Mastering Microscopy: Approaches to Polarized Light Microscopy Instruction (Lesson Plan)

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Audience: Conservation Graduate Students

Winterthur/University of Delaware Program in Art Conservation

The Colonial Williamsburg Foundation
"THAT THE FUTURE MAY LEARN FROM THE PAST"

1. Introduction

Polarized light microscopy (PLM) is a fundamental, yet often underutilized, technique for the identification of pigments, fibers, and other microscale components of cultural heritage. This four-day PLM workshop is part of ARTC667 taught to first-year graduate students at the Winterthur/University of Delaware Program in Art Conservation (WUDPAC), to prepare them to use PLM in their upcoming coursework and future careers. *Part I: Introduction to PLM,* is taught in the fall semester, followed by *Part II: Pigment Identification with PLM,* taught at the beginning of the spring semester.

Student Learning Objectives (SLOs)

- Apply PLM tools, concepts, and methodologies to recognize reported optical and morphological properties of various pigments and fibers.
- Cultivate PLM skills to characterize cultural heritage materials, starting with reference samples and working towards unknowns from actual objects.
- Establish foundation of PLM knowledge so that class materials can be used as 'refreshers' in the future, long after graduation.

2. Select References

a. Print books

i. Eastaugh, N., V. Walsh, T. Chaplin, R. Siddal. 2004. *The Pigment Compendium: a Dictionary and Optical Microscopy of Historical Pigments.* Oxford: Elsevier Butterworth-Heinemann.

ii. *Artists' Pigments: a Handbook of Their History and Characteristics.* Edited by Robert Feller, Ashok Roy, Elisabeth West Fitzhugh, and Barbara Berrie. 4 vols. 1986 – 2007.

b. Websites

i. CAMEO: Conservation and Art Materials Encyclopedia Online. [cameo.mfa.org/wiki/Main_Page]

ii. Olympus Microscopy Resource Center. "Polarized Light Microscopy." [https://www.olympus-lifescience.com/en/microscope-resource/primer/techniques/polarized/polarizedhome/]

iii. Carl Zeiss Microscopy Online Campus. "Education in Microscopy and Digital Imaging." [https://zeiss-campus.magnet.fsu.edu/index.html]

iv. Nikon's MicroscopyU. "Polarized Light Microscopy." [https://www.microscopyu.com/]

c. Papers

i. McCrone, Walter. "Polarized Light Microscopy in Conservation: A Personal Perspective." *Journal of the American Institute for Conservation* 33, no. 2, 21st Annual Meeting of the American Institute for Conservation of McCrone, Walter.

ii. "The Microscopical Identification of Artists' Pigments." *Journal of the International Institute for Conservation – Canadian Group* 7 (1&2): 11-34.

Top left image: Ashley Stanford (WUDPAC Class of 2024), photo by Miriam-Helene Rudd. I would like to acknowledge my WUDPAC microscopy instructors who influenced this course: Melanie Gifford, Deborah Mayer, and Mary McGinn.

3. Lesson Plan

Part I: Intro to PLM

General SLOs: *effectively use the PLM to recognize optical and morphological properties of pigments and some fibers, understand reference materials, articulate observations*

i. PowerPoint Lecture: Intro to PLM for Pigments

Introduces the instrument and its operation, concepts of polarized light and refraction, PLM terminology, references/sources, presentation of morphological and optical properties observed in PPL and XPL (later integrated through class exercises)

ii. Class Exercises (synchronous)

a. Kohler illumination
b. Calibrating the Ocular Scale
c. Measuring Particles using Martin's Diameter
d. Determining Relative Refractive Index/Becke Line
e. Isotropism, Birefringence, and Polarization Colors
f. Understanding Extinction
g. Pleochroism

iii. PowerPoint lecture: Identification of Synthetic Fibers with PLM

Briefly introduces plant fiber/animal hair microscopy (taught in detail during textile and paper block), focus on select synthetic fibers (excellent for illustrating Sign of Elongation)

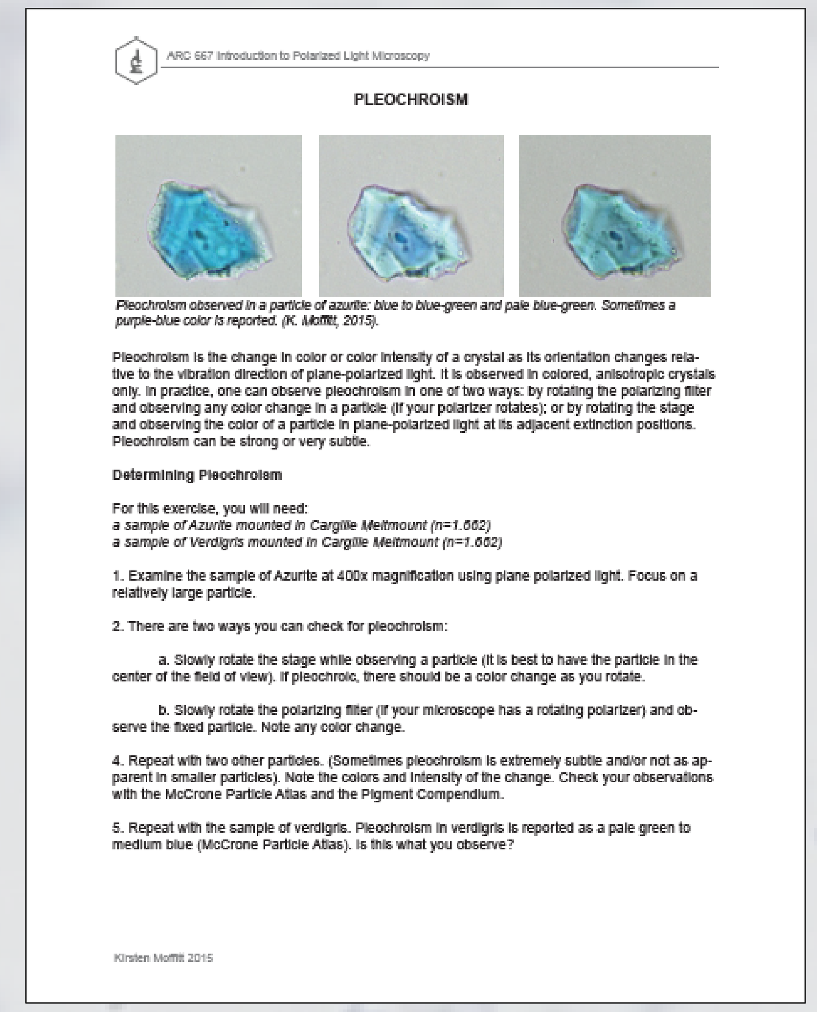
iv. Class Exercises

a. Sign of Elongation
b. Synthetic Fiber ID challenge (asynchronous) & group review

Correctly identify four 'unknown' synthetic fibers using PLM

c. Unknown challenge (asynchronous) & group review

Identify an unknown (reference) pigment or fiber provided by the instructor, accompanied by object context relevant to student's area of interest (ie: is this blue pigment consistent with the proposed date of this painting? If not, explain), group review as exercise in sharing and communicating results.



ARC 667 Introduction to Polarized Light Microscopy

PLEOCHROISM

Pleochroism observed in a particle of azurite: blue to blue-green and pale blue-green. Sometimes a purple-blue color is reported. (K. Moffitt, 2015).

Pleochroism is the change in color or color intensity of a crystal as its orientation changes relative to the vibration direction of plane-polarized light. It is observed in colored, anisotropic crystals only. In practice, one can observe pleochroism in one of two ways: by rotating the polarizing filter and observing any color change in a particle (if your polarizer rotates); or by rotating the stage and observing the color of a particle in plane-polarized light at its adjacent extinction positions. Pleochroism can be strong or very subtle.

Determining Pleochroism

For this exercise, you will need:
a sample of Azurite mounted in Cargille Meltmount (n=1.662)
a sample of Verdigris mounted in Cargille Meltmount (n=1.662)

1. Examine the sample of Azurite at 400x magnification using plane polarized light. Focus on a relatively large particle.

2. There are two ways you can check for pleochroism:

a. Slowly rotate the stage while observing a particle (it is best to have the particle in the center of the field of view). If pleochroic, there should be a color change as you rotate.

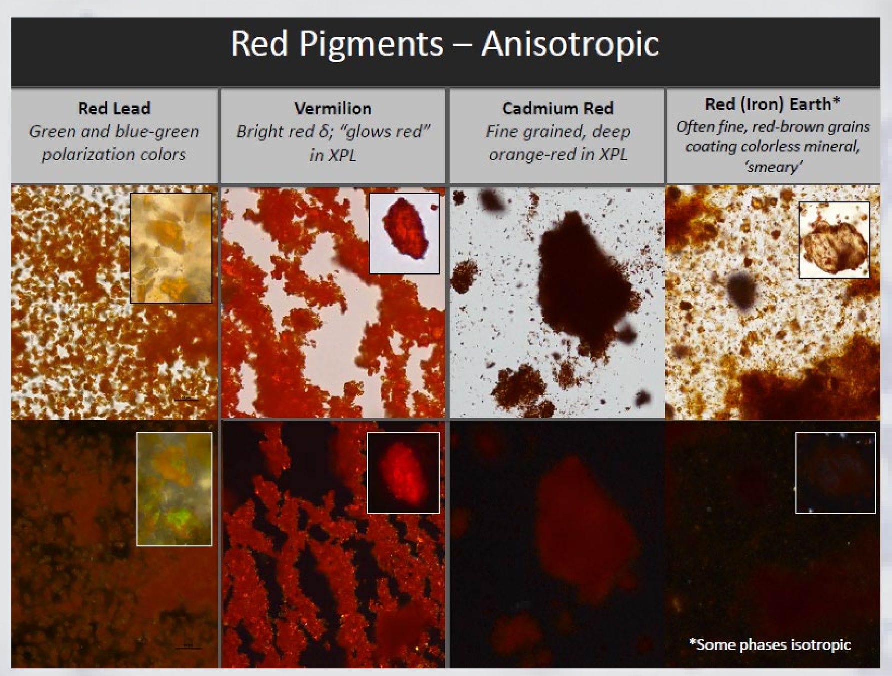
b. Slowly rotate the polarizing filter (if your microscope has a rotating polarizer) and observe the fixed particle. Note any color change.

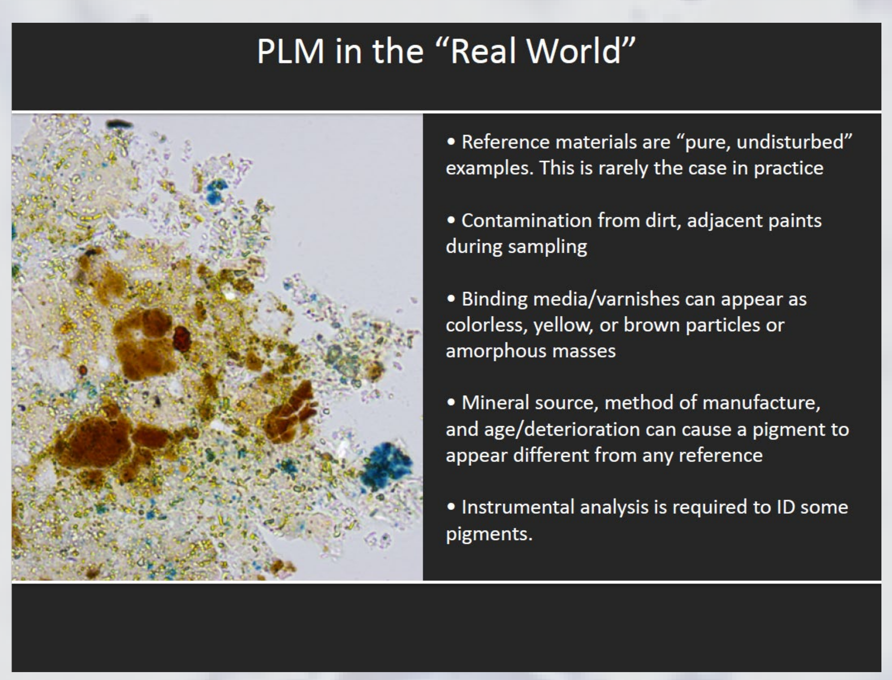
4. Repeat with two other particles. (Sometimes pleochroism is extremely subtle and/or not as apparent in smaller particles). Note the colors and intensity of the change. Check your observations with the McCrone Particle Atlas and the Pigment Compendium.

5. Repeat with the sample of verdigris. Pleochroism in verdigris is reported as a pale green to medium blue (McCrone Particle Atlas). Is this what you observe?

Kirsten Moffitt 2015

Worksheet for Pleochroism class exercise (ii g). Format includes photomicrographs of the behavior, explanation of the behavior, recommended pigments for the exercise, step-by-step instructions, and expected outcomes.





Lecture slides from 'Part II: Pigment ID with PLM', which groups pigments by color and tackles sample collection, documentation of results, and interpretation of unknowns.

Part II: Pigment Identification with PLM

General SLOs*: Integrate Part I concepts to the identification of pigments; gain confidence collecting and mounting samples from heritage objects, and expand skills to interpret unknowns from aged, soiled, and sometimes inhomogeneous 'real world' materials*

i. PowerPoint lecture: "Lightning Review" of PLM Concepts from Part I

ii. Class Exercises (synchronous, as in Part I)

1. Reviewing Optical and Morphological Properties with the PLM
2. Calibrating the Graticule Cross-Hairs
3. Determining the Angle of Extinction

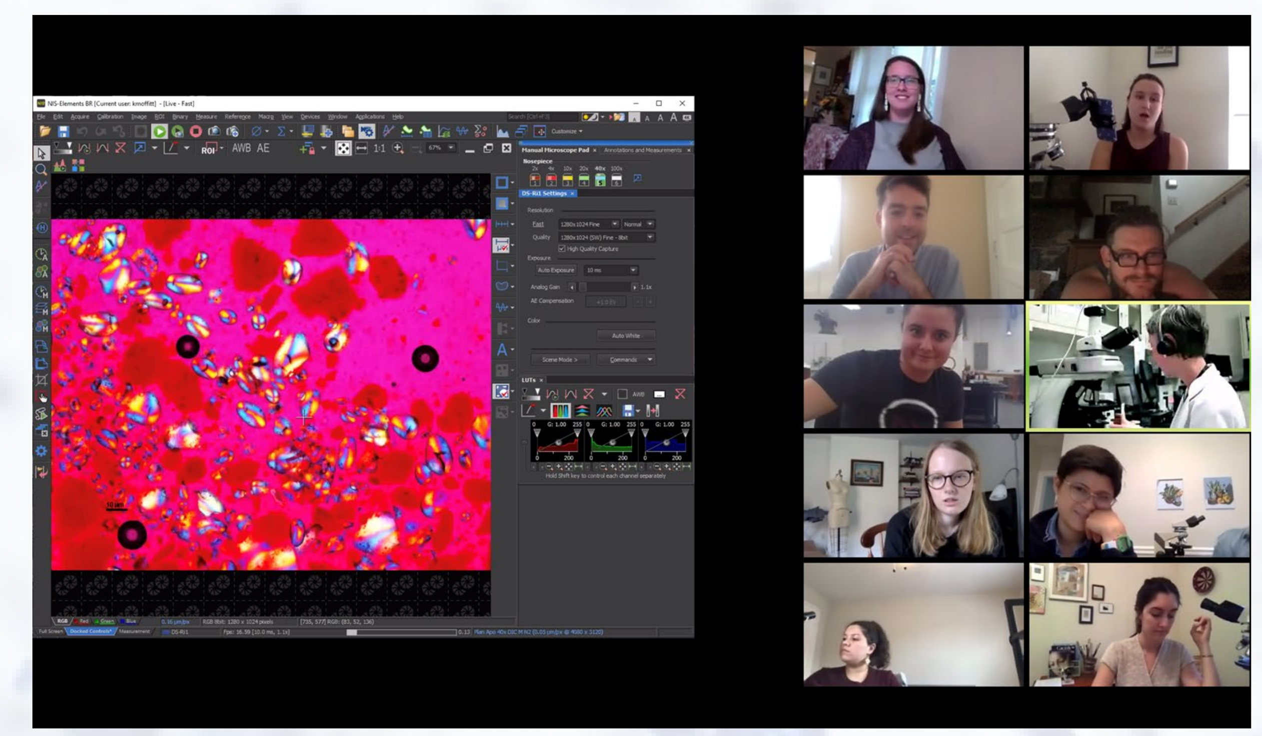
iv: Powerpoint Lecture: Pigment ID with PLM (organized by color)

1. Class Exercise: Identifying Pigments from Paint mock-ups A-D (asynchronous)
   Mixtures of historic pigments ground in oil and painted onto wood substrates. Exercise in sampling, evaluating mixtures, recognizing organic binding media, dirt, etc…
2. Class Exercise: Identifying Pigments from Technical Study Objects (asynchronous)
   One-on-one meetings with instructor and student to discuss object in question, formulate questions that can be answered with PLM, design sampling strategy, assist with collecting and begin interpreting samples. This takes up most of class time.
3. Class Exercise: Identifying Pigments from Colonial Williamsburg objects (asynchronous)
   Mounted samples from actual CW objects already analyzed by instructor. Examples are from aged, soiled objects that reflect 'real world' examples where PLM provided critical information beyond data from instrumental analyses. Students are provided with object history and objective of analysis and must put results in context. After exercise, students are provided with the object's analytical report to see how PLM contributed to the overall study.
4. Group Review/Discussion of all results (each student gives a brief PPT presentation)
   Students give brief Powerpoint presentations of preliminary findings from Technical Study objects, and group review of exercises 1 & 3. Student learning outcomes are assessed.

4. Methods for Student Engagement

There is much material to cover, so the atmosphere is kept light and fun. Concepts introduced in the lectures are immediately solidified through synchronous class exercises. Students are encouraged to gather around the microscopes of classmates who find an excellent Becke line, or a perfect example of pleochroism in a particle. This keeps the students physically active, giving them small breaks and lessening eye strain, while allowing them to see the variety that can exist within samples.

Asynchronous class exercises are as important for personal growth and skill development. Individual instruction is possibly the most crucial portion of the workshop as students learn to collect and interpret samples from their study objects. At the end of Part II, Powerpoint group reviews are valuable opportunities for articulating findings and communicating the value of microscopy to their research question. Inconclusive findings can be teaching tools that illustrate the limitations of the technique, and foster conversations about additional analysis. Group reviews are key to assessing learning outcomes.



Zoom teaching the class of 2023

Challenges: During the pandemic, PLM (Part I) was taught virtually, and was ultimately a great success. Each student was provided with a microscope to use at home with inexpensive smartphone eyepiece adapters, and a box of reference slides (compiled and mailed by the instructor). The instructor lectured and led exercises from her microscopy lab at Colonial Williamsburg, switching between a webcam which allowed the students to simultaneously see her at the microscope, as well as a microscope camera which allowed students to see the instructor's field of view.

The virtual platform had surprising and delightful advantages: thanks to the adapters and wireless technology, we could view each other's samples in live time and discuss them. Similarly, online/digital references could be shared and viewed together for discussion. Because the students were working independently, they developed a striking proficiency with their instruments, troubleshooting issues on their own as they arose.