Dichroic Light Polarizers

from Tourmaline

to Bernotar and Polaroid Filters

Two centuries of thin polarizers

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Icelandic Spar

Late XVIIth. century:
Double Refraction of Icelandic Spar (calcite) discovered and studied by

1669: Rasmus BARTHOLIN (1625-1698)

1690: Christian HUYGENS (1629-1695)

Birefringent crystal, n_o and n_e

Icelandic Spar rhomboid
Length 60 mm. UNIL/EPFL Collection Inv. 603.0322

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18th c. { Progress on geometrical optics/vision/optical instruments
Diffraction discovered, not understood
Light generally considered as made of corpuscules

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> 1798: Further study of double refraction in a crystal by Etienne-Louis MALUS (1775-1812)
1810: *Théorie de la double réfraction de la lumière dans les substances cristallines*

until...

Discovery of Light Polarization

Paris, end of 1808:

"… one day, in his house in the rue d'Enfer, Malus happened to examine through a doubly refracting crystal, the rays of the [setting] sun reflected by the glass panes of the windows of the Luxembourg Palace. Instead of the two bright images which he expected to see, he perceived only one, — the ordinary, or the extraordinary, according to the position which the crystal occupied before his eye. This singular phenomenon struck him much.

…

But when night came, he caused the light of a taper to fall on the surface of water, at an angle of 36°, and found, by the test of a double refracting crystal, that the light reflected from the water was also polarized, just as if it had just emerged from a crystal of calc spar."

[Biography of Malus by François Arago, 1854/1855; english translation 1859]

Polarization by reflection had been discovered, along with its relationship with polarization by refraction, or by double refraction.

This discovery immediately attracted the attention of the most eminent savants of the time: Arago, Biot, Brewster, Fresnel, Herschel, Seebeck, ...

Instruments (examples)

J. B. Biot: Polariscope
(from 1816)

@ D. Bernard / M. Anselmo, U. Rennes
Maker: SOLEIL, Paris

F. Arago: Polariscope / Polarimeter
(from 1811)

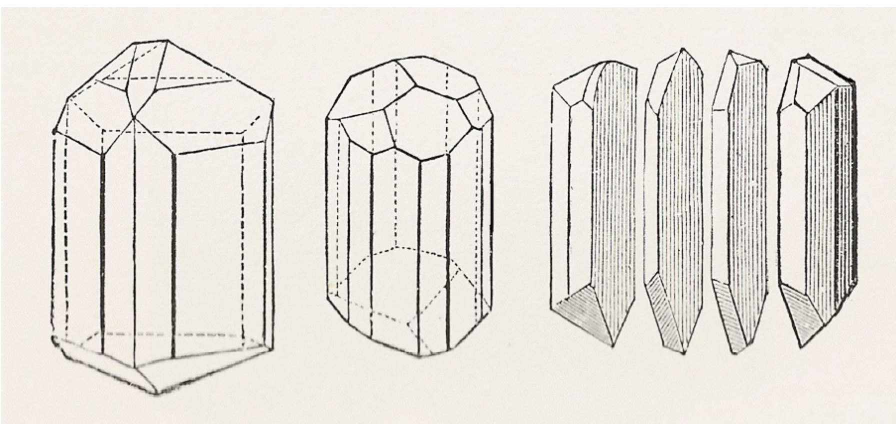
@ D. Bernard / M. Anselmo, U. Rennes
Maker: SOLEIL, Paris

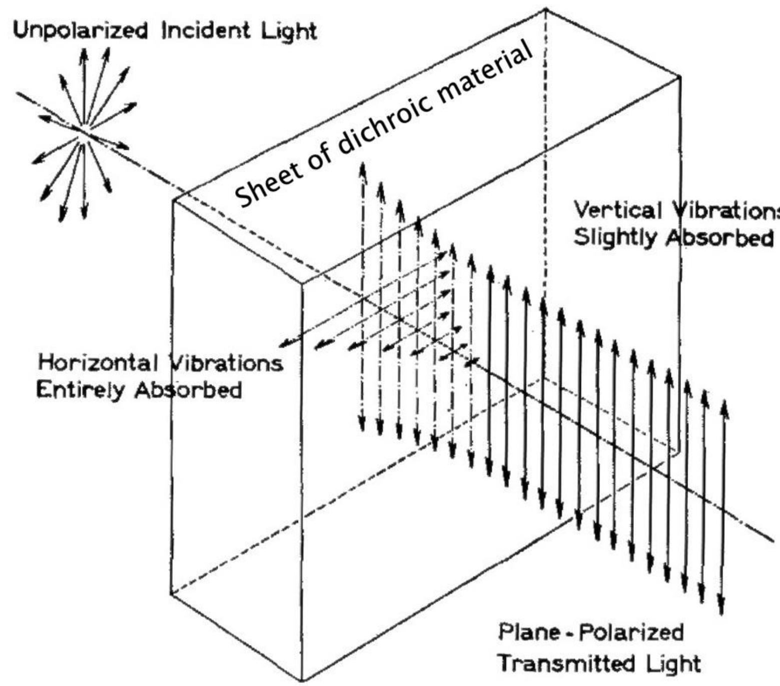
Another polarizing mechanism remained to be discovered : Dichroism

Tourmaline: first Dichroic Polarizer

Tourmalines are part of a crystalline mineral group,
with a wide variety of colours,
now reminded for its electrical properties
(pyroelectricity).

Jean-Baptiste BIOT observed in 1814 that thin sections (1 to 2 mm thick)
of *coloured* tourmaline crystals, cut parallely to the axis, behave as linear light polarizers.

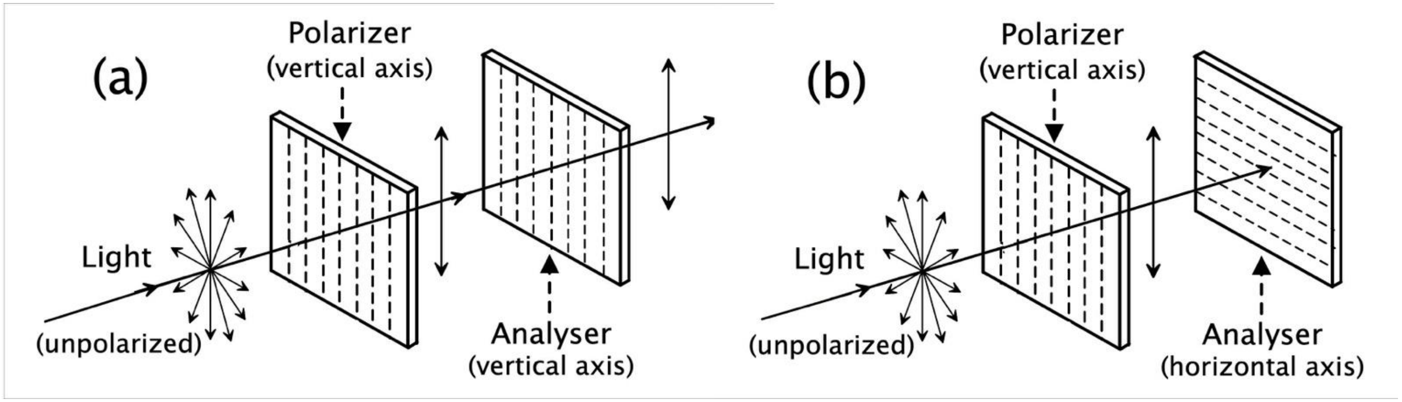




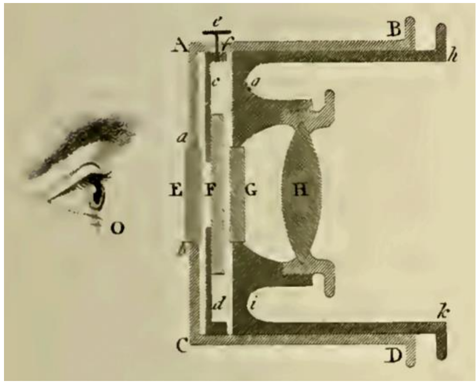
The first thin linear polarizers had been discovered.
Drawbacks:
– area limited to 1 to 2 cm^2
– too much residual colour

1820: Tourmaline Polariscope of John F. W. HERSCHEL (1792-1871)

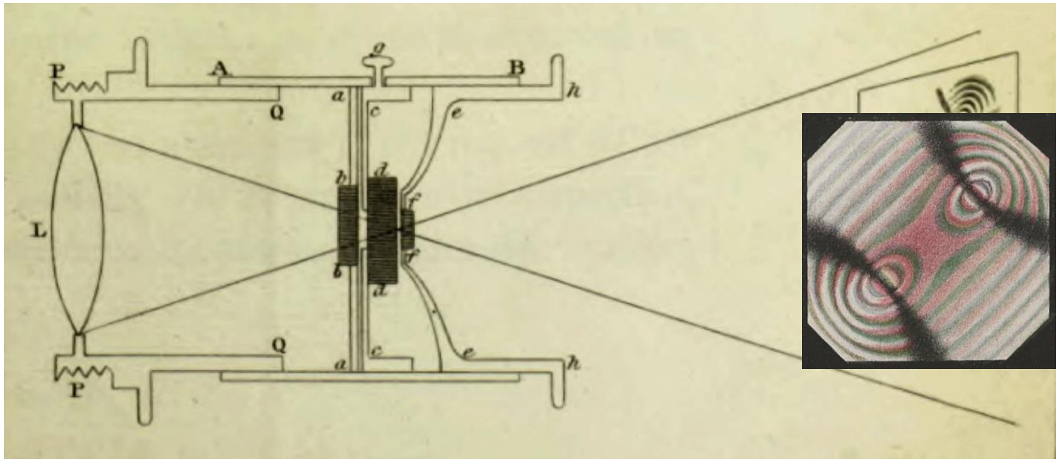
Polariscope: sample placed between 2 polarizers, one rotatable
Not designed for precision measurements, as opposed to a *polarimeter*



Herschel had 2 models built, mainly for examining mineralogical sections.



Hand-held

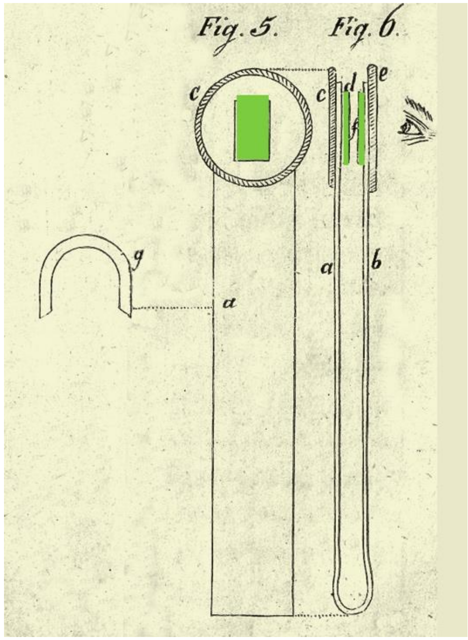


For projections

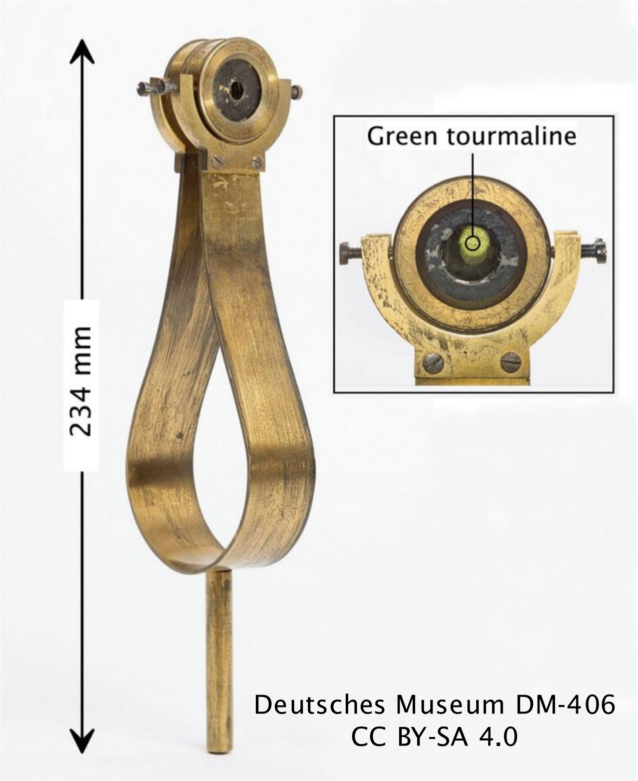
First portable, hand-held polariscope
Not a success, too complicated, but Herschel had shown the way.

1827: Tourmaline Tongs of Karl Michael MARX

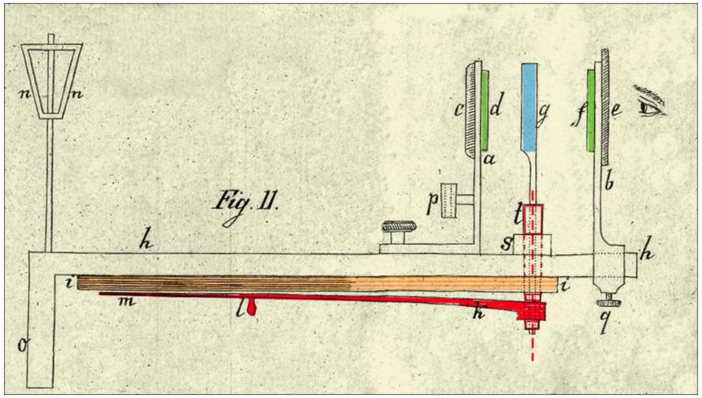
K. M. Marx (1794-1864) was professor at the Carolinum of Brunswick.
In 1827, he describes 2 models of hand-held tourmaline tongs, for crystallography/mineralogy.
Publication in German at Halle (Sachsen), widely ignored.
Simpler than Herschel's polariscope, but not enough for commercial success.



Hand-held



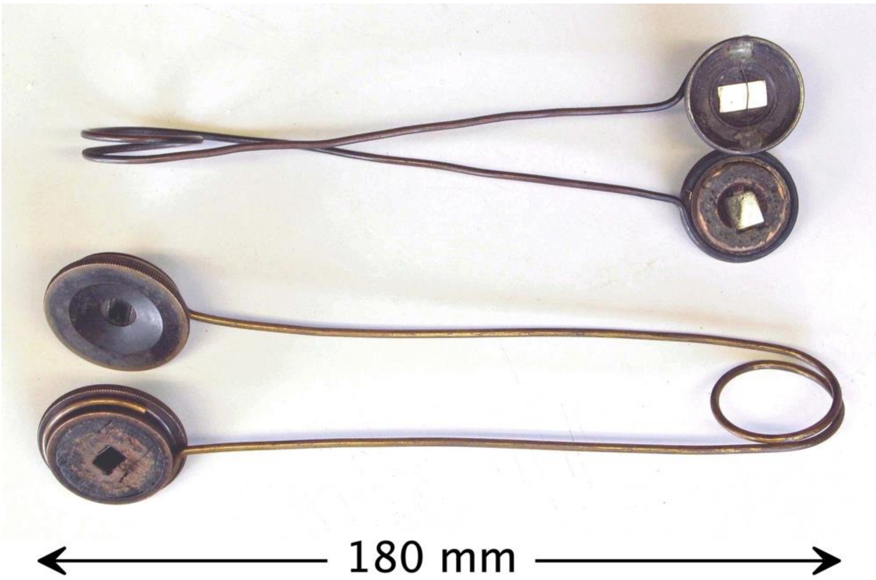
Used by Georg Simon Ohm (†1854) at Munich
(wood handle missing)



Hand-held,
allowing rotation of the sample

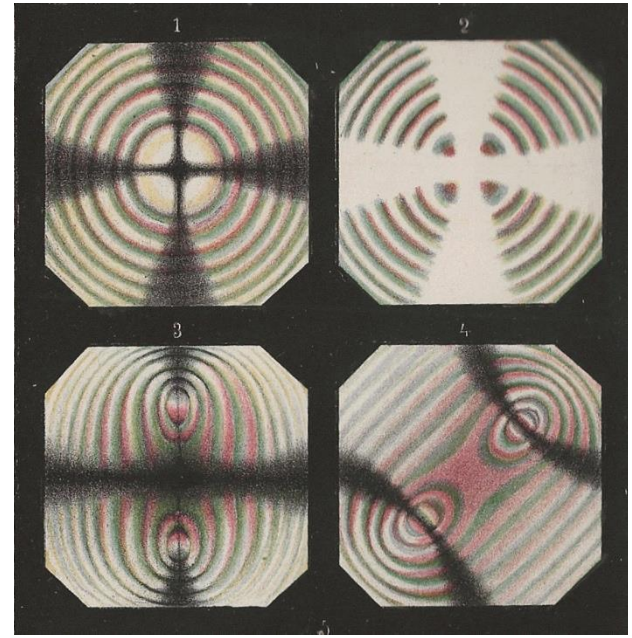
The late Paolo Brenni was the first to identify K. M. Marx as the inventor.

Standard model of Tourmaline Tongs: simpler construction



Wire Tourmaline Tongs
UNIL/EPFL Collection Inv. 603.0469

Top: uniaxial crystal (calcite $CaCO_3$)



Bottom: biaxial crystal (niter KNO_3)

Extremely popular among mineralogists and cristallographers for showing the coloured rings of thin slices of crystals.

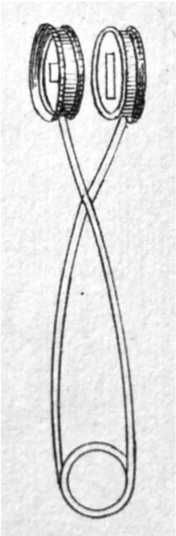
Model to be found in all physics textbooks and instrument makers' catalogues until 1930. Often offered along with a collection of prepared slides (mica, quartz, calcite, etc.).

Price varying accordingly to the size and quality of the tourmalines. For almost a century, it remained the cheapest available polariscope.

Cheaper than the popular Nörrenberg polariscope (a rather bulky laboratory instrument).

Wire Tourmaline Tongs

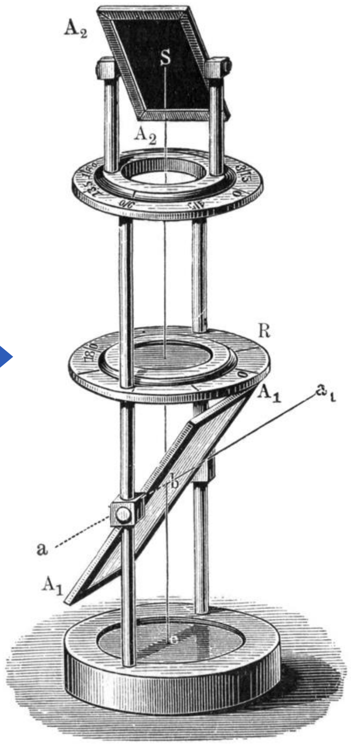
Who invented them?


Pouillet/Schnuse (1843) – Taf. 28, Fig. 313

First dated mentions:
– first image in Pouillet, *Lehrbuch der Experimentalphysik...*, übersetzt von Dr. Schnuse, Bd. 2, 1843
– image (1843) and attribution to Nörremberg *[sic]* in Joh. Müller, *Lehrbuch der Physik und Meteorologie*, 1856 and later editions
– description and manufacturing process ("do-it-yourself") given by J. Frick in his book *Physikalische Technik*, 1850 and later editions.

We can therefore confidently attribute the invention of the wire tongs to Johann Gottlieb NÖRRENBERG (1787–1862).

– While at Paris (1829-1832), he invented his *polariscope*, but left it to a French colleague to publish it.

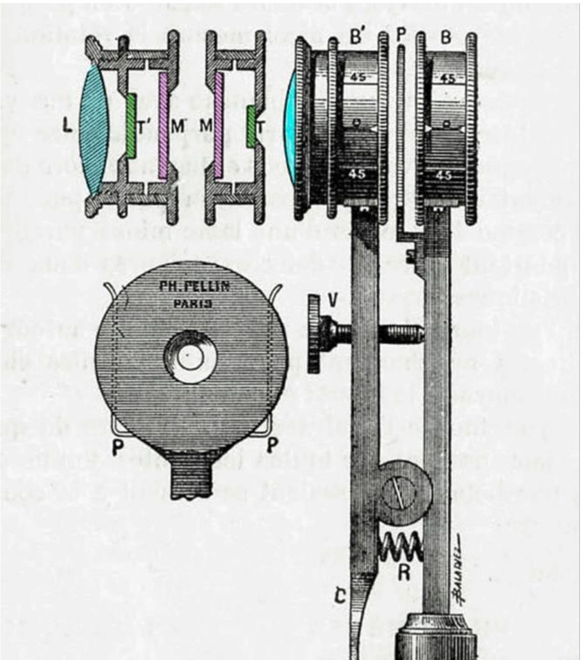


– At Tübingen from 1832 to 1851, he worked on crystallography but he was averse to publish in writing, preferring to communicate orally.

He was an original character, with little money but known for his talent for tinkering, making instruments from whatever was at hand, for instance his mechanically simple tongs.

Advanced Tourmaline Tongs: Augustin Pierre BERTIN (1818-1884)

Bertin, in Strasbourg and later in Paris, published extensively on crystallography and mineralogy.
For his experiments, he had several sophisticated models of tongs built.



T, T' : tourmalines
M, M' : ¼ wave mica

Bertin (1879)
Catalogue Ph. Pellin (1900)

U. Lille – Ph 2.83

Bertin comments:
"For a long time, tourmaline tongs were the only apparatus used for observing fringes". (1879)

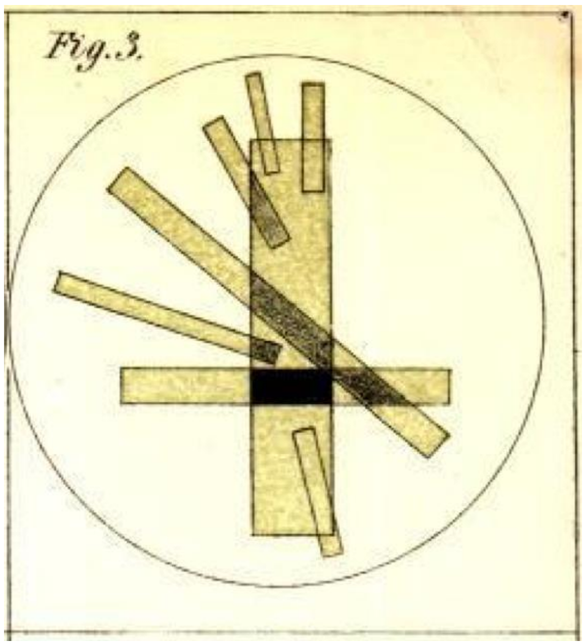
Bertin observes that Biot had discovered in 1814 the properties of thin slices of tourmaline, but that no word about tongs can be found in Biot's *Traités de physique* (1816-1825).
So who invented them?

1852: HERAPATH and *Herapathit*

Dr. William Bird Herapath FRS, FRSE (1820 –1868) was an English surgeon and chemist active in Bristol and London.

1852: During an analysis (?), he made the chance discovery of small "brilliant emerald-green crystals", less then 0,1 mm thick, but almost colourless when examined by transmitted light.

Through a microscope:

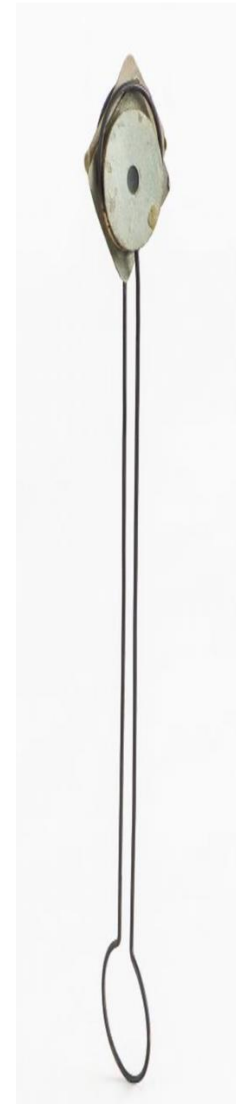


Herapath, Phil. Mag., 1852

Crossed crystals block the light.
They are dichroic polarizers!

This discovery aroused enormous interest in Europe.
This material (iodoquinine sulphate) was immediately named *Herapathite*.
Could it one day replace tourmaline?

But Herapath was unable to make crystals larger than 1.5 cm x 0.75 cm...



Ohm's Herapathit tongs (Deutsches Museum Nr. 2173, CC BY-SA 4.0)

1852–1930. Tourmaline continues to dominate the market

From 1852 to 1930, many attempts were made
to manufacture large *single-crystal* Herapathite polarizers.

Even when technically successful, no commercial production followed.

Ferdinand BERNAUER (1892-1945)

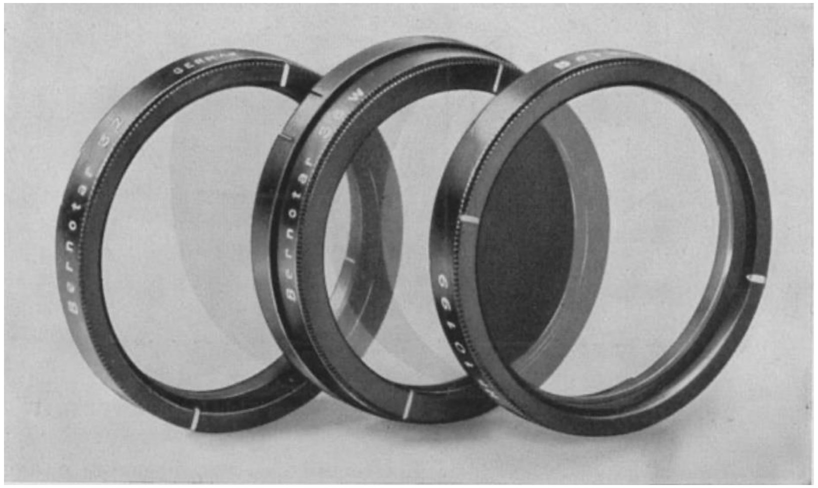
Mineralogist, geologist, then vulcanologist in Berlin.

Found an usable process for making large single-crystal herapathite.

1935: Polarizing *monocrystalline* filters manufactured and marketed by Zeiss-Jena under the name *Bernotar*.

Main use: photography, to eliminate annoying reflections.

1939: War!
No further developments in Germany



Zeiss *Bernotar* filters, parallel and crossed
Diameter up to 60 mm, max. 100 mm
In production until after 2000

Edwin H. LAND (1909-1991)

David Brewster, in his 1858 book on kaleidoscopes, envisaged the use of herapathite polarizers to obtain spectacular interference colours.
Reading this book sparked Land's interest in these crystals.
He realised the enormous difficulty of producing sufficiently large crystals.

Faced with this near-impossibility, in 1927 he set about manufacturing sheets containing millions of micro-crystals of herapathite, perfectly *aligned* in a transparent matrix.

These filters were marketed from 1935 under the name *Polaroid Type J*.

Immediate replacement of tourmaline for scientific applications.

Constructing projectors for teaching becomes easy:

Polaroid Type J, dia. 40 mm
(Cat. Cenco 1941, price USD 6)

Tulip of gypsum (24 mm square) between 2 Polaroid filters
UNIL/EPFL Collection Inv. 603.1023

Main targeted applications by Land: sunglasses, photography

Polarized sunglasses

Photography: elimination of reflections on the water surface, without (left) and with (right) polarizer

Photography: contrast enhancement, without (left) and with (right) polarizer

Still relevant today!

Of the other applications being considered in 1938, only a few were successful. These included the projection of stereoscopic images, viewed with polarizing glasses.

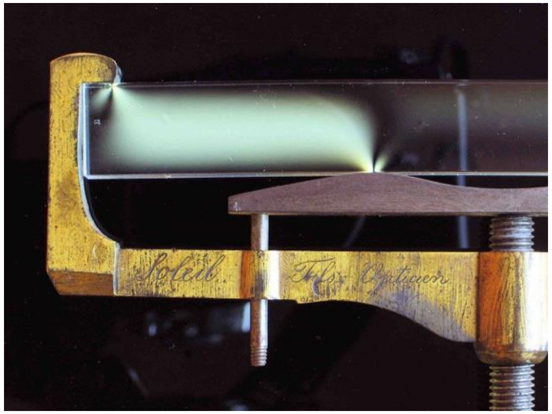
Further developments:

1938: Production of large sheet of easier to fabricate *H* polarizers, made of stretched foils of polyvinyl alcohol impregnated with iodine.

Studies of mechanical stress using photoelasticity are now feasible!

Photoelasticity:
Visualisation and analysis of stress in mechanical parts and built structures

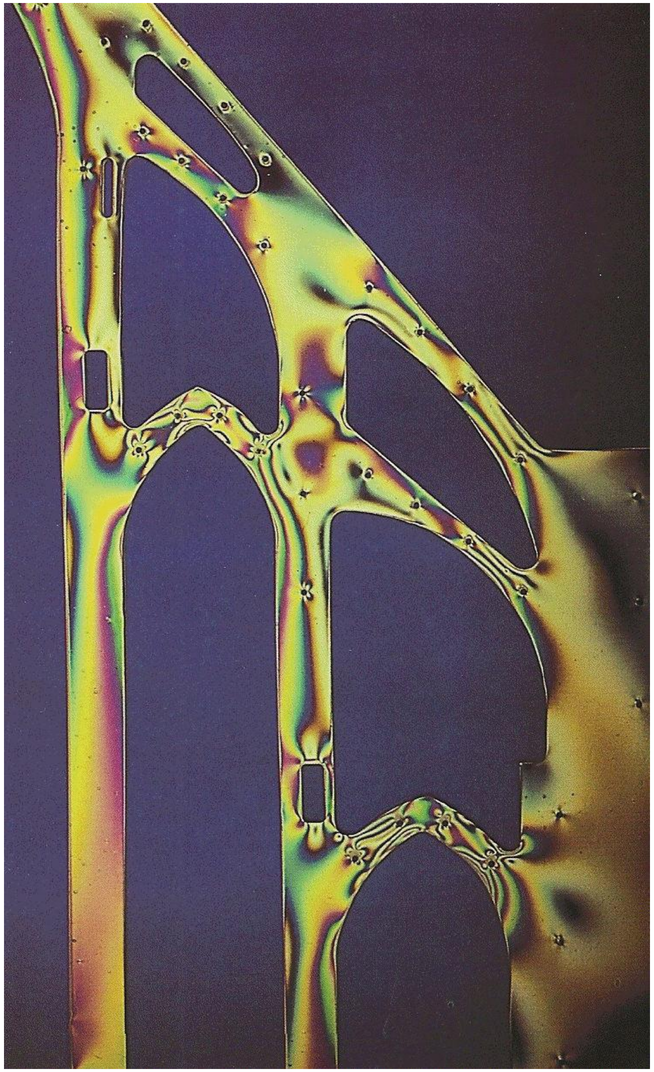
Stress-induced birefringence already discovered and studied at the beginning of the XIXth c. by Seebeck, Brewster, Fresnel, ...



Demonstration glass press

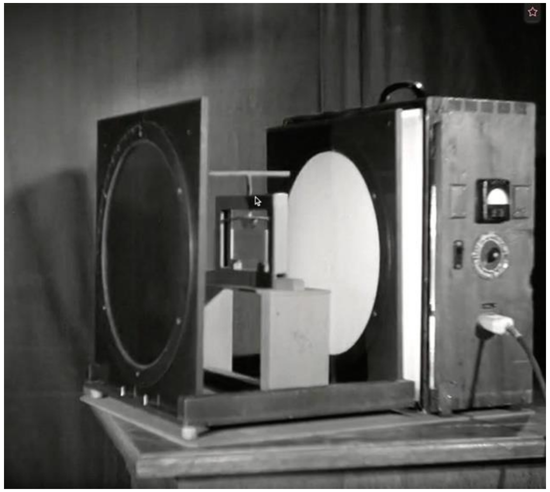
Soleil Fils, Paris, mid XIXth. c.
UNIL/EPFL Collection Inv. 603.0256

Late 1930s: Availability of large sheet polarizers and stress–free transparent epoxy plastic to make models



Bourges Cathedral choir model

Robert Mark, 1982



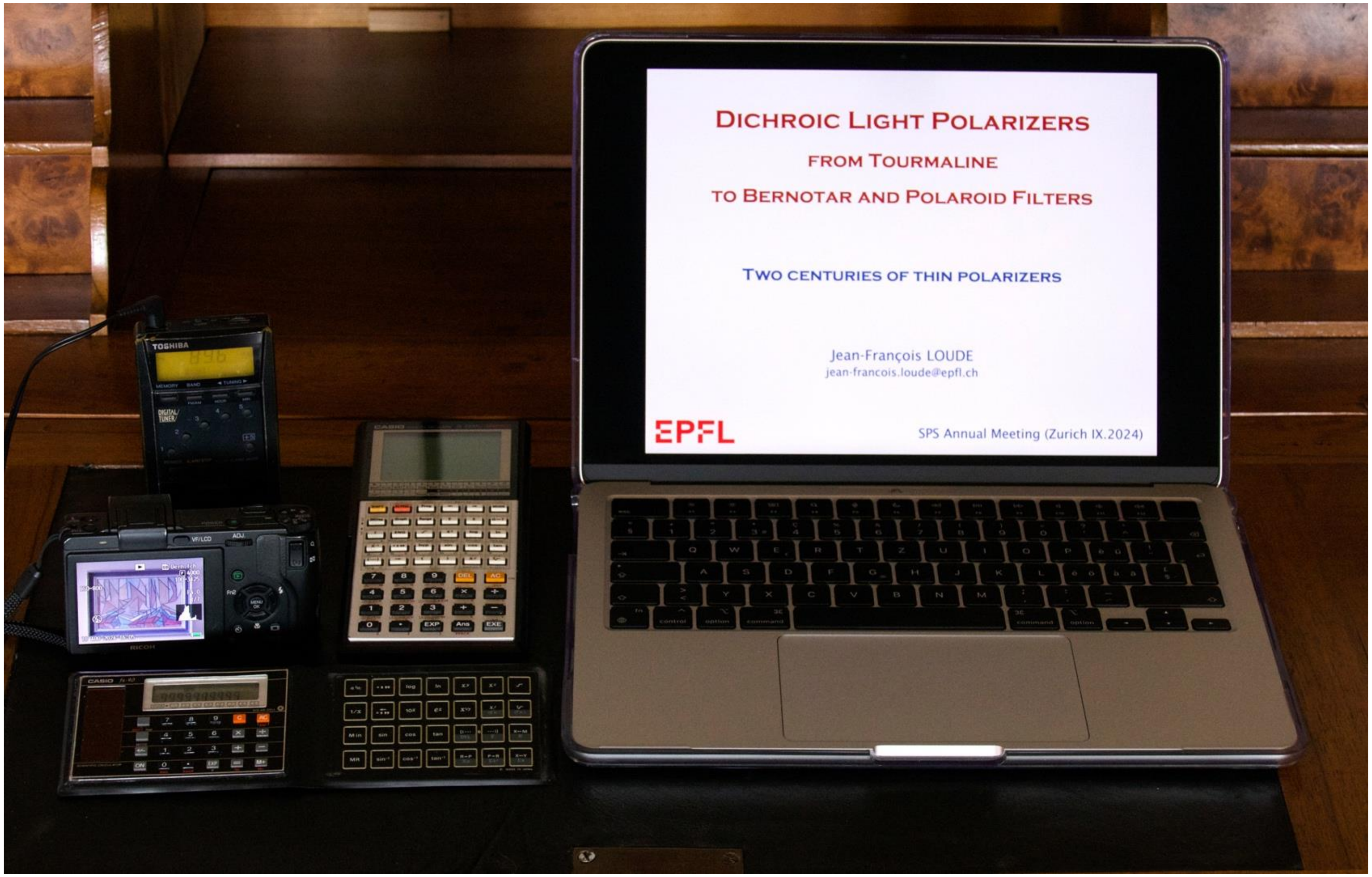
Photoelasticity setup

Föppl, Göttingen, 1949

Late XXth. c: Liquid Crystal Displays

LCD: complex, multi-layered system with a liquid crystal film sandwiched between electrodes and two sheet polarizers. Major Swiss contributions to their development.

From around 1980, LCDs gradually replaced seven-segment (or more) Nixie tubes, incandescent filaments, vacuum fluorescent tubes and LED digital displays.



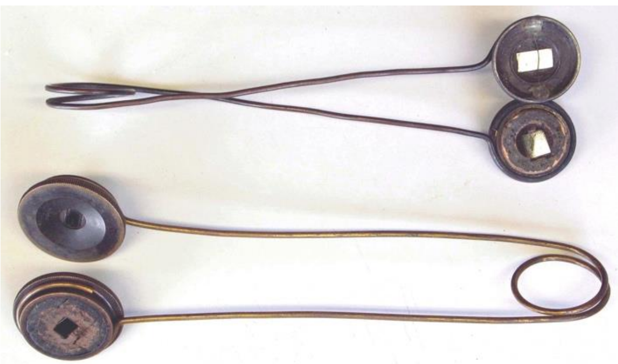
A few examples of LCD displays, from the early 1980s to 2024

Recapitulation

Objects / instruments — Use / users

1810

Tourmaline Tongs
(first pocket polariscope)



Crystalline Polarimetry
/
A few scholars and lecturers specialising in crystallography and mineralogy

Herapath 1852

Eyeglasses: distinguishing between quartz and glass
/
Opticians

1930

New dichroic materials
Polarizing sheets (Bernotar, **Polaroid**)
of increasing size

— Anti-reflection filters / Photographers
— Anti-glare sunglasses / Anybody

— Stress analysis in
– mechanical parts / engineers
– built structures / engineers, historians

1980

B/W Liquid Crystal Displays (LCDs)

Displays (watches, hand-calculators, ...) / Everybody

2000

Large Graphic Colour LCDs

TVs, computers screens / Everybody

Thank you for your attention !

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impossible to name here, who contributed information and pictures,
notably through the Web,
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for its continued support.

Bibliography

A long list of the consulted books, scientific articles
and manufacturers' catalogues is available from

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Summary

The surprising optical properties of tourmaline were studied soon after the discovery of the polarization of light. Thin slices worked as polarizers, enabling the construction of simple, handheld polariscopes.

The tourmaline tongs described by Karl Michael Marx in 1828 were a great success, especially after Nörrenberg simplified their construction.

The fortuitous discovery in 1852 of almost colourless herapathite aroused great interest.

However, efforts to produce crystals exceeding about one square centimetre remained unsuccessful until the early 1930s, when Ferdinand Bernauer in Jena and Edwin Land in the USA succeeded in manufacturing large sheets, thus extending the field of applications beyond mineralogy.