Some topics in polarized-light microscopy, 1890-1930 (L.K., Jan. 2015)

Biological research

According to Lecher (1917, p. 290) and Köhler (1926), polarizing microscopes have been of much use to biologists when probing various animal and human organs. In histology, research on muscles that had started around the middle of the 19th century was continued by Rollett (1891), Engelmann (1895), Schultz (1895) and Hürthle (1909), to name a few. The detailed structure of nerve fibers was also studied in polarized light (Göthlin 1913, Fig. 1). Schmidt (1920, 1924) confirms that examination in a polarizing microscope is an important aid in ascertaining the structure of many tissues in addition to muscles and nerves: he presents examples concerning bones, teeth (cf. also Ebner 1906), sinews, hair, horn, scales, shells and exoskeletons of invertebrates, foraminifera, corals, pearls, sponges and so on. See for instance thorough studies by Kelly (1901), Bütschli (1908) and Karny (1913) on calcareous skeletons and other deposits in tens of animal species.

![Fig. 1. Left: Drawing of a nerve fiber seen in a polarizing microscope (Göthlin 1913). Right: Ramie fibers (from a tropical thistle) under the microscope when dyed with gold (a and b) or silver (c and d). Their colors change as the polarizer P is rotated (Ambronn and Frey 1926).](image)

In a review of Schmidt’s (1924) book (Naturwissenschaften 12, p. 745-746), polarizing microscopes are said to have been for a long time an indispensable tool in human histology and pathology. By cursory inspection of publications from that period, it is evident that this often relates to the nature of a variety of pathological conditions, such as in the digestive system (see Ebstein 1888 and Schmidt 1924 on kidney- and gallstones, Panzer 1906 on inflammations), eyes (Lauber and Adamüü 1909, Kranz 1927 and references therein), skin, cancerous tumors (White 1909), spinal fluids (Donath 1905) and so on. Among the commonest of such conditions are deposits of liquid crystals with a clear double refraction, including cholesterol and myelin; see Kaiserling and Orgler (1902), Löhlein (1905) and Adami and Aschoff (1906). Anitschkow and Chalatow (1913) found that if rabbits ingest food rich in cholesterol, it accumulates in various organs where its presence can be demonstrated by a polarizing microscope. This discovery was not followed up much in the next 30-40 years with regard to a connection between cholesterol in human food and in the cardiovascular
system, but it was later seen to be quite important. Liquid crystals present in brain tissue were shown to be composed of galactosides (Rosenheim 1914, 1916).

Microscopes were also used in the characterization of hundreds of crystalline materials isolated or synthesized during biochemical research, to aid in their identification. Examples include nucleic acids (Kossel and Neumann 1893), glycosides (Koenigs and Knorr 1901), glucosamine (Müller 1901), sugars (Will 1885, Ekenstein 1896, Tanret 1903, Dufet 1904a), the bile acids studied by Wieland and Sorge (1916, Anhang), and alkaloids (Wolffenstein 1894, Willstätter et al. 1923). A notable work in this general field was the study by Reichert and Brown (1909) on hemoglobins from a large number of vertebrates.

Turning to the vegetable kingdom: one of the pioneers in studying plant tissues by polarizing microscopes was H. Ambronn. He had towards the end of the 19th century used such microscopes when investigating colloid suspensions of matter in liquids, but in 1913-19 he carried out noteworthy research (e.g. Ambronn 1916) on the structure of cellulose. Here one had to distinguish between the conventional double refraction of crystalline substances and an analogous phenomenon caused by the shape of grains or grain parts, even when they are composed of isotropic materials. This phenomenon which was called rod- or plate-refraction depending on circumstances, had in fact been a subject of discussion in 1840-60; it was revived by Wiener (1904) and by Braun (1905). Ambronn himself resurrected C. Nägeli’s micellar theory of cell structure, which had been largely forgotten for twenty years. Additionally, Ambronn and others studied the optical properties of various gels (e.g. Neubert 1925).

The double refraction observed in the fibers of many industrially valuable organic materials (wool, cotton, hemp, silk, wood, etc.) is due to their being composed of elongated sub-parallel molecules. Polarizing microscopes have been of much use in research on such fibers in the 20th century (cf. Schiller 1906, Bowman 1908, Herzog 1909, 1916, Harrison 1918, Frey et al. 1926, and Hartshorne and Stuart 1950, p. 439-452). Treatment of fiber samples with certain colored chemicals, metal salts, iodine or other compounds (dichroic staining) can enhance their double refraction, see for instance Ambronn (1896), Frey (1925), Ambronn and Frey (1926, p. 176-185; Fig. 1), and McGraw-Hill (1992). This technique was used after 1940 in the production of polarizing filter sheets which performed better than the original Polaroid foils containing herapathite; in recent years it has also been employed in combination with liquid crystals in digital and television displays.

For some decades, biologists were not quite happy (see Ebner 1892) with the polarizing microscopes on the market, which was dominated by petrographers. Eventually, the Zeiss company offered some accessories for their benefit, upon the advice of the physiologist T. Engelmann (Siedentopf 1902). The Leitz workshop sold Nicol-prism arrangements that could be fitted to ordinary biological microscopes (Schmidt 1924, p. 19). Later, Schmidt (1925) persuaded Leitz to produce a specially designed polarizing microscope for biologists (Fig. 2). It was to some extent simpler than the petrographic models, but contained a type of analyzing prism (see Ehringhaus 1920) which improved the resolution of delicate features. Without doubt, these instruments were not only valuable when studying
modern tissues, but also in microscopic paleontology. One example would be in oil exploration, where the fossilized remains of organisms in ocean sediments can reveal much about their age and economic potential.

Chemistry, including microchemistry

In publications from even before 1900, many instances may be found where polarizing microscopes were essential in studies of crystallization. They could also aid in recognizing materials which were only available to the scientist in very small quantities. Among those contributing to the development of such “microchemical” techniques were Reinsch (1881), Haushofer (1883), Behrens (1891; Behrens-Kley 1915) who asserts that polarizing prisms are indispensable for such work, and Pozzi-Escot (1900). Emich’s (1911) book on the subject gives many examples of polarization techniques in the microscopic identification of compounds. Emich (1916) also points out that small-scale polarimetric observations were of great value to E. Fischer (see Fischer 1911) in his research on polypeptides. E.M. Chamot designed a simple microscope with Nicol prisms for chemists, produced by Bausch & Lomb from 1899 to the early 1930s (Fig. 2). See Chamot’s (1915) book on these microscopes; one optional accessory was a 10-cm. tube which could be inserted into them for approximate measurements of optical activity in liquids. Books by Johannsen (1914, chapter XL), Rosenbusch (1924, chapter on microchemical reactions p. 742-761) and Hartshorne and Stuart (1950, p. 422-433) explain the use of polarizing microscopes in chemical analysis.
Reflected-light microscopy, ca. 1900-20

The early history of this field has been described by Orcel (1972). As is well known, many useful metals such as iron, lead, copper and zinc are present in the earth’s crust in the form of oxides, sulfides etc. rather than pure elements. The grains of these “ore minerals” are generally semiconductors and therefore opaque in thin section. Several of their properties aided geologists in distinguishing them in hand samples or under the microscope: density, hardness, color, magnetism, effects of acids, and so on. Chemical analyses were time-consuming, and it might be difficult to isolate fine-grained ores from their silicate matrix. Additional rapid and dependable analyzing methods were therefore needed, especially in prospecting, mapping of mineral bodies, and mining operations. The first attempts to employ light reflected from polished surfaces in microscopic studies of ore minerals were possibly made by H. Baumhauer around 1885. Drude (e.g. 1887) and Voigt (1891) published theoretical papers dealing with the reflection, refraction and propagation of polarized light in absorbing crystals. Similar studies on metals and alloys followed (Drude 1890), cf. a note in La Nature 26(I), 139-140, 1898. Charpy (1896) introduced various techniques for this purpose, and they were advanced further by W. Campbell around 1907 (Orcel 1972).

The state of polarization of light reflected normally from a polished ore-mineral surface depends on the mineral, also varying with the angle of the surface relative to crystal axes if the crystal is anisotropic, and with the wavelength. This can be utilized in two ways, as in transmitted-light microscopes. On one hand a polished rock section containing different ore minerals may be viewed through Nicol prisms (and usually other accessories) to discern variations in brightness and color between grains. For instance, in igneous rocks magnetite (Fe₃O₄) and ilmenite (FeTiO₃) often occur side by side or even as intergrowths, and in polarized light they are easier to distinguish than in ordinary light because magnetite is cubic while ilmenite is trigonal and therefore anisotropic (Fig. 5). Short’s (1931) handbook on the microscopic determination of ore minerals where the various methods of identification are described, stresses that “The most useful test that can be applied to determine an unknown mineral is the test for anisotropism.”. One the other hand, measurements on the intensity and polarization of the light reflected from individual grains may be employed for quantitative estimates of their composition.

A major step forward in this field was taken with J. Königsberger’s (1901a, 1908) microscope designs. In his first model, the light incident on a polished specimen was unpolarized, and a Nicol prism, a tilted glass plate and a Savart plate (of specially cut quartz or calcite) were used for analyzing the reflected light. In later models by him (Königsberger 1909, cf. Schlossmacher 1924) and other designers, the incident light was first made linearly polarized by a Nicol prism, and the rotation of its plane of polarization upon reflection was measured with another Nicol prism and a quartz plate (Fig. 3). Königsberger points out in his papers that for instance the quality of coal may be estimated from the anisotropic reflectivity of polished samples; this technique was later used extensively.

In papers in 1908-10, Königsberger quotes some cases where useful information on metallic specimens may be obtained by microscope examination in reflected light; additional
examples are given by Endell and Hanemann (1913). The book on microscopy by Spitta (1907, p. 291-301) contains descriptions and illustrations of microscopes for metallurgical use from four manufacturers. However, neither he nor Johannsen (1914) mentions any polarizing arrangements for these. After World War I, ore microscopes developed rapidly: F.E. Wright replaced Königsberger’s quartz plate with an Iceland spar rhomb (see figure in Kristjansson 2000), later introducing a new type of quartz wedge (Wright 1919b, B in Fig. 3). Methods for varying the illumination of specimens by means of Nicol prisms were also developed.

Fig. 3. Left: Two schematic diagrams of early reflected-light microscopes, by Königsberger (1908) and Wright (1919) respectively. Right: An optical bench with light coming from the right through an optional Nicol prism N, illuminating small particles in the ultramicroscope at the left end. Illustration from a Zeiss advertising leaflet, c. 1905.

Ultramicroscopes

In so-called ultramicroscopes (Fig. 3) particles in colloidal suspension in liquids or in glass (Siedentopf and Zsigmondy 1903, Cotton and Mouton 1903) could be made visible even if they were smaller than the wavelength of the light used. With illumination coming from the side, the particles (such as microorganisms) appeared as luminous specks on a darker background. Ultramicroscopes were marketed for decades by the Zeiss company and others. With an optional Nicol prism in the light path, some information could be obtained about the shape of the particles, and the presence of fluorescence in the liquid could also be detected.

Reflected-light microscopy after 1920

The firms of C. Reichert and E. Leitz became known for their reflected-light microscopes. The latter originally produced the Erzmikroskop MO (Fig. 4), later a versatile instrument designed by Scheffer (1919) where ore microscopy was one of the available
options. Following the appearance of H. Schneiderhöhn’s (1922) text on the use of reflected light and the marketing by Leitz of their large Erzmikroskop MOP in 1923, “whirlwind development” of this field within petrography took place (according to Schneiderhöhn in a 1941 Leitz Festschrift). Glaser (1924) describes various design features in reflected-light microscopy, intended for instance to study internal tensions in metal alloys. It appears to me from a cursory look at the literature, that while polarizing arrangements are fairly widespread in present-day microscopical metallography, they were not much used before 1930 (Schwarz 1931). Their application in metal research also has been relatively less than in work on ore minerals (Fig. 5). This is perhaps due to the fact that many common metals and alloys belong to the cubic crystal system, and in others the reflections are not very dependent on polarization direction (Dayton 1935). In a review paper, Mott and Haines (1951) state that uranium (orthorhombic) and beryllium (hexagonal) are the metals most often investigated in polarizing microscopes, which is connected to their role in the harnessing of nuclear energy.

Fig. 4. Left: Erzmikroskop MO by E. Leitz, for which optional Nicol prisms were available after c. 1912. From Schneiderhöhn (1922). Right: Frick's (1930) photometric attachment with two Nicol prisms is seen to the right of the top of a reflected-light microscope.

The photometric attachment of Frick (1930, Fig. 4) for reflection microscopes may be mentioned here. Berek (1931) published an important paper on precise analyses of ore minerals in such microscopes, where Nicol prisms were used both in the measurement of polarization and intensity of the reflected light. This was possible due to Berek’s patented invention of a new glass prism which altered the direction of a light beam by 90° without affecting its state of polarization. These microscope photometers were produced to 1960 at least. Hoffmann and Jenkner (1932) confirmed a result by Königsberger referred to above, that the reflectivity of a polished coal-sample surface increased with the quality of the coal. This has been economically important in coal technology (Broadbent and Shaw 1955).
Iceland spar in interferometry

Two instruments invented by J. Jamin in the late 1860s were intended for measurements of very small distances or of very small variations in refractive indices, with the aid of interference of light. One of them which employed silver-coated glass plates and unpolarized light, became popular. Occasionally, Nicol prisms and a phase compensator were also made use of, for instance by Clark (1906) in research on the optical properties of thin carbon films. Jamin’s other type of instrument (Jamin 1868) which was based on interference between polarized rays, was largely forgotten (see however Kerr 1888) until revived by Skinner and Tuckerman (1911), Sagnac (1911) and others. They pointed out that through a certain kind of interference effects, the half-shade arrangement of Brace (1904a) could make the path difference of two rays visible as a change in light intensity even if it was less than 0.01% of a wavelength. The method required high-quality polarizing prisms and was difficult to use, but Lebedeff (1930) found a practical way of employing it in microscopes (Fig. 5).

![Jamin interferometer](image)

**Fig. 5.** Left: Grain of an iron-titanium mineral in Tertiary basalt from Baffin Island in reflected polarized light. The width of this polished section is approx. 0.3 mm. The bright lamellae are magnetite (isotropic) within a matrix of ilmenite (anisotropic). Silicates are dark brown. Photo: L.K. 1970. Right: A schematic diagram of Lebedeff’s (1930) interferometric method to display small changes in the thickness or index of refraction of the specimen A (such as a histological thin section) as changes in brightness. Q<sub>1</sub>, Q<sub>2</sub> are two identical thin Iceland spar plates, P<sub>1</sub>, P<sub>2</sub> are Nicol prisms and L is a quarter-wave plate (Françon 1957).

Rapid technical development of this method took place from around 1950. Production began of interference microscopes with Nicol or Wollaston prisms, for examination of transparent objects (especially biological materials) where the refractive index varied very little across a sample slide (Françon 1952, Smith 1955, Huxley 1957). These microscopes resembled to some extent the simpler and better known phase-contrast microscopes for biologists, which edged them off the market after 1970 (according to Dunn 2005). Living cells could be studied with the interference microscopes (e.g. Davies et al. 1954), which is said to have led to notable discoveries concerning the structure of cells and their movements. Analogous techniques in polarized light were also applied to the study of small deformations of surfaces, of air currents in wind tunnels, and of other phenomena involving very small variations in the phase of a light wave (Françon 1957, 1963).