volt), which can be centred, and a stabilizing unit with continuous voltage selector (6–12 volt).

Aperture diaphragm, with centring device, is required for work with prism reflector and with high-aperture objectives, as well as for reducing light intensity.

Illuminator aperture diaphragm, with centring device, for delimitation of areas suitable for measurement.

Prism reflector. The microscope should have facilities for changing reflectors. Measurements in white light should be performed with a glass-plate reflector. A prism reflector, however, is preferable for work in monochromatic light. Light intensity is thus increased by a factor of 5, as there is no loss of light by beam-splitting.

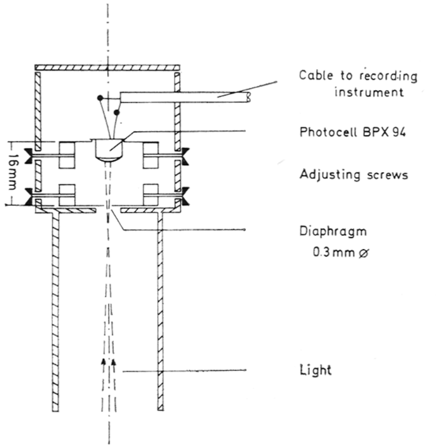
Polarizer. A removable, rotating polarizer is used with advantage in measurements of bireflectance; it can be removed for work with isotropic minerals.

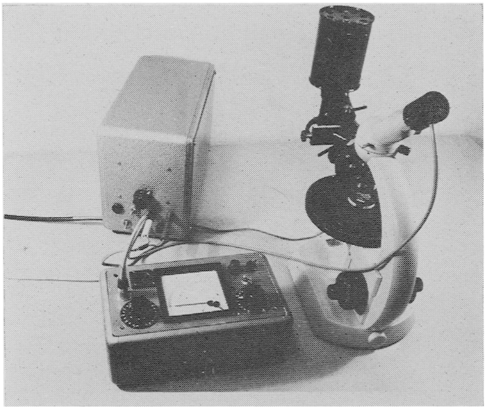
Objectives used for photometer work should be constructed so as to minimize glare and keep its effects within the general range of errors.

Photoelectric equipment. This consists of cell holder and recording instrument. The cell holder contains a measuring diaphragm (of 0·3 mm diameter) and a BPX 94 silicon photoelectric cell (fig. 1). The distance between photocell and measuring diaphragm is 16 mm. The cell holder is of compact construction; it has the diameter of a standard microscope eyepiece (23 mm), for which it can easily be exchanged. It is linked to the recording instrument by a cable (fig. 2). Lay-out and constituent parts of the recording instrument are summarized in figs. 3 and 4. There are preamplifiers, amplifiers, an ammeter, zero- and sensitivity-adjustment; the instrument can be plugged directly into the mains (220 volts).

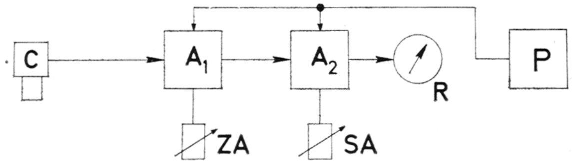
Development of the miniphotometer

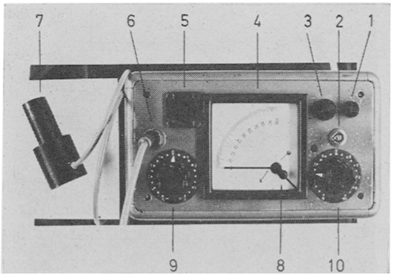
The guiding principle for the development of the miniphotometer was to accommodate the instrument to standard reflected light microscopes without alterations—except those of the light source. A Zeiss Standard KK 08 microscope has been used





FIGS. 1 and 2: FIG. 1 (left). Schematic sketch of cell holder. FIG. 2 (right). Miniphotometer attached to reflected light microscope.



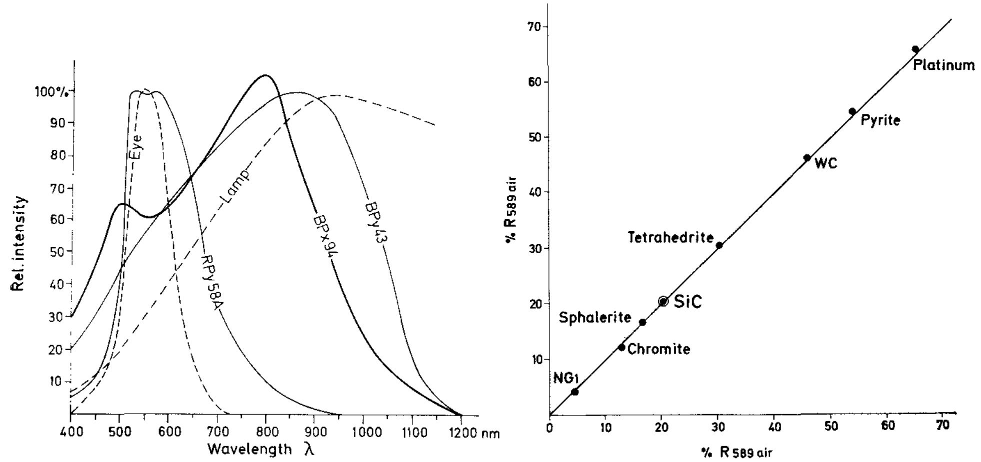


FIGS. 3 and 4: FIG. 3 (left). Schematic diagram of miniphotometer: C, cell holder; A_1, preamplifier with BFS 21 and BFW 11; A_2, main amplifier with TBA 221; R, ammeter; ZA, zero adjustment; SA, sensitivity adjustment; P, power supply. FIG. 4 (right). The recording instrument: 1, fuse; 2, switch; 3, control lamp; 4, reading; 5, support for cell holder; 6, socket for connecting cable to cell holder; 7, cell holder; 8, zero adjustment (mechanical); 9, zero adjustment (electrical); 10, amplifier adjustment.

successfully for the work reported in this note. A measuring diaphragm of 0·3 mm diameter has been decided upon as it provides an optimum compromise between spot size and light intensity.

Only cadmium sulphide or silicon cells (photo diodes) would respond to the relatively low light intensities passing through the measuring diaphragm. Photomultipliers are too expensive for serial construction. Selenium barrier-layer cells have convenient curves of spectral sensitivity, similar to that of the human eye. Their photon 'recovery', however, is unsatisfactory. A CdS cell (RPY 58 A of Valvo Ltd., Hamburg) has, in fact, been tested in a pilot instrument. It was found to give a very slow response with low light intensities; measurements and particularly zero point adjustments occupied considerable time. An added technical problem was the necessity of providing for homogeneous illumination of the cell surface to obtain reasonably linear results, and this required a beam diameter of about 7 mm. To achieve this, the photocell would have to be mounted at least 150 mm behind the diaphragm, resulting in an unwieldy cell holder and a light intensity of less than 0·1 Lux on the cell surface.

Experiments with a Siemens silicon photocell (BPY 43) indicated excessive sensitivity in the infra-red, compared with the visible section of the spectrum (fig. 5). Significantly better results are obtained with a silicon cell with improved blue-sensitivity (BPX 94 of Valvo Ltd.) both in white and monochromatic light. A publication issued by Valvo Ltd. (1973) described a high-performance amplifier. To suit our purpose, we have modified their circuit to include sensitivity adjustment. The performance of the amplifier is such that it permits measurements in monochromatic light throughout the visible spectrum (400 to 700 nm).



FIGS. 5 and 6: FIG. 5 (left). Spectral sensitivity curves of various photocells. FIG. 6 (right). Comparative reflectance values obtained by Zeiss MPM (line) and by miniphotometer (points).

The above arrangement has solved both problems—fast measurements are facilitated by the quick-response silicon cell, and a short cell holder suffices, as the silicon diode does not necessitate homogeneous illumination. Its sensitivity is slightly higher in the centre, and the diaphragm–photocell distance has been reduced to 16 mm. The diameter of the beam reaching the 1·2 × 1·2 mm cell is now 0·5 mm. This also assists in avoiding errors caused by minute movements of the cell holder within the microscope tube; the beam now remains constantly on the cell surface. The photoelectric equipment should comply with the following requirements: stability of the amplifier; sensitivity of the measuring device and quick response; zero-point constancy for significant periods and minimum oscillations of the ammeter during measurements; and good linearity of photo current and readings. Zero-point constancy and amplifier linearity are indeed excellent. There is very little amplifier drift; temperature-dependence of light sensitivity is almost unnoticeable. The cell holder should be protected from heat. Good results have been obtained with a Zeiss Standard KK 08 microscope over extensive test periods.

The new miniphotometer permits reflectance measurements of grains down to 50 μm diameter in white and in monochromatic light. The mode of operation is briefly summarized below.

Measurements in monochromatic light are performed using a continuous band or line interference filter covering the visible spectrum (400 to 700 nm). The desired wavelength can be selected accurately on a scale. The maximum transmittance (τ-max) of these interference filters depends on the wavelength and varies from 20 to 25 %. The width-of-transmission curve (HW) varies from 12–16 nm (Verlauf–line filter VERIL S 60) and from 25–30 nm (Verlauf–band filter VERIL B 60), depending on wavelength. If line filters (S 60 and S 200) are used for wavelength below 550 nm, the secondary maximum within the short-wave section of the infrared should be blocked by a suitable additional filter, of instance BG 18.

The following reflectance standards have been recommended by the Commission on Ore Microscopy (COM) of the International Mineralogical Association:

NGl (glass),	$R \approx 4$ %,	for measurements in the range	R0 to 10;
SiC,	$R \approx 20$,	for „ „ „ „	R10 to 30;
WC, (W, Ti)C,	$R \approx 45$,	for „ „ „ „	R30 to 60.

These standards are, at £35 apiece, still comparatively expensive; additional sets of 'secondary' standards can be prepared from suitable minerals (sphalerite, 17 %; pyrite 54·5 %; platinum 70 %). It should be stressed that we do not recommend to replace the official COM standards by secondary standards. Each laboratory employing the miniphotometer should, of course, have available one set of COM standards. Secondary standards are recommended, for instance, for classroom use, where each student could be provided with a set. Their reflectance has to be measured against primary standards and it should be checked from time to time.

Operation and application

Adjustments. Prior to the commencement of measurements all optical parts of the microscope (light source, aperture diaphragm, illuminator aperture diaphragm, prism reflector, and objectives) should be centred carefully. After exchanging glass-plate reflector and prism reflector, the illuminator aperture diaphragm and objective have to be recentred. The measuring diaphragm in the cell holder is adjusted only once in relation to the eyepiece crosswire by 4 screws (fig. 1).

Choice of magnification and measurement area. The illuminator aperture diaphragm is closed to select an area suitable for measurement. The image of the diaphragm should be contained completely within the area to be measured. This aspect determines the choice of magnification.

It is of paramount importance that standard and object be always illuminated and adjusted under identical conditions. In the course of extensive serial measurements the initially fixed reference value should be controlled and, if necessary, corrected at regular intervals.

TABLE I. *Comparison of results obtained on the Zeiss MPM and on the miniphotometer*

Mineral	Miniphotometer				Zeiss MPM				IMA-COM Tables (1970)	
	R_{470}		R_{546}		R_{470}		R_{546}		R_{470}	R_{546}
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Range
Cassiterite	11·0–13·0	—	10·5–12·5	—	11·0–12·8	—	10·7–12·3	—	11·3–13·0	10·9–12·4
Chromite	—	12·5	—	12·0	—	12·3	—	11·9	11·9–13·8	11·5–13·3
Wolframite	15·3–17·7	—	15·3–18·0	—	15·5–18·0	—	15·5–18·2	—	15·8–18·5	16·0–18·7
Sphalerite	—	17·5	—	17·0	—	17·1	—	17·0	16·7–18·3	16·1–18·0
Ilmenite	16·8–20·5	—	16·5–20·0	—	17·0–20·7	—	16·8–20·3	—	17·3–20·6	17·0–20·1
Tetrahedrite	—	31·5	—	32·0	—	31·0	—	31·8	30·2–31·3	30·5–33·0
Pyrrhotine	31·5–36·0	—	34·7–40·0	—	32·0–36·3	—	35·3–40·1	—	30·8–35·5	34·7–39·9
Pyrite	—	47·0	—	54·0	—	46·3	—	53·4	46·0–46·5	53·6–54·0
Nickeline	38·7–46·0	—	48·3–51·5	—	38·0–45·6	—	48·0–52·1	—	37·4–44·9	47·2–51·6
Platinum	—	63·0	—	66·7	—	62·1	—	65·9	—	—
NGl	—	4·5	—	4·5	—	4·6	—	4·4	—	—
(SiC)	—	(21·0)	—	(20·5)	—	(21·0)	—	(20·5)	—	—
WC	—	47·0	—	46·8	—	46·5	—	46·1	—	—
	R_{589}		R_{650}		R_{589}		R_{650}		R_{589}	R_{650}
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Range
Cassiterite	10·5–12·0	—	10·5–12·3	—	11·0–12·3	—	10·8–12·1	—	10·7–12·1	10·5–11·9
Chromite	—	12·3	—	12·1	—	12·7	—	11·8	11·5–13·3	11·2–12·7
Wolframite	15·3–18·0	—	14·8–17·0	—	15·1–17·8	—	15·0–17·5	—	15·7–18·4	15·4–18·0
Sphalerite	—	16·8	—	16·3	—	16·7	—	15·5	15·9–17·7	15·7–17·2
Ilmenite	17·7–21·0	—	16·5–21·0	—	16·8–19·8	—	17·0–21·0	—	17·3–20·2	16·6–20·4
Tetrahedrite	—	30·8	—	29·5	—	30·3	—	30·0	30·5–32·8	28·9–30·3
Pyrrhotine	37·0–43·0	—	37·3–44·0	—	36·8–42·5	—	36·5–43·4	—	35·8–43·1	37·2–43·2
Pyrite	—	55·3	—	56·0	—	54·6	—	55·5	55·0–55·4	55·9
Nickeline	54·0–57·5	—	59·0–61·5	—	52·5–56·6	—	58·1–60·6	—	53·3–56·0	59·1–60·1
Platinum	—	67·0	—	70·5	—	66·0	—	69·4	—	—
NGl	—	4·2	—	4·0	—	4·4	—	4·0	—	—
(SiC)	—	(20·3)	—	(20·0)	—	(20·3)	—	(20·0)	—	—
WC	—	46·3	—	46·3	—	45·9	—	45·8	—	—

Results

Comparative measurements at standard wavelengths 470, 546, 589, and 650 nm were made on the miniphotometer described in this note using a continuous band interference filter VERIL B60 with HW-max = 25 to 30 nm of Schott u. Gen., Mainz, and on a Zeiss MPM spectral microphotometer with continuous line interference filter VERIL S 200 with HW-max = 15 to 18 nm. Reflectance data of well-polished sections of some isotropic and anisotropic minerals have been obtained using standards NGl. For control purposes, NGl and WC have also been measured against SiC. The results are summarized in Table I and fig. 6. The straight line in fig. 6 is based on data from the Zeiss MPM. Average values obtained by the miniphotometer are plotted as points. Intensive tests carried out over several months have established the reliability and the high standards of precision of the miniphotometer.

With the exception of limitation in spot-size (minimum, 50 μm), the performance of the instrument does not differ significantly from that of larger and more expensive microphotometers.

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