Producing Clean Backyard Compost: Evaluating the Risks of Common Organic Raw Materials

Robert J. Rafka, Ph.D., FRSC

URI MG Class of 1998, Hall of Fame 2011
Connecticut Compost Alliance

Connecticut College, 14 March 2024

- Composting is chemistry!
- Commercial testing and its limitations
- Risks and benefits of selected compost raws
- PLM to detect microplastic contaminants
- Questions and answers

We Create Compost to…

- Produce a product that benefits soil health and plant growth.
- Divert selected organic materials from the waste stream and extend the useful lifespan of our landfills.
- Mitigate climate change by reducing methane emissions from landfills.

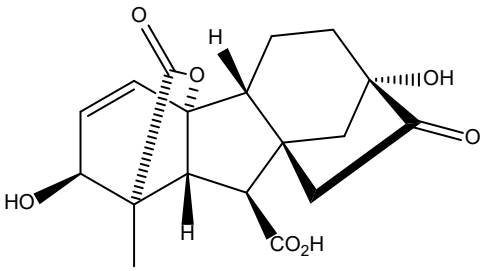
Composting is Chemistry

- Composting is a complex set of exothermic, heterogeneous chemical and biochemical reactions that (for the most part) convert complex macromolecules into smaller, simpler chemical entities.
- As with *all* heterogeneous reactions, the process is accelerated by agitation, stirring, increasing the temperature and the concentration.

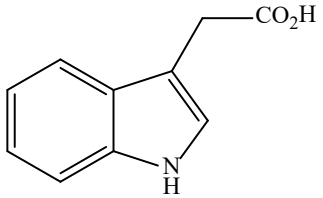
Making big ones into little ones

Composting is Chemistry

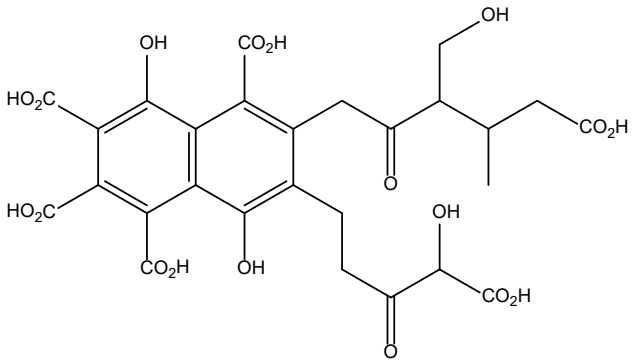
- Some chemical species are stable and remain unaltered during composting.
- Composting can create *more-toxic* chemical species from less-toxic ones.
- *Composting recycles the <u>last</u> generation of plants to leave valuable compounds behind for the <u>next</u>.*
- The *chemical* science associated with composting is still rapidly evolving.



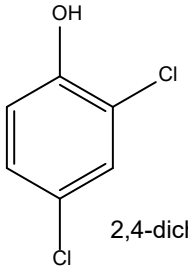
Gibberellic acid



Indole-3-acetic acid



Model Structure of Fulvic Acid



2,4-dichlorophenol

Converting Organic Raw Materials into Compost

- Compost can be created from a plethora of organic raw materials. *Think* carefully and *choose* wisely!






Organic Raw Materials Should be Diverse

- Consider what enters your composter as you would selections from a buffet line or a salad bar.

- Compost derived from multiple source materials *balances* added nutrients and *minimizes* risks.

Risks of Single Source Composts

- Marine plants could, *depending on the method of preparation*, contain excessive levels of salt (NaCl).
- Grass clippings (*depending on the source*) may contain undesirable herbicide and/or pesticide residues.
- Poultry manure is high in soluble nitrogen salts.
- Fallen leaves decay slowly unless the particle size is reduced and nitrogen levels augmented.

An Old Chemistry Aphorism (pre-Rachel Carson):

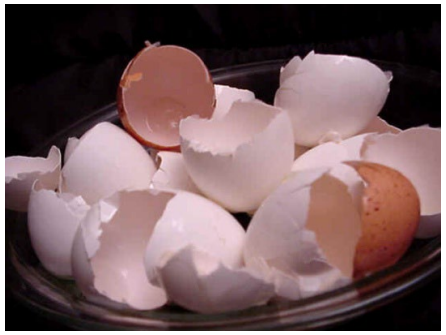
- *"The solution to pollution is dilution."*
- Could this outdated statement apply to choices made by the home composter?
- *Perhaps*…

Chemical Testing *vs.* Careful Choices of Raws

- UMass discontinued its compost testing program in January 2017.
- Penn State offers a range of compost tests ranging from basic ($45) up to a highly advanced test panel that includes toxic metals *and PCBs* ($360).
- UMaine also offers two tests at $60 and $70 but no tests for toxic metals or organics.

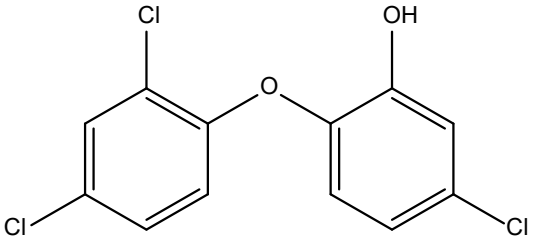
We'll Consider These Potential Raw Materials

- Sawdust
- Newspaper
- Leaves
- Garden waste and weeds
- Coffee grounds/filters
- Kitchen waste (incl. citrus peels)
- Bones [$Ca_3(PO_4)_2$ in a protein matrix]
- Eggshells ($CaCO_3$ as above)
- Wood ashes and lime (alkalizing agents)
- Grass clippings
- Herbivore manure
- Dryer lint and vacuum cleaner bag dust
- Tea bags

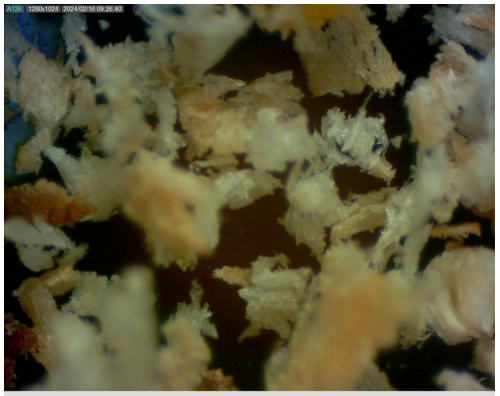


Sawdust

- Small particle size facilitates decomposition.
- Bark is replete with lignin and inorganics (ash component).
- Hardwood *vs*. softwood particles rot similarly.
- Avoid painted, stained, or finished wood (various organics).
- Same for pressure treated (copper).
- Wood composites (laminates) contain glue, plastic*, and antibacterial/antifungal preservatives including triclosan.

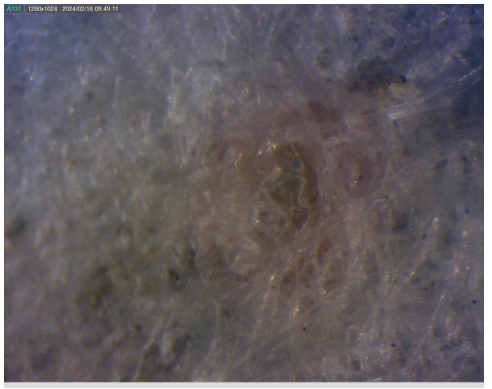


Triclosan

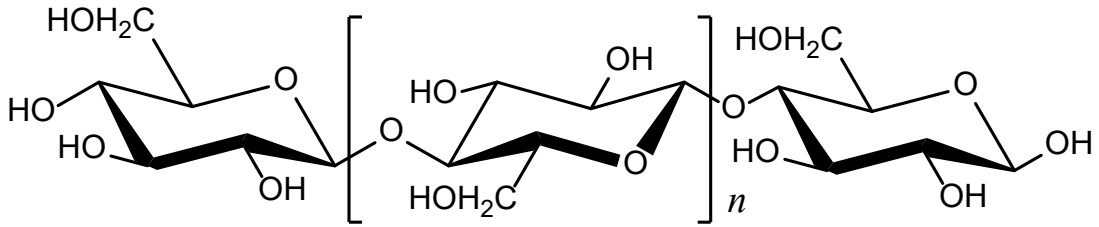

sawdust, 40x, top light

Newspaper

- Generally OK to incorporate… shredding helps.
- *Fisherman out there… remember Buss Bed-ding?*
- Avoid glossy and/or colored inserts.
- Modern, soy-based inks should present no problems.
- Newspaper is mostly cellulose and not especially nutritious.



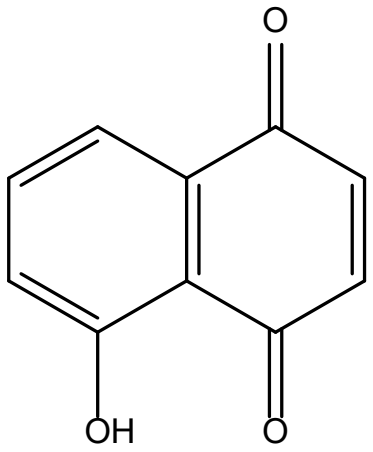
paper towel, 40x, combined light



Cellulose

Leaves

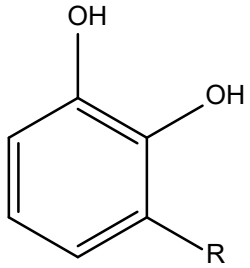
- No transportation $$$ or mess if collected on own property.
- Few weed seeds.
- Consider the lifecycle of a deciduous tree…fallen leaves contain few nutrients but considerable tannins/phenolics.
- Oak leaves exhibit a waxy, water-repellant coating.
- Certain species (hickories, walnuts, pecans) contain allelopathic* compounds including juglone.
- Mechanical maceration hastens decomposition as does augmentation with nitrogen (alfalfa meal or urea).



Juglone

Garden Waste and Weeds

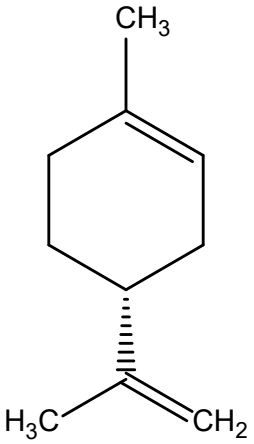
- Generally OK.
- After frost, tomato and pepper plants ground to green/brown “mush” using lawn mower. Worms appear to enjoy it.
- Weed seeds may survive relatively cool peak temperatures.
- Noxious weeds like poison ivy should *always* be excluded.



Urushiol
R = long alkyl chain (some unsaturated)

Kitchen Scraps

- Worm's favorite…but avoid fatty or greasy wastes.
- Collected below sink in covered, stainless pail.
- The pile is *over-fed* in August/September when canning side-streams abound.
- Small amounts of dairy products and cooked meat scraps are incorporated into the pile during colder months.
- Citrus residues present (temporary) challenges and are <u>rock bottom</u> on my worms' favorite foods list.



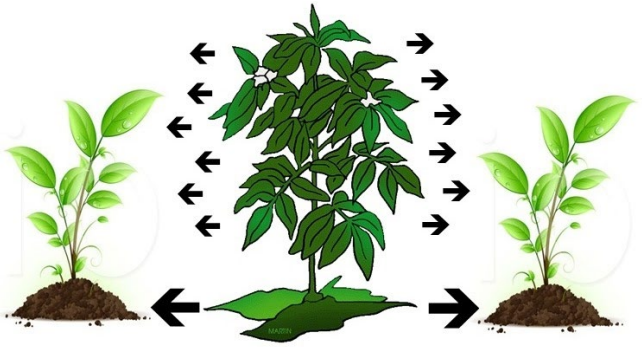
R-(+)-limonene

Coffee Grounds

- Available at Starbucks in iconic silver bags.
- Worms love grounds…especially in winter when other food is scarce.
- Grounds *and filters* break down readily.
- Caffeine is allelopathic* and incompletely removed during brewing, so limit the amount of this stream.
- Label on bags says to stay under 20%... **the solution to pollution?**
- *You may choose to augment coffee grounds with shredded newspaper (reading material) should residual caffeine provoke worm insomnia.*
- Later, we'll examine photomicrographs of coffee filters and tea bags.

Allelopathic Agents in Compost Raws

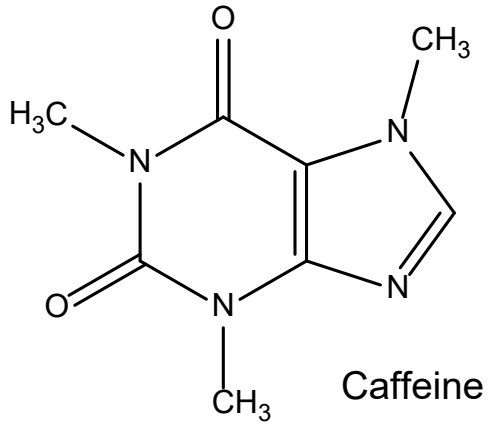
- Secondary metabolites are compounds not normally associated with growth, development, or reproduction.



- Allelopathic compounds are secondary metabolites that plants produce to gain an advantage by hindering or killing neighboring plant species.

Coffee Grounds

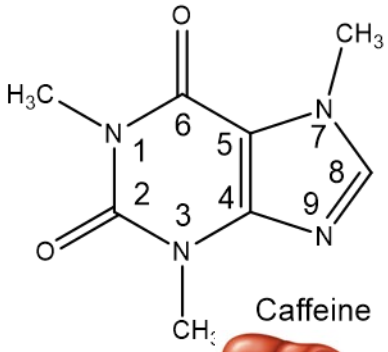
- The coffee plant (*Caffea arabica*) produces 1,3,7-trimethylxanthine in its seed pods.
- You know it as caffeine.

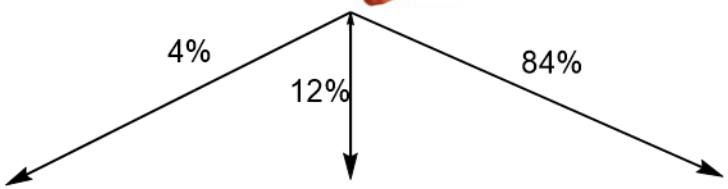


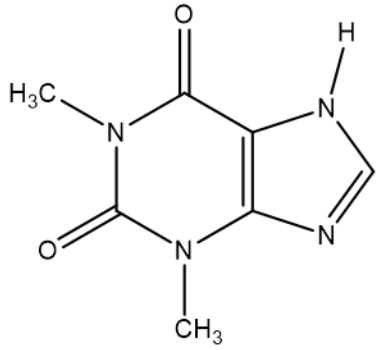
Caffeine

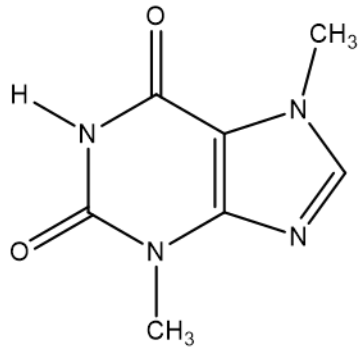
Caffeine Metabolism in Humans

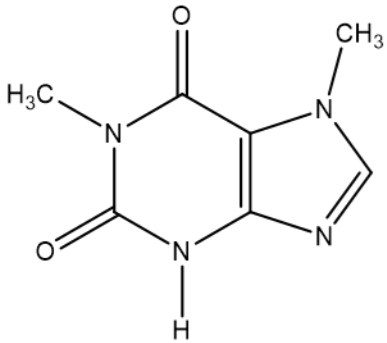
- The metabolic fate of caffeine *in your liver* is well-established.






Theophylline


Theobromine


Paraxanthine

Fate of Caffeine in a Composter

- What are the effects on the community of macro- and micro-organisms in your composter when a bolus of coffee grounds is added?
- Insert *your guess* here _____.
- Composted products of caffeine = ???

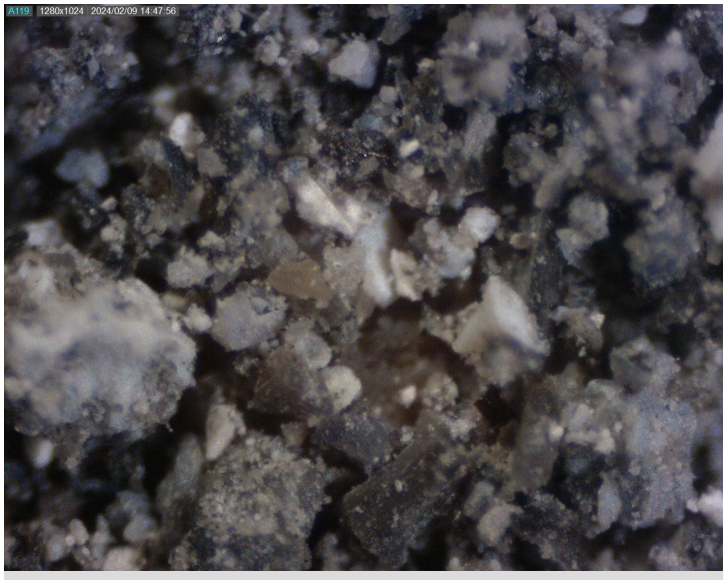
The Final Fate of Allelopathic Residues

- The effect of composting on allelopathic chemicals like caffeine and juglone is unclear.
- However, it's quite likely that dilution, elevated temperatures, and time all facilitate their degradation.
- After 6 months to a year, levels of undesirable organic species should be substantially reduced.
- Commercial compost operations utilize bioassay use-tests.

Bones

- Tricalcium phosphate [$Ca_3(PO_4)_2$] along with protein binder.
- Composting leads to slow decomposition, grinding helps.
- Calcination removes protein and produces a friable residue.
- Bone ash (*vs.* bone meal) doesn't attract curious animals.
- Acrid aroma of burning bones may frighten neighbors.

DIY bone crucible in use



Bone ash, top light, 40x

Eggshells

- Calcium carbonate in a protein matrix.
- Also degrade slowly, pulverizing helps.
- Calcium is a component of worm slime.
- *Avoid too many shells*…they act as a pH-raising agent like lime or ashes.
- Can be burnt in woodstove and incorporated into ash stream.

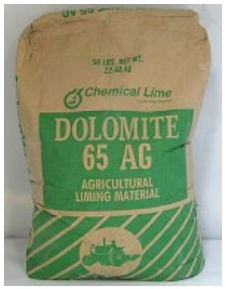
Compost pH and Alkalis

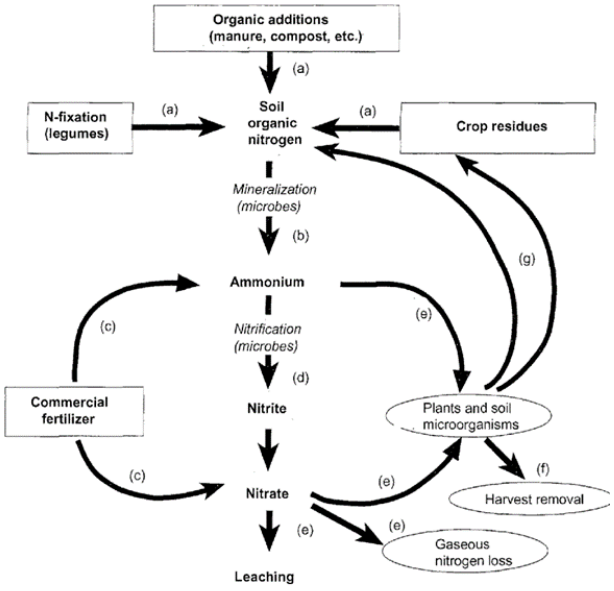
- Throughout the composting process, the pH of decomposing organic matter is slightly acidic and exhibits pH swings within this range.
- ***Finished*** compost usually produces a pH between 6 and 7, *regardless of the source materials**.

* *Your mileage may vary, some exclusions apply.*

Addition of Alkalis Leads to N-Loss

- Limestone is calcitic calcium carbonate ($CaCO_3$) and its pH is ~8.3 (dolomitic contains $MgCO_3$ as well).
- Seashells and eggshells are also comprised of $CaCO_3$ (in a proteinaceous matrix).
- Organic nitrogen proceeds through the NH_4^+ species on its way to the final NO_3^- form.
- "Adding lime ($CaCO_3$) is generally *not recommended* because it causes NH_4^+ nitrogen to be lost to the atmosphere as NH_3 gas. Not only does this cause odors, it also depletes nitrogen that is better kept in the compost for future use by plants"*.

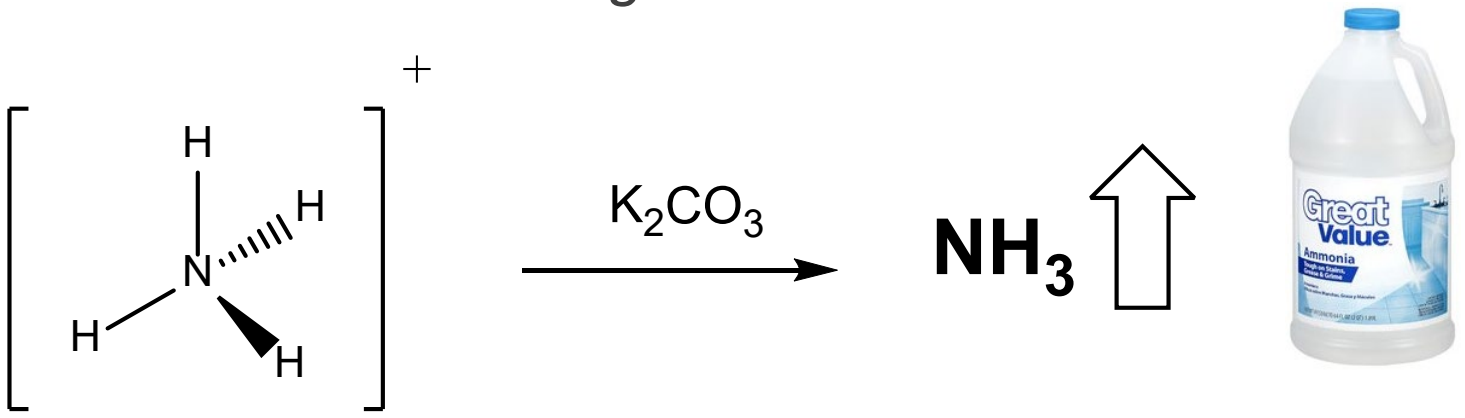




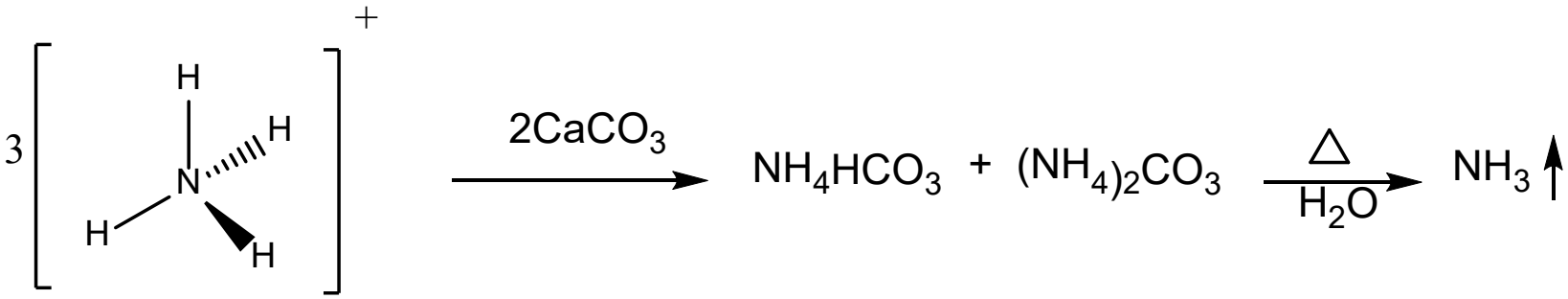
*http://compost.css.cornell.edu/monitor/monitorph.html

Wood Ashes are Even Worse…

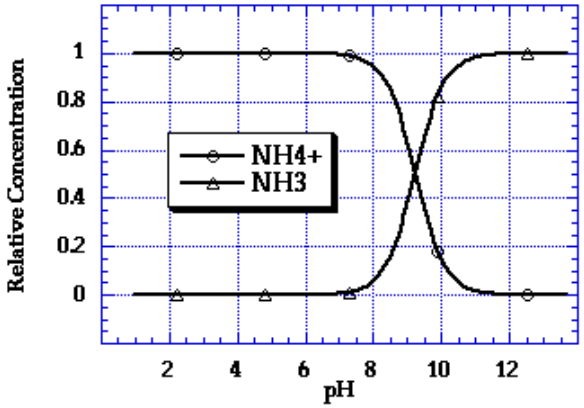
- Ground limestone is semi-soluble and exhibits a low ratio of surface area to volume (bigger chunks).
- Wood ashes are *more* alkaline (aq. K_2CO_3 is pH 11.6!), *more* soluble, and *much finer* than $CaCO_3$.
- The resulting loss of N as NH_3 upon addition of wood ashes to compost can be very rapid*…imagine a broken bottle of cleaning ammonia*.



The Chemical Explanation



- Ammonium bicarbonate (NH_4HCO_3) is the more-stable of the two salts, but still decomposes at 60°C (140°F).



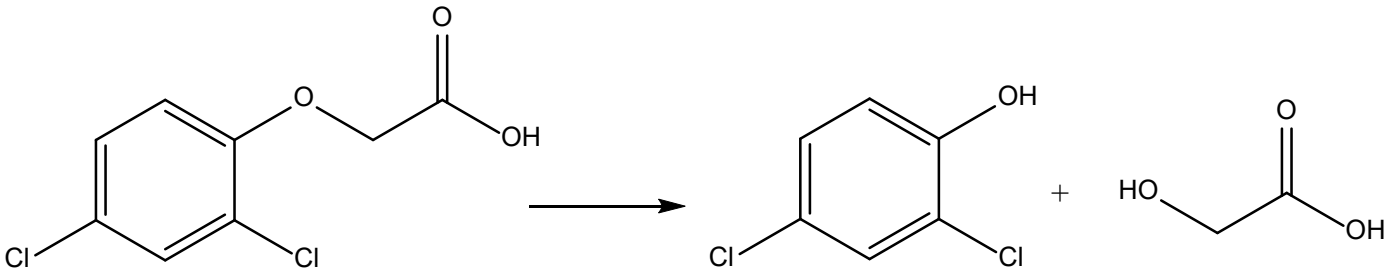
*http://compost.css.cornell.edu/odors/ammonia.html

Grass Clippings

- Grass clippings of unknown provenance might be OK but could contain variable levels of pesticide and herbicide residues.
- Initial effect may be observed as decreased vitality within your composter's macro- and micro-organism community.
- Clippings present physical and sensory challenges.
- Dry clippings for use as a physical fly deterrent.

Chemical Degradation of 2,4-D

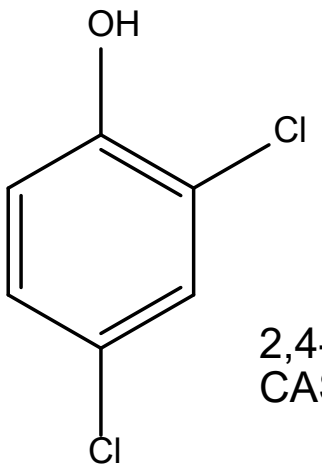
- Introduced in 1945, 2,4-dichlorophenoxyacetic acid (2,4-D) is a synthetic auxin used to control broadleaf weeds in lawns.
- Variable half-life ($T_{1/2}$) in soil in the range of ~10 days. A 2003 WHO report suggests that $T_{1/2}$ may be as long as six weeks in *acid* soils.
- Acute (rat, oral) toxicity is low: LD_{50} = 639 mg/kg.
- Initial decomposition step produces glycolic acid (related to acetic acid) and 2,4-dichlorophenol by the route below:



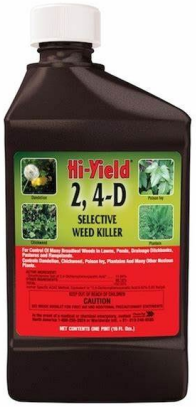
2,4-dichlorophenoxyacetic acid (2,4-D) | 2,4-dichlorophenol | glycolic acid

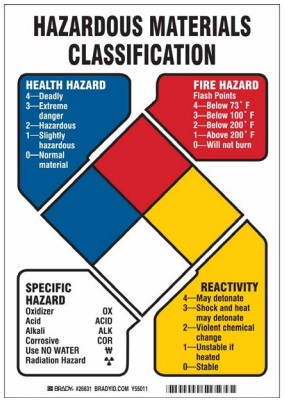
An Excerpt From the 2,4-Dichlorophenol MSDS

- LD_{50} (rat, oral) 47 mg/kg of body weight (14x that of the parent)
- Chronic exposure - Carcinogen (mouse)
- Chronic exposure - Teratogen (rat, mouse)
- Chronic exposure - Mutagen (rat, hamster, mouse)



2,4-dichlorophenol
CAS# 120-83-2





Acute Toxicity Data in Perspective

- Imagine a group of 10 rats that each weigh what I weigh (183 lbs, *very scary*).
- Each rat receives a single 3.9 g dose (47 mg/kg body weight) of 2,4-dichlorophenol in his Purina rat chow.
- All 10 then take a nap *and 5 never wake up*.
- For reference, a US nickel weighs exactly 5 g.

Composting Herbivore Manure

- Interesting weed seeds!
- Catastrophic effects of residual worming agent on my red wigglers?
- Copper sulfate ($CuSO_4$) from hoof baths
- Pathogenic bacteria
- Antibiotic residues

Composting with Manure

- Composting manure is considered risky if HIGH temperatures (160-170^{o}F) aren't reached.
- Compost created without manure is **safer** and still quite beneficial.
- Do not apply raw or aged manure to edible crops.

If Manure is Added to Your Composter

- Keep compost pile apart from edible crops.
- Apply finished compost in fall before ground freezes.
- Wash hands with soap and water after handling!

If Using Composted Manure and Unsure if High Temperatures were Achieved

- Incorporate into soil as soon as the soil can be worked.
- Avoid harvesting crops whose edible portion touches the ground (leafy greens) for 120 days after application or 90 days if edible portion is above ground (corn).

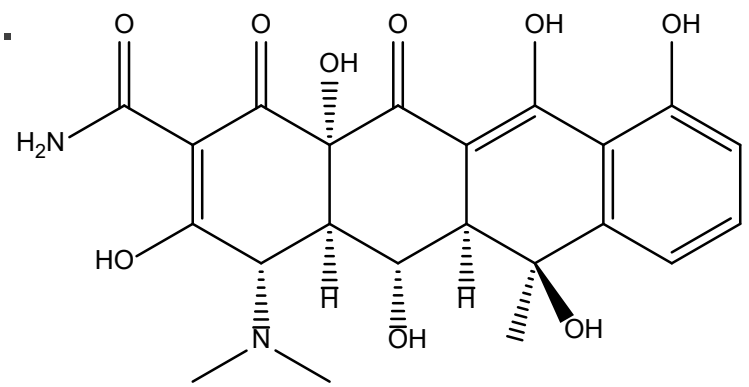
What About Antibiotic Residues When I Add Manure to the Composter?

- A report by British researchers* quantified antibiotic resistant genes in soil samples dating back to 1940.
- For every drug class investigated, antibiotic resistance has been steadily increasing.
- Genes that confer resistance to tetracycline antibiotics have spiked in recent decades, becoming 15x more abundant than in the 1970s.
- *What residues would be expected after the composting process?*

Environ. Sci. Technol., DOI:10.1021/es901221x as reported in *Chemical & Engineering News*, 4 Jan 2010.

A Recent Report From the USDA Could Be Cause For Concern

- The USDA has reported research* on the degradation of oxytetracycline (Terramycin®) in manure.
- Oxygen, appropriate moisture levels, and elevated temperatures all hasten the molecule's demise.
- Degradation was found to be faster in concentrated manure versus soil, likely because of the higher microbial load.
- And the conditions in *your* pile are?



Terramycin (oxytetracycline)

* *Agricultural Research*, Feb 2010, p.22.

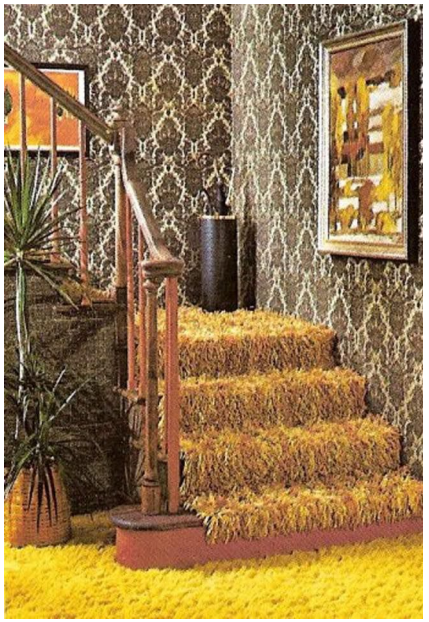
Antibiotic Resistance in River Sediments

- Research from Virginia Polytechnic Institute focused on antibiotic resistant genes in river sediments.
- Their conclusion was that “when humans or animals ingest antibiotics, they excrete both the drugs and bacteria resistant to those drugs.
- The antibiotics and resistant bacteria then enter rivers through wastewater-treatment plant effluents or runoff from livestock operations.
- In river sediments, bacteria can share antibiotic resistance genes with each other, spreading resistance”.
- *Might it be possible to imagine manure compost in place of river sediment?*

**Environ. Sci. Technol.,* DOI: 10.1021/es302657r (2012)

Dryer Lint and Vacuum Cleaner Bag Residues

- Google the terms **dryer lint** and **compost** then do the same for **vacuum cleaner bag dust**.
- The information you'll retrieve will be contradictory and (depending on the site) alarmingly unscientific.
- Depending on the composition of your carpeting and what you wear, both streams could be sources of ubiquitous and deleterious microplastic fibers.
- More on these later…*with photomicrographs!*

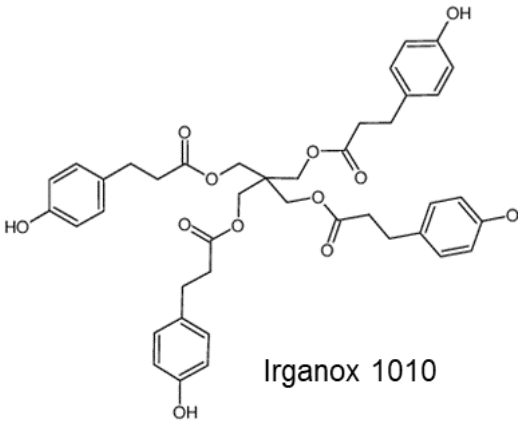


Tea Bags and Microplastics

- Because of differences in the brewing process, tea bags are constructed quite differently than coffee filters.
- Photomicroscopy tells a compelling tale (stay tuned!)
- Tea bags in compost can lead to microplastic contamination.
- Are microplastics harmful?
- It depends on both their size and the company they keep…

Physical *vs.* Chemical Degradation

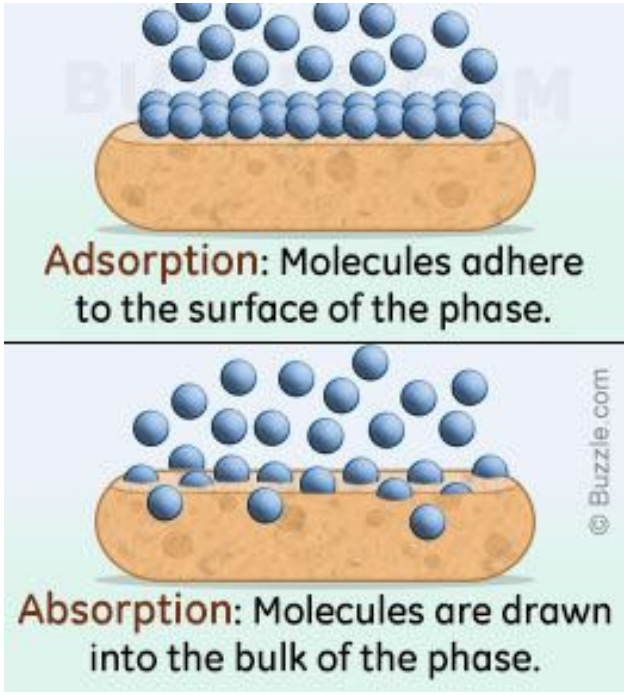
- By design, plastics are quite resistant to both *chemical* and *microbial* degradation.
- Antioxidants can further enhance their useful lifespan.
- Tendency is to mechanically (*vs.* chemically) degrade to afford smaller and smaller particles *of essentially the same chemical composition.*

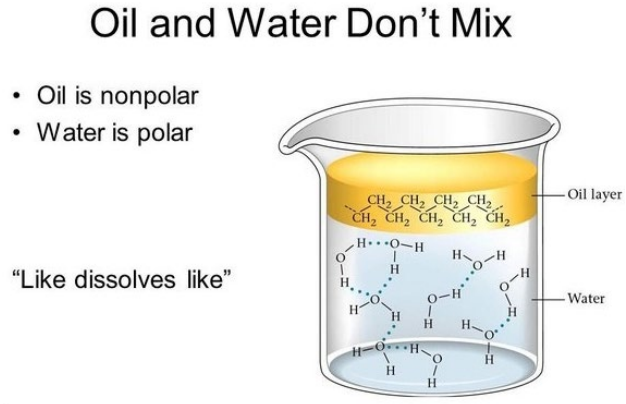


Irganox 1010

The Problem with Microplastics

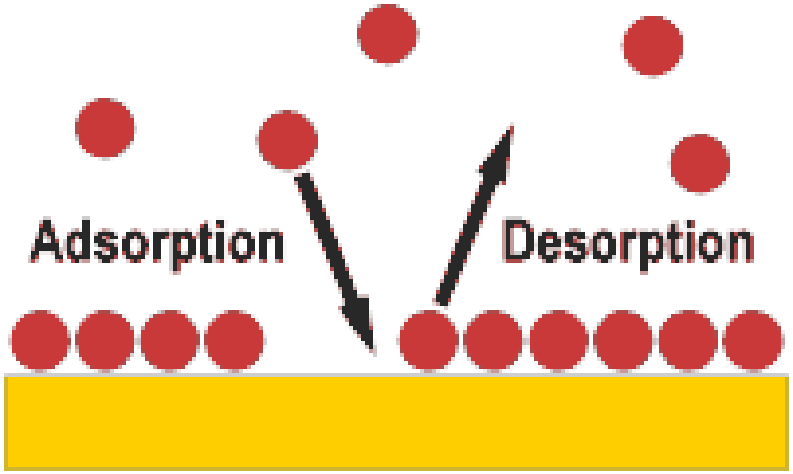
- Plastics, although largely chemically inert, exhibit substantial *adsorbtive* properties.
- Able to pick up (adsorb) specific classes of organic molecules they encounter.
- Especially greasy (lipophilic) *molecules…remember the old chemical aphorism that "like dissolves like".*



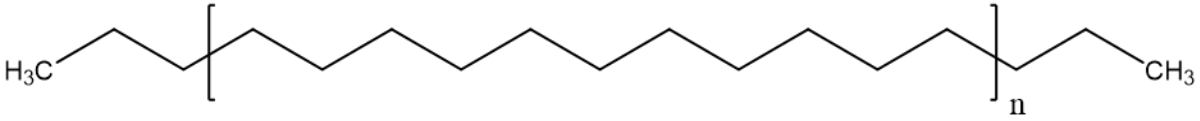


The Problem with Microplastics -II

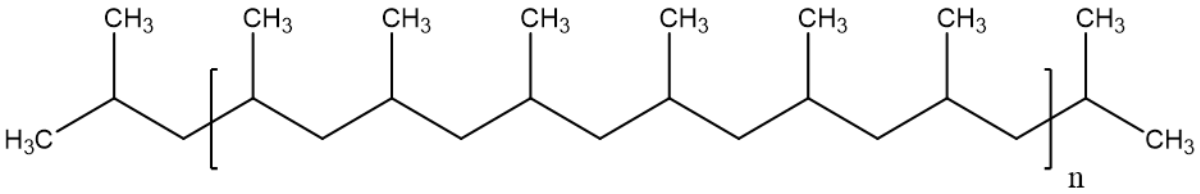
- In theory, microplastics can deposit (desorb) these toxic molecules elsewhere depending on the chemical conditions encountered.
- Small size is absolutely key to their adsorbtive properties…



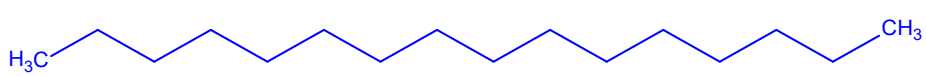
Microplastics and the Company They *Could* Keep



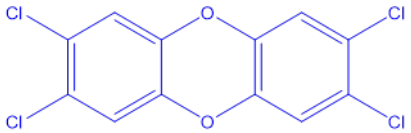
polyethylene



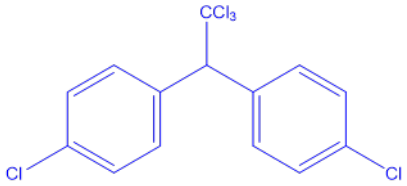
polypropylene



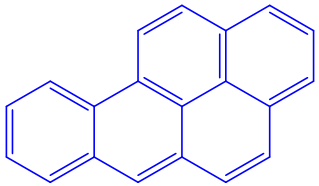
cetane from diesel fuel



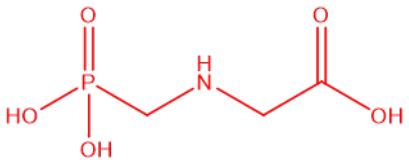
dioxin



DDT



Benzo[a]pyrene



But NOT glyphosate

Microplastic Contamination in Compost

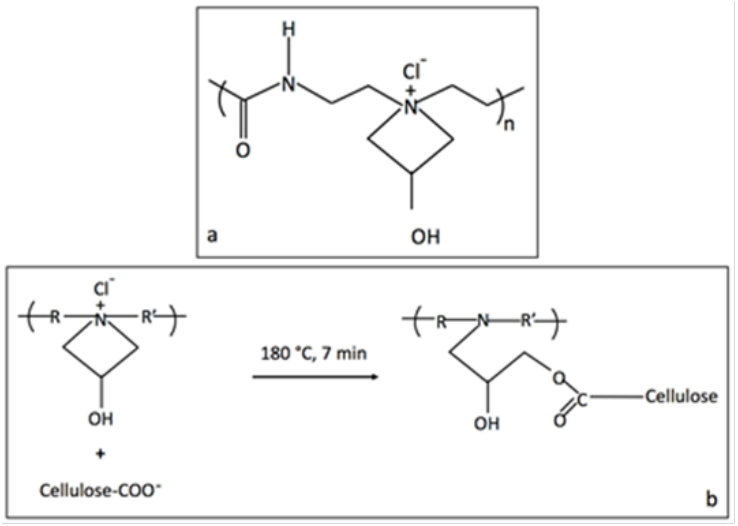
- **Commercial**: coated paper products, paper towels, plastic bags, stray plastic cutlery, food packaging
- **Backyard**: tea bags, missing kitchen scrubbies, paper towels, *residues* from plastic garbage bags, items labeled as compostable which exhibit incomplete breakdown

Coffee Filters *vs.* Tea Bags

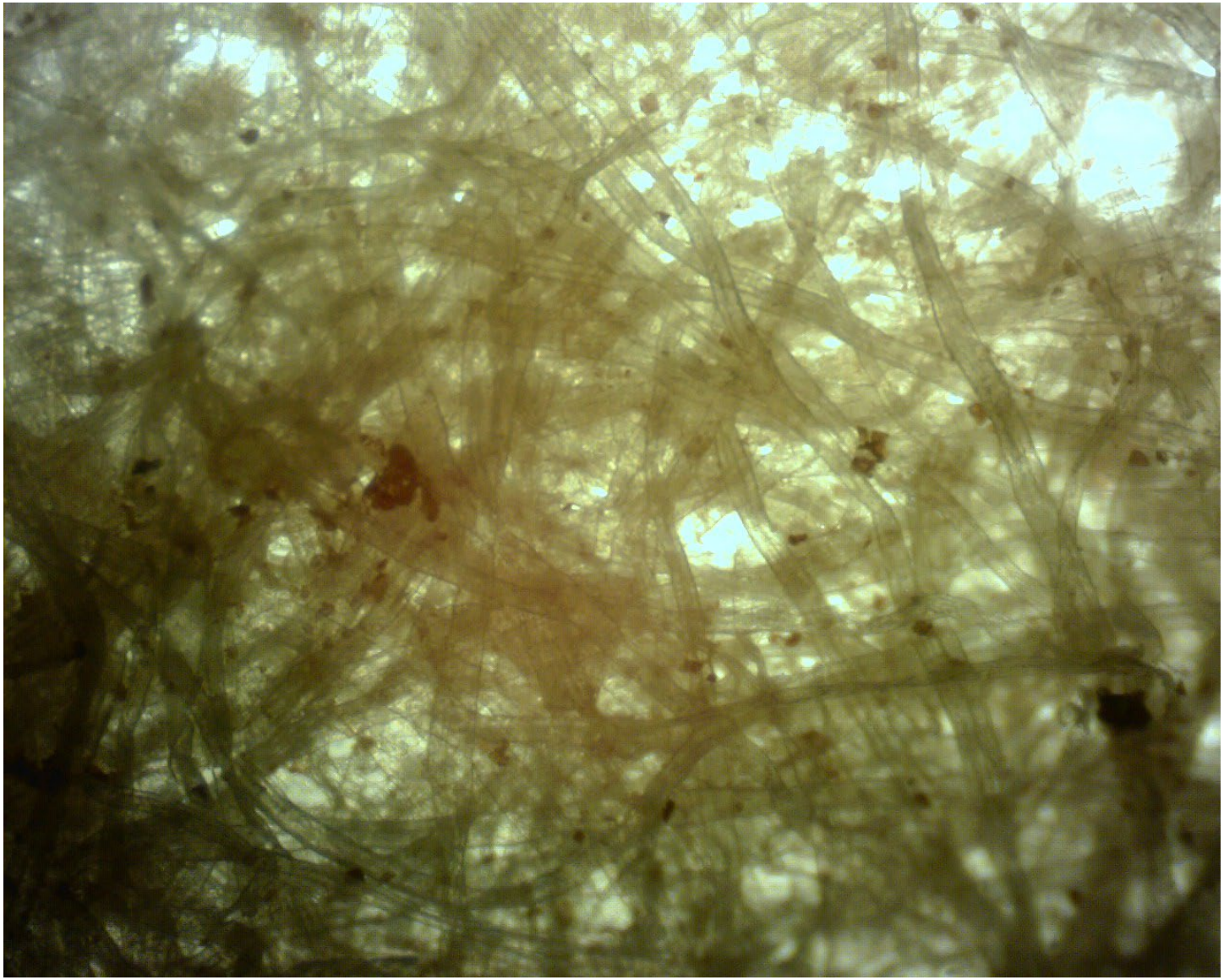
- Coffee filters quickly degrade whilst (most) tea bags don't.
- Tea bags persist because they're a mix of cellulose and plastics.
- Coffee filters are wet-strengthened using a chemical additive [*polyamideamine-epichlorohydrin (PAE resin)*].

Degradation of Coffee Filters

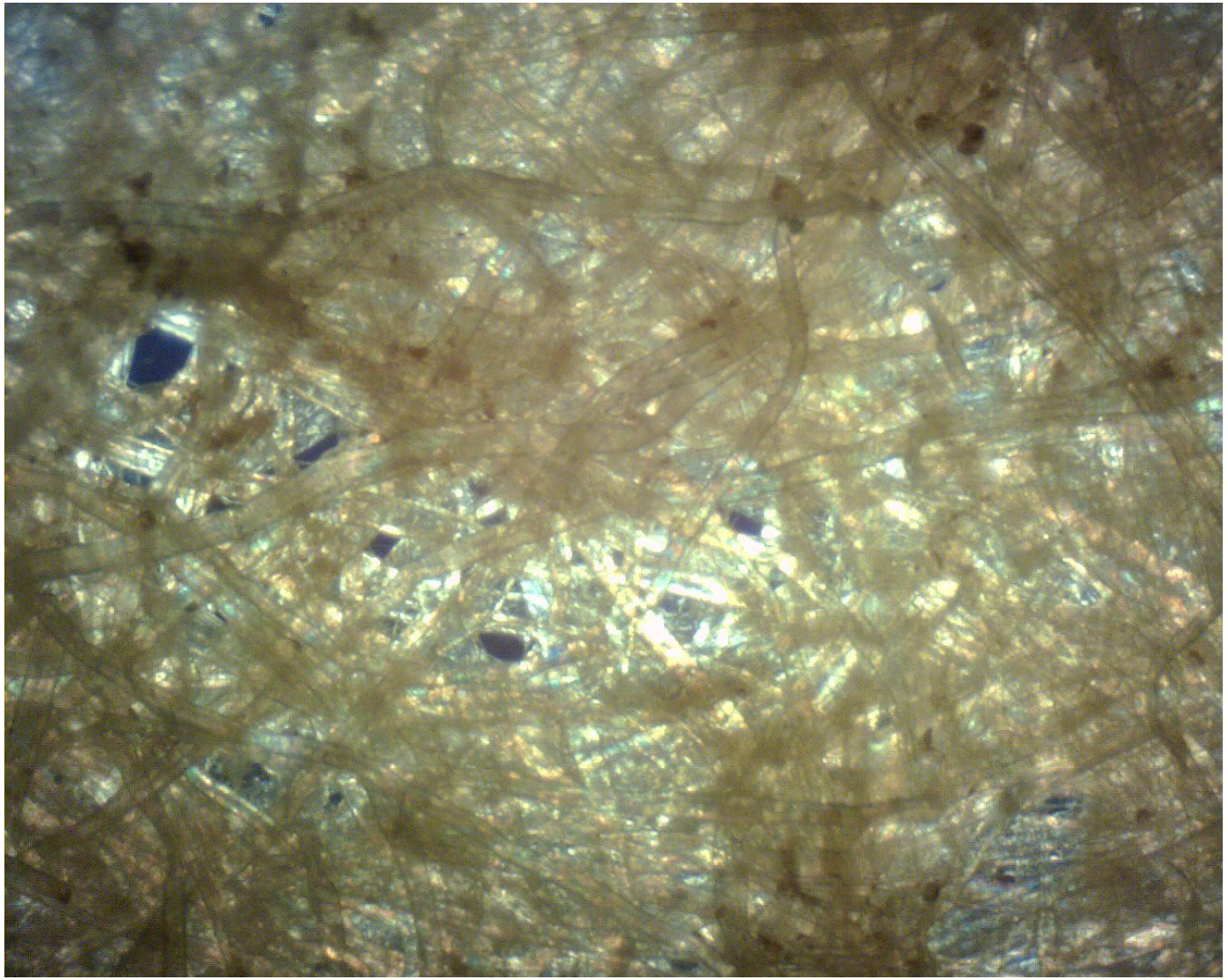
- The modified polymer readily degrades under home composting conditions to produce no obvious residue.
- Worms devour spent filters with glee…*or with as much excitement as hungry worms typically emote.*
- No toxic residues would be expected from the cross-links (*ACS Green Chemistry Award 2017*)



Fetco Coffee Filter, 40x



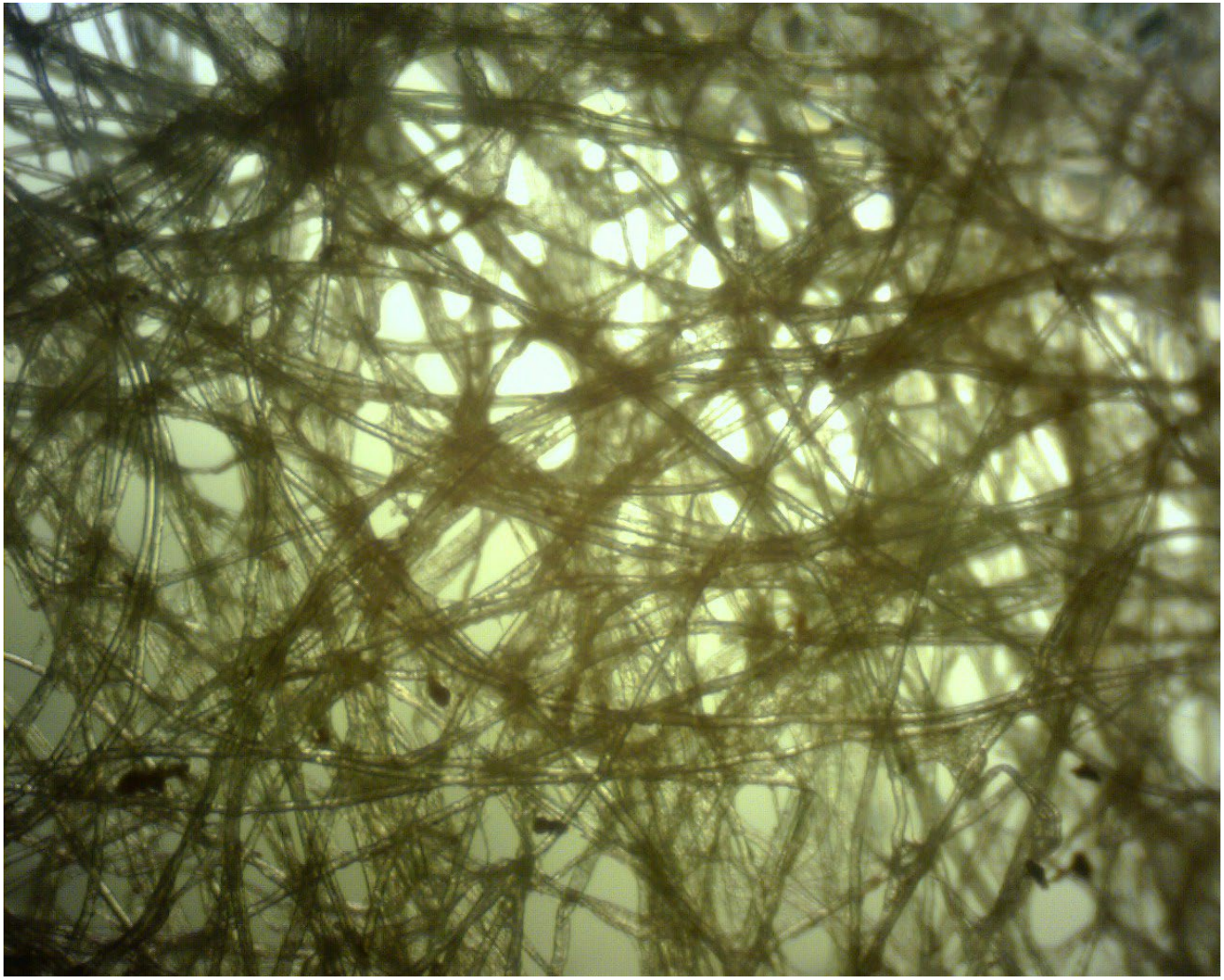
Fetco Coffee Filter, 40x, crossed polars



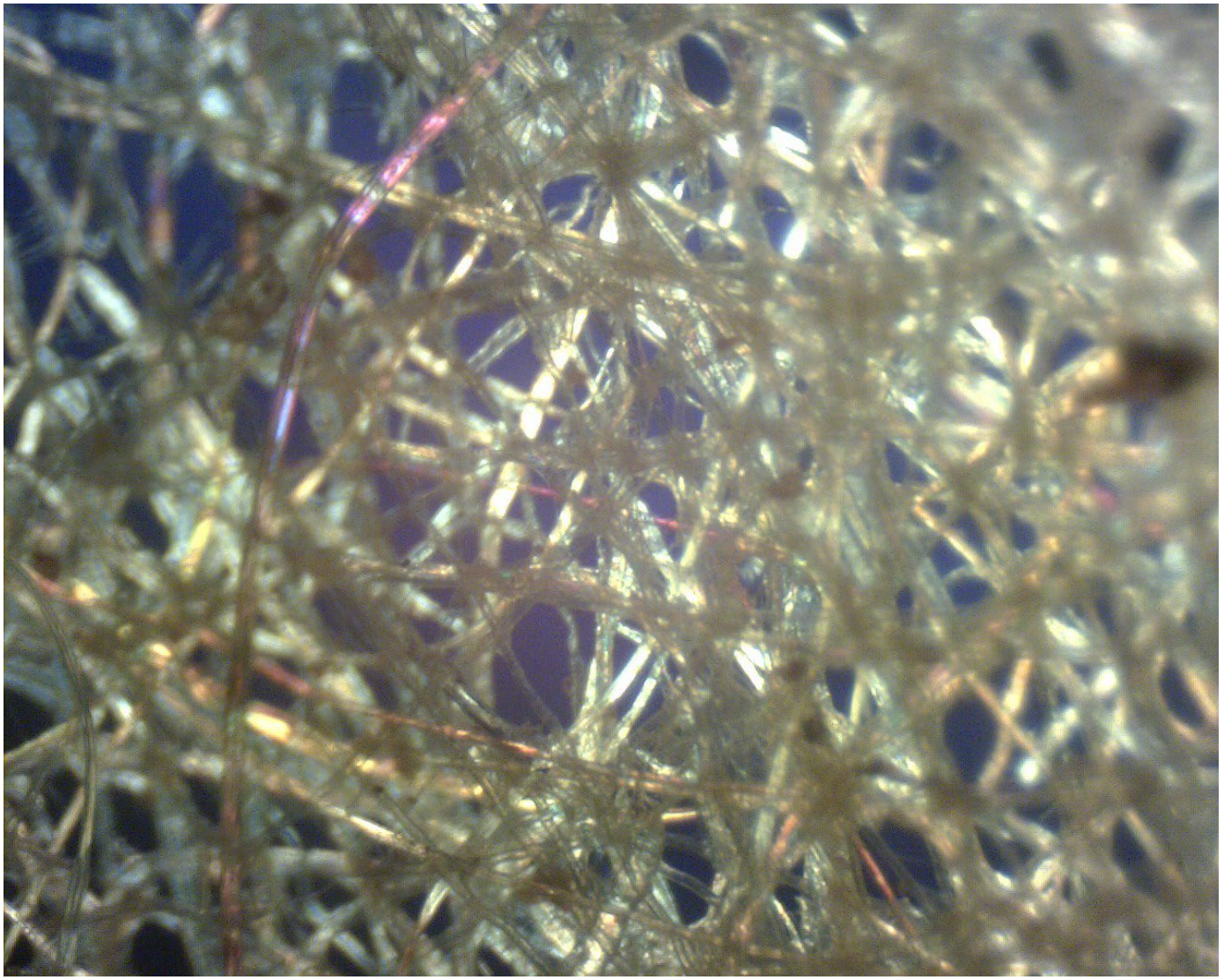
Tea Bags

- According to the manufacturers, tea bag materials range from pure synthetics (nylon) to completely compostable…*and many synthetic-cellulose blends in between*.
- Bags can be removed essentially intact after a typical one-year pile cycle.
- What micro-residues might they impart?

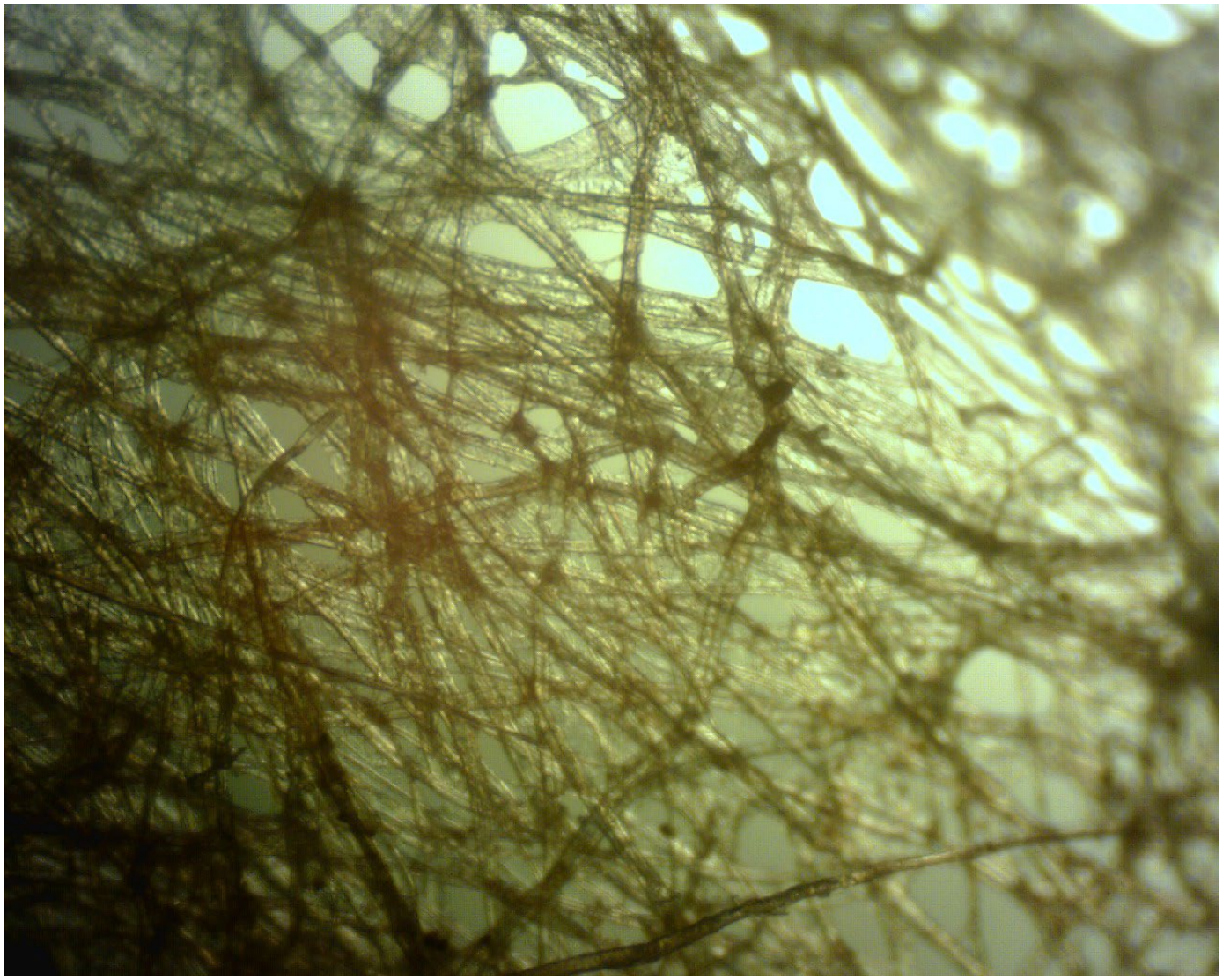
PG Tips, 40x



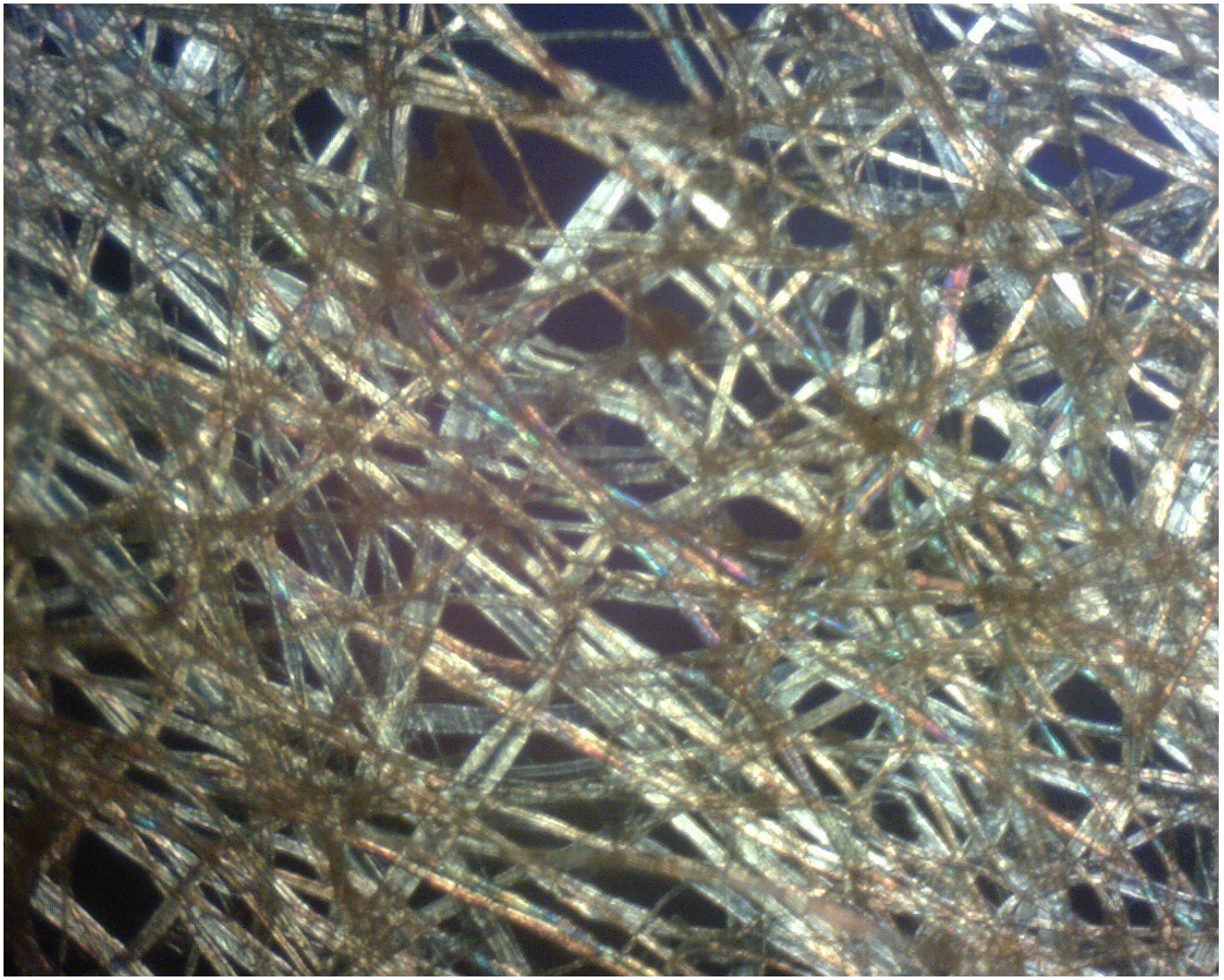
PG Tips, 40x, crossed polars



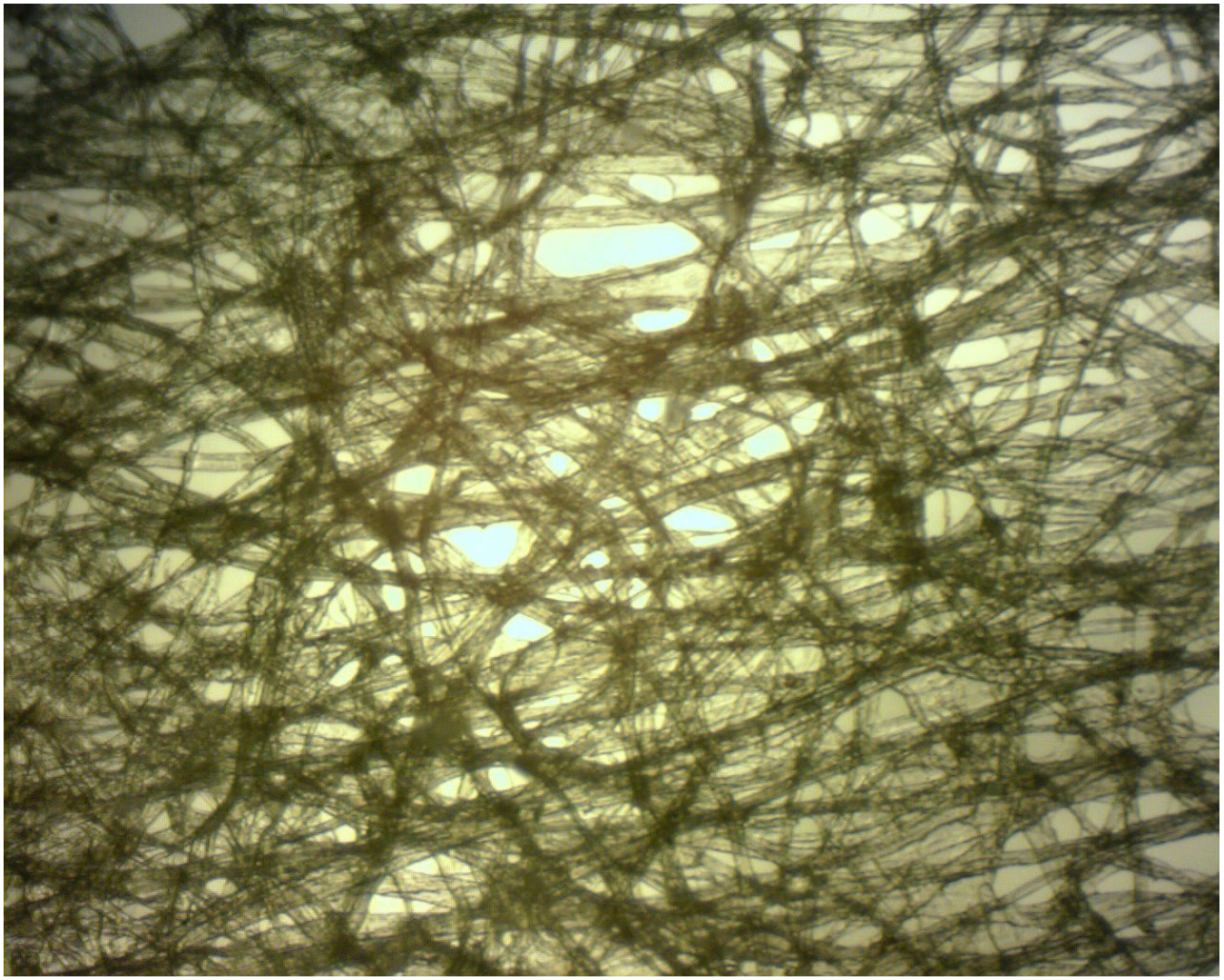
Tazo, 40x



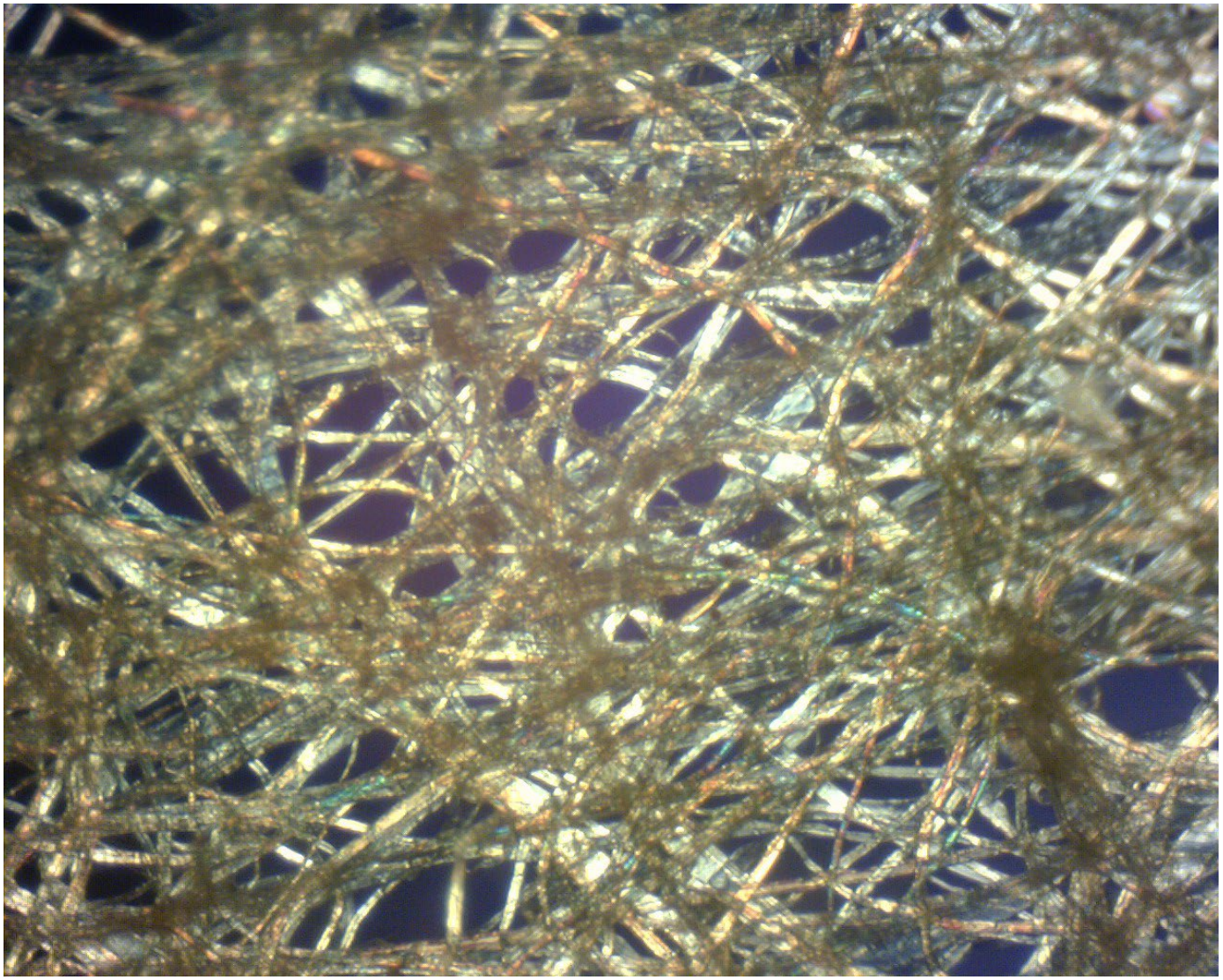
Tazo, 40x, crossed polars



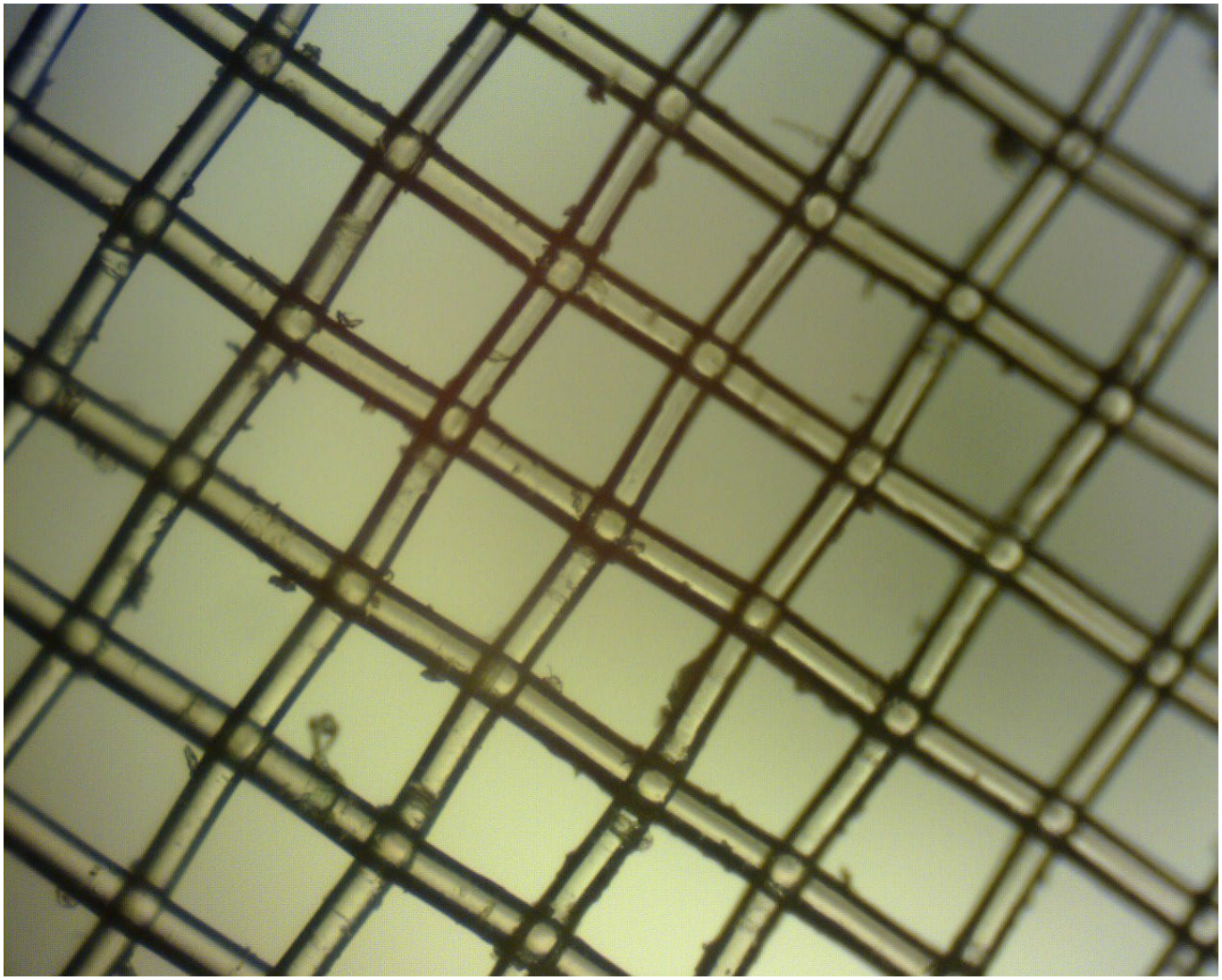
Twining, 40x



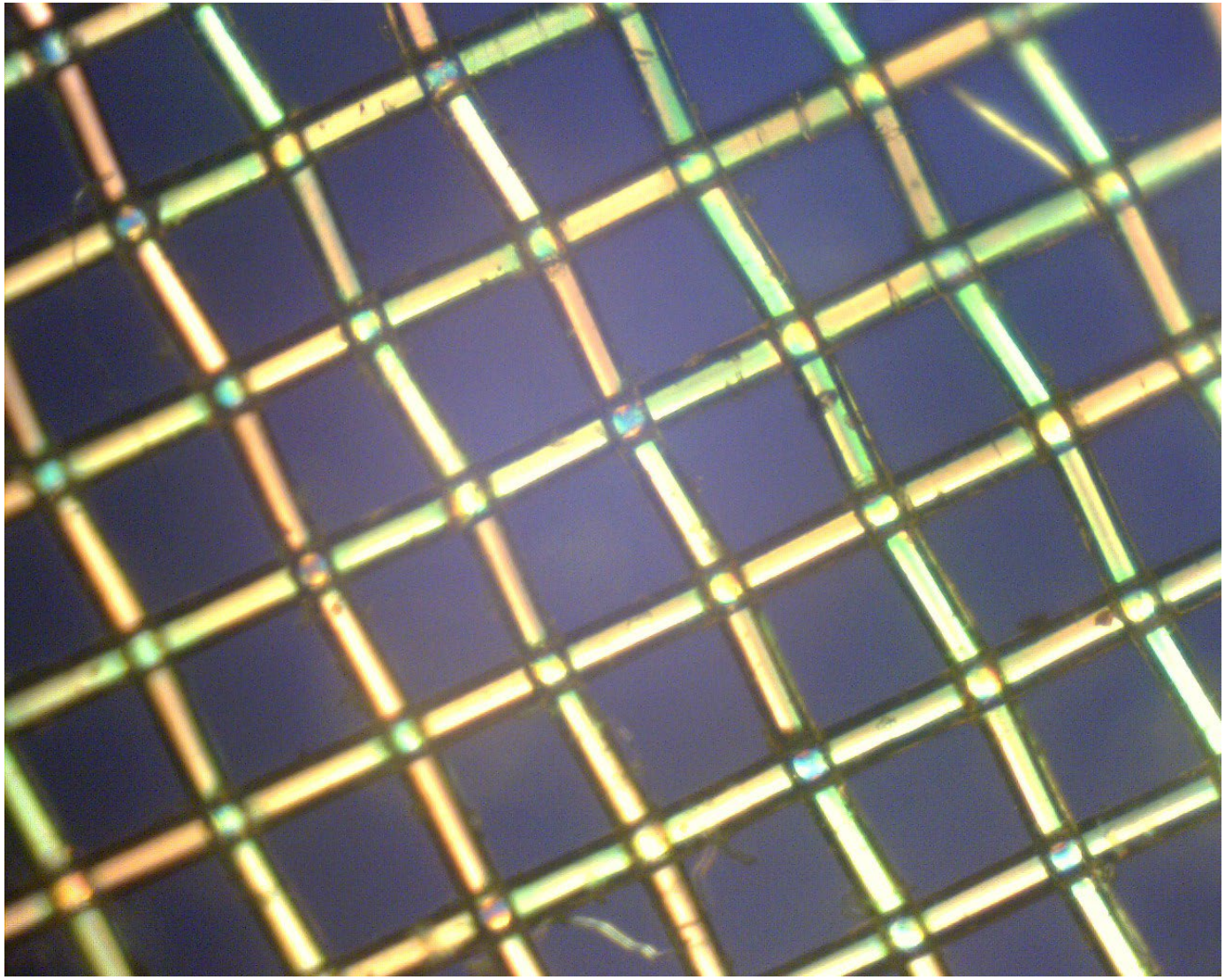
Twining, 40x, crossed polars



Harney, 40x



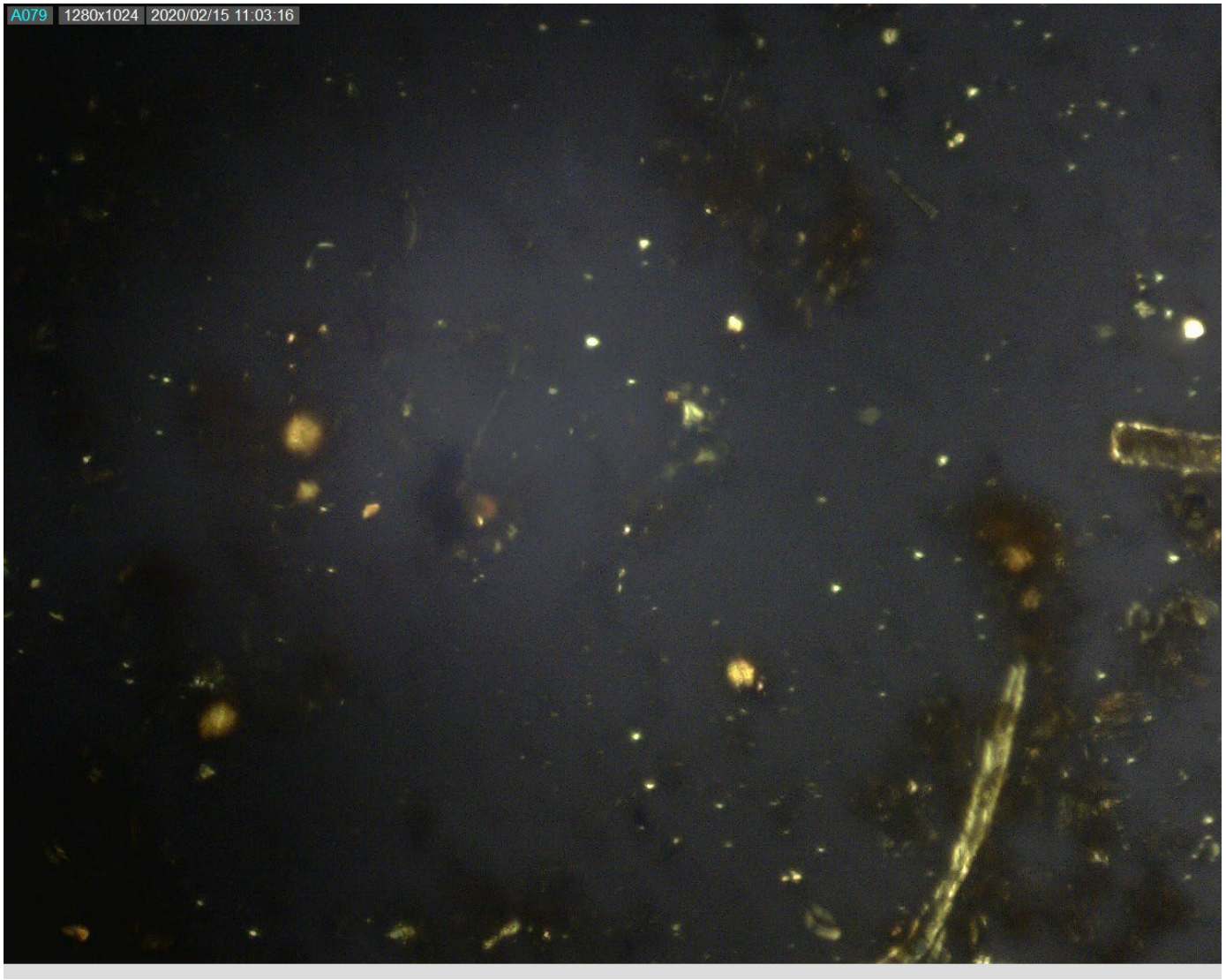
Harney, 40x, crossed polars



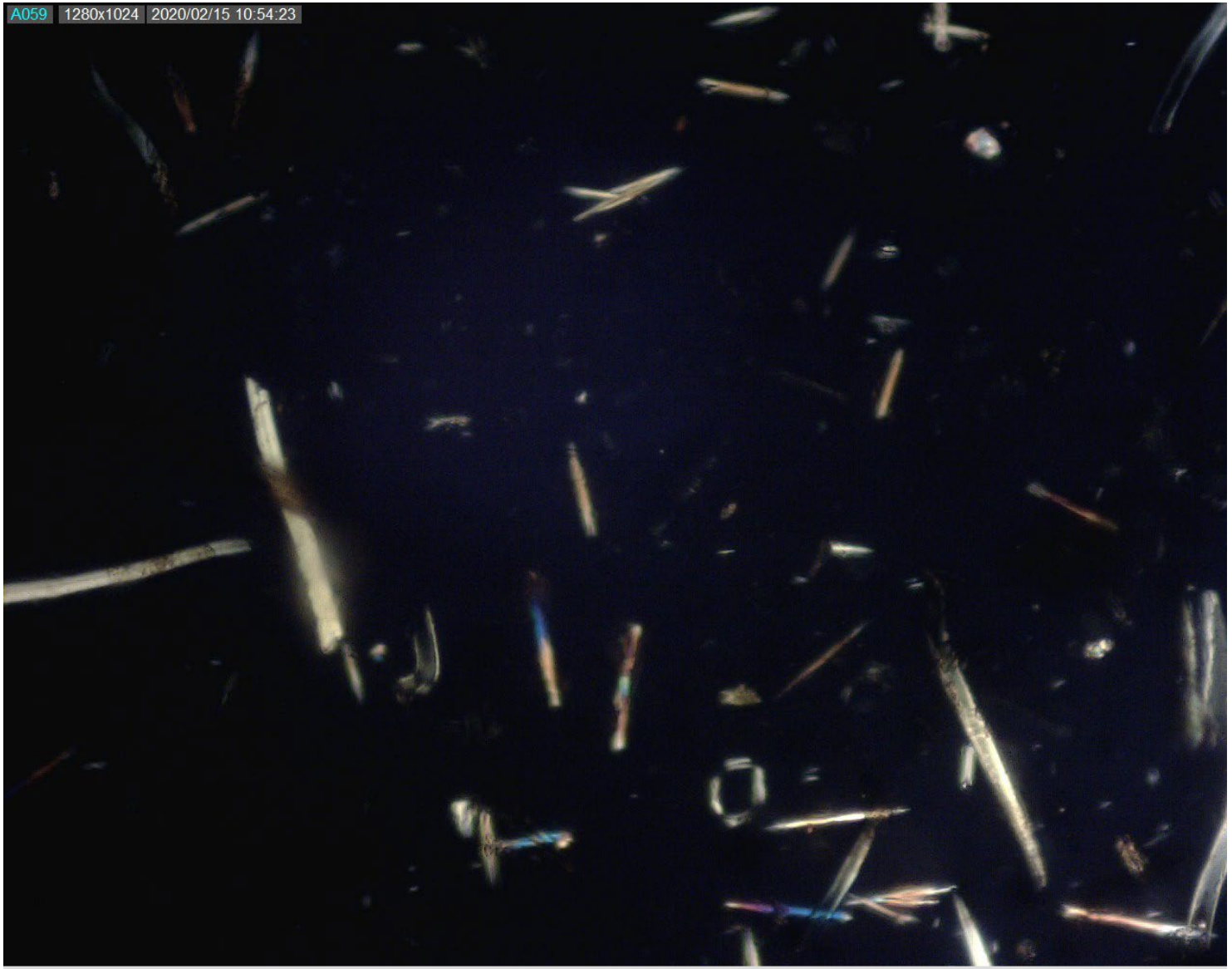
Microplastic Residues in Brewed Tea

- Research from McGill University suggests that tea brewed from tea bags may contain a multitude of fibrous microplastic particles.
- I attempted to replicate their findings by brewing loose tea *vs.* tea in a nylon bag.

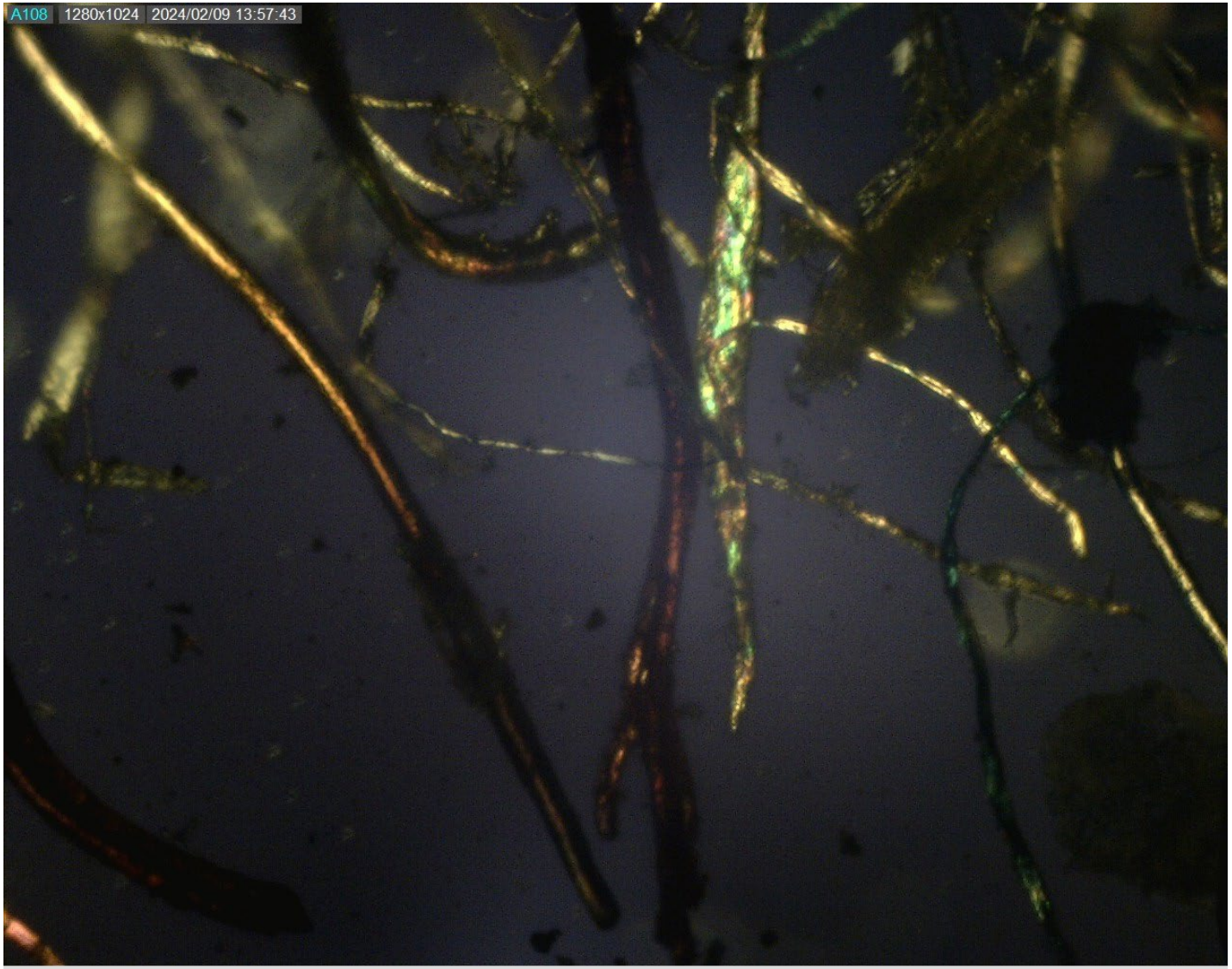
Concentrate, Loose Tea, 100x, crossed polars



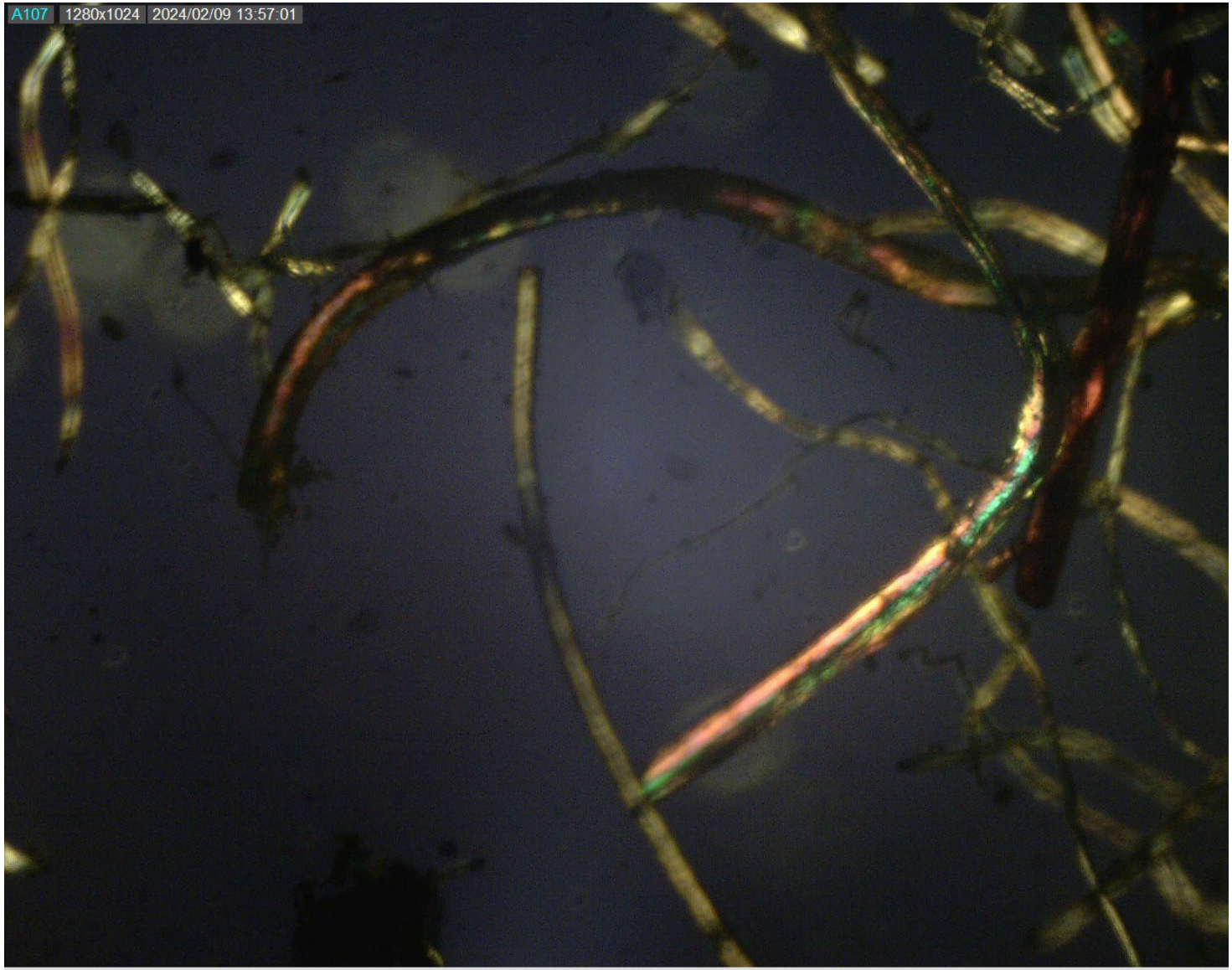
Concentrate, Nylon Tea Bag, 100 x, crossed polars



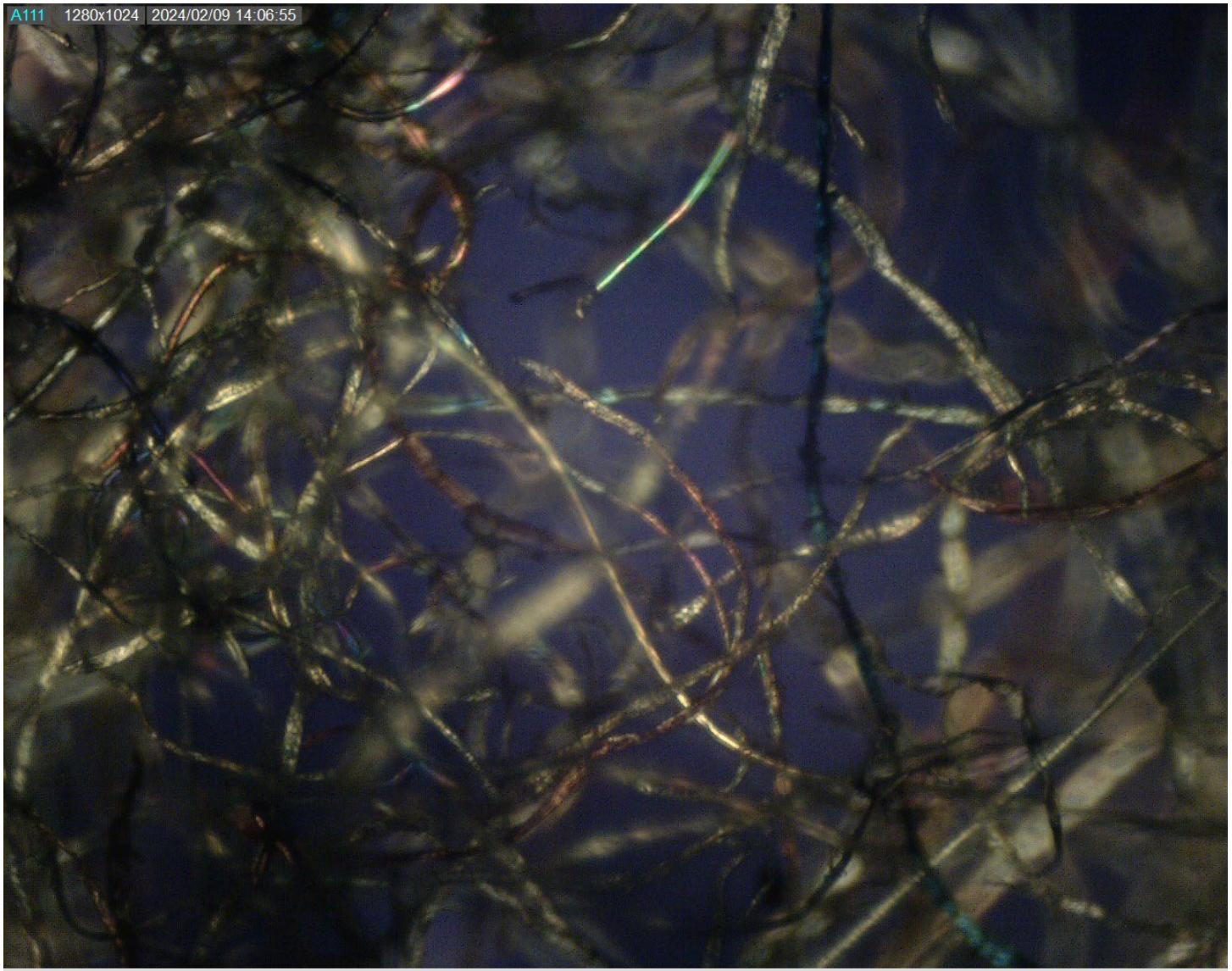
Vacuum Dust, 40x, crossed polars



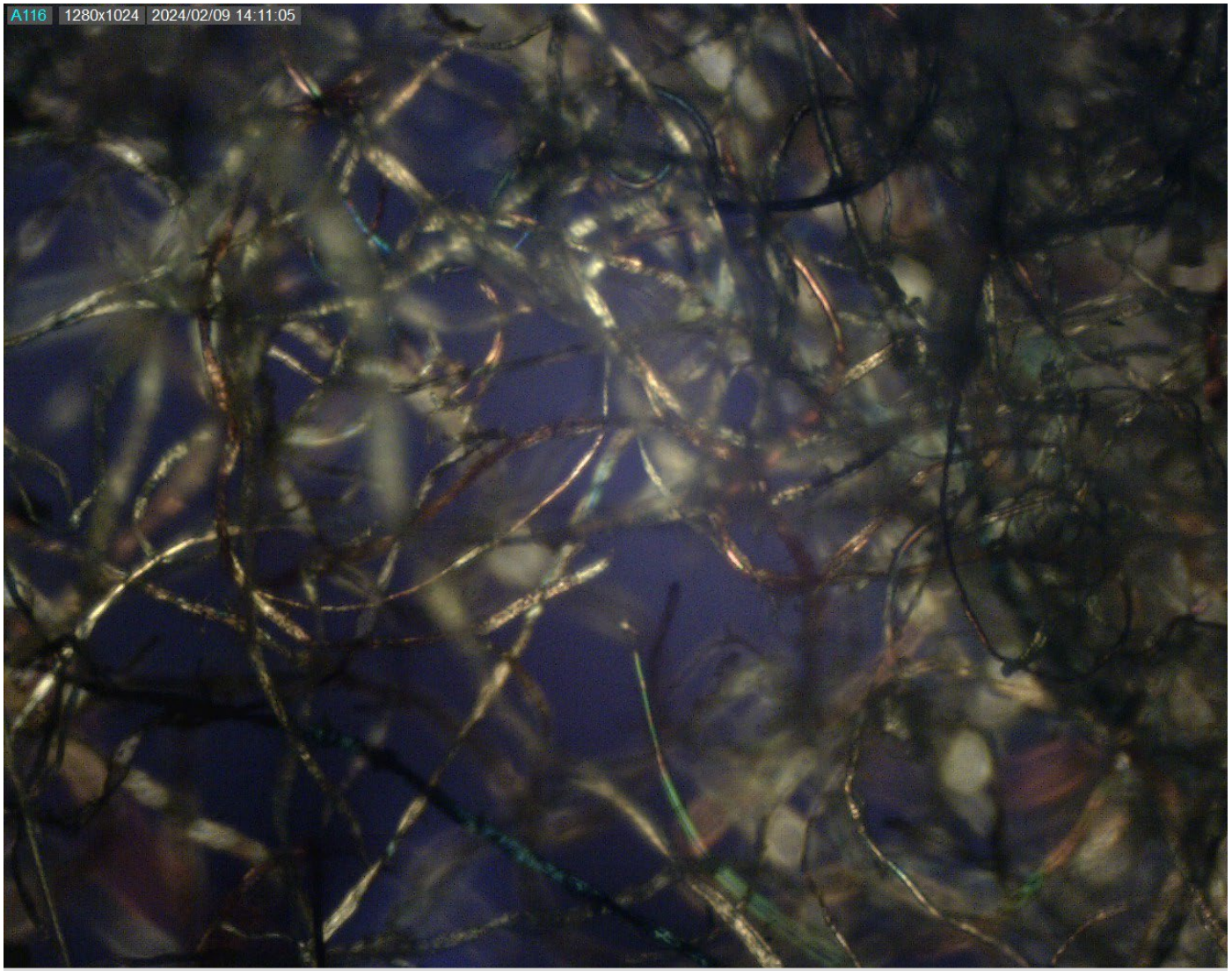
Vacuum Dust, 40x, crossed polars-II



Dryer Lint, 40x, crossed polars

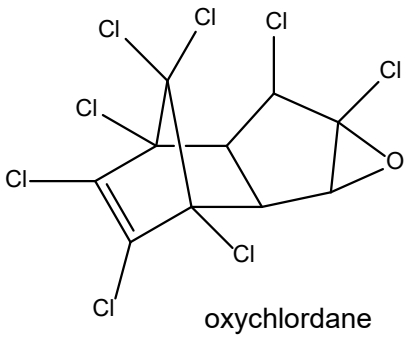


Dryer Lint, 40x, crossed polars-II



Closing Thoughts-I

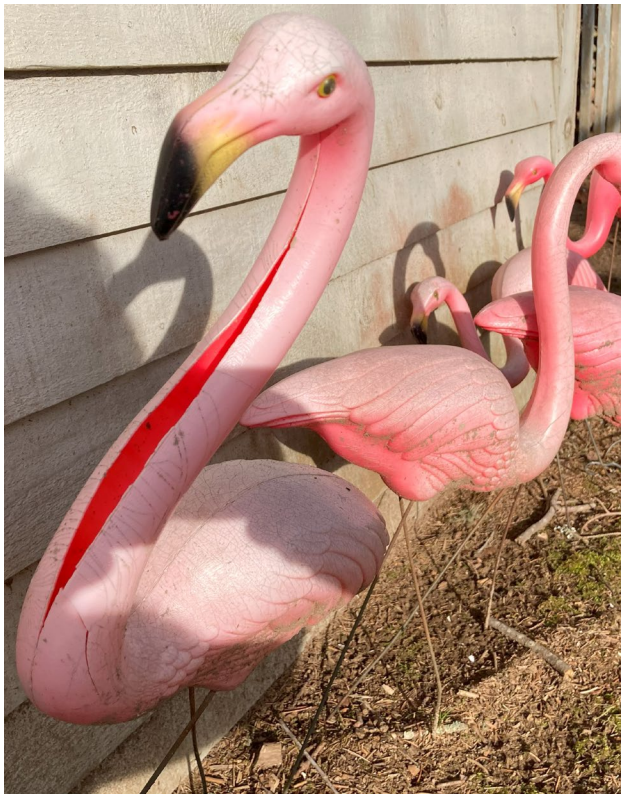
- Carefully consider all your incoming compost raws.
- Aim for a mix of clean streams to balance both nutrients *and* potential risks.
- *The solution to pollution…?*
- Laboratory testing is expensive and not a panacea.
- Composting is a powerful technique but can't degrade everything (*including toxic metals, persistent organics, some antibiotics, and especially microplastics*).



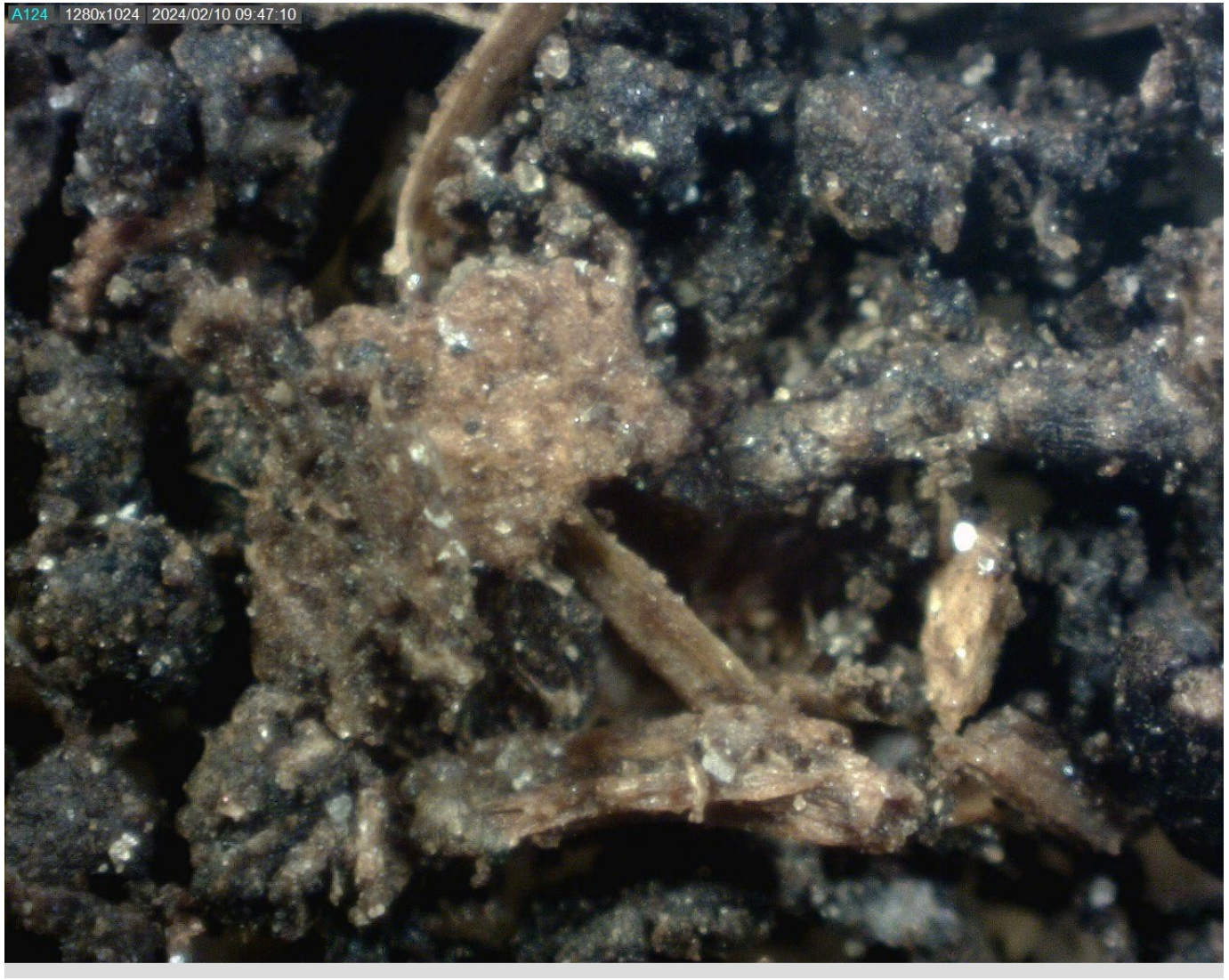
oxychlordane

Closing Thoughts-II

- Compost is a highly complex and challenging analytical matrix… *laboratory testing is still in its infancy*.
- Polarizing light microscopy is an inexpensive, versatile, and *semi-obscure* technique that may aid in the analysis of compost for microplastic residues.
- Although the practice of composting is very old, our scientific (especially chemical) understanding of it is very young *and still emerging*.



So…What's in *Your* Compost?



Leaf mould, top light, 20x