Painting with Polarization

with Professor Aaron Slepkov

Light is fascinating. The splitting of light through a prism demonstrates its variety of wavelengths and constituent colours. Natural light can be transformed into polarized light, for example, by passing it through a special film that acts like a filter.

Types of filters called polarizers can be fitted to optical equipment like microscopes. Birefringence is clearly seen under the microscope in the geology lab as students look at geological thin sections, but the bright, mosaic of colours seen is often mistakenly called ‘interference colours’, yet interference has little to do with this process, as Professor Aaron Slepkov tells us. Birefringence colour effects are due to the polarization of the light being altered through particular materials.

Above: “Stained Glass with Objects”. Colourless and transparent adhesive tape pieces are layered on a (20 cm X 25 cm) glass plate, illuminated by a white computer screen and photographed through polarized sunglasse. © Aaron Slepkov. © All rights reserved

Q & A - Aaron Slepkov

Firstly, please tell us about your experience in optics and why you started your project "Painting with Polarization".

To most of us, light itself is the opposite of a "material". It has no weight; no substance. When I began my studies I saw light this way too. As a graduate physics student interested in photonics I began to see that at the cutting edge of technology light was being treated as a malleable and controllable substance. I coined the term "Lightsmith" as a vocational term for those of us who manipulate light as a substance from which we can create new tools. For two decades I've been working as a Lightsmith, conducting research in various domains such as laser microscopy and spectroscopy, atomic & molecular optics, and recently microwave biophotonics.

Recently I've been teaching about the curious effects of light polarization. Many fun demonstrations of the effects of polarization can make use of everyday household items such as polarized sunglasses, kitchen cling film, sugar syrup, or even ice.

Below: "Eclipse #1", mounted for sunlight illumination and displayed affixed to a window. This piece was created by cutting and layering three types of adhesive tape on the glass plate from a simple 8" 10" picture frame. All layers fit within the plastic frame, and include, from back to front: kitchen parchment paper as a diffuser, sheet polarizer with vertical polarization, glass, adhesive tape, and sheet polarizer with horizontal polarization. © Aaron Slepkov. All rights reserved.

At the start of the COVID-19 pandemic I began working with a gifted highschool student who wanted some experience with optics research. When I saw some examples of scotch-tape polarization images on social media I realized that a fuller scientific explanation of the phenomenon would make a great joint pandemic project. I had not expected it to blossom into the rich exploration that it has become.

Please explain the physical underpinnings of the artistic colours that arise from birefringent materials.

In principle, we perceive each distinct colour as a range of wavelengths and intensities. A narrow range of intensities around 420 nm is perceived as blue, but also a broad range of wavelengths (white light) where red is filtered out can also appear as a kind of blue. Thus, each of the extremely wide range of colours that we can see can be obtained by filtering out portions of the white light spectrum.
Light is linearly polarized when the direction of the electric field (within the electro-magnetic wave) is aligned in a particular direction. A birefringent material has two (or three) perpendicular directions that each permits light polarized along it to travel with a slightly different speed. In practice, this means that if polarized light is incident along some direction between these primary axes in a birefringent material, the polarization of the light will be rotated or otherwise altered.

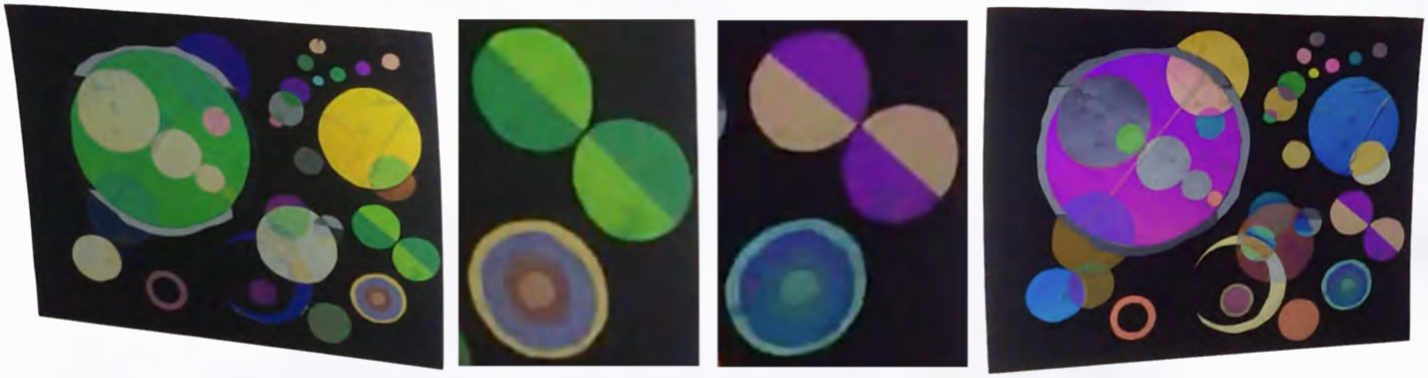
So, a birefringent material modifies the polarization of the light. The amount to which the polarization is altered depends on the wavelength of the light, the thickness of the birefringent material, and the microscopic orientation of the birefringent material with respect to the incoming polarization. Finally, a polarizer is an optical gate that both sets the emerging polarization and blocks light depending on how mismatched the incoming polarization is. Light with co-aligned polarization to a polarizer is fully transmitted, light that is perpendicularly-polarized is fully blocked, and light in an intermediate state is attenuated to varying degrees. Polarization filtered colours arise when a birefringent layer—such as scotch tape, cellophane, or cling wrap—rotates the polarization of different wavelengths of the incident light such that a final polarizer acts as a filter that excises a portion of the spectrum, thereby transmitting a uniquely-modified spectrum which we perceive as a distinct colour. Adjacent regions with different birefringence lead to different colours.

How can one observe birefringence colours at home?

In principle all that's needed is a polarized light source, a transparent sample with regions of varying birefringence, and a polarizer for observation. Most display screens such as a cellphone, a laptop, or a flatscreen TV monitor emit polarized light, so they are a good starting point. Alternatively, a sheet polarizer as the backing layer will polarize the light, so that you can even use sunlight as the lightsource. A fun and simple sample can be made by layering strips of packaging tape in various thicknesses and orientations on to a glass plate (obtainable from a $2 picture frame). Most, but not all, household adhesive tapes are birefringent, as is kitchen cling film. Mixing different tape samples increases the range of colours that can be observed. The glass is non-birefringent but makes a convenient substrate for the tape. Passing the polarized light through the sample doesn't lead to any observable colouration until observed through a final polarizer. Polarized driving sunglasses are very effective. Thus, with a white LCD screen and polarization sunglasses, you don't need to purchase dedicated polarization film. However, for a permanent display that can be observed by a crowd, the birefringent sample needs to be sandwiched between polarizer film. The relative orientation of the three layers completely transforms the colour scheme!

When looking at geological thin sections under the microscope with polarization filters, the bright colours are often described as *interference colours*. Why is this a misleading term?

While this phenomenon has been called *interference colours* for a century, I suspect that the misleading reference to interference has hindered a more widespread understanding of the underlying physics. When the birefringent material displays continuous local variation in thickness and/or birefringence, the resulting pattern of colours is highly reminiscent of those seen in soap bubbles, oil slicks, and other thin film interference phenomena. In those examples the colours come about from constructive and destructive interference of multiple reflections at the interface of samples with thicknesses on the order of the wavelength of light. Tiny variation in the thickness of the film leads to different colours experiencing



Above: Observation angle and the effects of film thickness on transmitted colour. Piece titled "Several more circles after Kandisky", transparent adhesive tape on glass plate (20 cm, 25 cm), illuminated by a white-background laptop screen with crossed-polarizer, and viewed from two different angles. Middle panels show a zoom-in region from the adjacent outer panels, highlighting colour differences. © Aaron Slepkov. All rights reserved.

complete interference and thus to different observed colours. The interference itself acts as a final filter for removing key wavelengths and creating colours. In the case of birefringence colours there is no interference to consider. All of the colours come from the filtering effect of the final polarizer. Therefore, I prefer to call this phenomenon polarization filtered colouration, but indeed it is identical to what has been known for a century as *interference colours*, and before that as *chromatic polarization*. Both phenomena are wonderful illustrations of the wave nature of light, but not of interference!

How did the artist Austine Wood Comarow utilize this phenomenon to create a range of creative pieces from small objects to installations?

Starting in the 1960's several artists have explored polarization filtered colouration as a unique medium. In the early days there was a lot of creative exploration of dynamic birefringence and the kinetic aspects of how observed colours change with viewing position and polarization angle. But nobody has pioneered this medium like Austine Wood Comarow. Early on, Austine coined the term 'pollage'—a portmanteau of polarization collage—and she has become synonymous with the artform. She studied the aethetic and scientific underpinnings of the technique in an MFA thesis in 1981—believing at the time that it was indeed rooted in interference effects—but has since taken the artform in wildly creative and expanded directions. Her early works used true cellophane film as the main birefringent sample, but have since expanded to other birefringent materials. Over a career that spanned five decades, Austine's pollage art has been featured in museums all over the world; from Epcot Center in Florida, to the Singapore Science Centre, and la CSI in Paris. Her clever use of additional polarizer elements within the pollage can create a uniquely dynamic colour experience. Sadly, Austine died in 2020.

Final thoughts

With a background in optics, Professor Aaron Slepkov exposes us to the hidden physical realm behind light and birefringence — what people commonly, but incorrectly call interference colours. It is the properties of light, when shone through a polarizing filter, that reveal a variety of wavelengths in a rainbow of colours.

By starting the project Painting with Polarization, Aaron continues to explore and share the physical underpinnings of these polarization based colours. Austin Wood Comarow was an established artist (who is now deceased), who really pioneered this art, and Aaron seeks to update the scientific explanations behind the phenomenon. He has explained to us the physical processes behind the beautiful diversity of colours that we can see from birefringence. But we do not have to look down a polarizing microscope, we can produce impressive birefringence displays using everyday items and materials.

Bio

Associate Professor Aaron Slepkov holds a Canada Research Chair in the Physics of Biomaterials and leads The Slepkov Biophotonics Lab group at Trent University in Canada where researchers curiously investigate projects across the disciplines of Nonlinear Optical Microscopy, Physics Education Research, and Mad Science.

Links

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