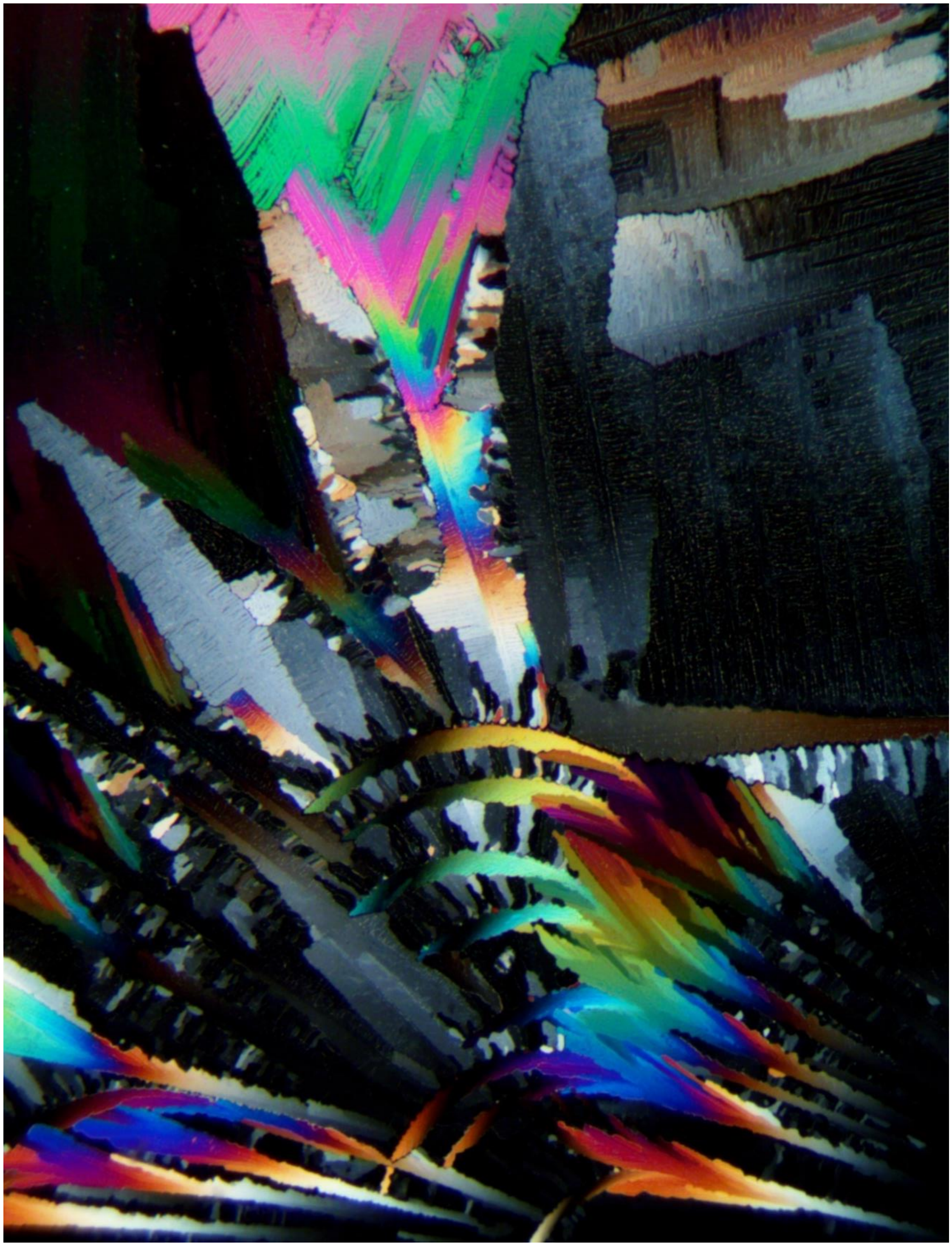
Urea and the demotion of Man



Micscape Magazine May 2023

by Ed Ward, Minnesota, USA

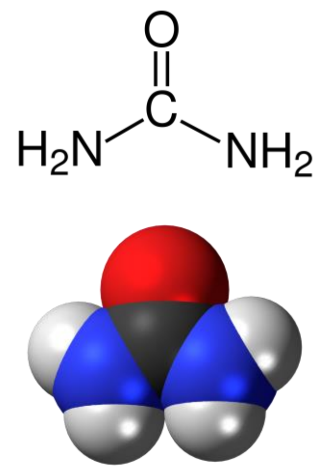
New *Pink Floyd* album cover?
No, it's urea crystals from melt
2.5X objective, crossed polars

Urea and the "demotion" of Man

by Ed Ward, USA

Inspired by *Micscape* magazine, I recently made microscope slides from "pet safe" ice melt salt, made of urea. When viewed through a microscope with polar filters, crystals of urea are beautiful. Our own bodies make urea, and it is also an important industrial chemical. Urea has a "vital" place in the history of organic chemistry, and is one chapter in a story of how man's place in the universe has seemingly tumbled down to become less favored over time.

$CO(NH_2)_2$



Urea molecular structure

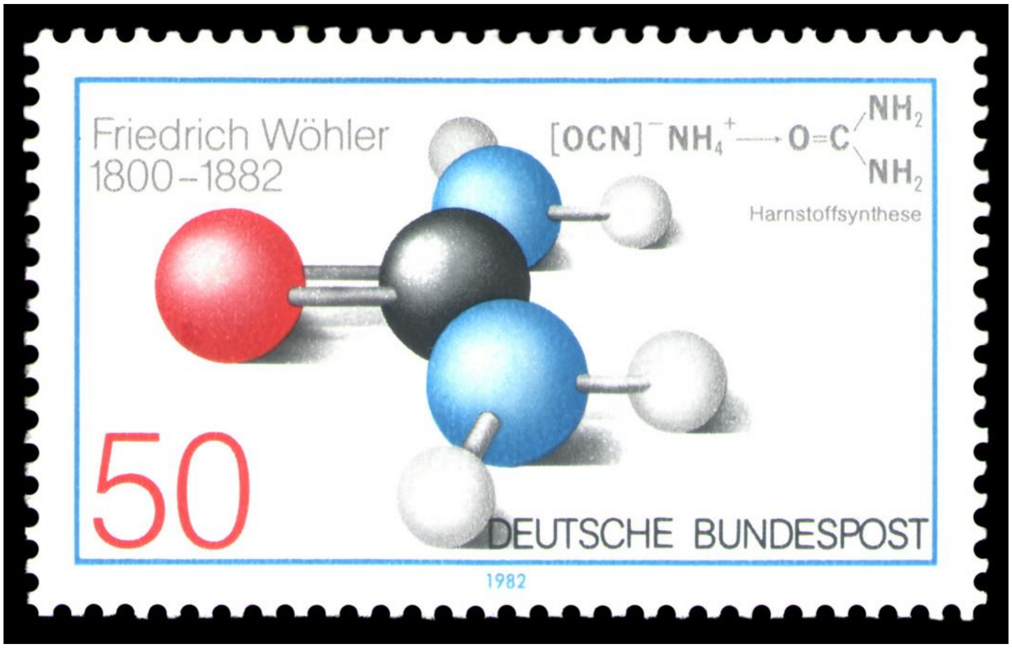
← urea crystals, melted under a coverslip, 4X objective, crossed polars

Vitalism and the origins of Organic Chemistry

Urea (aka carbamide or carbonyldiamine) is a simple nitrogenous organic chemical with the formula $CO(NH_2)_2$. It is an end product of the catabolism (biologic breakdown) of most nitrogen containing biologic molecules, including proteins and DNA. Our kidneys then dump this waste product into the urine. Urea was first discovered by Dutchman Herman Boerhaave in 1727 after evaporating his urine for over a year. In 1773, Frenchman Hilaire Rouelle rediscovered urea in urine by evaporating it and treating it with alcohol. The chemical composition of urea was discovered in 1817 Englishman William Prout, again obtaining and purifying it from urine. Containing atoms of carbon and hydrogen and being present in living beings, urea is therefore an "organic" compound. No organic chemical had been synthesized in 1817; all were obtained from tissues or fluids of living or once living organisms. The scientific orthodoxy of the day was "vitalism", holding that all living cells contained a "vital force" and that science could never reproduce the chemical properties of life. It was noted when flesh or organic chemicals were heated, they often coagulated or "denatured" in an irreversible way, as though something living was killed. Vitalism was promoted by the world's leading chemist, **Jacob Berzelius** in Sweden. The "father of chemistry", he coined the terms "organic chemistry" and "protein" and developed the chemical formula notation we still use today. Through experimentation and quantitative manipulation, he made chemistry into a true science. But Berzelius clung to the theory of vitalism, believing there was something special about the chemistry of life. In his 1815 chemistry textbook (one of the first ever) he defined vitalism as a fundamental property of organic chemicals. Organisms could make organic compounds only because they possessed a god given "vital force". Berzelius declared in 1815 that no organic chemical would ever be produced from ordinary chemicals. Berzelius trained various foreign students in his lab, including Friedrich Wöhler, who proved his teacher wrong just 13 years later.

Wöhler and emerging German scientific dominance

Friedrich Wöhler (born 1800, died 1882) was a gifted German inorganic and organic chemist. Multiple fields of modern science developed quickly during his lifetime. In 1828 he isolated the metallic elements beryllium and yttrium for the first time. That same year Wöhler synthesized urea by mixing ammonium chloride and silver cyanate solutions, trying to produce ammonium cyanate, which he then heated, and out came urea. At first he thought ammonium cyanate NH_4OCN, was urea $CO(NH_2)_2$, but he soon understood the two chemicals were isomers (composed of the same atoms but joined in a different arrangement) and heating shifted the bonds, turning the former into the latter. He immediately understood the great importance of doing the synthesis starting with inorganic compounds. Wöhler wrote to Berzelius, his old professor in Sweden, in 1828 "**I must tell you I can make urea without the use of kidneys of any animal, be it man or dog"** and "ammonium cyanate is urea". Berzelius was not at first persuaded that his former student had indeed synthesized a chemical of life from dead chemicals. But the synthesis of urea was the beginning of a slow end for vitalism. In 1844 another organic chemical (acetic acid) was inorganically synthesized. In 1858 Frenchman Louis Pasteur still alluded to a "vital force" causing fermentation, which he correctly showed to be caused by tiny living organisms. But Pasteur was one of the last "vitalists". Soon many thousands of organic chemicals were synthesized and manipulated, mostly in Germany. Clearly the chemistry of life was just complex carbon based chemistry, not special magic. Vitalism died. The leading edge of science and technology moved to Germany. Robert Koch discovered bacteria caused infections, proving the Germ theory of disease in the 1880's. 19th century German chemists started Merck, Pfizer and many other drug companies. In 1898 Bayer AG invented both aspirin and heroin and it soon became the world's biggest chemical and drug company. The industrial production of urea (now about 200 million metric tons annually, mostly for fertilizer and plastics) was invented by German chemical engineers in 1924. The Bosch–Meiser process makes urea from carbon dioxide and ammonia (the ammonia needed is produced by the Haber-Bosch process, an industrial synthesis developed by Carl Bosch in a different partnership). By 1900 German chemists and doctors led the world, and German supplanted Latin, French and English as the most important language of worldwide science.



German stamp commemorating the centenary of Wöhler's death and his synthesis of urea

Religious Orthodoxy: man is special

The 19 century growth of science and engineering in Germany ran up against the Christian church dominating intellectual life in Europe for a thousand years. A priest was often the only literate person in a village. Most western scientists were also Christian theologians. Truth was decided by discussion among religious scholars, then sometimes forcibly enforced by the Inquisition. Religion and science alike were handed down by authority. Holy Scriptures told us (in Latin) that man was created in the image of God, to have dominion over the whole earth, and the sun circled the earth (an interpretation of an Old Testament story). It was plain to see that we humans lived at the center of everything, and living things had God-given supernatural stuff inside. All men were sinners, but they could be redeemed and live forever in heaven after a brief, often brutal earthly life. Man was a special creation, occupying a spot just a little lower than God and his angels. In 1650, **Archbishop James Ussher**, one of the best scholars of the day, used the Bible to calculate the date of creation as 22 October 4004 BC. Man was special, living at the center of a tidy little 5654 year old world. Religion and science were complete truths, in perfect agreement. It was a comforting alignment, but in the next few hundred years observation and experiment would repeatedly adjust man's position in the cosmos.

Scientific Orthodoxy: man is not so special

Even before Ussher, a few open minded scholars did their own investigations of the world around them. On his deathbed in 1543 Polish Renaissance polymath (and canon of the church) **Nicolaus Copernicus** published *De Revolutionibus Orbium Coelestium* (in Latin "On the Revolutions of the Heavenly Spheres"). Heliocentrism, his theory that the earth orbits the sun, was revolutionary, and a threat to orthodox authority. In 1633 Italian scientist **Galileo Galilei** was placed under house arrest for the remainder of his life, largely because of defending heliocentrism, including evidence he had seen through his telescopes. Soon most scientists were persuaded the sun was the center of the universe. **Isaac Newton**, arguably the most brilliant scientist of all time, discovered the mathematical laws that govern the movements of the planets around the sun, published in *Philosophiæ Naturalis Principia Mathematica* in 1687. Some considered this as relegating God to the role of a watchmaker rather than actively holding the heavens together in real time. Newton himself was an intensely religious man who thought his discoveries magnified God. And what is the sun? Anaxagoras in ancient Greece proposed the sun was a star, but we didn't find good scientific confirmation until 2300 years later. Eventually 19th century spectroscopic analysis of dark absorption lines in the rainbow allowed identification of helium and chemical elements in the sun, and then in other stars. By 1890 Edward Pickering and Annie Jump Cannon at Harvard Observatory had classified over 10,000 stars into spectral types. The sun is just an ordinary G2V main-sequence star, one of multitudes. In the early 20th century Edwin Hubble used Cephid variables as "a standard candle" (a technique recently invented by Henrietta Swan Leavitt) to prove the Andromeda nebula was really a distant galaxy, not within our own Milky Way galaxy. By 1929 Hubble used spectral red shift to show distant galaxies are all moving quickly away and realized we live in an expanding universe. In 1964 Wilson and Penzias couldn't get rid of a hum in a Bell Labs radio telescope in New Jersey, discovering the radio afterglow of the initial Big Bang explosion that created the universe. Ground based and orbiting telescopes then refined our view of that cosmic background radiation, found the expansion of the universe is accelerating and discovered most stars probably have planets around them. Today's scientific big picture is of a vast, 13.79 billion year old universe, with tiny earth orbiting an ordinary star, one of perhaps 200 billion stars in an ordinary spiral galaxy, itself one of about 2 trillion galaxies. There are 10,000X more stars in the universe (about 10^{23}) than all the sand grains on earth (about 10^{18})!

It's not just astronomers that diminished the position of man. Wöhler's 1828 synthesis of urea without a kidney helped end vitalism, making the chemistry of life nothing special. **Charles Darwin** put man on one small branch of a great tree of life in *On the Origin of Species* in 1859. In 1862, about 200 years after Bishop Ussher's calculation of a less than 6000 year old earth, physicist Lord Kelvin used two heat loss equations to calculate the earth was 20 or 400 million years old. Darwin thought life needed even more time to have evolved from a single ancestor into all the life we see today. Geologists, especially Charles Lyell, also thought that more time was needed for erosion and other very slow processes to have shaped the modern earth. The biologist and geologist were correct. The modern estimate of the age of the earth is 4.55 billion years, based on radioactive isotope abundance in meteorites (formed at the same time as the earth and sun), first published by Clair Patterson in 1956. How quickly knowledge is created in our modern world. Replacing authority with rational skepticism and experiment improved life at a fast clip. Biology and Biochemistry are now huge fields with an intricate, but always incomplete, unfolding story of living organisms as told through biochemicals, cells, organs, and development as individuals and populations. I am constantly amazed by science and in awe of hidden beauty in the world. My photomicrograph of urea is untouched; it looks like stained glass because polar filters reveal urea molecules twist the light waves passing through. Every millisecond inside of every one of your 30 trillion cells, millions of molecular machines randomly bump against each other quadrillions of times (Brownian motion, first figured out by Einstein). Some stick together for a bit, a few break, most bounce off. Somehow all that chaos makes your life happen. In 2003 we read our own DNA, God's instructions for building a human body, over 1 billion 3 letter words spelled out using 4 different letters.

The history of science says humans were usually wrong when they thought of man as special. The chemistry inside you is not magic. Like urea, your body is made mostly of hydrogen, oxygen, carbon and nitrogen, all common atoms in stars. Man is one of over 1.5 million known species of animals. You share ancestors with apes, bugs, trees, bacteria and all life. You do not live in the center of the universe (it has no center, as all space expands). You and everyone you know or ever heard of, live on Carl Sagan's "pale blue dot," an insignificant planet revolving around an average star, hanging alone in the void of dark space. Almost all of the history of the universe happened before you got here, and our entire species (like others) will be extinct in a cosmic blink of an eye. The "scientific" view of man seems sort of sad, but science has proven itself millions of times to be by far the best way to understand and manipulate the world.

Modernity: choose your own worth

Fear not, for man has not really been demoted by every discovery of science. As we discovered how big the universe is, we also discovered smaller microscopic things down to quarks, so on a logarithmic scale your almost 2 meter tall body is actually about an average size between the smallest known particles and the size of the whole universe. By numbers, most living organisms are bacteria, so your body is millions of times bigger than average living things. And even if we are tiny and transient in a huge, incomprehensively old universe, that does not determine the value of human beings. We live by our wits, generated by a brain with over 100 million neurons making over 100 trillion synaptic connections: your head contains the most complex object in the known universe. The modern, scientific view of man as a clever, hypersocial, bipedal great ape is a cause for joyful wonder, not despair. Our value as humans is not defined by our location or physical size or by an ancient holy book, but by our own choices.

Humanity's self- evaluation has changed many times in many places. Most of what you believe and do was learned from other people in your social group. We live our lives inside passed down cultures: ideas (language, religion, money, war, peace) and physical things (cathedrals, houses, cars) of our own construction. History has left humans with primate instincts, "stone age emotions, medieval institutions and recent god-like powers" (modified after AO Wilson). *Homo sapiens* is capable of both great evil and beautiful acts of kindness. You are a living contradiction of love/hate, smart/dumb, together/alone. Therefore, you have to choose.

Wöhler's synthesis of urea did not really demean human life. It was part of a relatively new, modern human journey of Discovery, Renaissance, Enlightenment and Science that can set you free from earlier ideas. Religious believers understandably worry that a godless person who sees that beliefs change over time has no morals, but that need not be the case. Even in the midst of despair, each of us can each choose good values. The great diversity of beliefs should reveal the stupidity of killing others just for having different beliefs. All people carry emotional and social baggage, but healthy humans have an inner voice telling them to treat others well. Modern humans are adaptable creatures who constantly learn new things and make up most of our own realities. That means we are free to make the world a better place if we personally and collectively choose to behave better. Even though we used to be war-loving creatures, Europe has probably had less war in the past 75 years than in any other time in the past 4000 years. Human life expectancy rose faster in the 20th century than ever before. Average human lives are now far less painful in the scientific age than they were in medieval times.

In much of Europe, polls now say that about half of people don't believe in God, although many still identify themselves with a church. Even if we no longer believe everything from our faith traditions, there is still much good to be learned there. Many important social movements, including the abolition of slavery, the suffrage of women, the liberation of the Indian subcontinent and the American civil rights movement were led by heroic people of faith. If old faiths fade, hopefully they are being supplemented by personal conscience and by social values we can all believe in: life, freedom, fairness and the pursuit of happiness. The real heart of both faith and science traditions says all humans are close kin. In every age some ignore that deep wisdom, blaming some "other" groups of people for ruining everything. Yet the world hasn't come to an end, but instead has gotten better for most people in the age of science. As the spread of industrialization allowed poor populations to develop economically, global average life expectancy grew from about 32 years in 1900 to about 73 years today.

During my 63 year lifetime the average human escaped from extreme rural poverty, moved to the city and can now expect to live a longer life than rich Americans did in the 1950s. Modern technology enables huge reductions in suffering, and much more. Your amazing latest phone and your modern house filled with nice things were all invented using the tools of science.

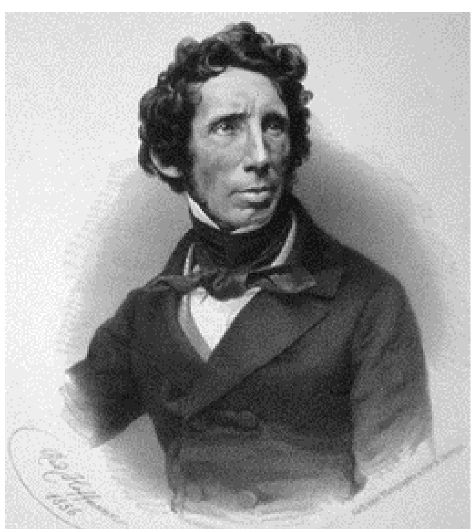
Science is not your savior

As much as I trumpet science, it cannot by itself answer all our questions. There is no particular set of morals dictated by science (even if some rationalists think so). Science has been used to give masses of people better lives, and to vaporize the masses. The history of Friedrich Wöhler's own nation is just one powerful cautionary tale of the limits of science (the US has vaporized masses by atomic explosion). At the end of the 19th century Germany was unquestionably the most modern and scientific nation in human history up to that time. But with great knowledge came great power, and unfortunately mass madness. Twice in the 20th century Germany tried to take over Europe. Good people became cogs in an evil system. The best science and engineering were used to mass murder 6 million scapegoated ethnoreligious victims with evil, industrial efficiency. Germany was beat back at great cost both times.

If not for a small, delayed American kindness at the end of World War 2, World War 3 might have happened by now. The US initially deindustrialized Germany again in 1945, but the resulting starvation and suffering was so terrible it prompted a rethinking. Starting in 1948 the German Marshall Fund of the United States spent the equivalent of $173 billion in today's dollars to rebuild Germany. America helped turn an enemy into a trading partner, a strong democracy, a force for European and world unity, and a friend of ours.

Sometimes the smart thing and the kind thing are one and the same. Maybe that can be the salvation of individuals, nations and the world. You can **choose to make man special again** in the way that really counts, by treating all your fellow humans with respect and kindness.

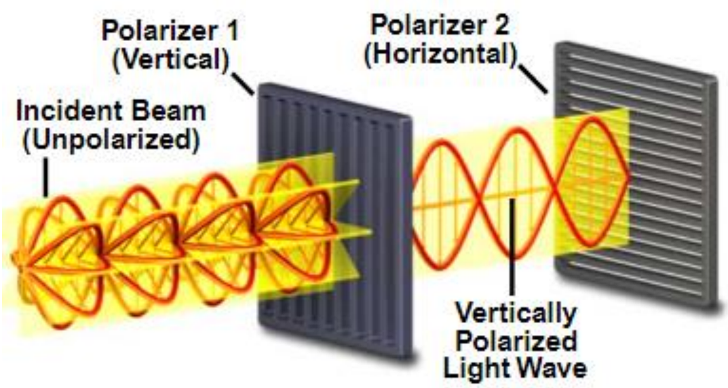
Friedrich Wöhler in 1856, age 56
lithograph from photograph (Wikipedia)



Essay by
Ed Ward MD
Minnesota, USA
May 2023

Extra sections for microscope enthusiasts: Intro to Polarizing Microscopy

Specialized polarizing microscopes cost thousands of dollars, but using polarized light to reveal detail and beauty in select specimens is easy to do with almost every microscope. Ordinary light has waves oriented in every direction, but a polar filter lets through only light waves vibrating in one direction. If a second polar filter is turned 90 degrees to the first, no light passes. But if a specimen that twists the direction of light is placed between the two filters some light gets through and becomes rainbow colored. From Nikon's MicroscopyU site:



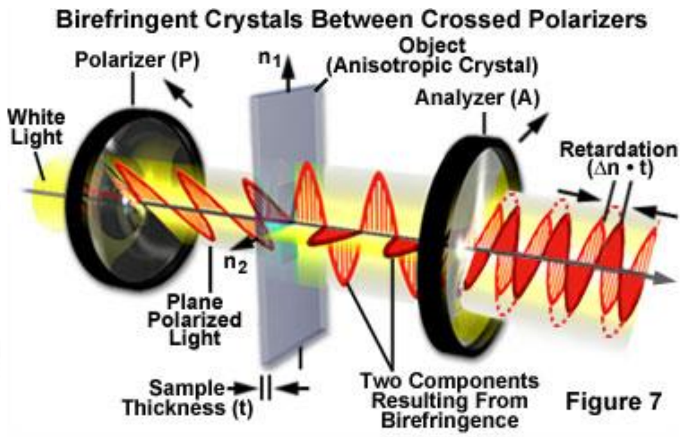
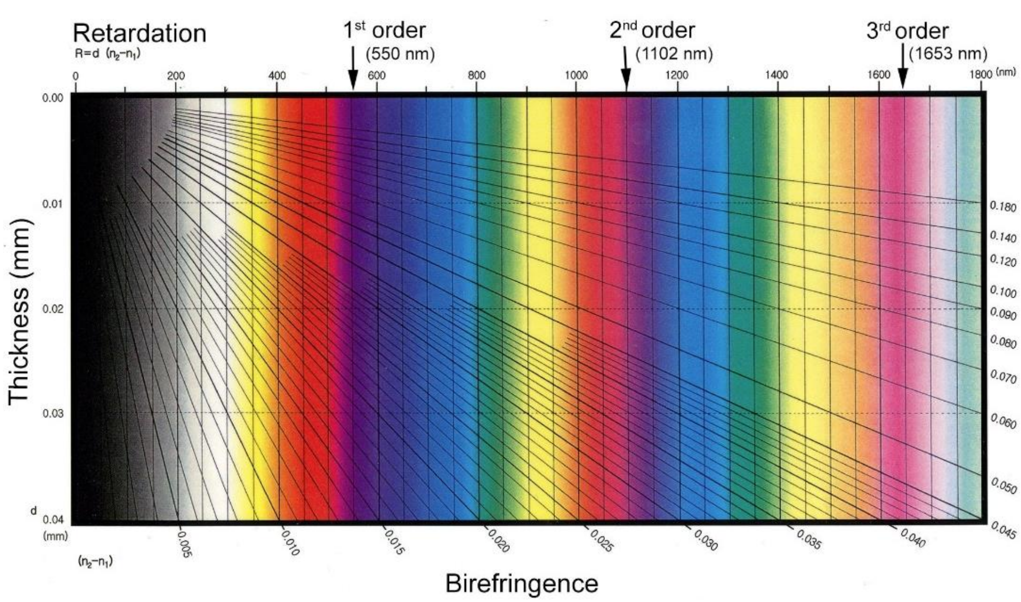


Figure 7

Many crystalline (chemicals, minerals) and some biologic substances (cellulose, keratin, stacks of proteins in muscle) are **anisotropic** (asymmetric in molecular structure) so the speed of light through it (refractive index) differs depending on direction (optical **birefringence**). The so called "ordinary" and slower "extraordinary" rays recombine by interference, producing new wavelengths (colors) and polarity of light. Anisotropic substances show a rainbow of colors (which change with rotation of the filter or specimen) when placed between crossed polars and are called birefringent. All the physics means many crystal substances can create a beautiful kaleidoscope of interference colors in a microscope with rotatable polar filters.

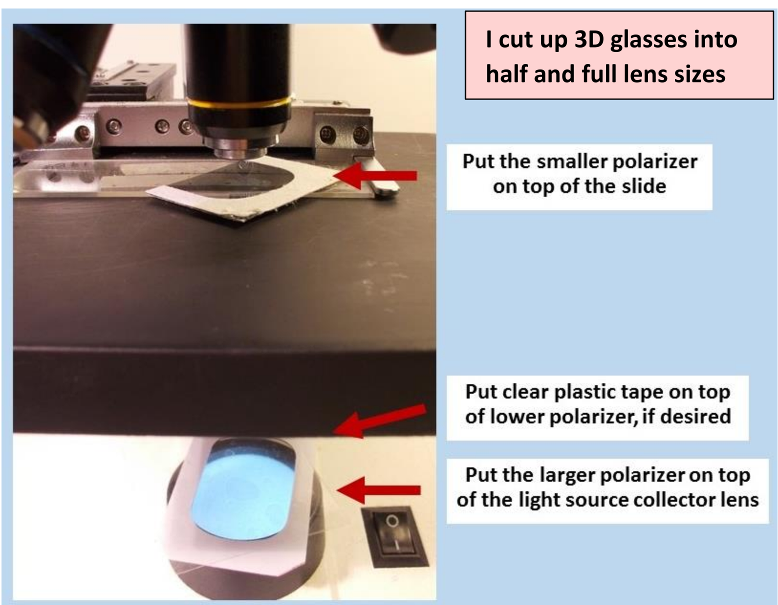
Figure 1



DIY Polarizing Microscopy

Professional polarizing microscopes are expensive, but very useful in geology and forensics to do “quantitative polarization”. The light path of an Olympus polarizing microscope is shown above. A specimen of a certain thickness and composition will produce predictable first, second and third order interference colors, which are shown on the Levy Michel chart.

But you don’t need a fancy professional microscope to enjoy polar specimens. 150 years ago microscopes became parlor entertainment. Lay people knew science was making life better, and some bought microscopes. A few Victorian microscopes were called “**polariscopes**,” equipped to reveal hidden optical properties. Victorian slide mounters sold slides of many subjects, including chemical crystals marked “for polariscope”. By slowly turning special filters, multiple bright colors appeared and changed continuously in an amazing microscopic kaleidoscope show. In a day when parlors were lit by candles it must have been very impressive to gathered friends, although modern kids can be hard to amaze. On my favorite microscope (used for the photos in this article) I used a camera linear polar filter sitting on top of the collector lens as a rotatable polarizer, pieces of clear tape (folded over themselves so not sticky) as optional retarders and an under the head analyzer. I’ve also used $2 3-D glasses and clear tape to make polarizer, analyzer and retarders for microscopes, and they work great:



The specimen slide must be between the two polarizing filters. I suggest:

- **larger filter on light source**
- **smaller filter on top of slide**

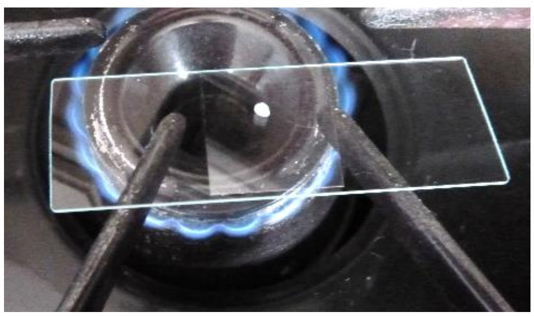
Alternatives include a filter just under the slide on stage, and upper filter on top of the eyepiece (or under head, if you know how.)

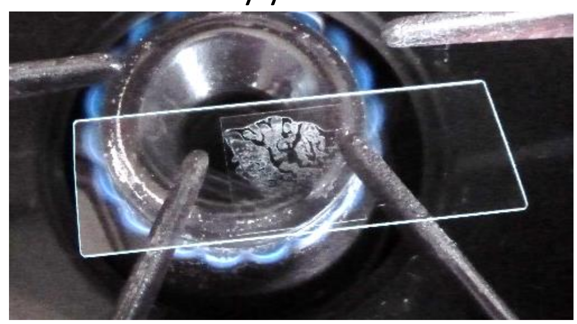
Try twisting one filter around in a circle while watching through the eyepiece. When the image is dark, only polar substances show through, often in rainbow colors.
To add more colors lay the compensator (folded clear plastic tape) on top of the bottom filter. Try rotating the various elements again.

Most things are isotropic, showing no polar effects. But organic chemicals including sugars and medications are often anisotropic, and may form birefringent crystals. In a few cases polar effects can identify a substance of medical importance such as urate crystals (in gout) or amyloid. Most sand, sugar, starch, bone, wood, keratin (hair), chitin (insect skin) and fresh muscle tissue is polar. Many natural and synthetic fibers like asbestos, cotton, wool, nylon and micro-plastics are polar. Make a polar kit and give it a try. Experiment with filter placements.

Urea Melt Slides

I'd seen many beautiful photomicrographs of urea online, so I was excited when my wife got Morton pet safe sidewalk melting salt, which is urea. It's pricey ($20 US for 3.4 kg) and didn't melt our driveway as well as standard sodium/calcium chloride melt salt. But it will fertilize the grass, doesn't poison dogs and makes beautiful microscope slides. Urea, $CO(NH_2)_2$, melts at 134C and the melting salt is comprised of easy to handle ~2 mm pellets. It is highly soluble in most solvents. I made nice sheets of translucent crystals by dissolving the melt salt in warm water or 90% isopropyl alcohol, and letting wet films evaporate on slides, with or without a coverslip. My favorite urea slides were created by melting it. I don't have a hot plate but the gas stove in the kitchen worked. I found it best to put a pellet or two under a coverslip on a slide, then turn the stove on to the lowest position possible. The urea would melt in about 30 seconds. I turned the stove off immediately. Otherwise, the urea bubbled and perhaps decomposed as it can at about 135 C into many compounds including ammonia, cyanate and biuret ($C_2H_5N_3O_2$). The exact breakdown pathways of urea both metabolically in organisms and inorganically in the lab have been much debated by chemists for many years. Be careful!!!





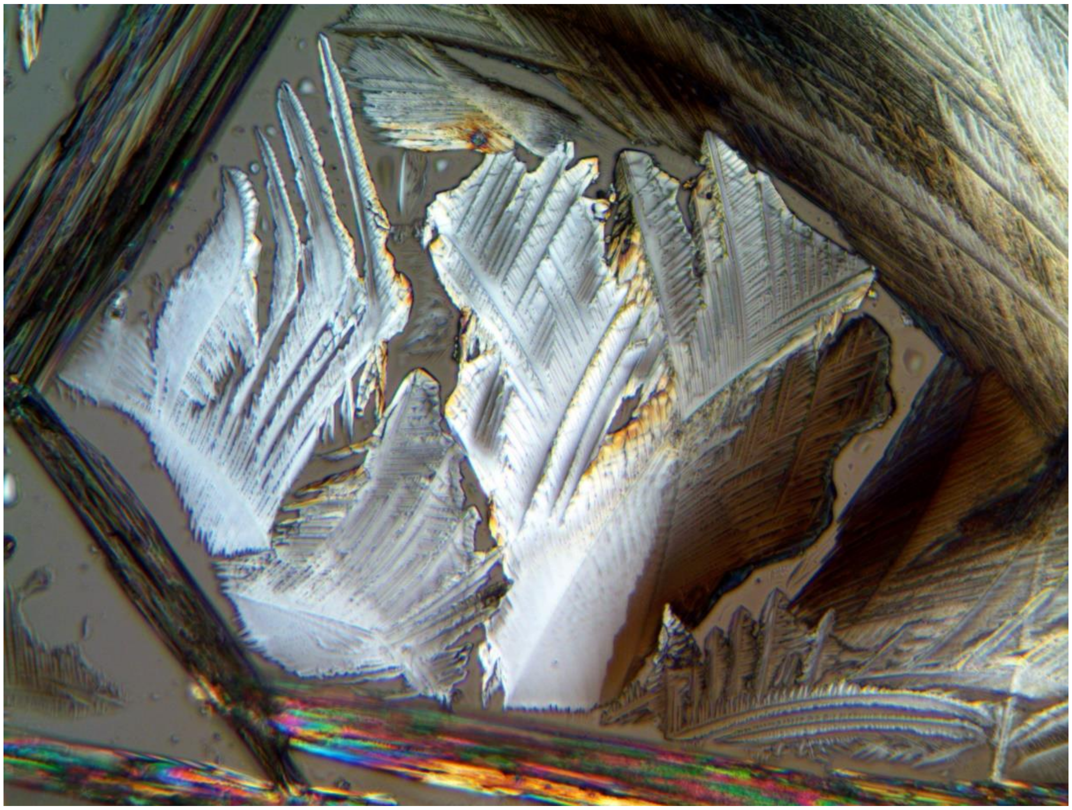
Safe-T-Pet melt salt is urea with a little propylene glycol and blue dye. A gas stove worked well for creating melt slides.

Urea melted under coverslip

4X objective crossed polars

Diastar microscope

Variscope 3.1 Mp USB camera



Urea from saturated solution in 90% isopropanol, no coverslip

10X objective crossed polars

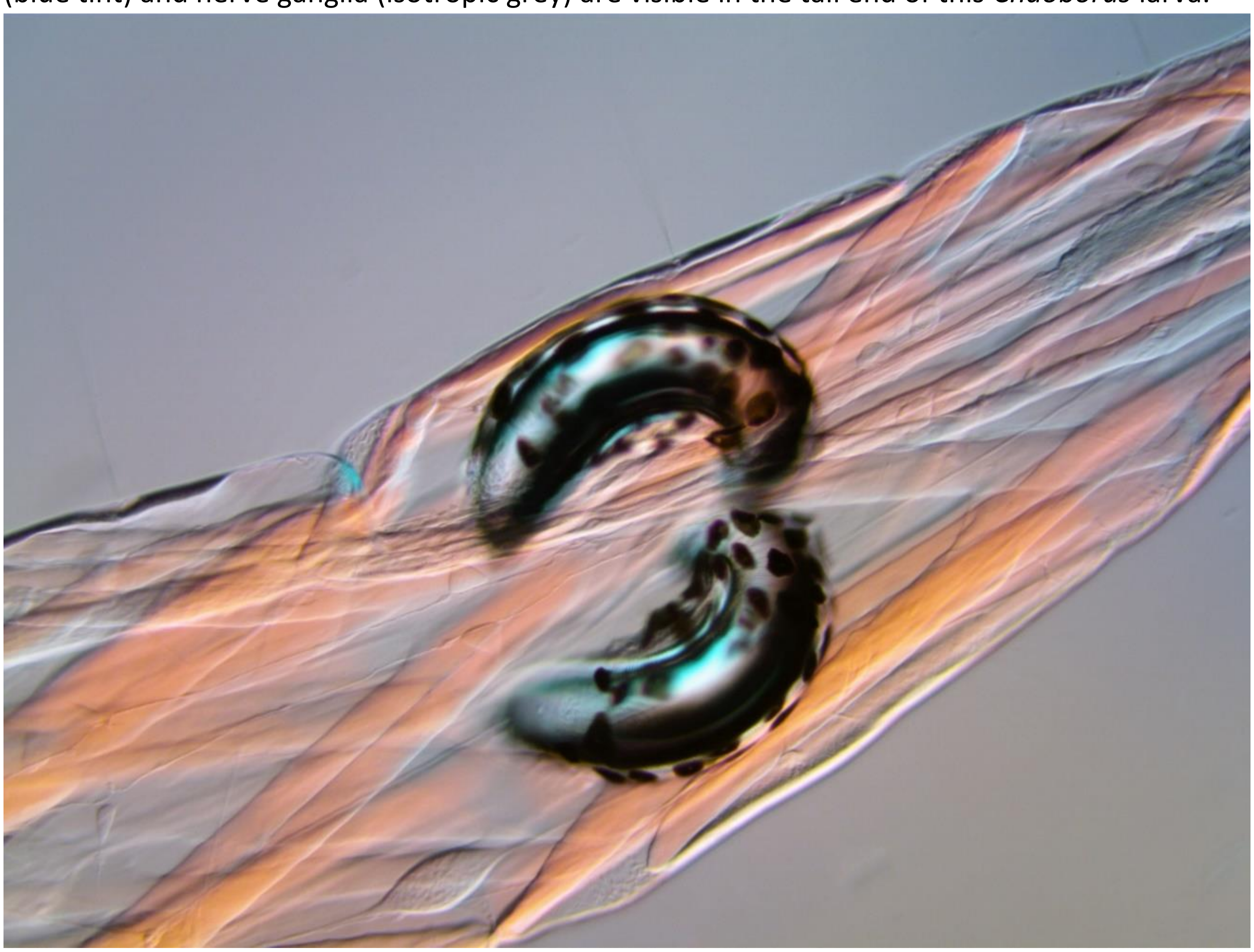
Rather different crystals than from urea melts

You never know exactly what you will get when you make slides of crystals; they form somewhat differently each time

Articles and photomicrographs

Ed Ward, MD
Minnesota, USA

Polar filters can highlight muscles inside aquatic arthropods. Muscles (orange), air bladders (blue tint) and nerve ganglia (isotropic grey) are visible in the tail end of this *Chaoborus* larva.



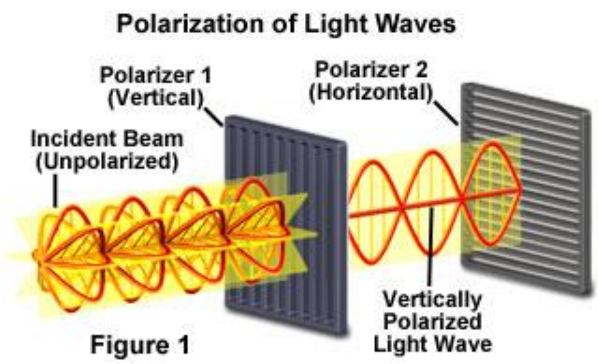
Chaoborus sp. "ghost midge" larva (transparent predator, netted from Mississippi River)

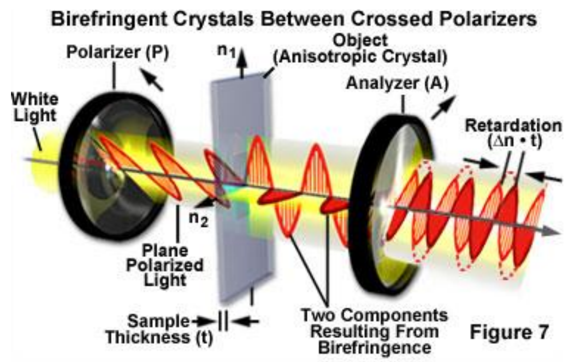
10X Fl objective, oblique lighting, partly crossed polars

Polarized Light Microscopy, a bit more about why it works

Light is a wonderful force of nature that lets us see the world with our eyes, and with light microscopes. Polarizing microscopes let us investigate special optical properties of some specimens. As Michael Faraday guessed and then eventually showed, light is an oscillating electromagnetic wave (carried by photon particles we can ignore for now). Light waves move along at about 300 million meters a second in a vacuum or air, but slows down in solid clear materials. Inside glass for example, light's electromagnetic field induces a weak opposing repelling electric field in the electrons of atoms in the glass, slowing the light down to about 200M m/s (refractive index 1.5, meaning light is slowed by 33%). Passing into or out of glass also bends (refracts) light rays, allowing a well designed system of lenses in a microscope to magnify specimens.

Ordinarily electromagnetic waves of light vibrate in all directions perpendicular to the ray. A **polarizer** blocks all except the light that is vibrating in just one direction. If a second polarizer (**analyzer**) is placed in the same orientation, light goes through, but if it is turned 90 degrees, the light is blocked, as seen below left. "Crossed polars", as this configuration is called, results in a black, lights out view for most specimens. But if parts of the specimen twist the angle of light ("birefringent") some light gets through, with changes, as seen on the right.





From Nikon's MicroscopyU

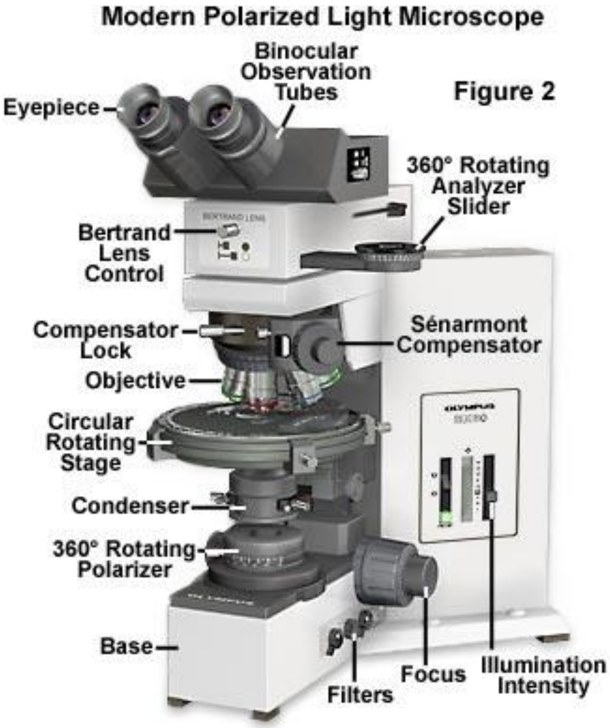
Now the birefringent parts of the specimen jump out in colors against the black background. If a **retarder filter** that phase shifts light (delays the wave peak a little, as do many plastics and clear minerals) is introduced, the light frequency (color) changes and things get really interesting and often quite beautiful. Special polarizing microscopes are expensive, but cheap polarizing filters work well with most microscopes.

Polar effects are only apparent for some specimens. These materials affect light differently according to the angle they are lit from and are called "anisotropic" (their atomic structure varies in different directions) and are optically "birefringent" (they slow the speed of light by different amounts in different directions). When placed between polar filters a birefringent specimen creates an "ordinary ray" and a slower "extraordinary ray" that eventually recombine with interference, creating a rainbow of colors, twisted at a different polarization angle. Minerals are commonly polar and geologists often use dedicated polarizing microscopes. Organic chemicals including sugars and medications are often birefringent, and some form intricate crystals as a bonus. In a few cases polar effects help identify a substance of medical importance such as urate crystals (in gout) or amyloid (in cardiomyopathy or dementia). Sand, sugar, starch, bone, wood, keratin (hair, skin), chitin (insect skin) and fresh muscle tissue are often polar. Many natural and synthetic fibers like asbestos, cotton, wool, plastics and nylon are polar. Go exploring. Get or make a cheap polar kit and give it a try. With a bright enough light source you can mix polar with oblique or dark field lighting. Experiment with filter placements.

More info on-line: microscopyu.com, Molecular Expressions Microscopy Primer at micro.magnet.fsu.edu, Micscape at microscopy-uk.org, microbehunter.com articles and forum

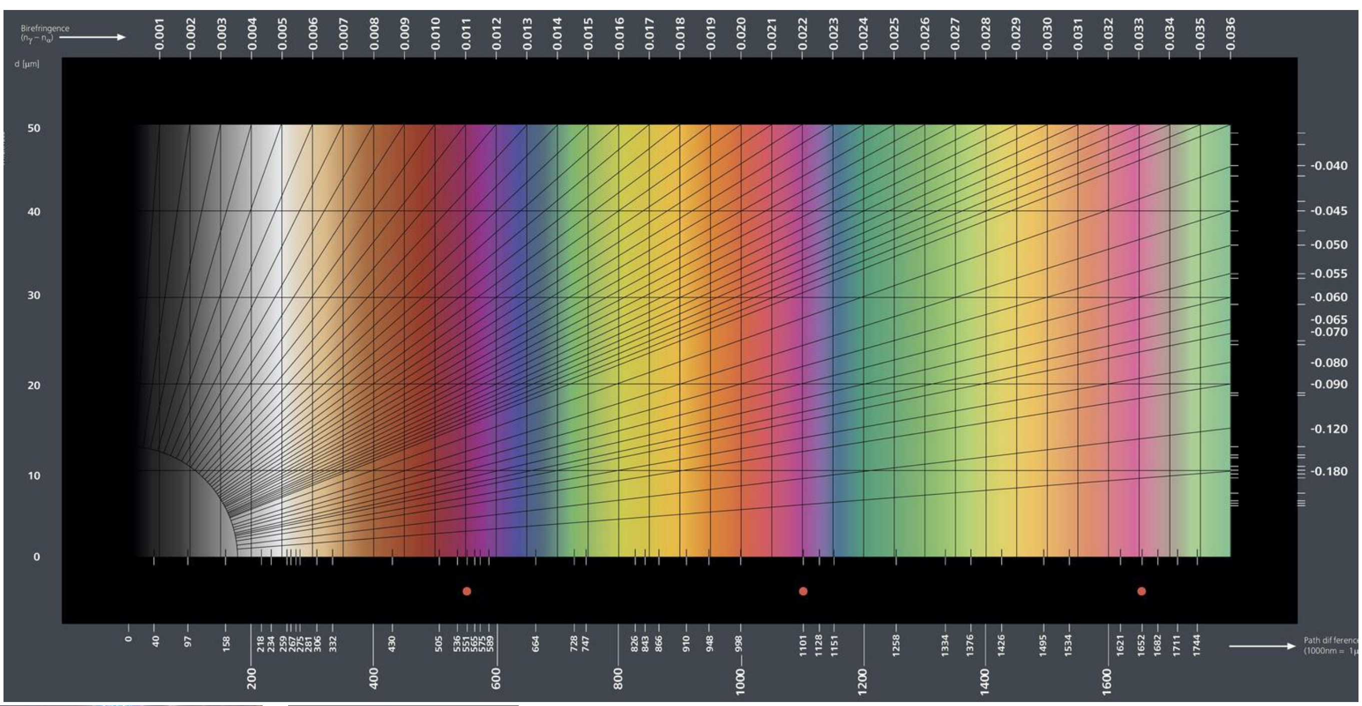
Quantitative Polarized Light Microscopy **(brief description by Ed Ward)**

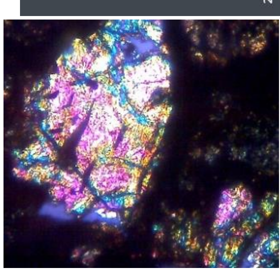
Dedicated professional microscopes for polarization are desirable for some geology and forensic studies.

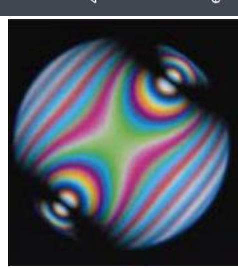


The example Olympus microscope at left is equipped for quantitative polar work. A birefringent specimen slide is put on the stage. Often the polarizer is tried first, then the analyzer up top, then the optional compensator (or lamba wave plates). The polarizer, stage (specimen) and analyzer are all easily rotated to change the optical effects. For conoscopy a Bertrand lens examines interference patterns at the objective back focal plane.

Below is a Michel Levy chart of interference colors, first published in 1888 in Paris (below is from SERC at Carleton College). Specimen thickness in microns is on the Y axis, amount of retardation (from wave plate or compensator) on X axis, and amount of bifringence is read from the diagonal lines with scale at top and right. If you know the specimen thickness (30 microns is standard for geology slides) the color under crossed polars helps identify the mineral. Using wave (λ) plates shifts the colors to the right, helping confirm the identification.







Mineral grains in geologic sections can be identified using multiple optical properties: Opaqueness? Color? Pleochroic? (different colors with different polar angles) Relief? (different refractive index than surroundings) Range of interference colors? Angle of maximum extinction? Length fast or slow? (if elongated or cleavage) Maximum birefringence? (on Levy Michel chart) Uniaxial or Biaxial Conoscopy?

As always, ***Micscape*** has lots of good information for amateur microscopists wanting to learn how to do it yourself. Good, inspiring articles on urea and other crystal microscopy include:

A Gallery of Urea Photomicrographs (using polarized light) by Brian Johnston, Oct 2022

A Tribute to Brian Johnston by Richard L. Howey, July 2014, great gallery of Johnston's images

Also see Richard Howey's own numerous crystal image galleries and picture stories

Uncrossing the polars - exploring parallel polars for qualitative crystal studies by David Walker July 2020, delves into some more technical aspects of polar microscopy

Polarised light microscopy with four different light sources by James Stewart, April 2023, is one of his many inspiring DIY articles that include home polar techniques

Preparation of Crystals for Observation by Robert Pavlis, July 2007, has practical and safety tips

---

Ed Ward, comments welcomed, email – eward1897 AT gmail DOT com

Published in the May 2023 edition of Micscape Magazine

www.micscape.com