Notes on the applications of polarized light in microscopy, to ~1870

These notes are an extension of some slides in a plenum lecture at the Scandem Conference in Reykjavík, in 2009. They are mostly copied from sections of my 2010 report: "Iceland spar and its influence on the development of science and technology in the period 1780-1930" with additions to Sept. 2014. Most of the references quoted below may be found in the report. - *Leó Kristjánsson*

Developments 1830-1850 in devices mostly intended for amateur microscopists

Brewster (1830a) points out that beautiful color effects will be seen if metallic salts are allowed to crystallize from solution under a microscope in polarized light. For this he recommends a glass-plate polarizer and a thin plate of agate or tourmaline as analyzer. The first one to equip a microscope with Nicol prisms was probably Talbot (1834a, 1837) who describes various observations with this equipment. Polarizing prisms for microscopes were sold as early as 1836 by the optician Andrew Pritchard in London: they are included in an advertisement in The Quarterly Literary Advertiser. Use of these as well as of tourmaline plates is mentioned by Goring and Pritchard (1837) and in a Watkins & Hill catalog in 1838. Powell & Lealand in London made microscopes with optional Nicol prisms in 1840-41 (Turner 1989, p. 120-122, Fig. 1). A new microscope by Ross (1843) also has polarizing and analyzing prisms among its accompanying apparatus, and so has one by Smith & Beck in 1848 (Turner 1989, p. 174-175, Fig. 1).

Books and papers (Goring and Pritchard 1838, Pereira 1843, Quekett 1848, Legg 1849) appearing in London in this time interval described the advantages of using polarized light for observations on a variety of crystals and biological materials. Goring and Pritchard's book contains an update of the latter's 1836 advertisement of polarization accessories and related preparations for microscopes, now including thin sections of various rocks. Polarized-light techniques seem to have been popular with amateurs who often were organized in clubs and who published magazines.

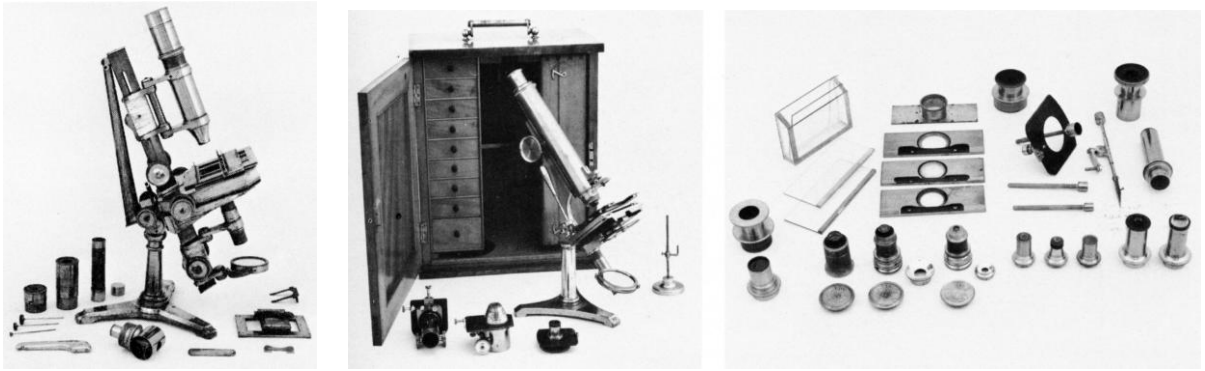

Fig. 1. Left: A microscope made by H. Powell in London 1840, with Nicol prisms and other accessories. Center and right: A Smith & Beck microscope c. 1848, with accessories.

In France, the optician C. Chevalier (1839; Mandl 1839) constructed a microscope with Nicol prisms for the geologist A. Brongniart. Lerebours (c. 1842, 1846) and Dujardin (1843) are also familiar with microscopes fitted with Nicol prisms and other polarizing arrangements. According to a short note on p. 414 of Comptes Rendus vol. 8, the opticians J.B. and H. Soleil presented in 1839 an instrument for measuring the axial angle in biaxial crystals. It is advertised by Lerebours and Secretan (1853), and it probably contained Nicol prisms. Leeson (1845, Fig. 13-1) described a device with an Iceland spar (or quartz) prism for measuring angles of crystals and some of their optical properties. This device seems to have been available as an option in at least some microscopes into the 20th century (Rosenbusch 1885, p. 17-18, Beck 1882, 1924, Groth 1905). Lima-de-Faria (1990) considers the first polarizing microscope to have been designed by Amici (1844); it has a glass-mirror polarizer and an Iceland spar rhomb analyzer. A description and a drawing of this instrument (Fig. 2) may in fact be found in an earlier book by R. Gerbi: Corso Elementare di Fisica, vol. 3 p. 229-231, Pisa 1832. Brewster (1848a) pointed out that bothersome reflections in microscopes may be reduced by the use of polarized light, and Brücke (1848) used a microscope with two Nicol prisms in work on colored rings in thin crystalline plates.

Developments in biology, 1840-70

It may be mentioned here in passing, that W. Nicol published in the 1830s some observations on thin sections from wood (including fossilized material), however without employing the polarizing prisms he had invented. I have only gathered limited information on how biologists made use of polarized light in microscopy in 1850-70, but it was known by 1840 that for instance bone and muscle tissue, seashells (cf. Carpenter 1844), and starch particles exhibited polarization interference colors in a similar way as crystals did. Erlach (1847) describes a microscope with two Nicol prisms with which he observed various plant and animal tissues, and he published drawings of these.

The microbiologist C.G. Ehrenberg (1848, 1849) refers to previous work by others and also lists many examples where in his own experience polarized light helps in the microscopic examination of biological specimens. It allows the observer to distinguish between organic and inorganic objects, as well as between crystallized and uncrystallized material. In those of his papers that I have seen, it is not stated what sort of polarizing apparatus he was employing. Mohl (1858, 1859) pointed out that Ehrenberg and other pioneers in the field did have various incorrect ideas, but he agreed that a polarizing microscope reveals features not seen in ordinary light, for instance in his studies of cell membranes. He found that crystals were present in much greater variety and numbers in the vegetable kingdom than was previously known. In Mohl's opinion Nicol prisms are far superior to other means of polarizing light. See also White (1858), Brücke (1858), Margo (1860) and Rouget (1862, Fig. 2) who published detailed observations of muscles from various animals accompanied by illustrations in color, and Klebs (1864) who investigated nerves in muscular tissue.

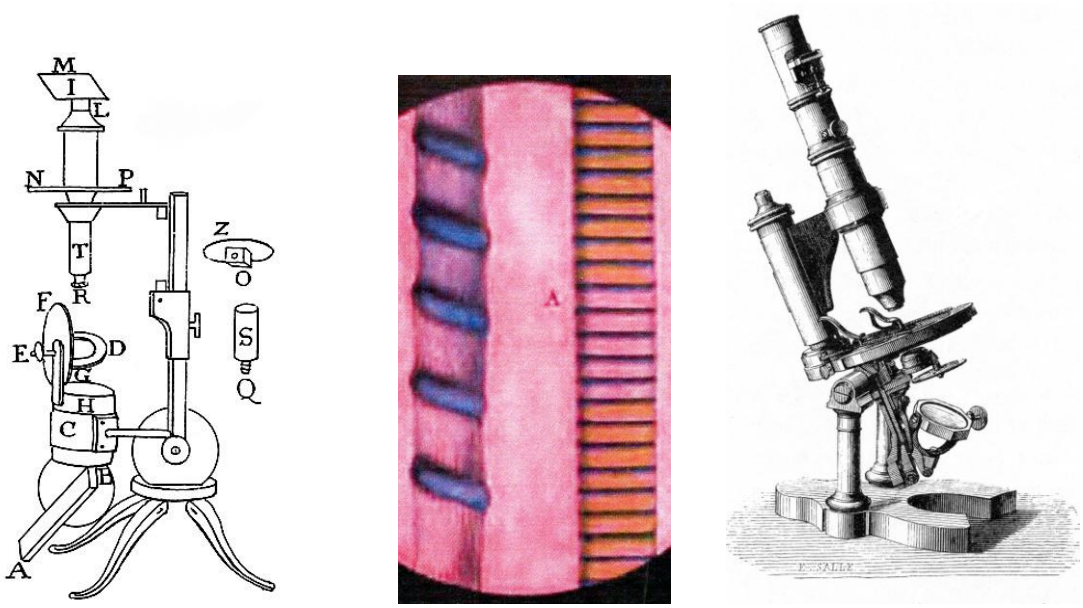

Fig. 2. Left: Amici's microscope, as illustrated by Gerbi in 1832. I is an Iceland spar rhomb. Center: Drawing of insect muscles, as seen in a polarizing microscope from A. Nachet (Rouget 1862). Right: Nachet's 1856 Grand modèle microscope, for which Nicol prisms were an optional accessory.

The well-known physiologist G. Valentin investigated in the period 1858-81 tissues from plants and animals, both with a Nörrenberg microscope (Fig. 3, see below) and a similar-looking setup designed by H. Wild. See for instance Valentin (1858) on the nature of the crystalline lenses of the eyes of many animals. His book (Valentin 1861) contains a detailed account of the properties of polarized light and appropriate microscopic equipment, as well as short descriptions of many types of tissues. C. Nägeli also published many papers from 1861 onwards on the detailed appearance of vegetable tissues in polarized light (e.g. Nägeli 1862). He considered starch grains, cellulose membranes and much other organic material to be composed of crystallized molecular groups which he called micelles, separated by thin films of water. “The crystalline nature of the micelles is especially obvious in polarized light” he states in an 1879 publication. A number of colleagues contested his interpretations, suggesting in particular (e.g. Wiesner 1886) that the double refraction observed in plant cells was due to internal tensions rather than crystalline structures. However, it is clear that Nägeli's work stimulated much research into fundamental aspects of botany and cytology for a century (Zsigmondy 1925, p. 39, see also Muralt and Edsall 1930).

Harley (1865), a professor of physiology and histology, introduced to German readers a binocular polarizing microscope which was already in wide use in England. Nägeli and Schwendener's (1867) popular comprehensive book on biological microscopy placed considerable emphasis on the advantages of polarized light. The book contains advertisements from microscope makers, several of which offer polarizing attachments. Dareste (1871) described particles in egg yolk which exhibited birefringent properties like starch. These particles consisted in part of lecithin which later turned out to belong to so-called liquid

crystals. Various other biological features were probed with polarized light, including cartilage (Müller 1861) and fish skin (Schultze 1861).

Developments including mineralogy and related subjects in 1850-70, before the widespread use of thin sections in research

Disney et al. (1928) and Turner (1989) describe many old microscopes preserved in a London museum, including some from the mid-19th century with fixed or detachable Nicol prisms. Among them are two from the makers Powell & Lealand delivered in 1850-53, one from Smith & Beck in 1850, one from A. Ross around 1853 and one from Negretti & Zambra around 1855. Bryson (1850) also refers to microscopes with Nicol prisms. In France, Nachet (1979, see Fig. 2) offers a microscope attachment with two Nicol prisms in his 1856 catalog. In the United States, polarizing microscopes were advertised by J. & W. Grunow (1856) and B. Pike (1856). Books and papers (Bird 1853, Hogg 1854, Pereira 1854) continued recommending the use of polarized light in various situations. However, I have not come across many papers by scientists in the U.K., France or the U.S. before 1855 on comprehensive studies involving polarization microscopy. In that year, one book (by H. Schacht, in Berlin) even asserts that "Polarizing outfits on microscopes are better suited for playing with beautiful color effects than for learning anything scientific". In the U.S., books by Wythe (1851) and Carpenter (1856) similarly emphasize such effects.

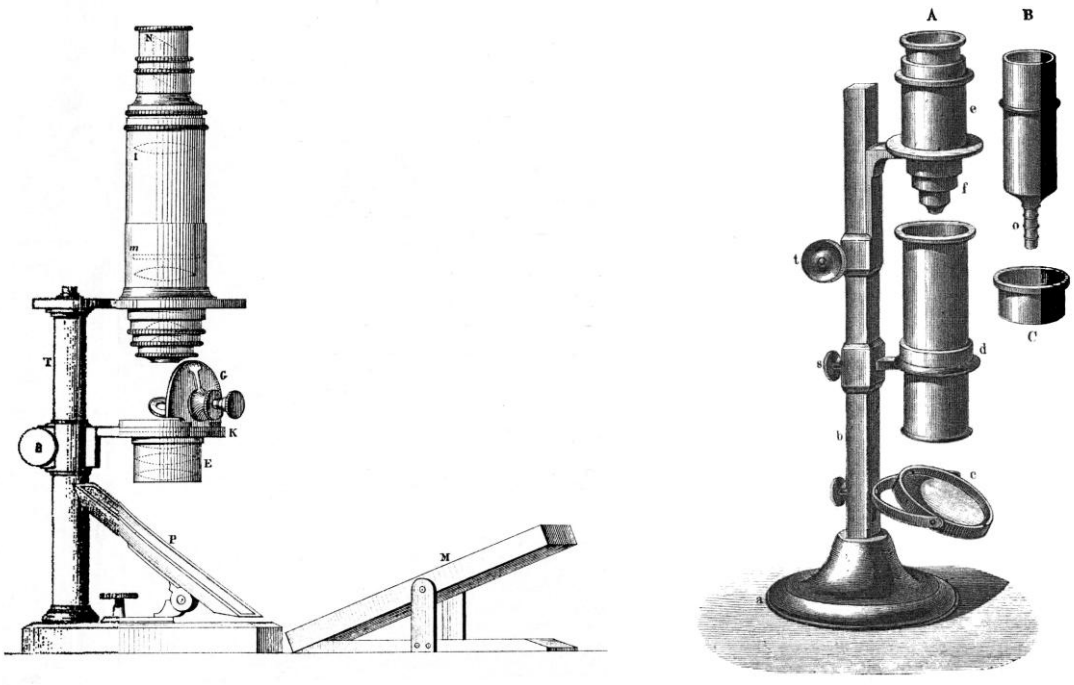

Fig. 3. Microscopes used for studying optical properties of plates cut from transparent crystals of minerals. Left: A microscope described by Des Cloizeaux (1864) with a glass-mirror polarizer and Nicol analyzer. Right: Improved model of a microscope invented by J. Nörrenberg. From a book on microscopy by Dippel (1867).

Marbach (1854) used a polarizing microscope when he recorded for the first time optical activity in the cubic crystal system, namely in sodium chlorate. In another paper, Marbach (1855) discussed the presence of double refraction in cubic crystals and related peculiar properties of various minerals (in fact noted much earlier by D. Brewster). These properties have since then been called "optical anomalies". Marbach did not describe his microscope or mention where it came from. However, it may be the same one as his teacher M.L. Frankenheim (1854, 1860) used in research on the growth and dissolution of crystals. Frankenheim's instrument had two Nicol prisms.

Kobell (1855) designed a microscope which he called a stauroscope, in order to identify minerals with the aid of interference patterns. It contained a glass-mirror polarizer and a tourmaline-plate analyzer. J. Nörrenberg demonstrated in 1858 his low-power mineralogical microscope with a double glass-mirror polarizer and a Nicol-prism analyzer, see Bertin (1863) and Groth (1926, p. 246).

A. Des Cloizeaux began studying plates of transparent minerals with Amici's microscope around 1855 (Des Cloizeaux 1855, 1857a) and with Nörrenberg's microscope around 1860, cf. his book on mineralogy (Des Cloizeaux 1862) and Bertin (1863). He investigated some 500 minerals and was the first of his countrymen to employ optical methods to any extent in mineralogical research (Lacroix 1893). See for instance Des Cloizeaux (1861) where a microscope with at least one Nicol prism is described. Grailich (1858) wrote a book on his studies of many minerals and man-made crystals; these were carried out to begin with in Kobell's stauroscope and a microscope of Amici's type, later in a much better Nörrenberg instrument for crystal plates with two Nicol prisms (Fig. 3). Rath (1860) and Dove (1861) were also familiar with such microscopes containing Nicol prisms, but their use was not common among geologists before 1865; see literature quoted by Young (2003).

Microscopes of designs illustrated in a large paper by Des Cloizeaux (1864, Fig. 3) were manufactured commercially into the mid-1870s at least. The polarizer is either glass plates (the method of Amici and Nörrenberg) or a Nicol prism, and the analyzer is a Nicol prism. He was the first to take photographs through such a microscope (see Des Cloizeaux 1855, and an obituary by A. Lacroix in Bull. Soc. Minéral. Fr. 20, 1897). Des Cloizeaux could measure the angle between the optical axes in biaxial minerals, and he (Des Cloizeaux 1866) installed a heated stage in a microscope to test the effect of elevated temperatures on minerals. V. v. Lang similarly constructed a specialized instrument to measure axial angles in 1862, and in a paper on a new model of this instrument he (Lang 1867) says that "…studies of the optical constants are becoming of more and more importance in the identification of minerals". Lang (1871) also improved Nörrenberg's microscope.

Rapid and important developments in microscopical petrography took place from the 1870s onwards. These will be dealt with in a separate document.