



Structural Colours

Blue fruits and bio-inspired photonics



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EPSRC Postdoctoral Research
Fellow, Bristol 2019-22

Caffè-Scienza Firenze
11/06/2021

- What is structural colour?
- How does it work?
- Structural colours in nature

QUESTIONS

- Structural colours in plants
- Seeing the invisible
- Useful colours
- Future pigments

chemical colour

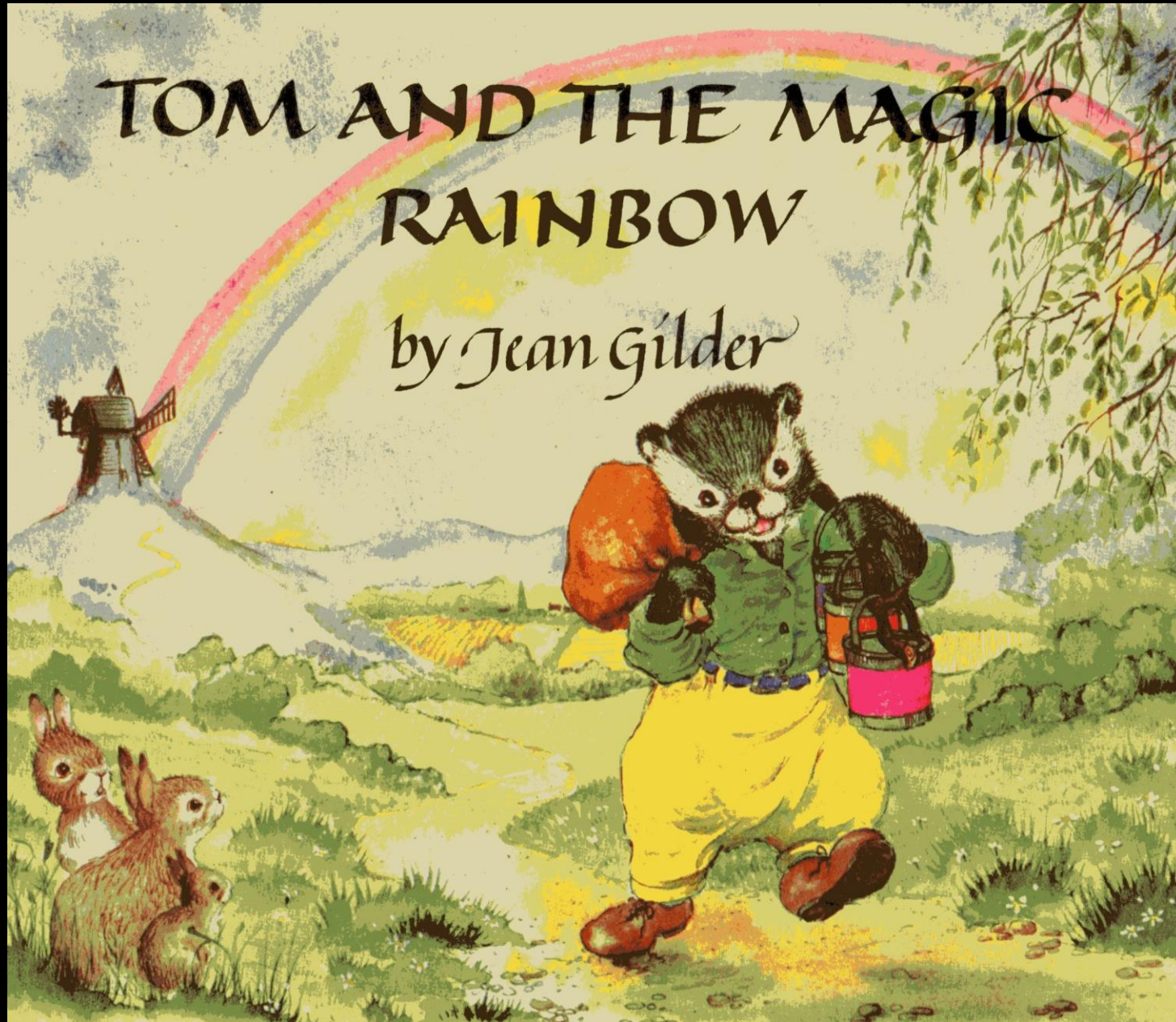


structural colour

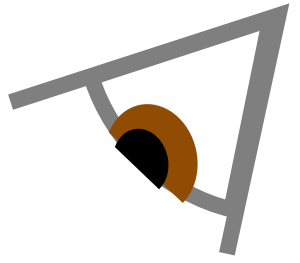


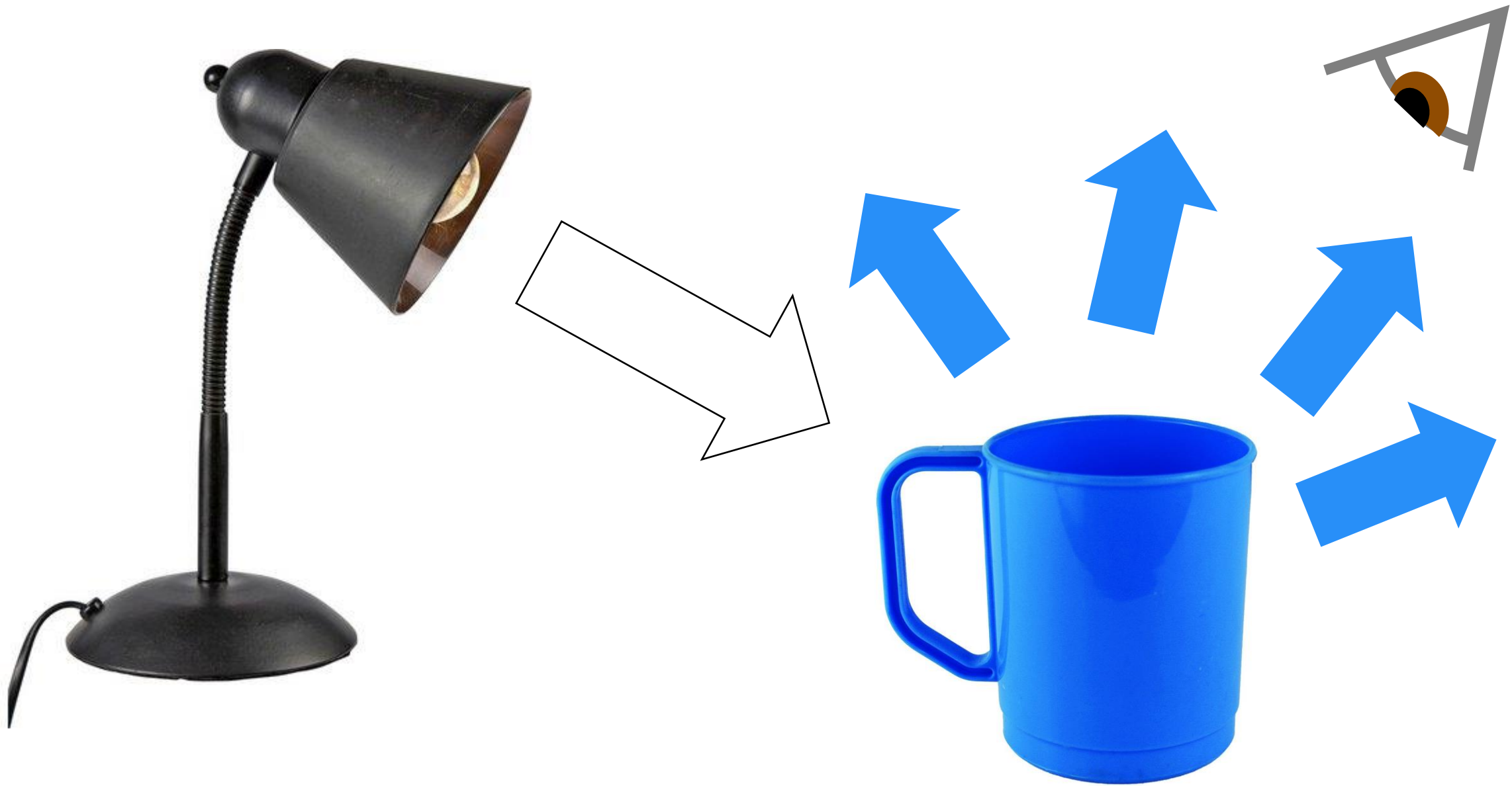
TOM AND THE MAGIC RAINBOW

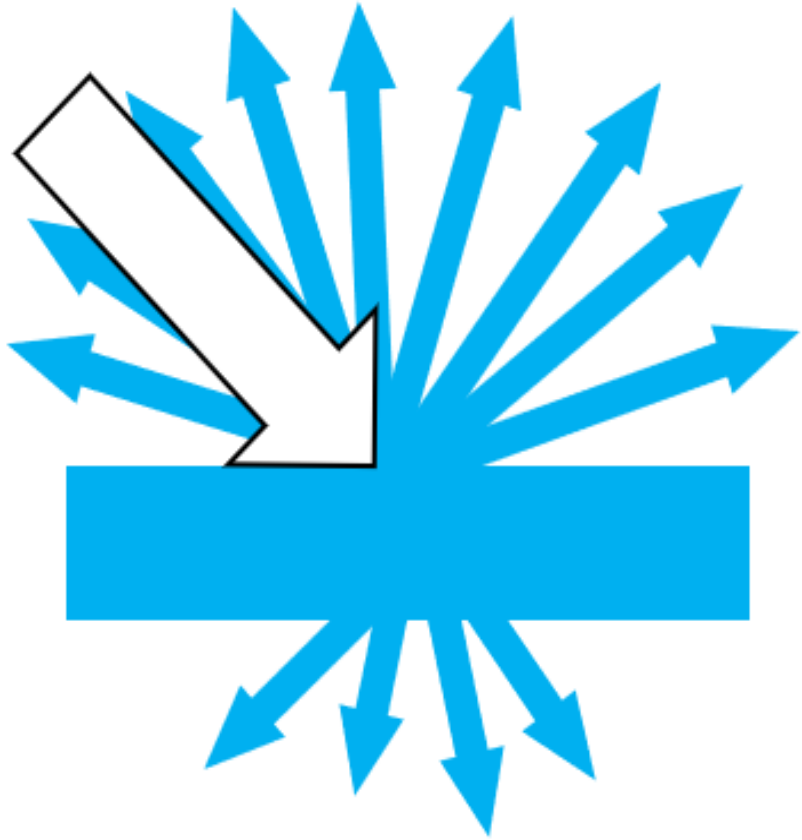
by Jean Gilder

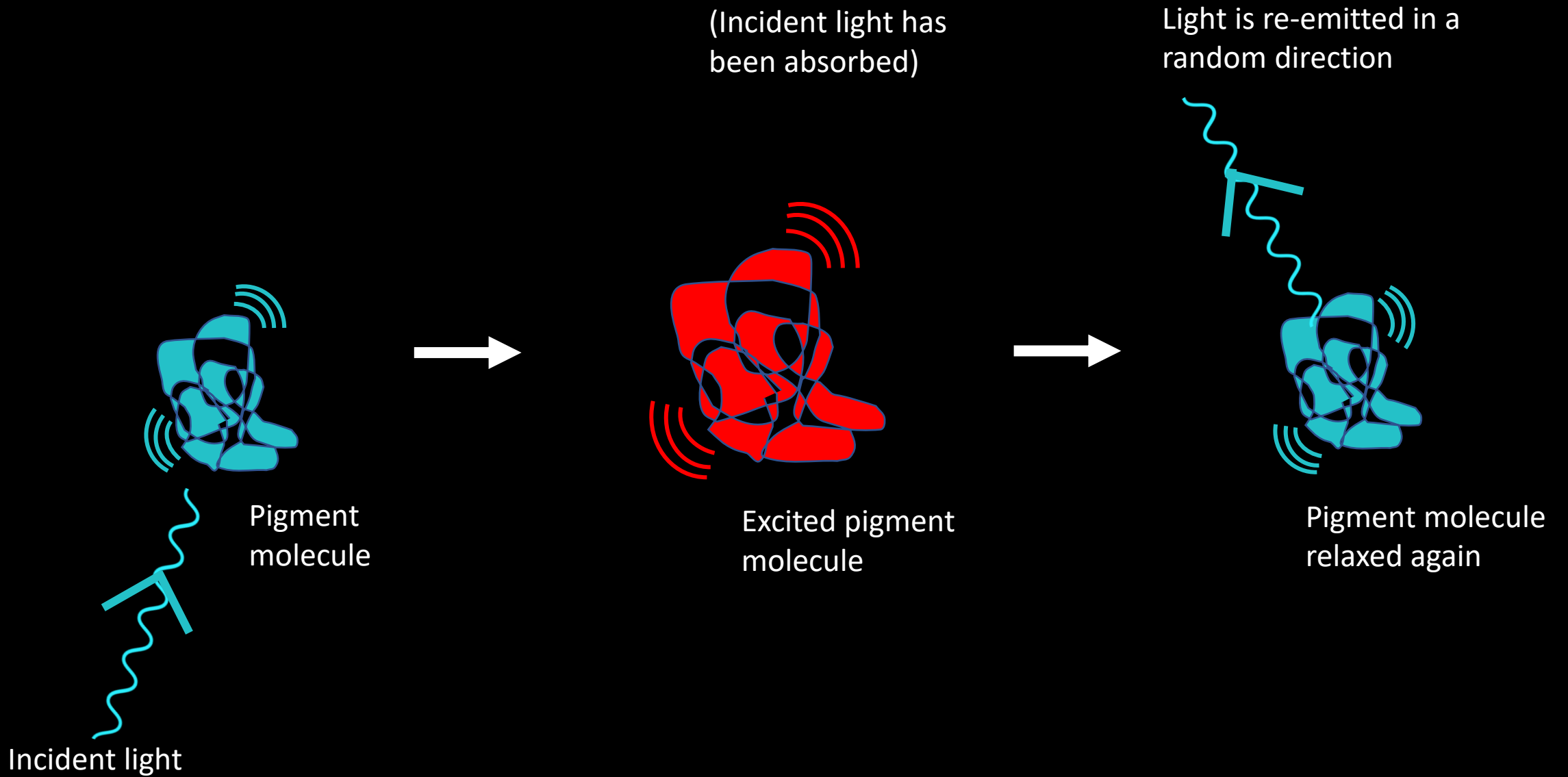


Normal
objects

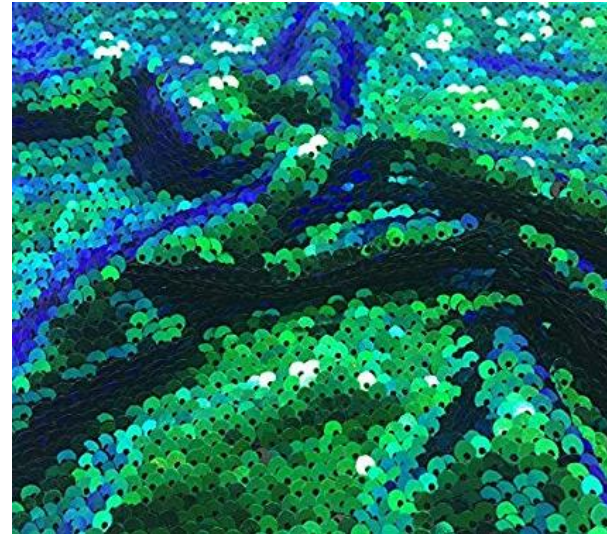
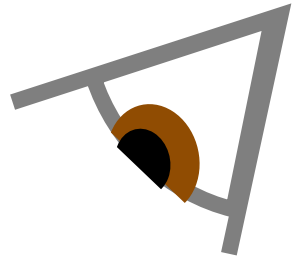


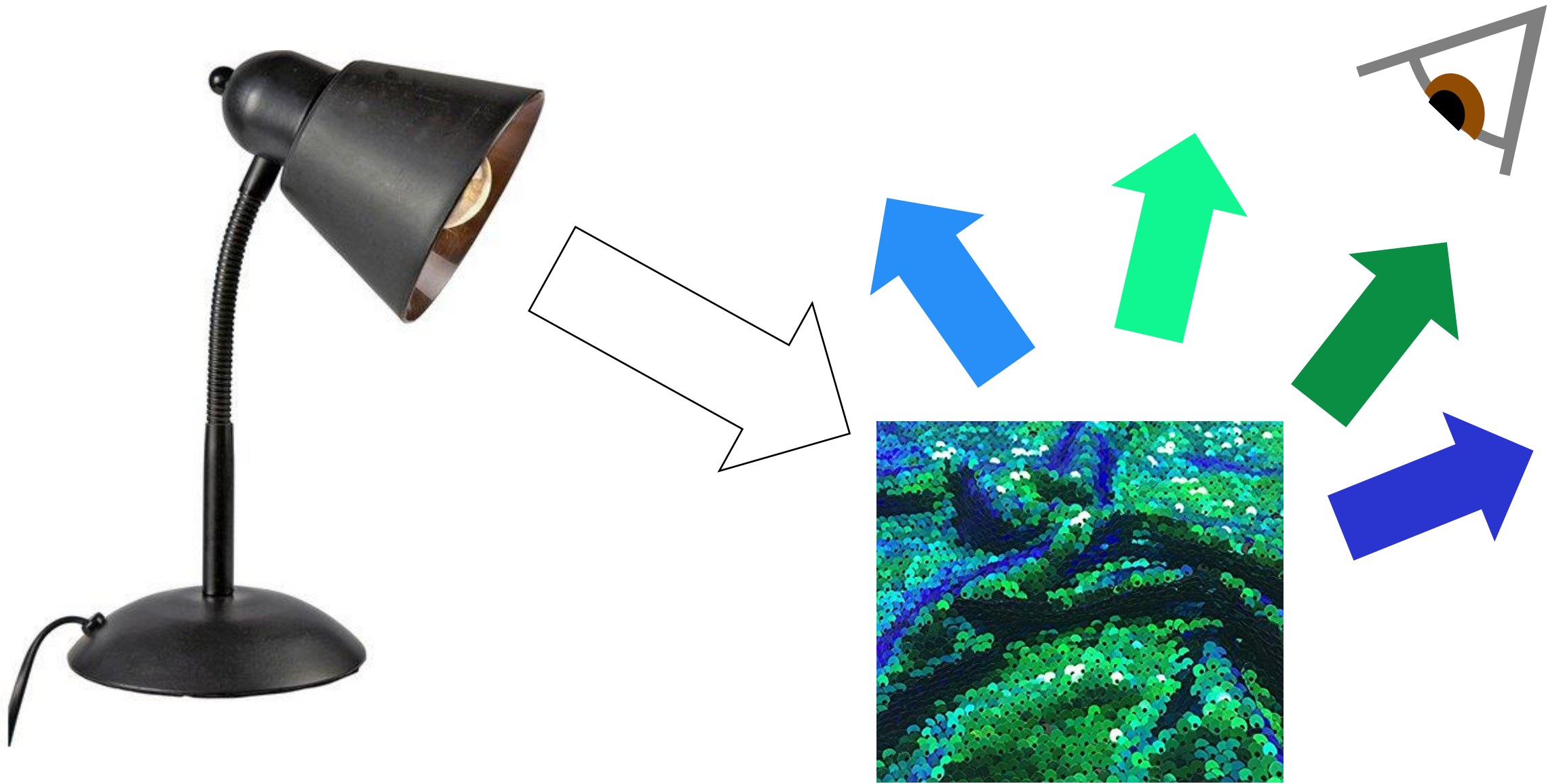


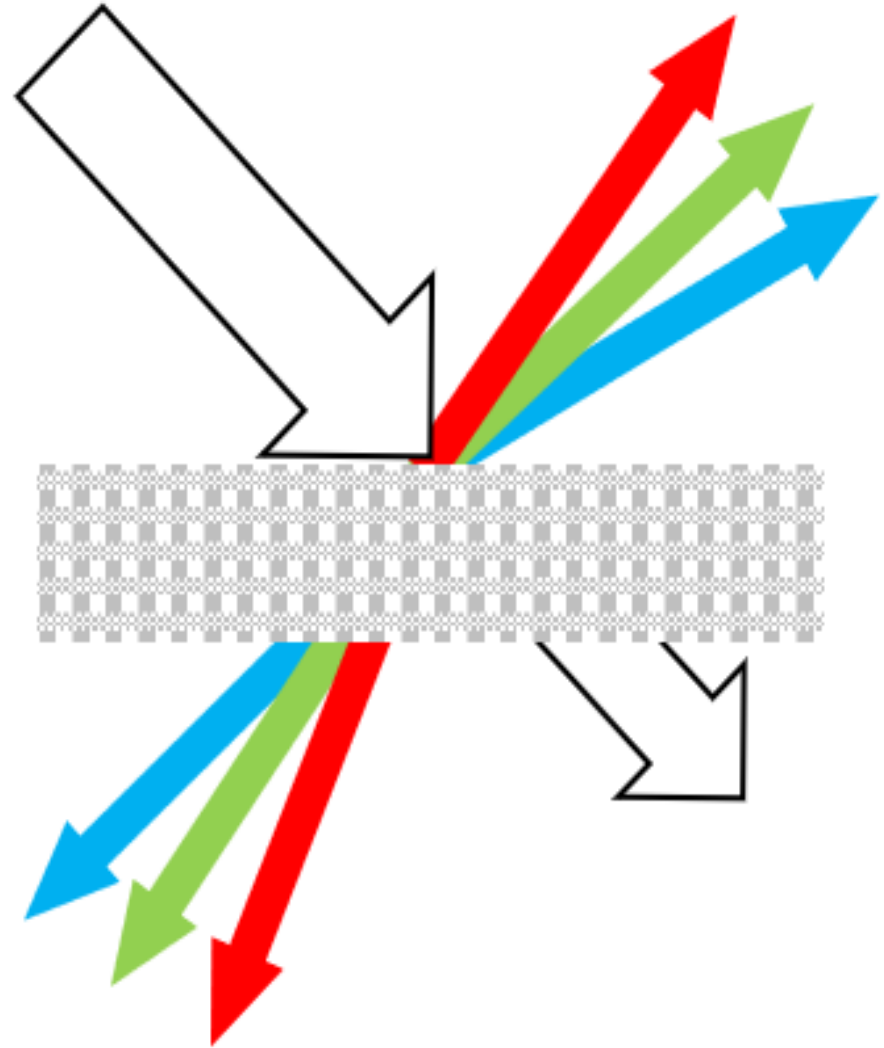
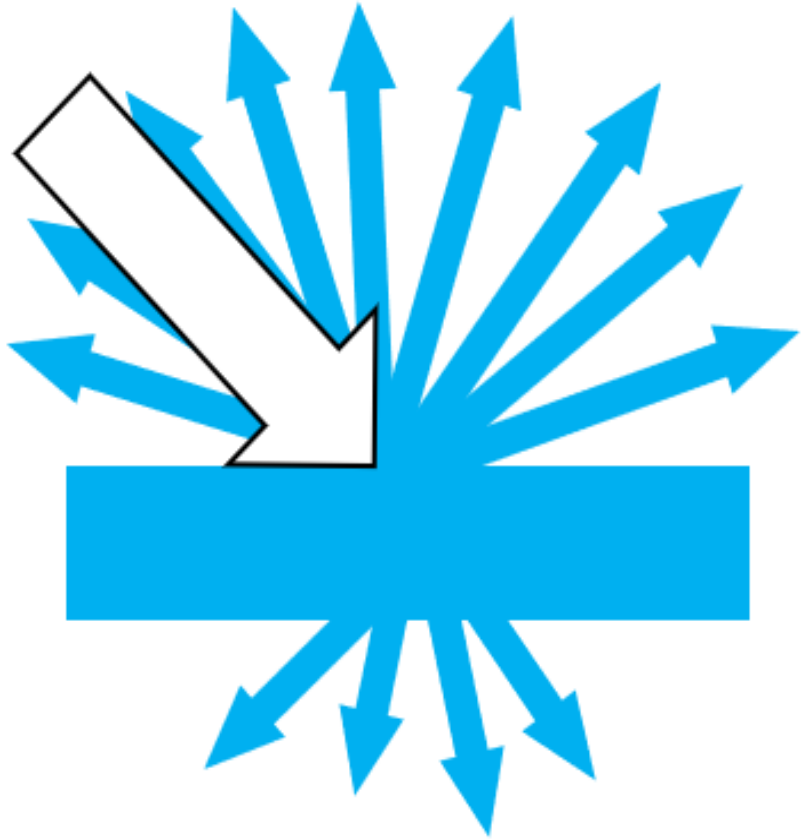




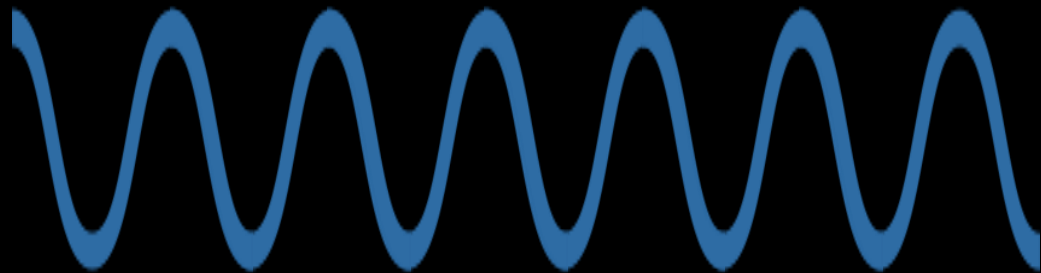
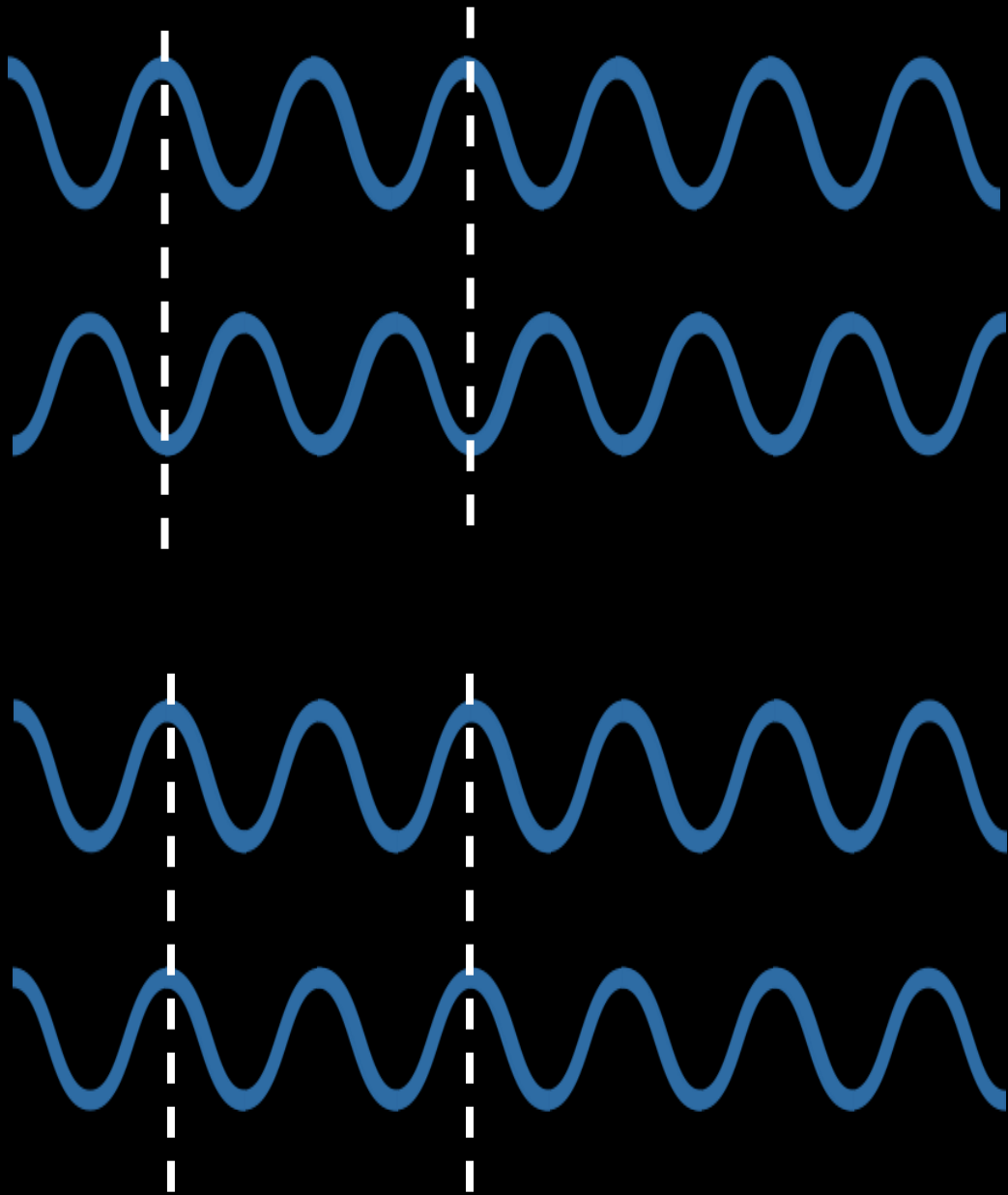
Iridescent objects

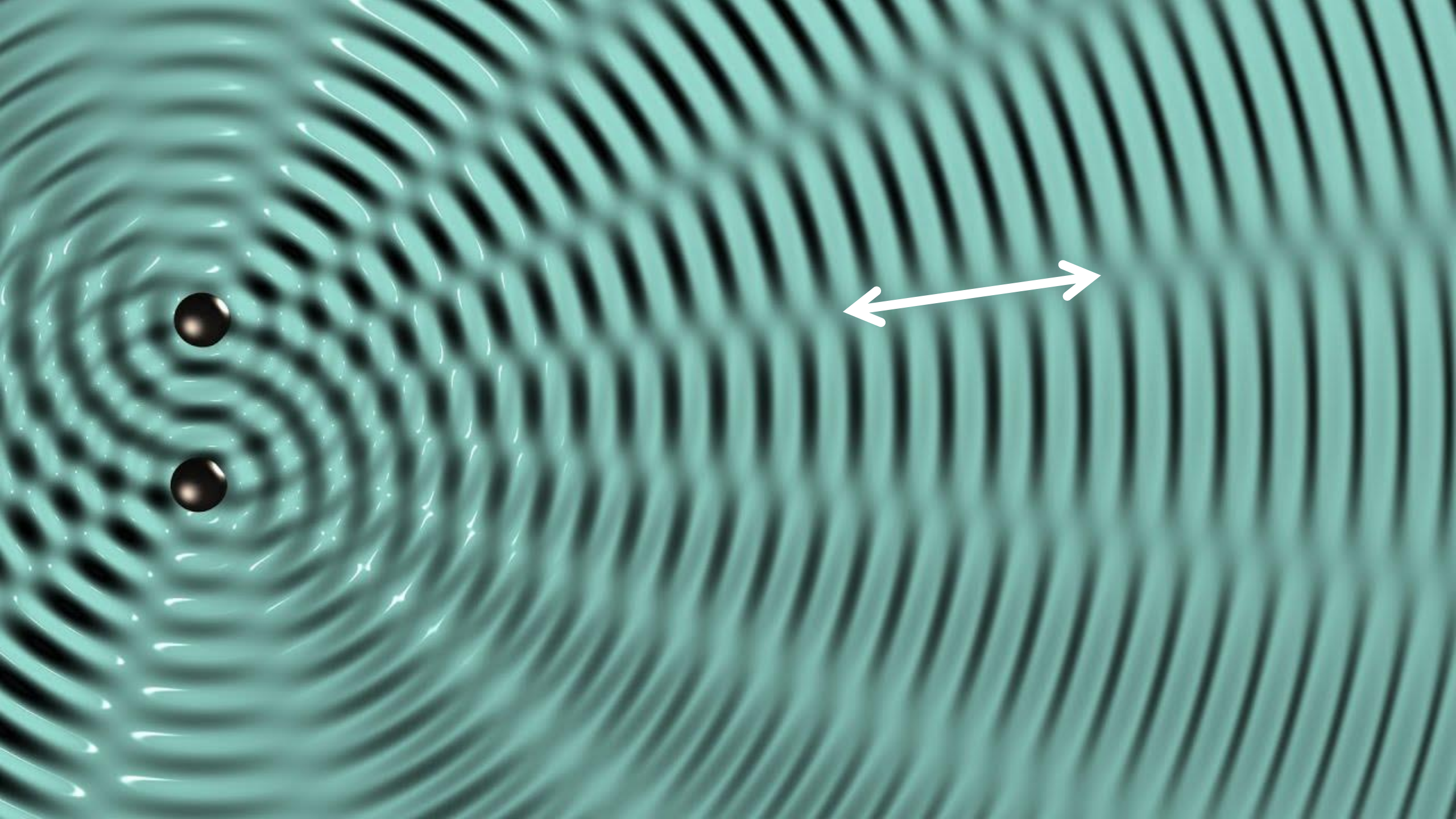




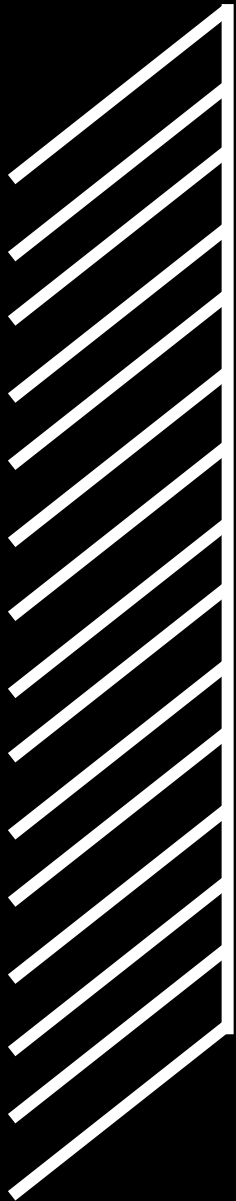


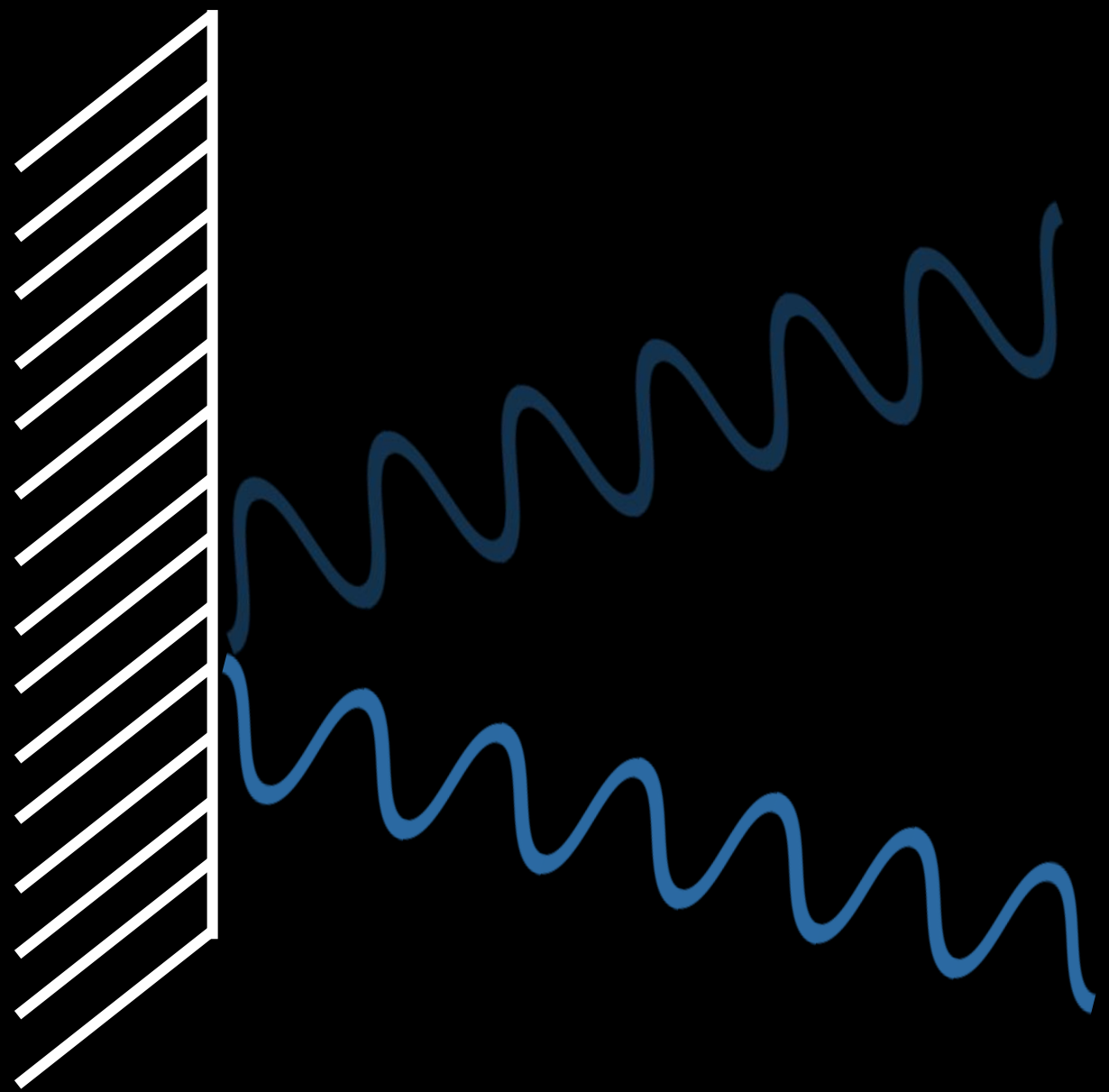
How does this happen?





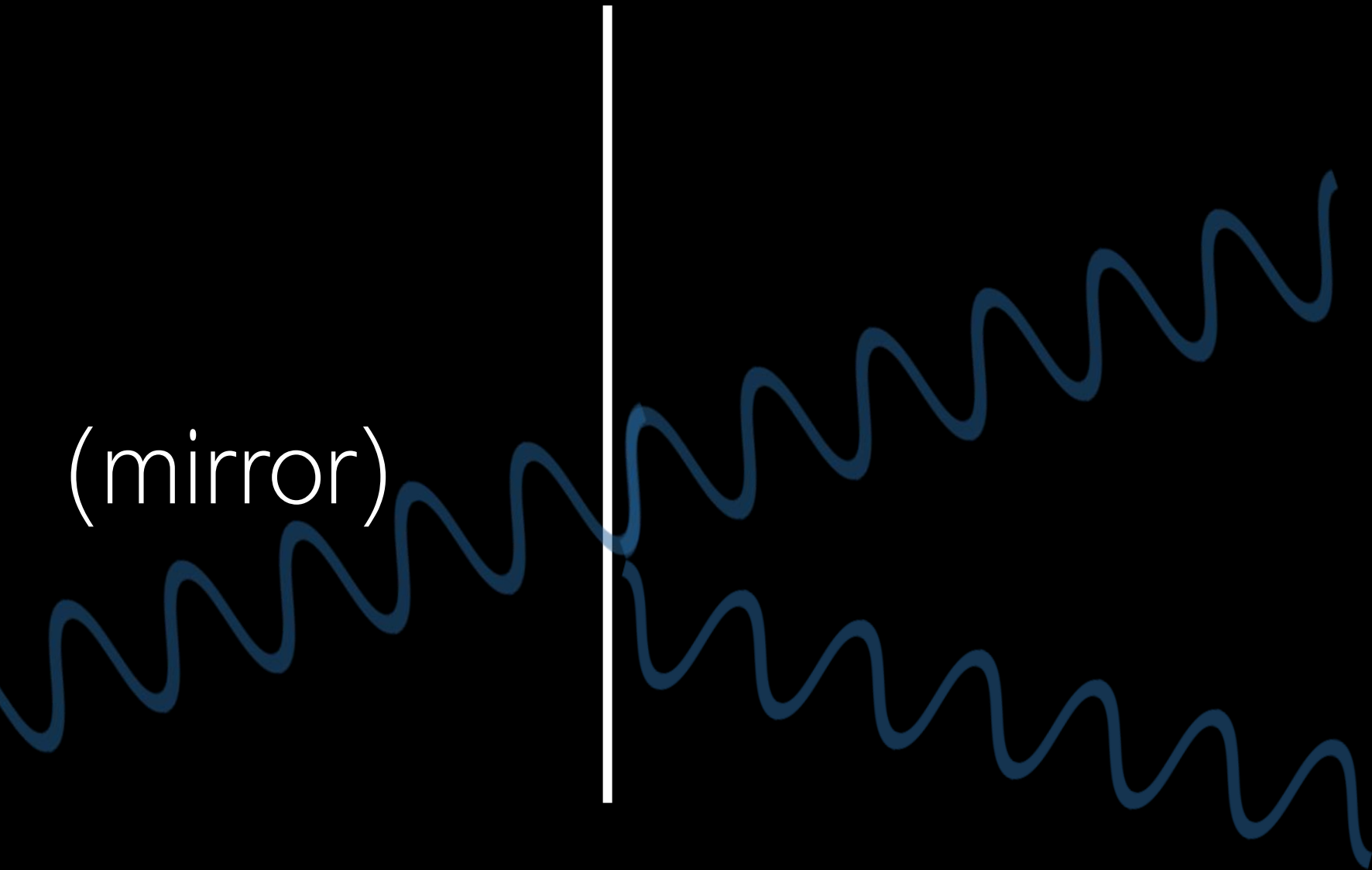
(mirror)

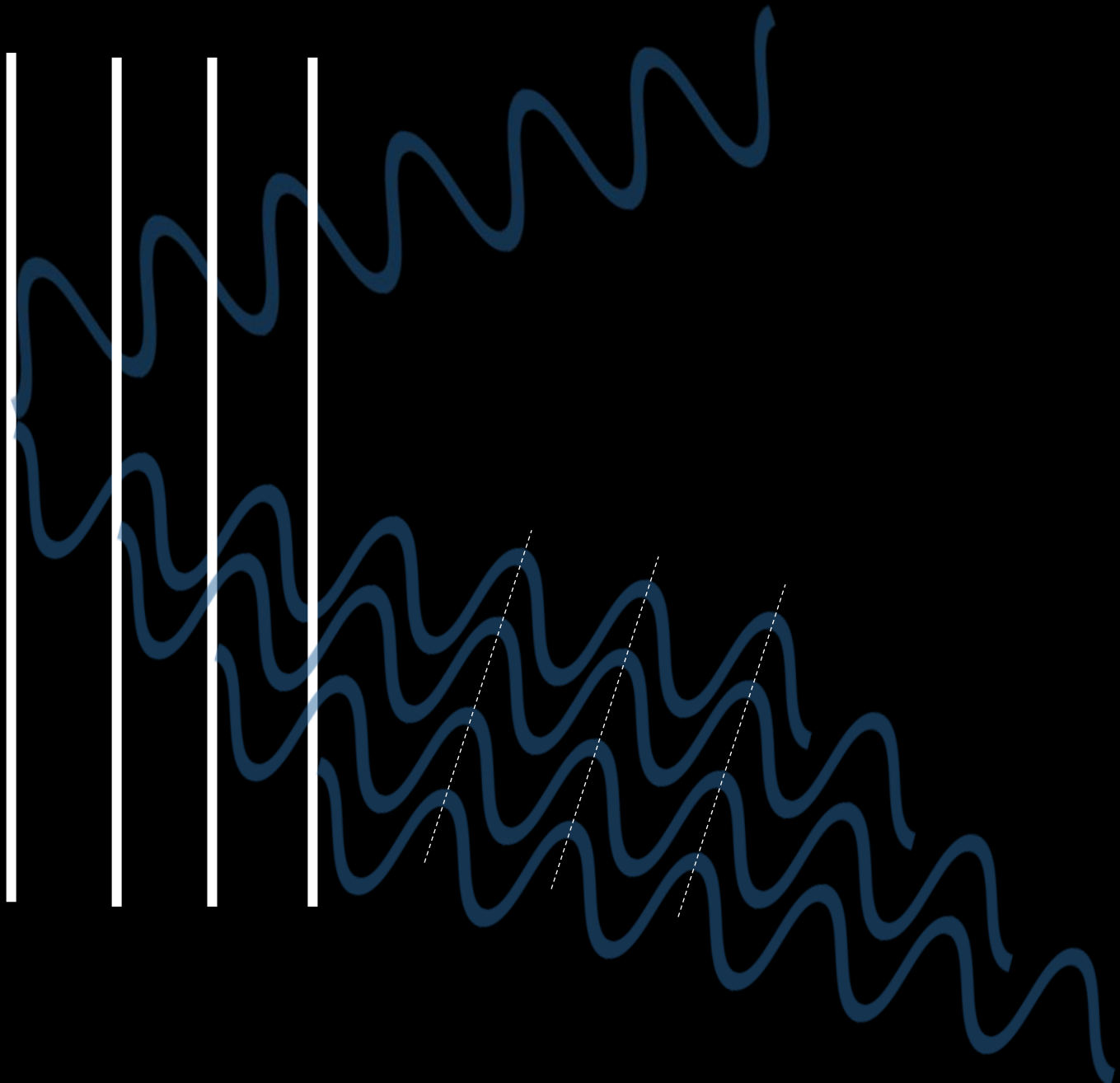


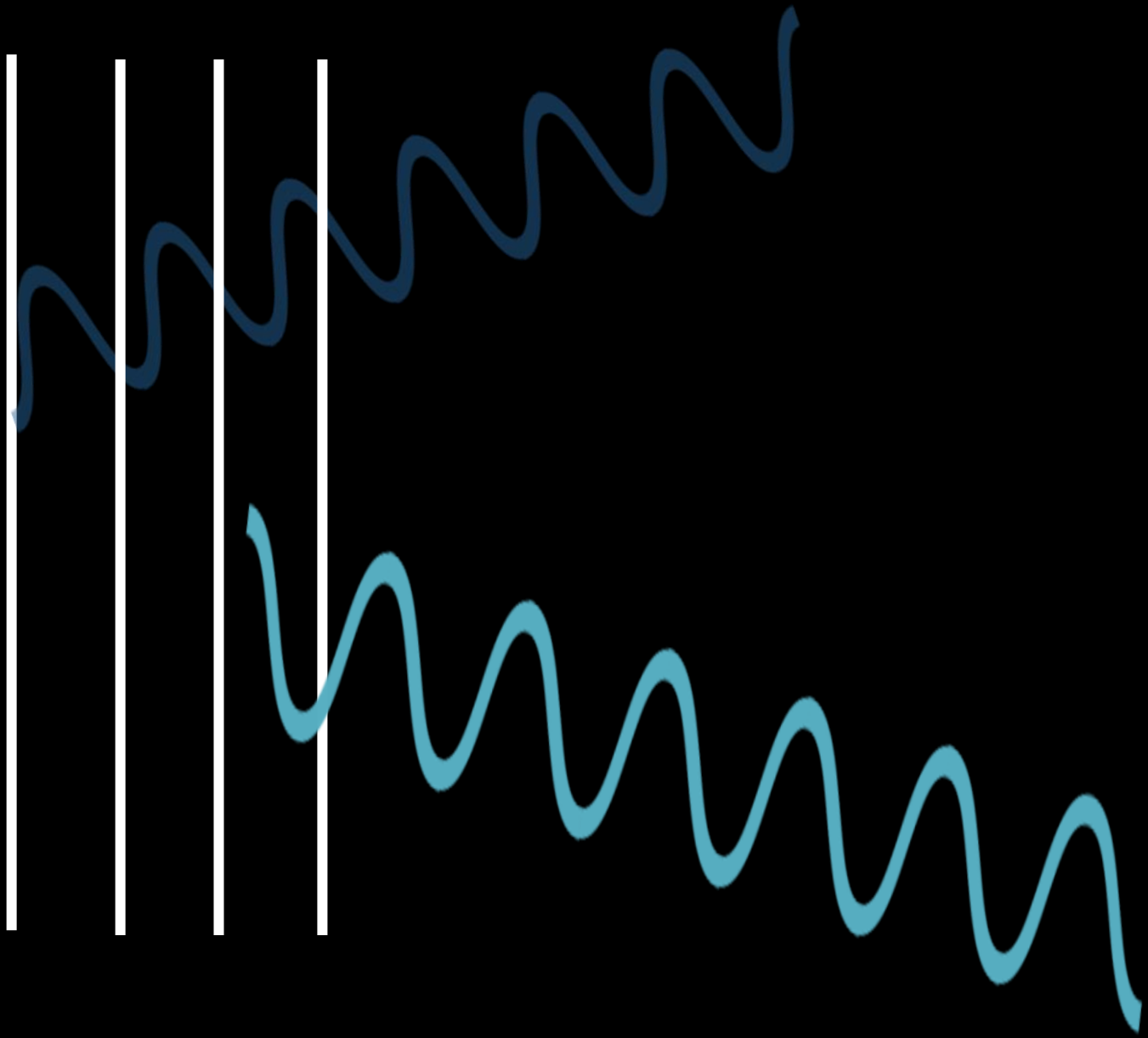


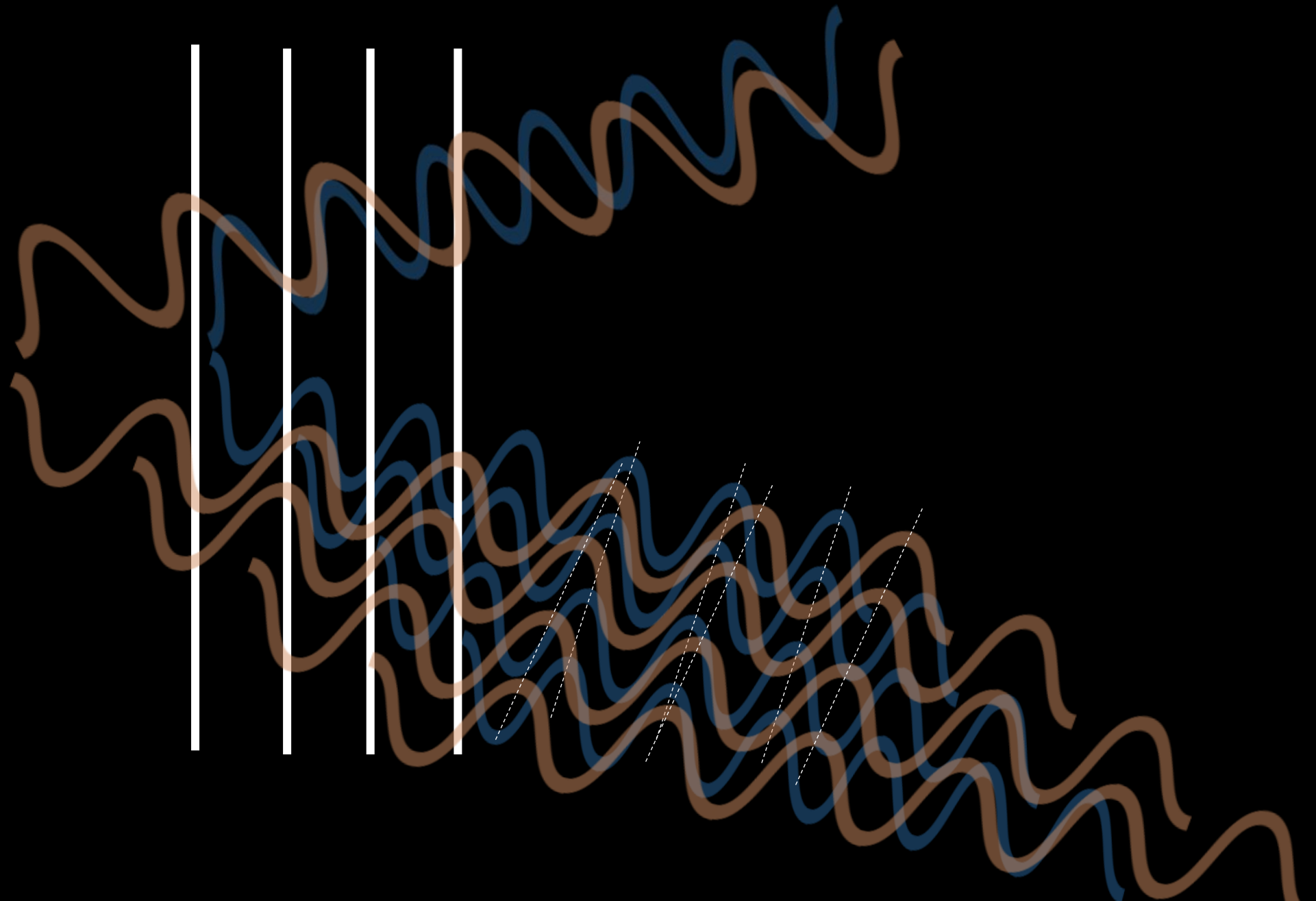
(mirror)

(mirror)

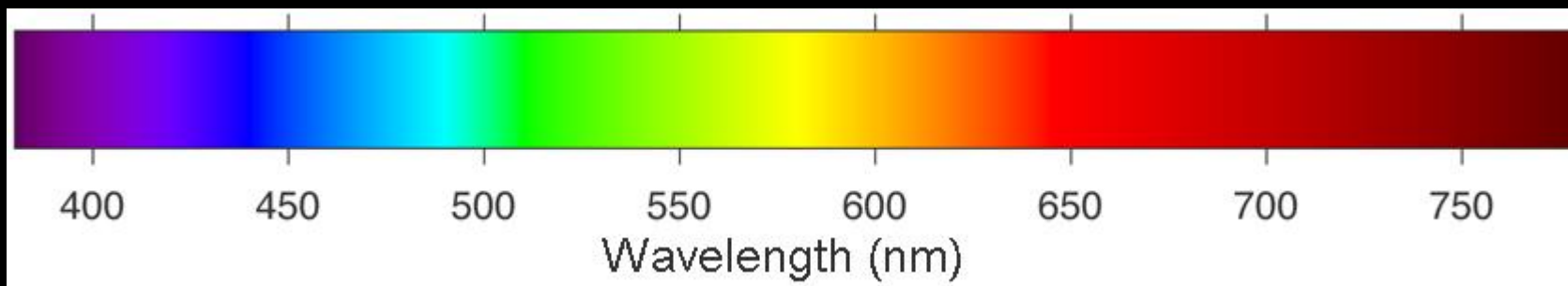
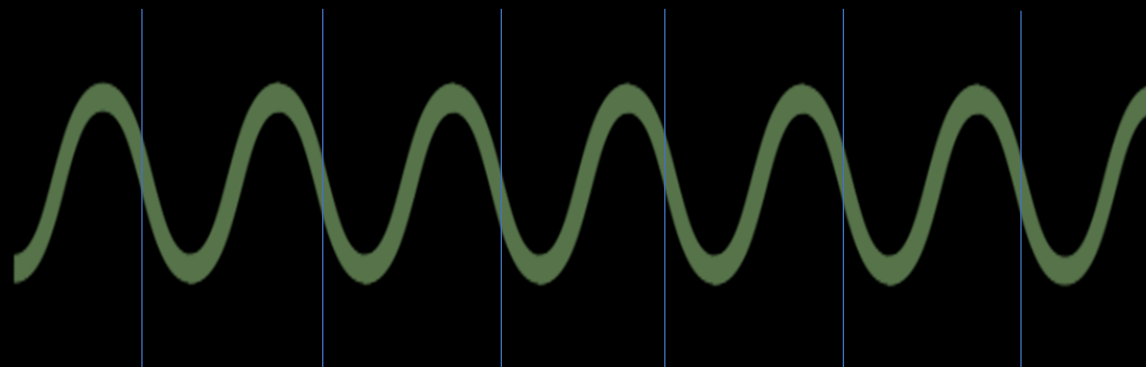


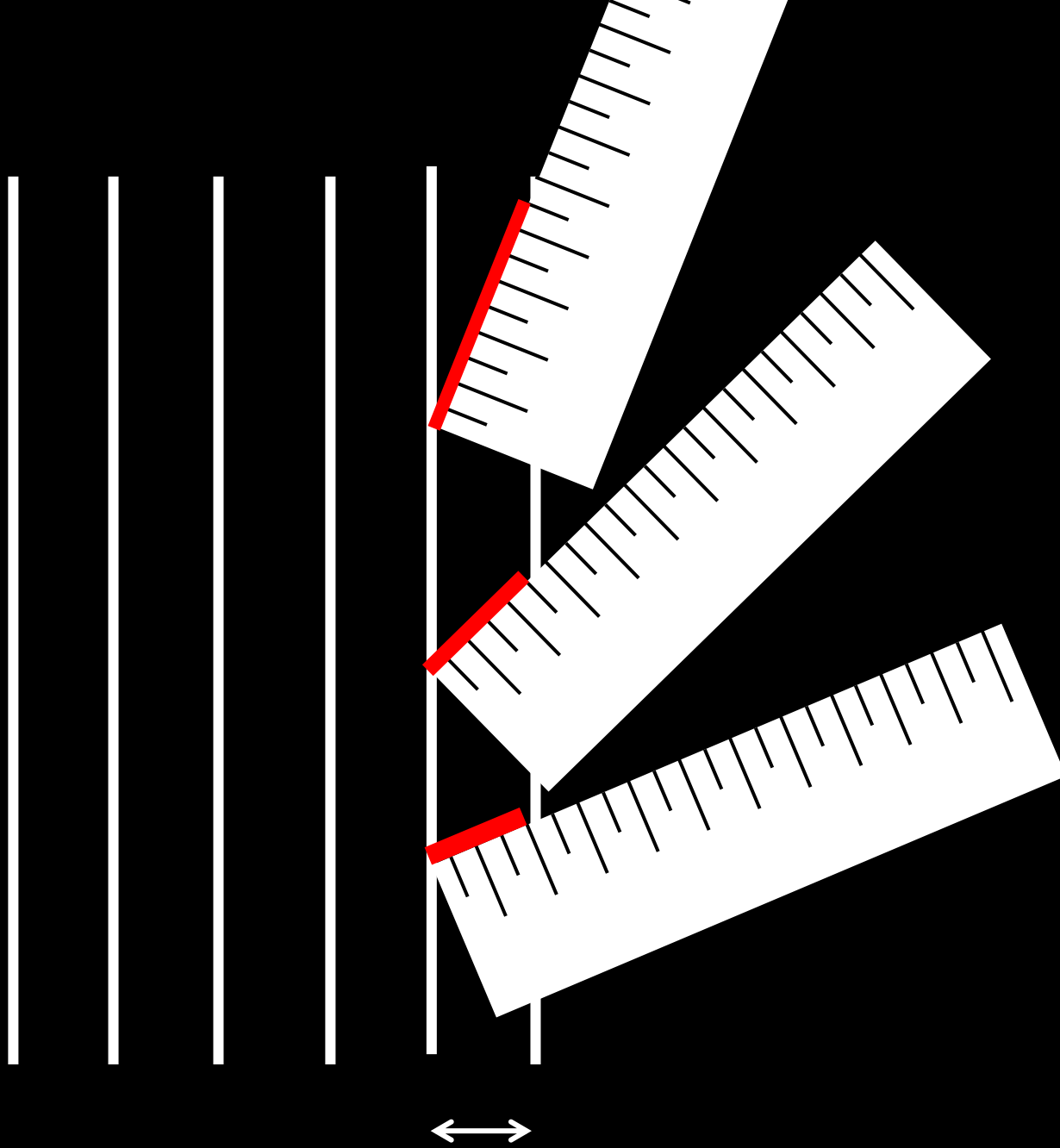






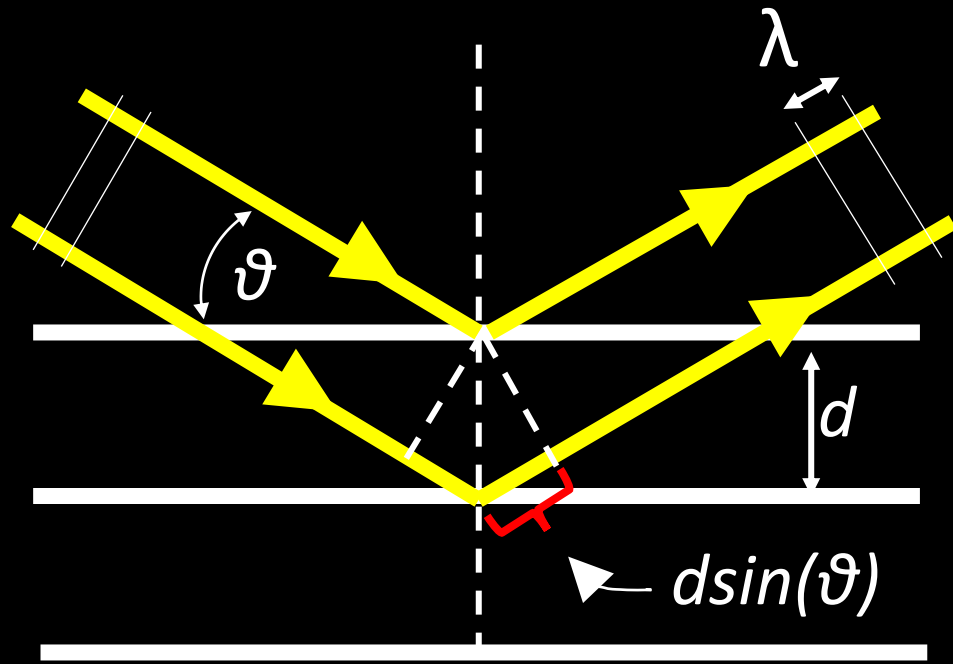
1 Wavelength (λ)





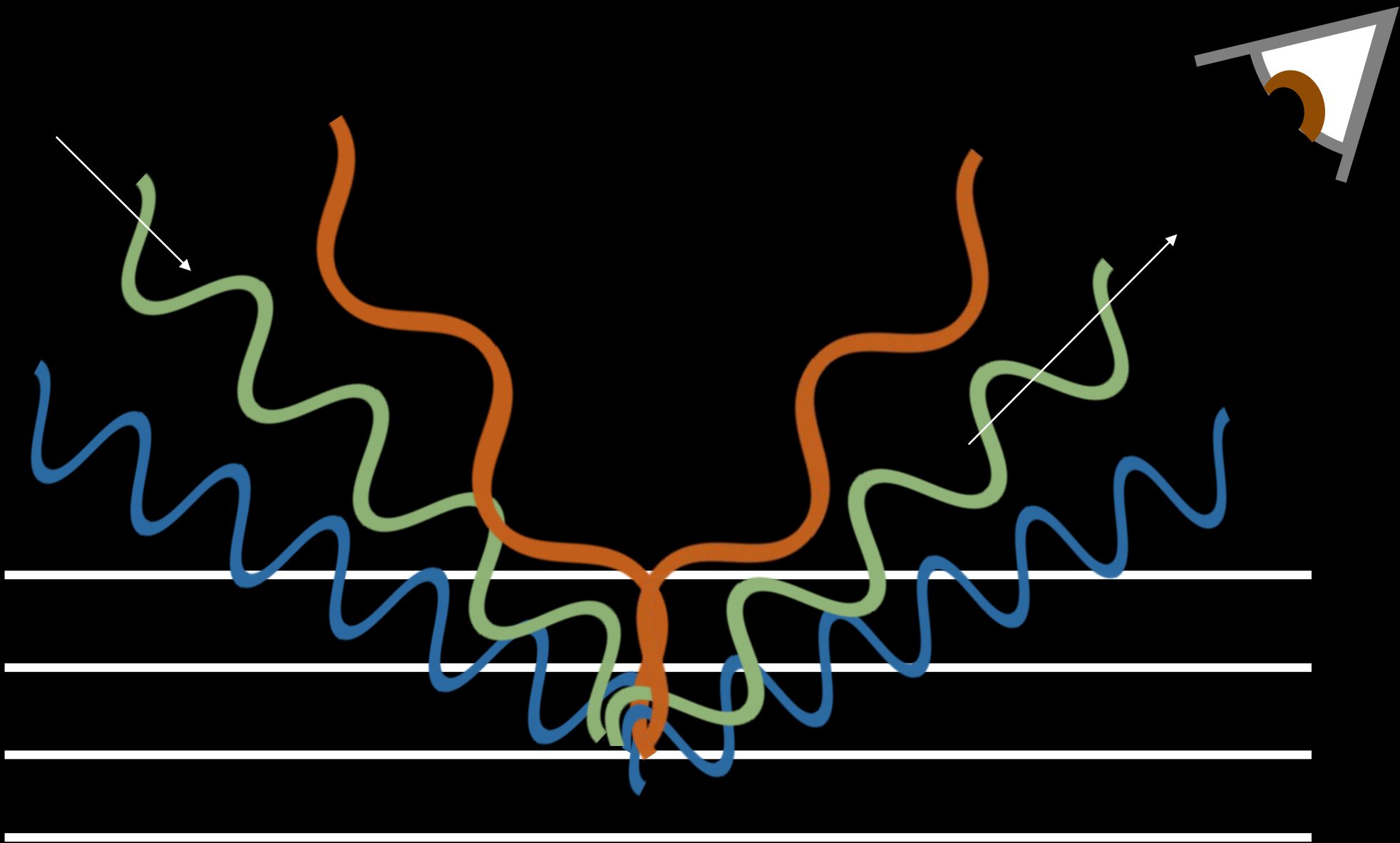
Angle of incidence
(and reflectance)

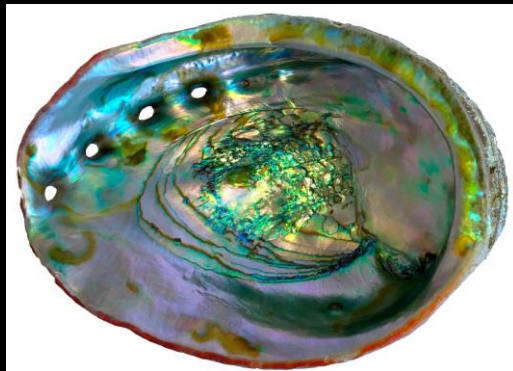
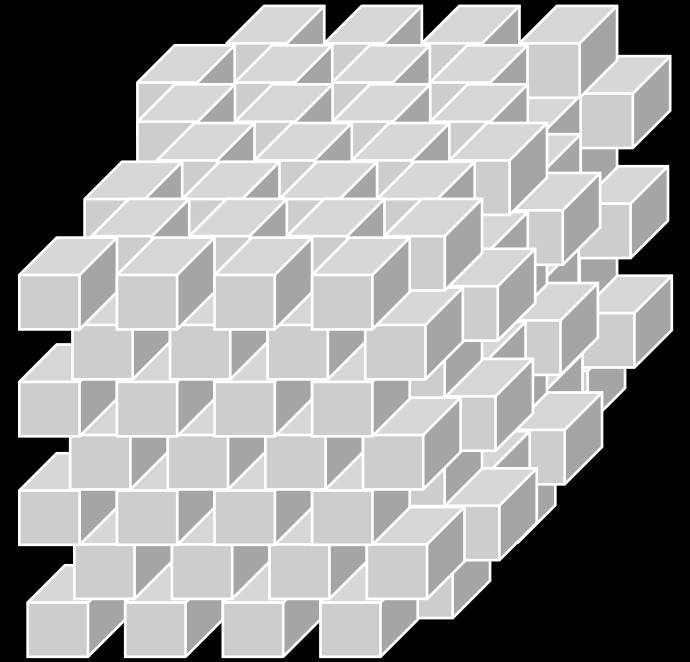
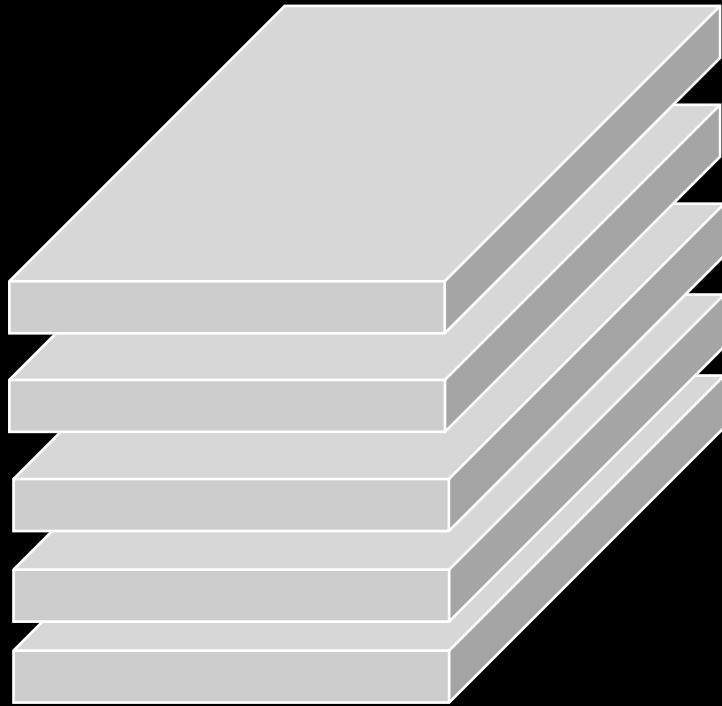
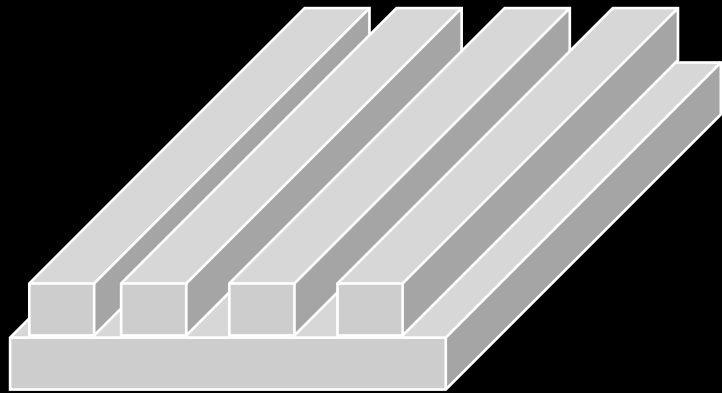


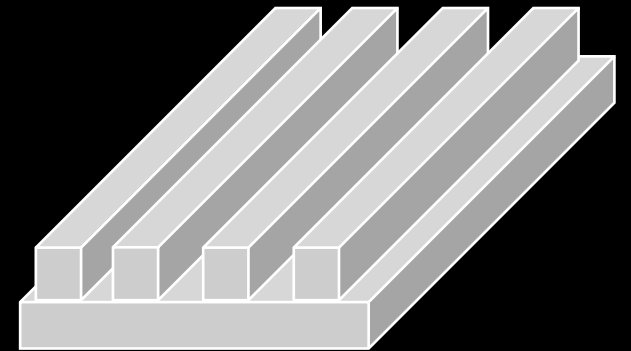
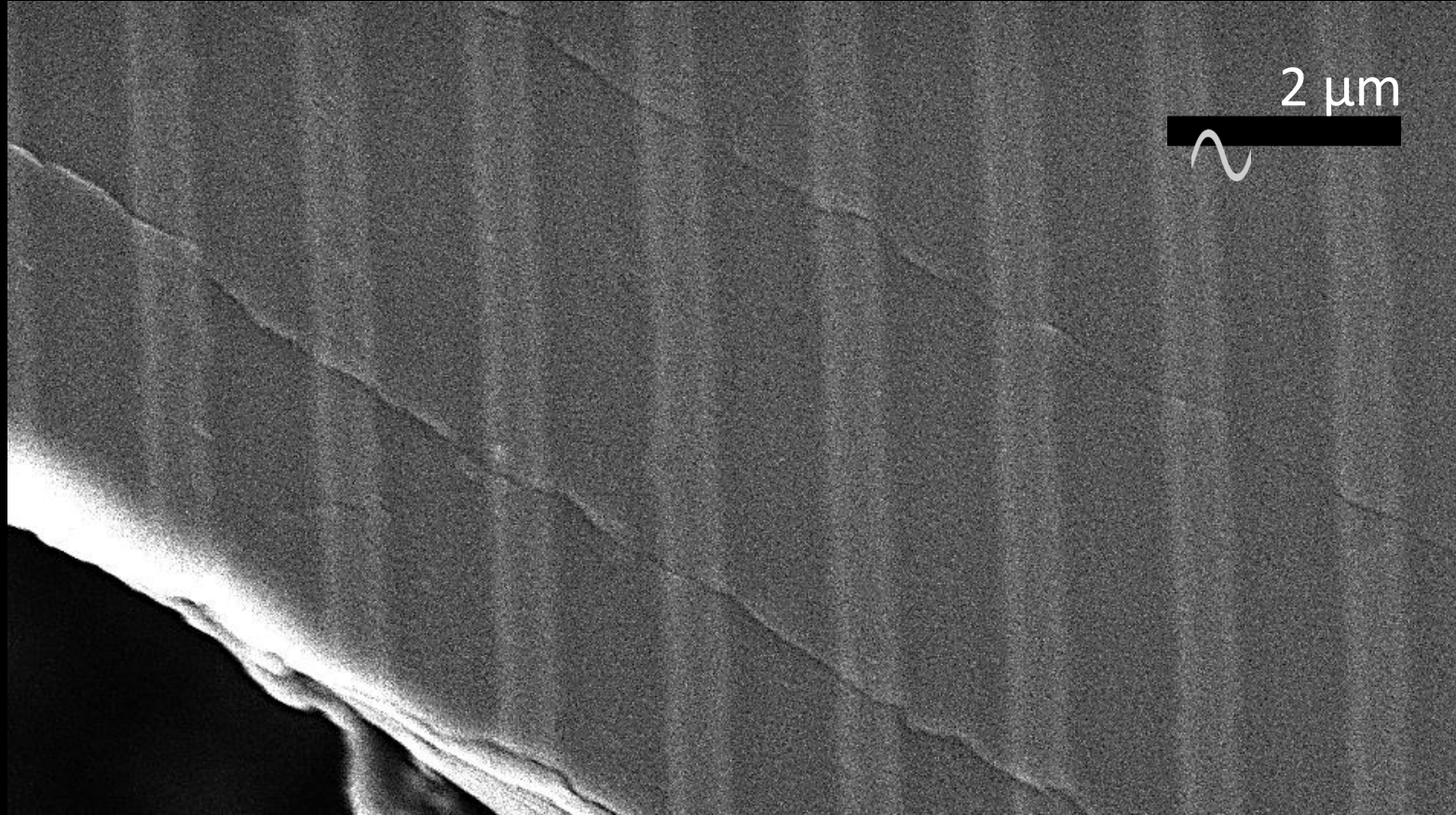


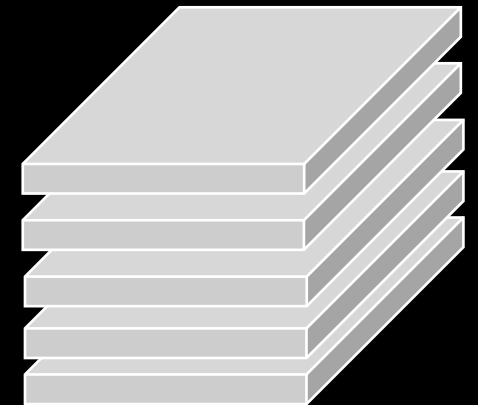
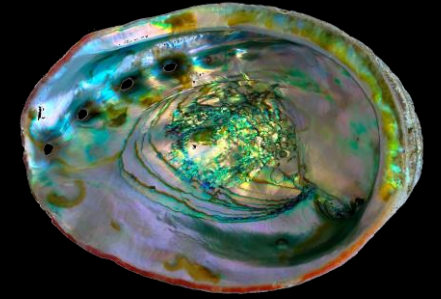
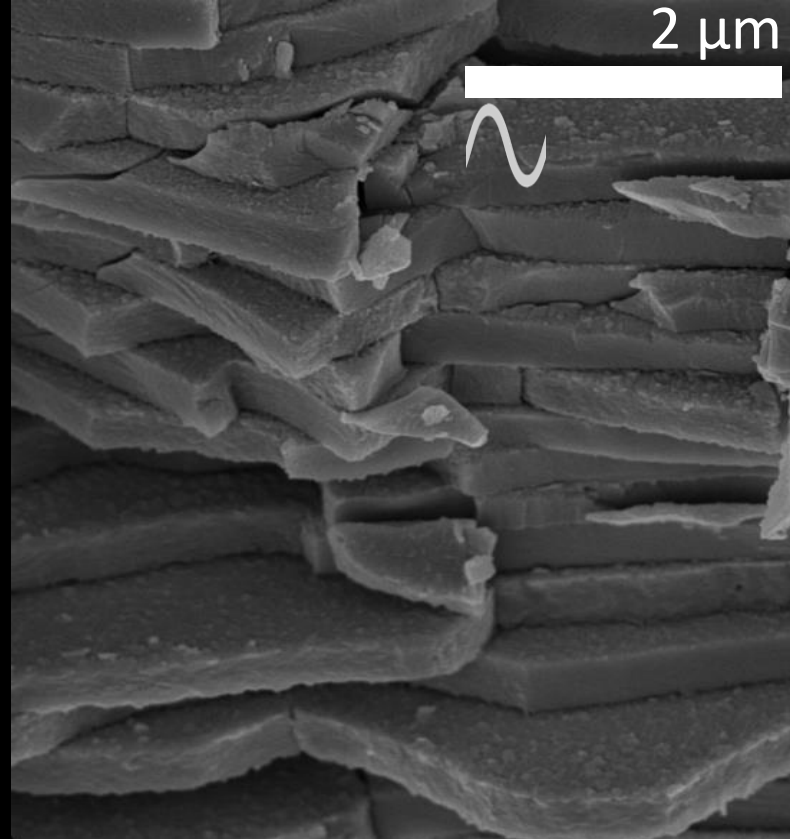
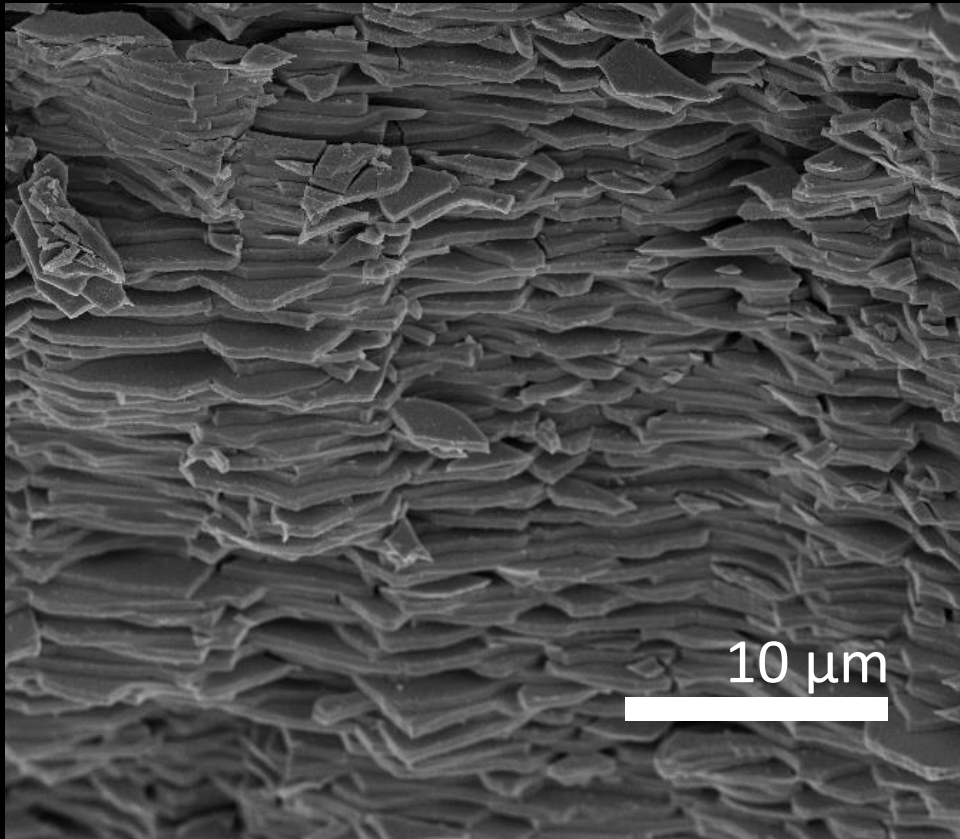
$$n \lambda = 2d \sin(\vartheta)$$

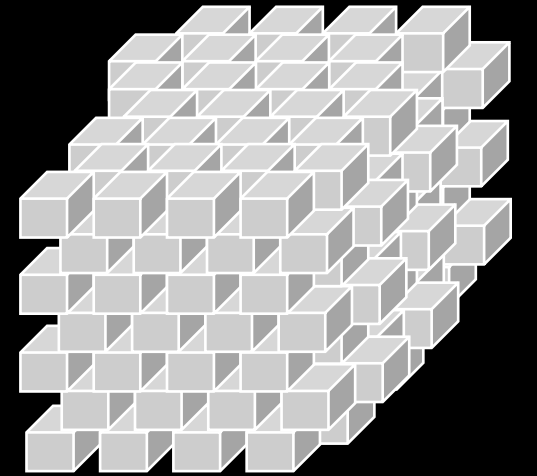
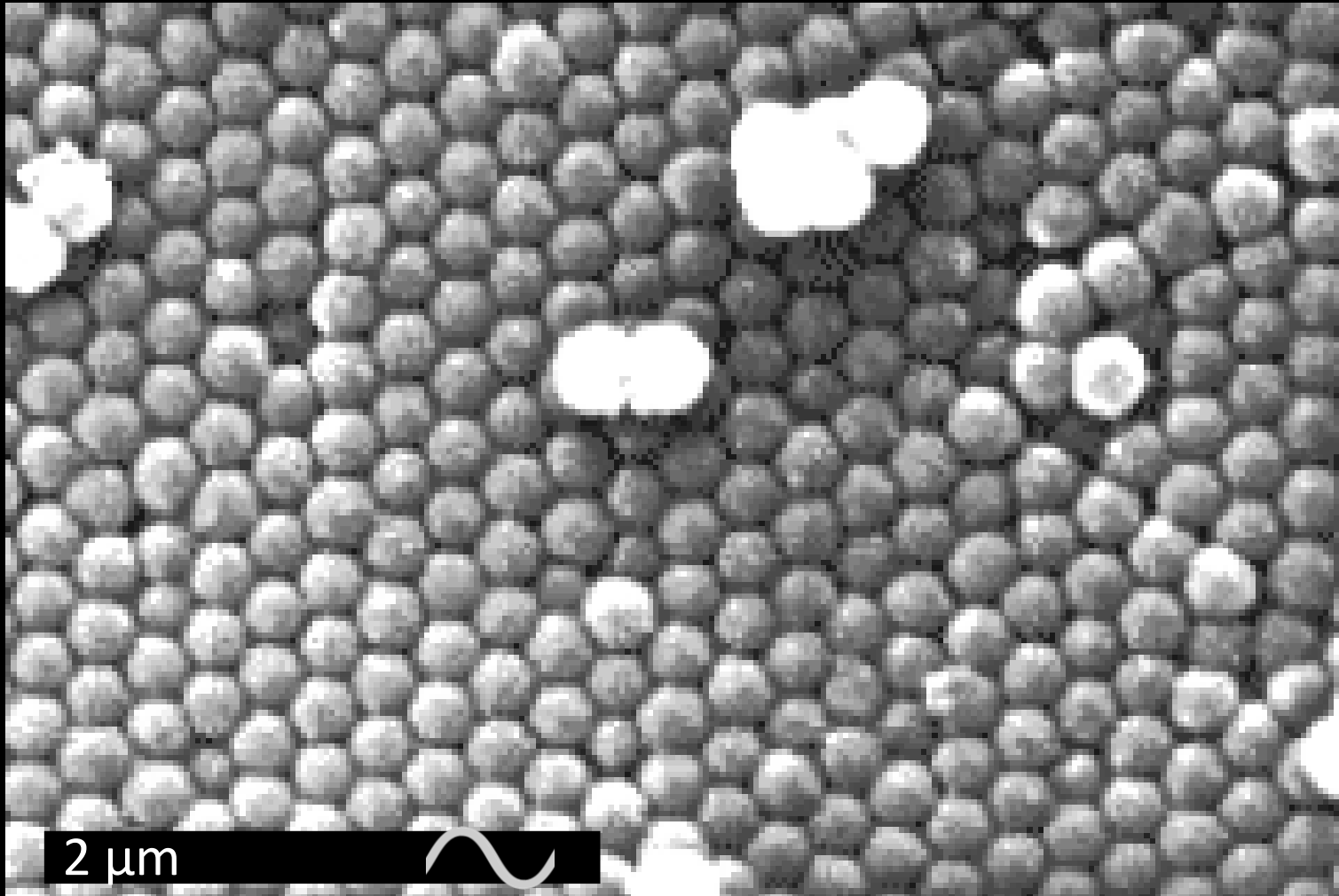
for $n = 1, 2, 3, \dots$





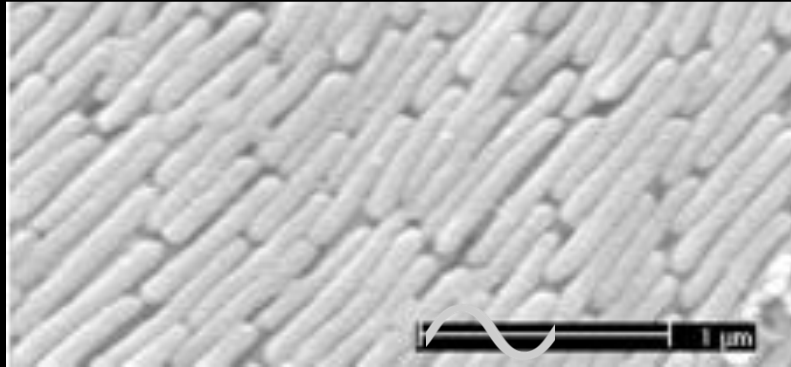
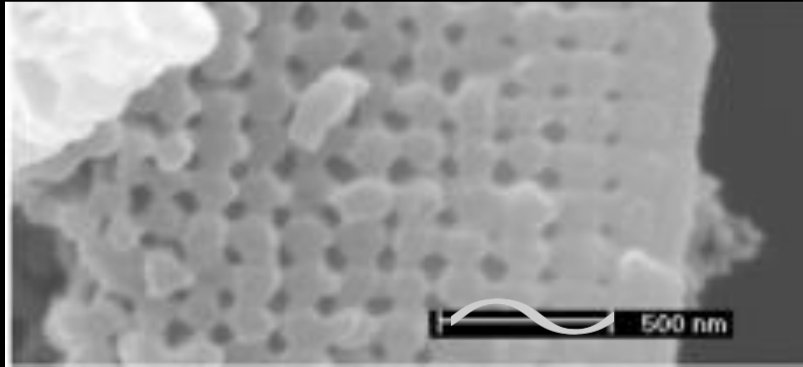
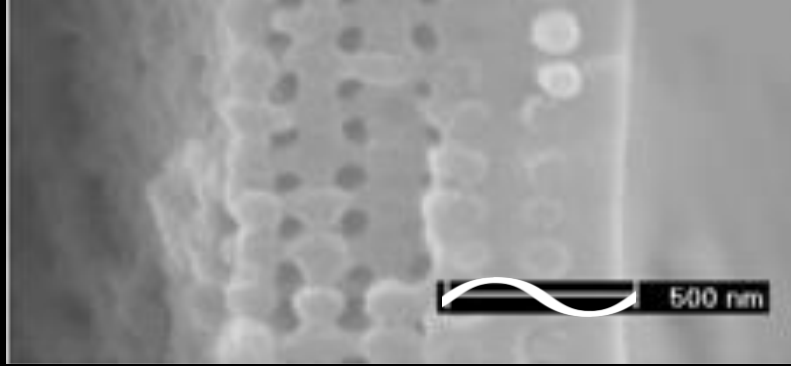
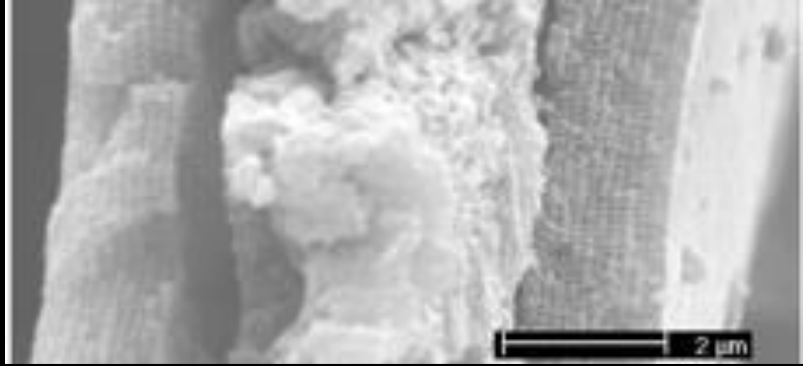


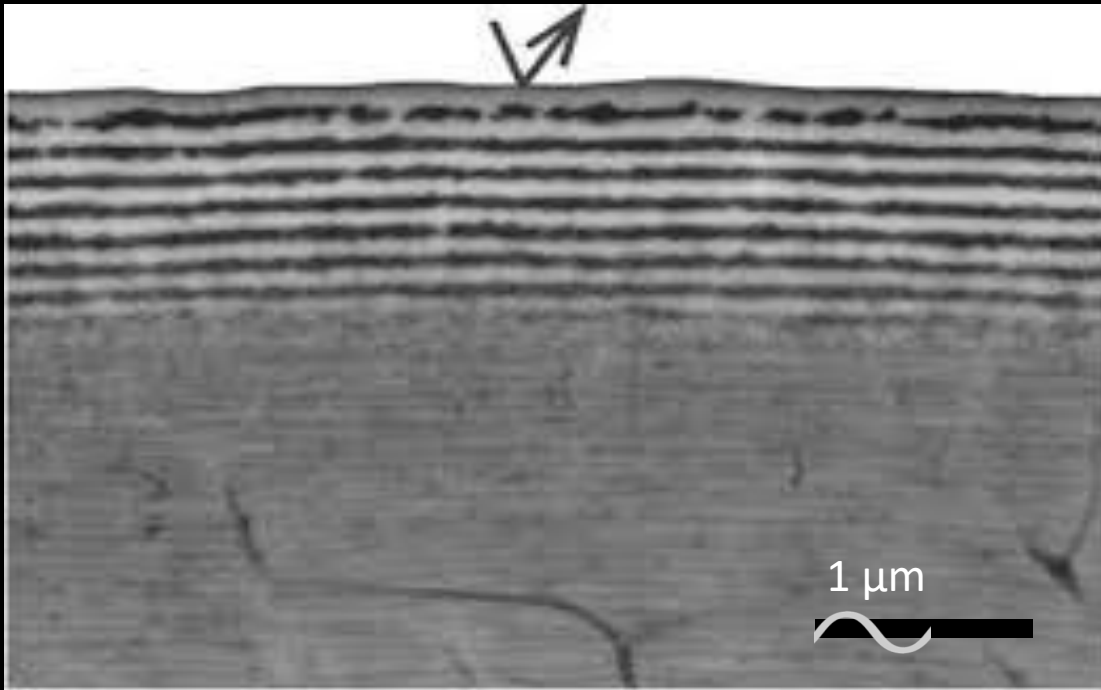


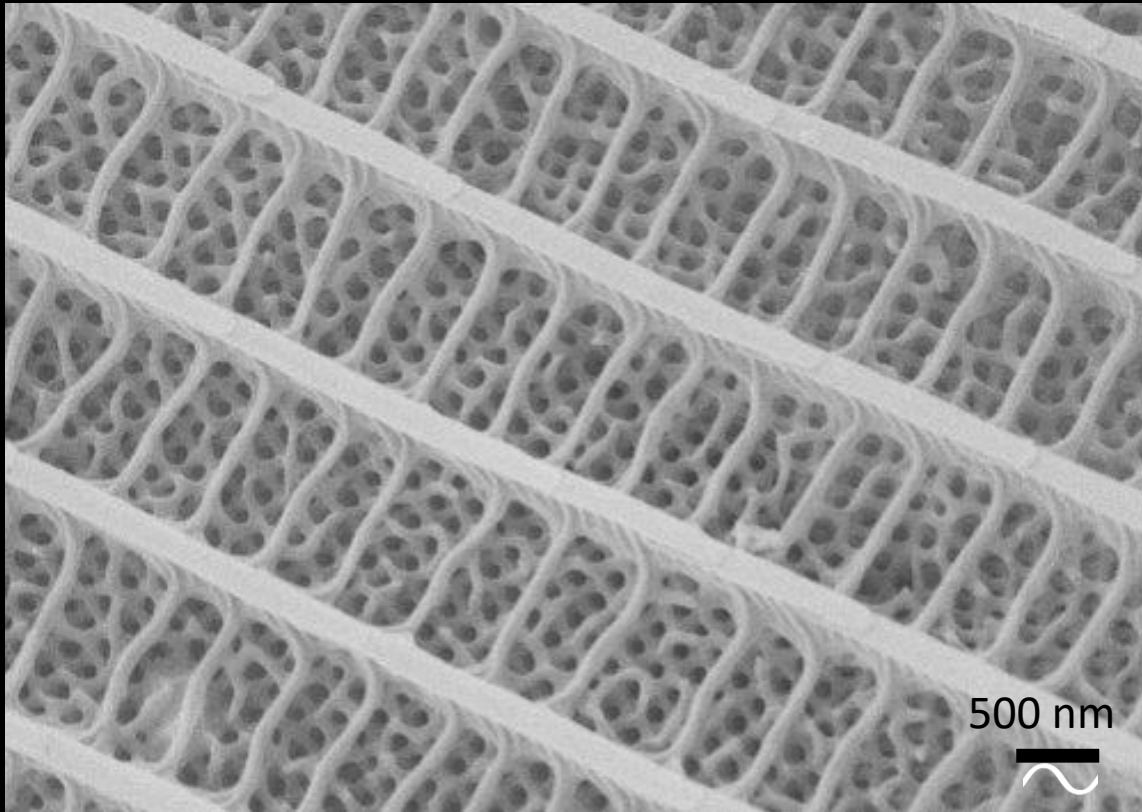


Nanostructure Produces Colour

Biology Produces Nanostructure

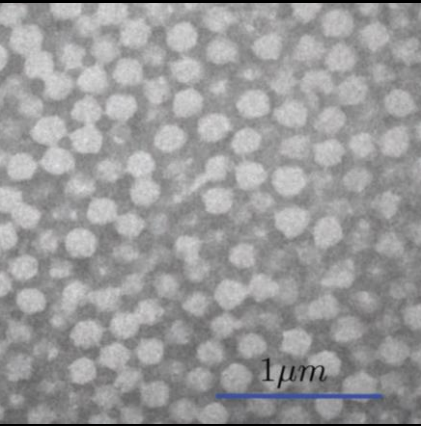




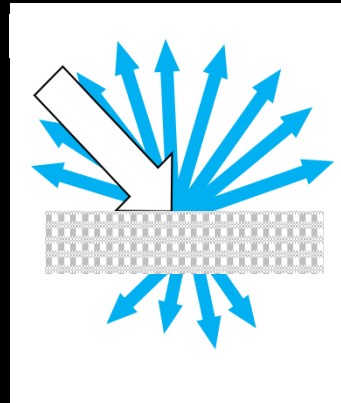
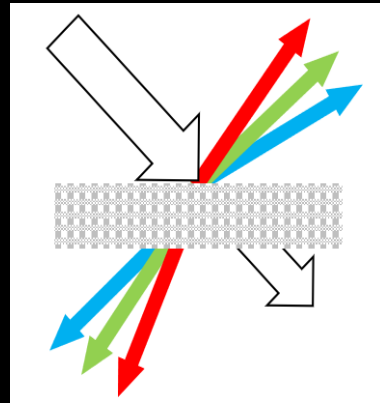
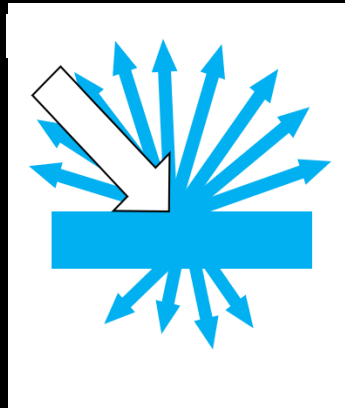
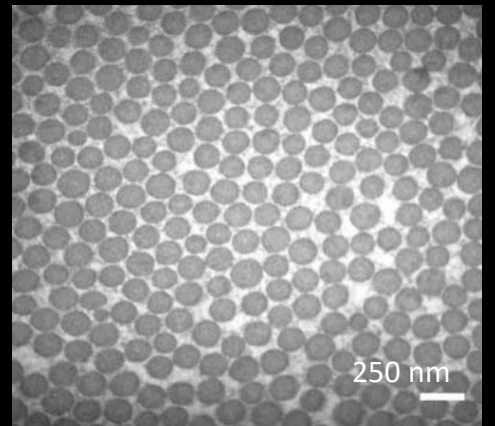
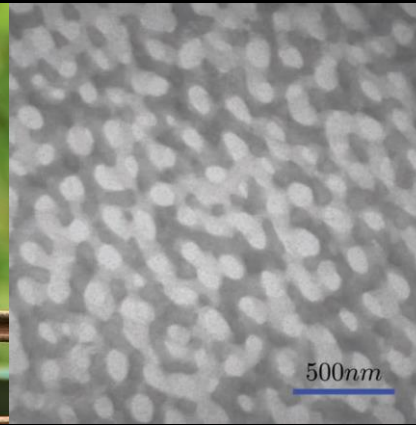




CC Klaus Rassinger



CC Bob Owen



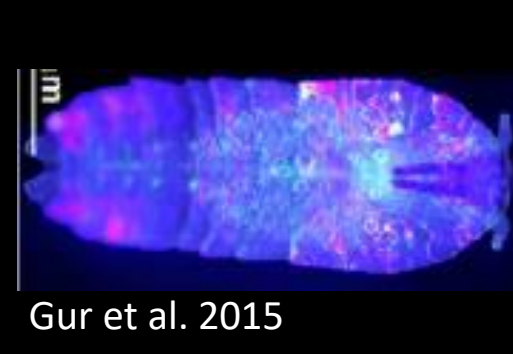
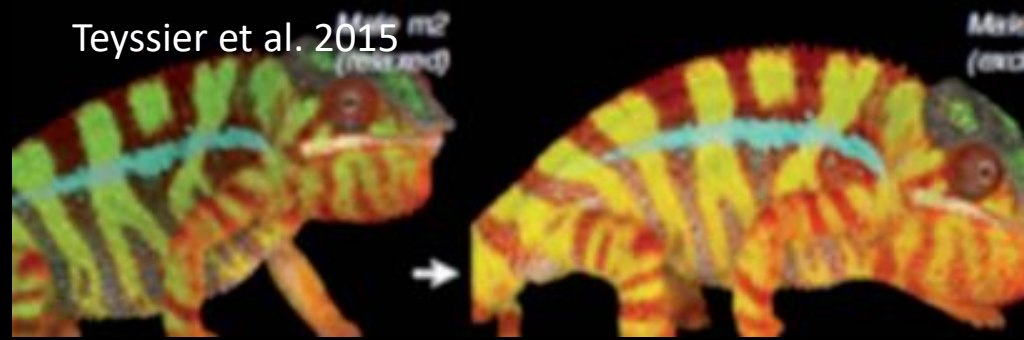
Prum J. *Exp. Bio.* 2004
Noh et al. *Adv. Mat.* 2010



Vargas et al. 2018



Wilts et al. 2014



- What is structural colour?
- How does it work?
- Structural colours in nature

QUESTIONS

- Structural colours in plants
- Flowers
- Fruits
- Seeing the invisible

Blue Pigments in plants



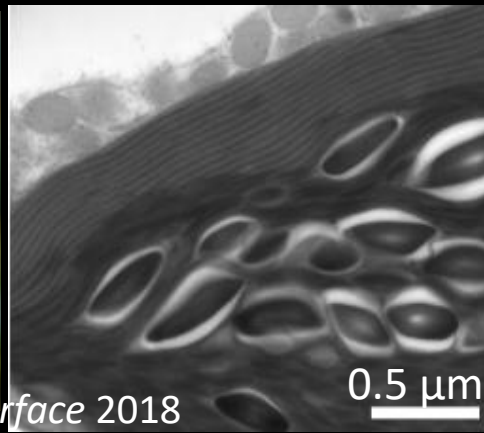
Isatis tinctoria
Ashley Walker



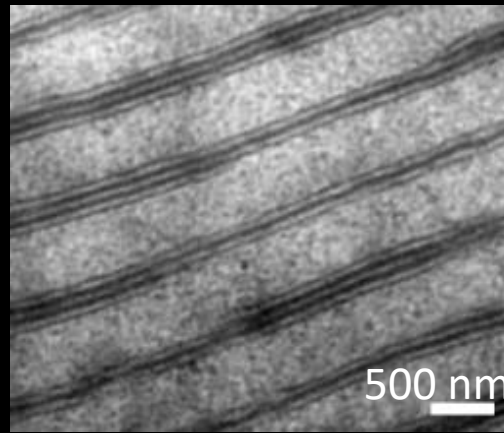


Selaginella erythropus

Masters et al. *J. Roy. Soc. Interface* 2018



0.5 μm



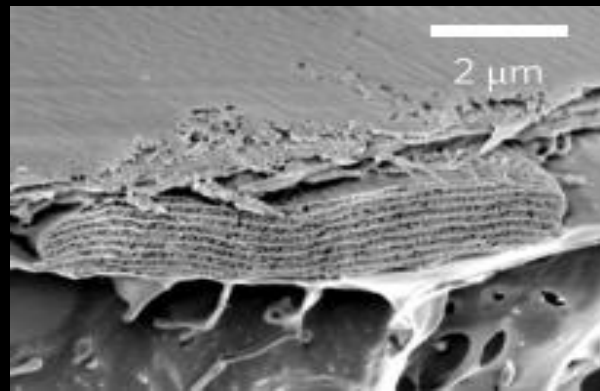
500 nm



Teratophyllum rotundifolium

Nasrulhaq-Boyce et al. *New Phytologist* 1991

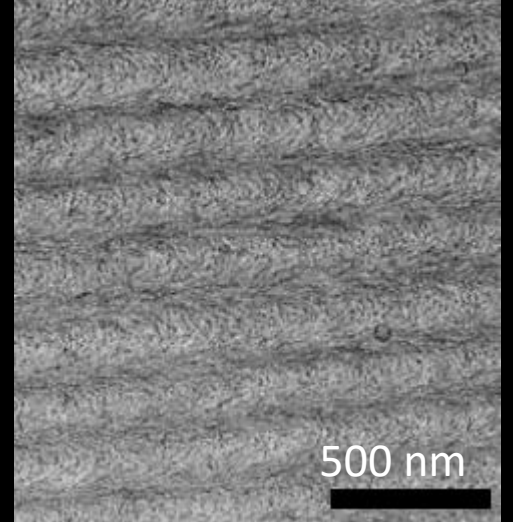
Clive Lundquist 2012



2 μm

Begonia (grandis x pavonina)

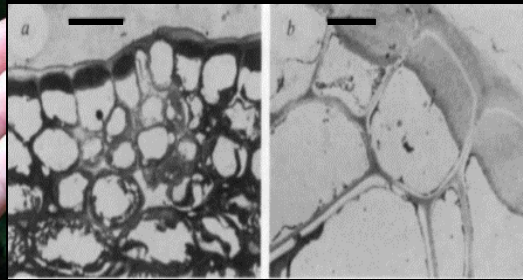
Jacobs et al. *Nature Plants* 2016



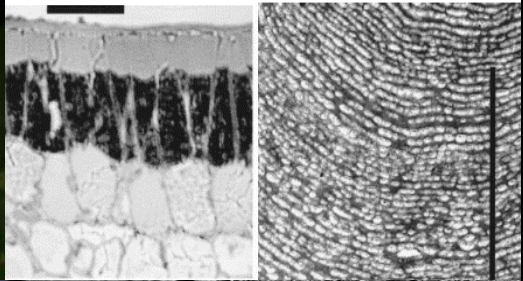
500 nm

Microsorium thailandicum

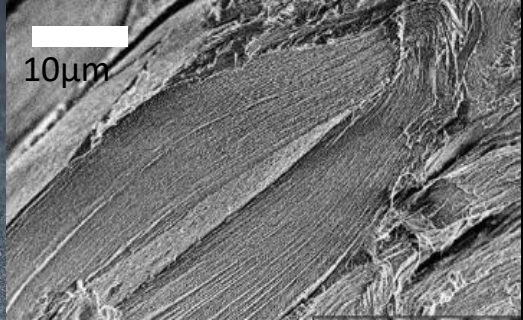
Steiner et al. *Interface Focus* 2019



Elaeocarpus angustifolius
20 μm, 10 μm
Lee et al. *Nature* 1991



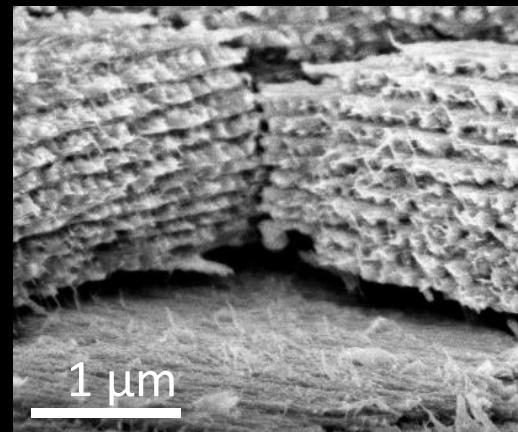
Delarbrea michieana
100 μm, 2 μm
Lee et al. *int. J. Plant Sci.* 2000

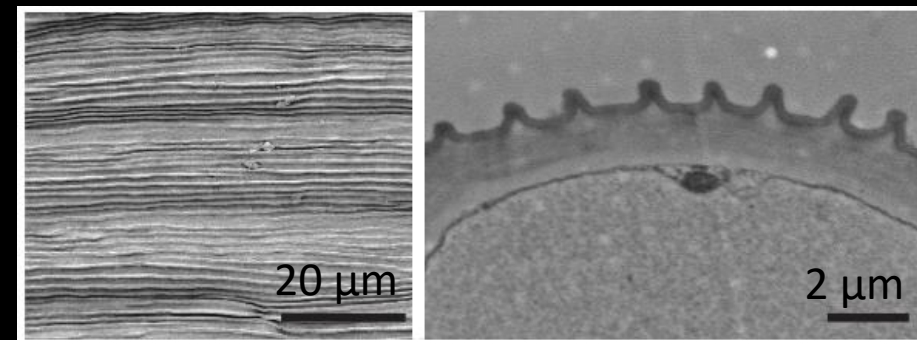


Margaritaria nobilis
Vignolini et al.
Interface 2016



Pollia condensata
Vignolini et al.
PNAS 2012





Why care about colours in plants?

- Understanding animal vision and plant-animal interactions
- Understanding plant evolution and development
 - Improving crops and plant breeding
- Biomimetic inspiration
- Plant biomaterials for engineering



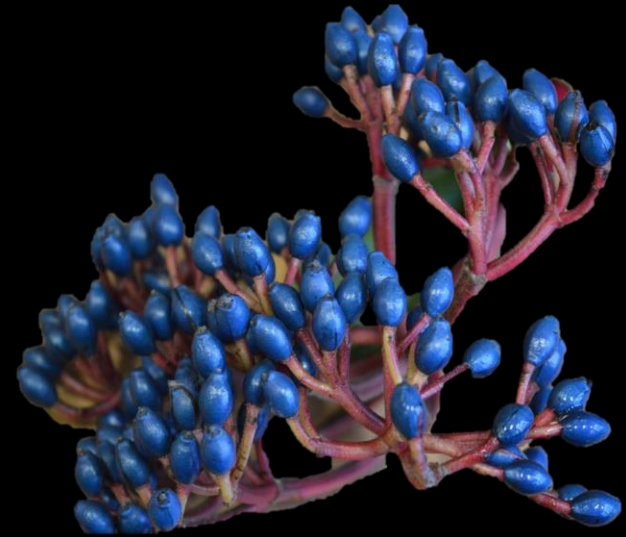
1

Pollia

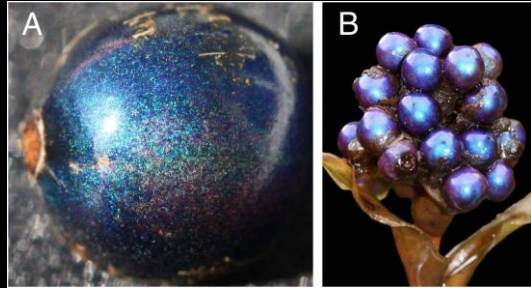


2

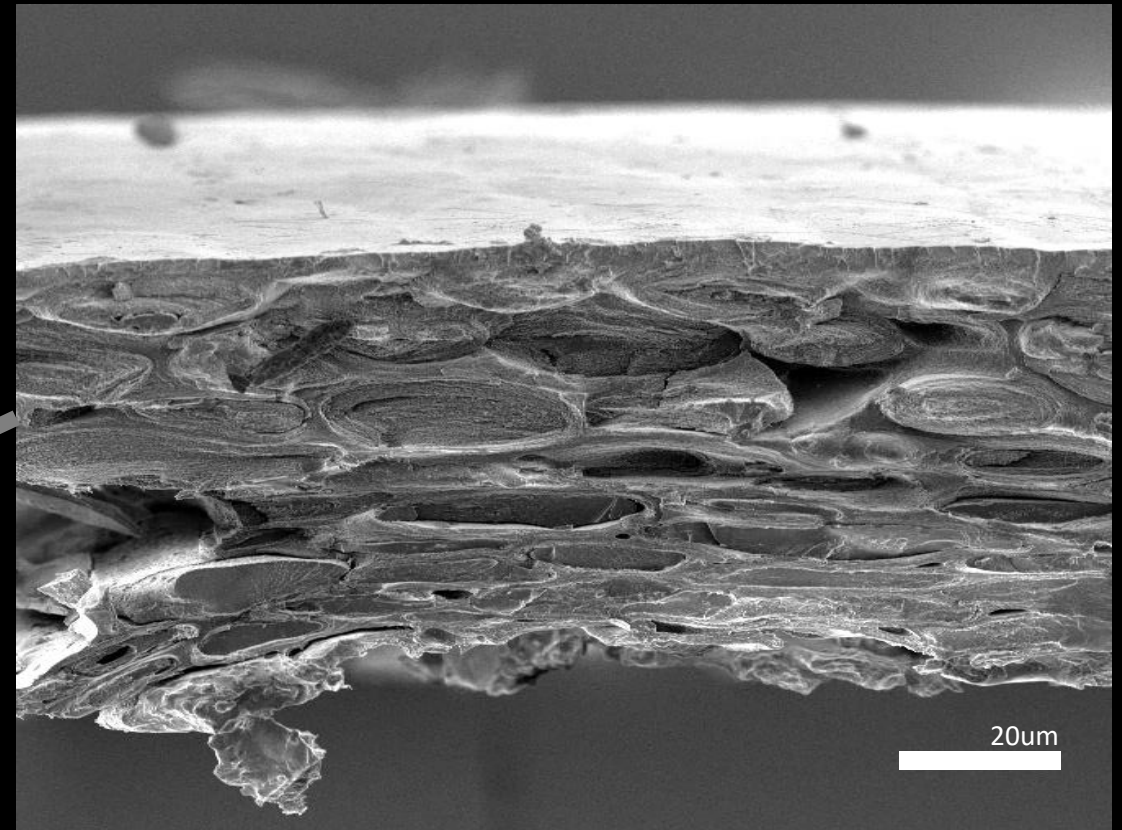
Viburnum



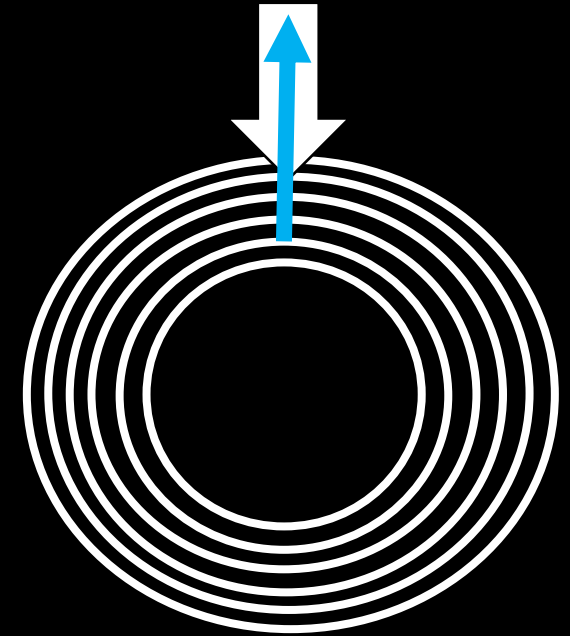
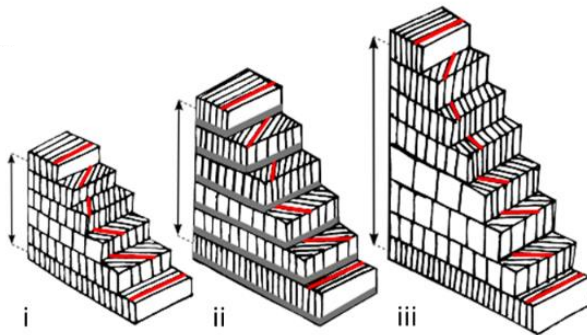
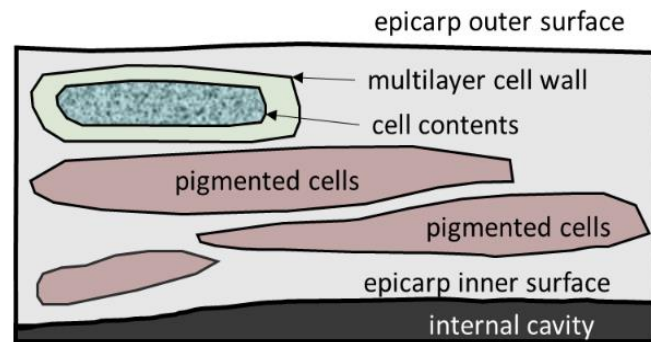
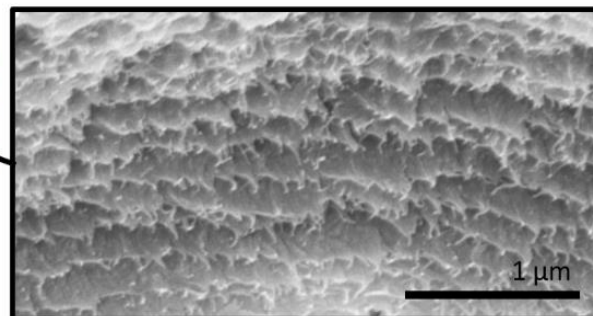
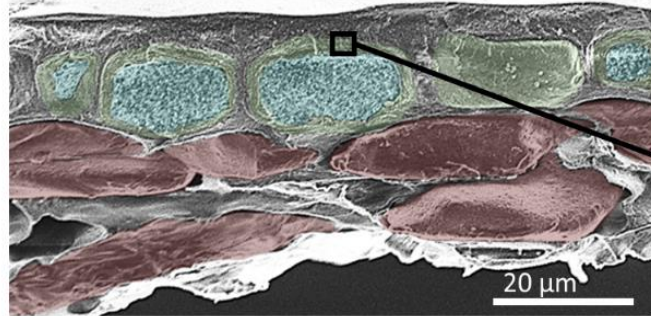
Pollia condensata



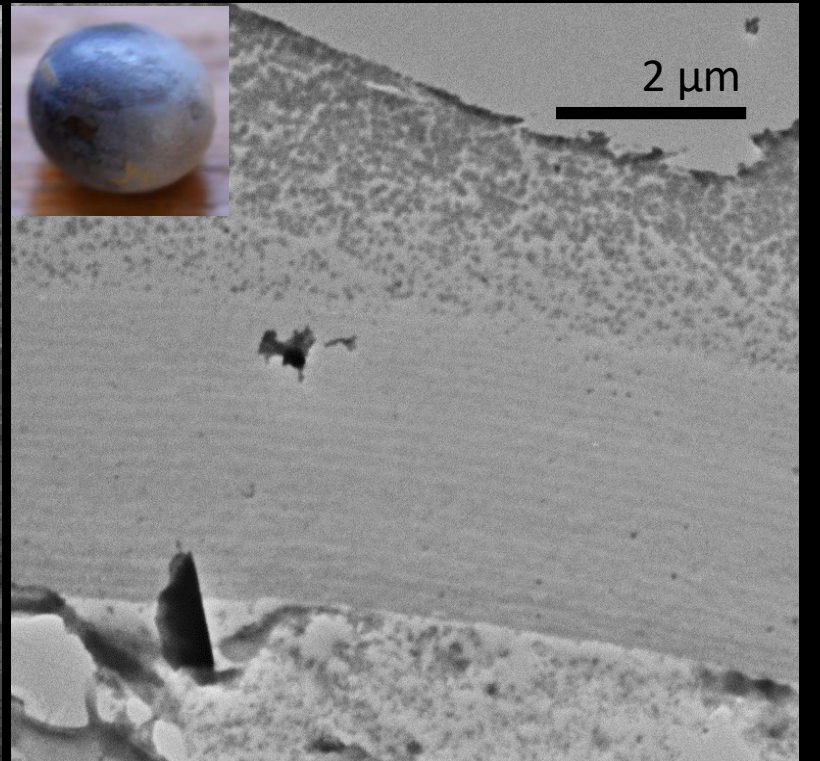
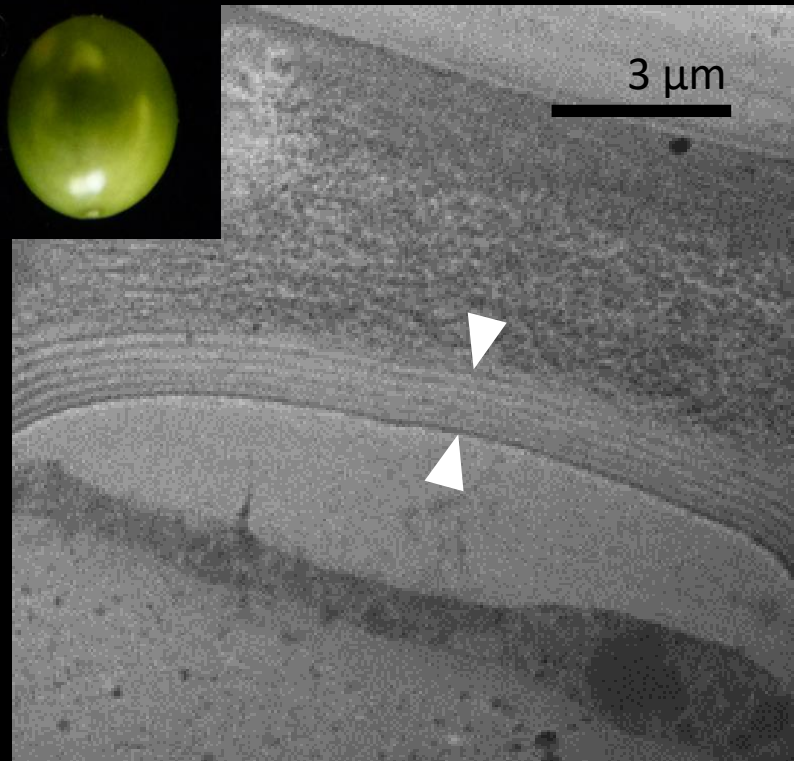
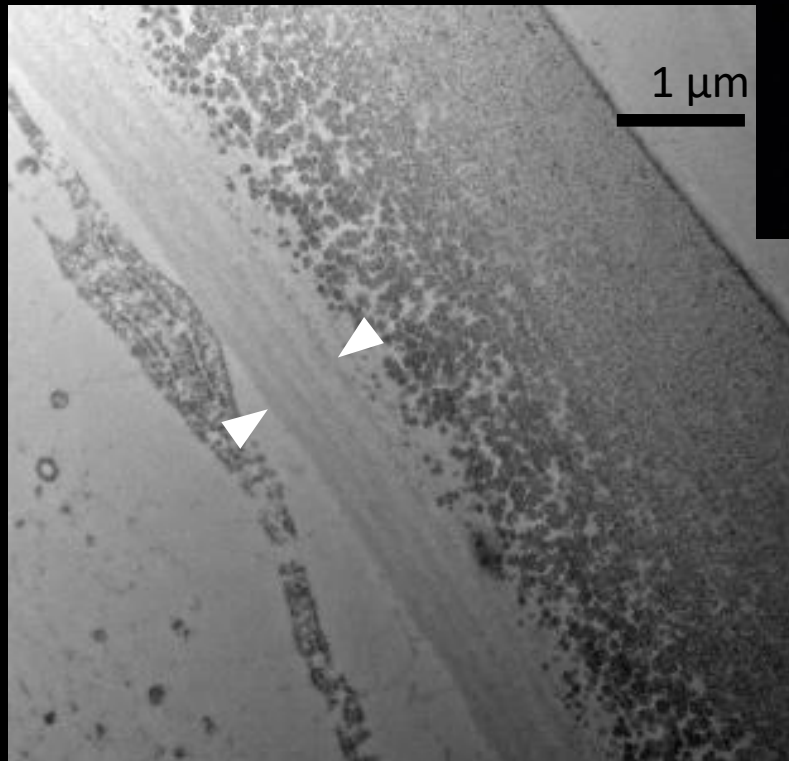
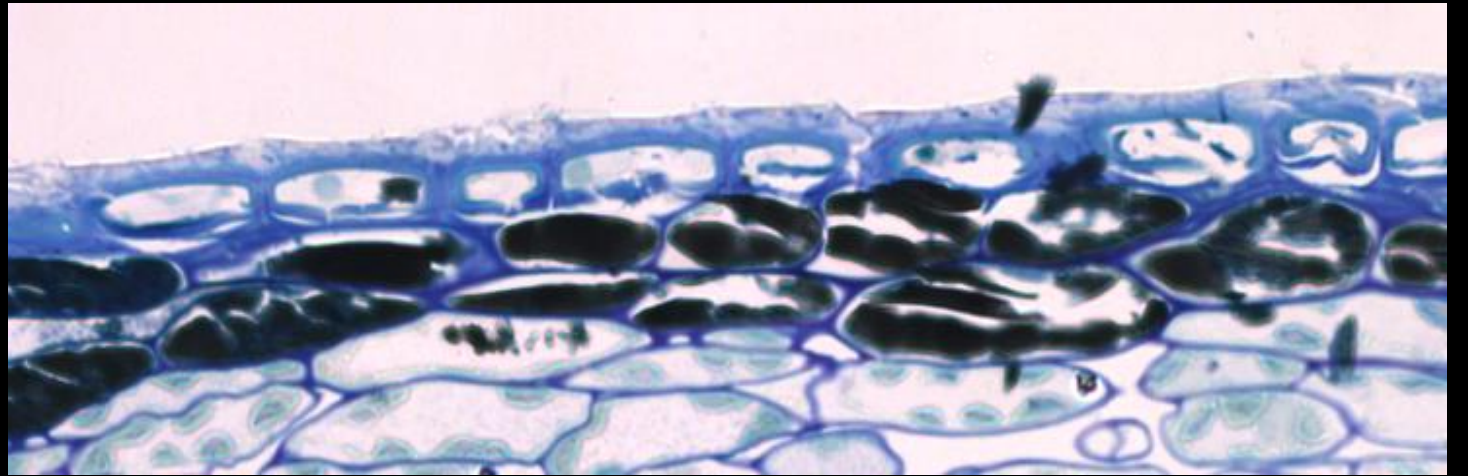
Pollia condensata
Vignolini et al.
PNAS 2012



Pollia japonica



How do cell walls grow?



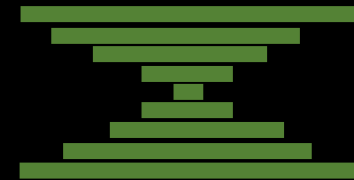
Blue-shift

No shift

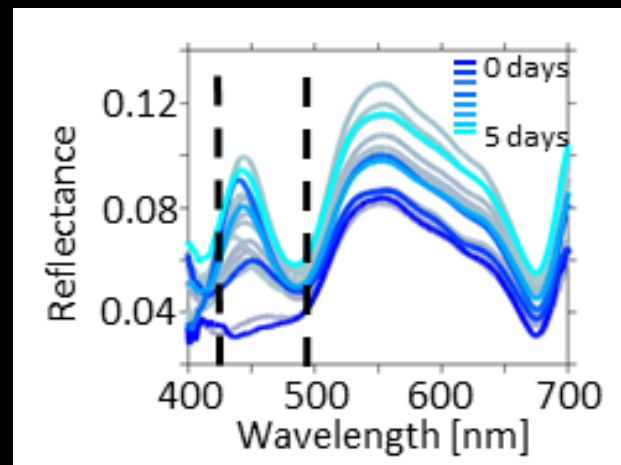
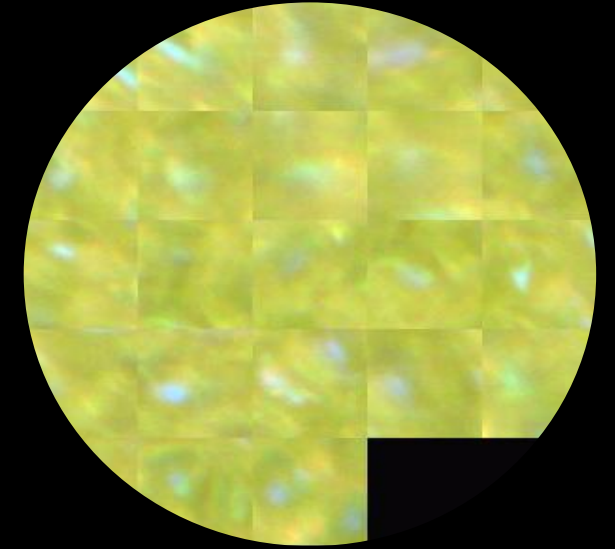
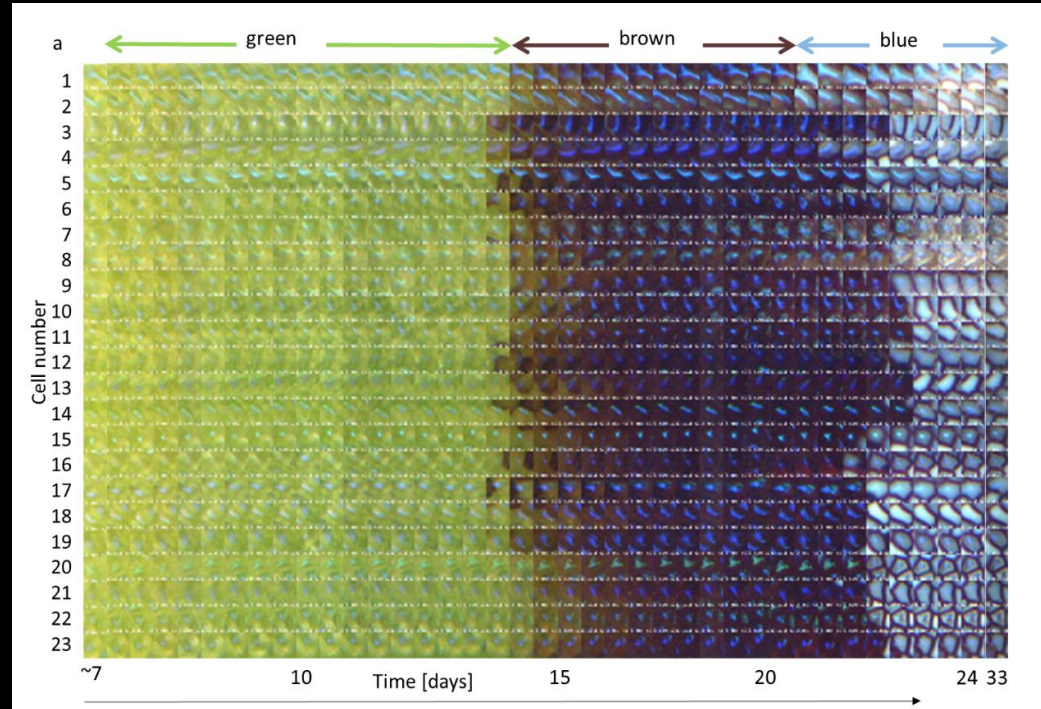
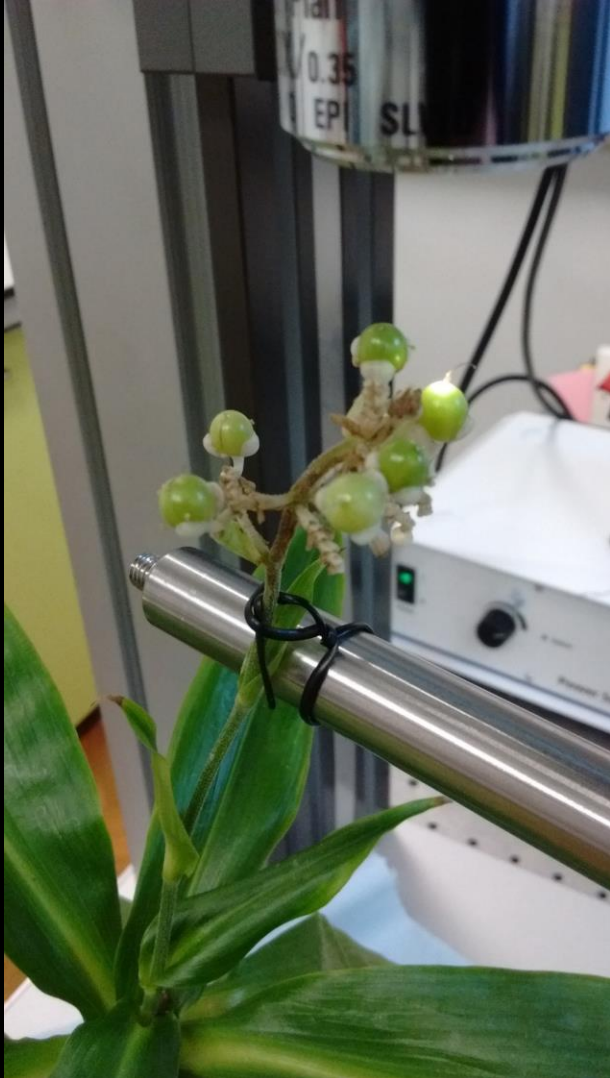
Red-shift



Growth
models



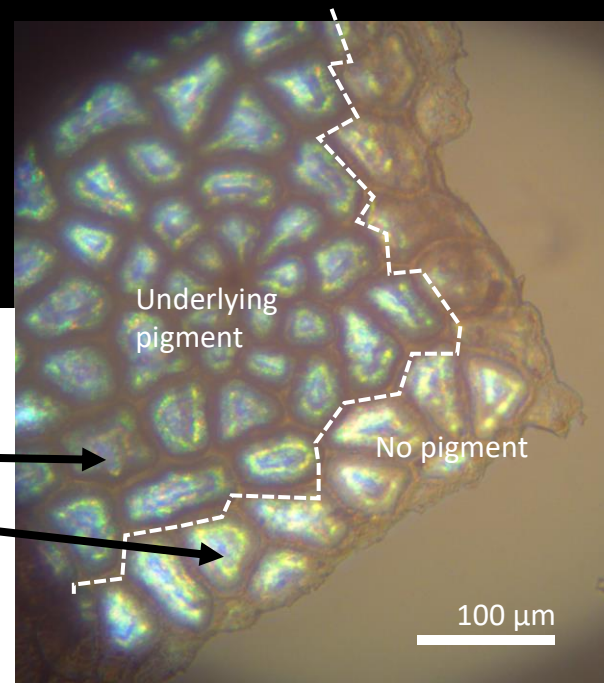
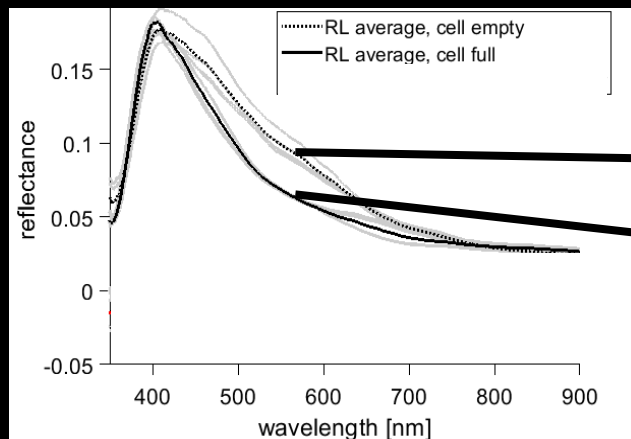
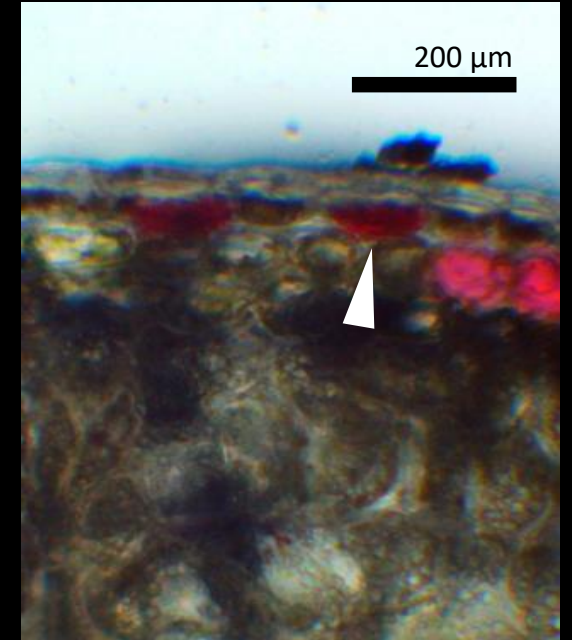
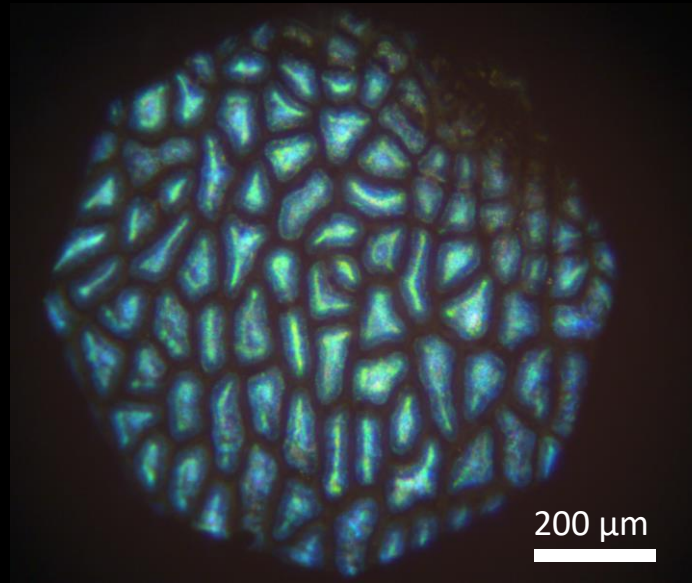
Pollia japonica



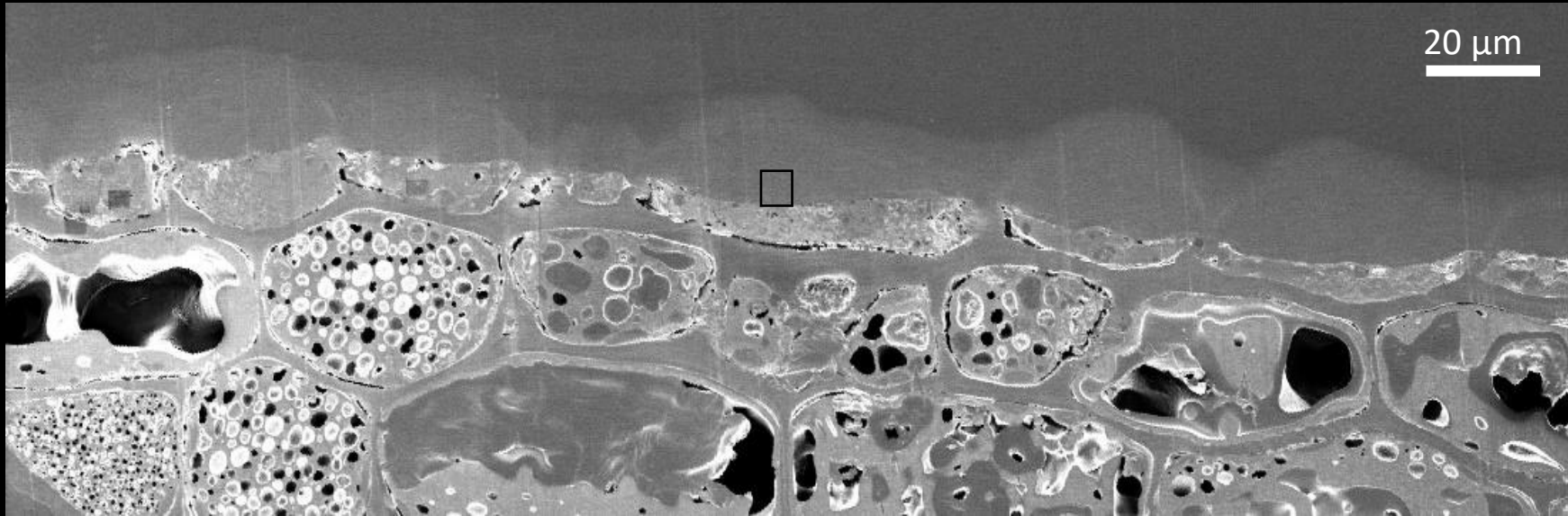
Viburnum tinus



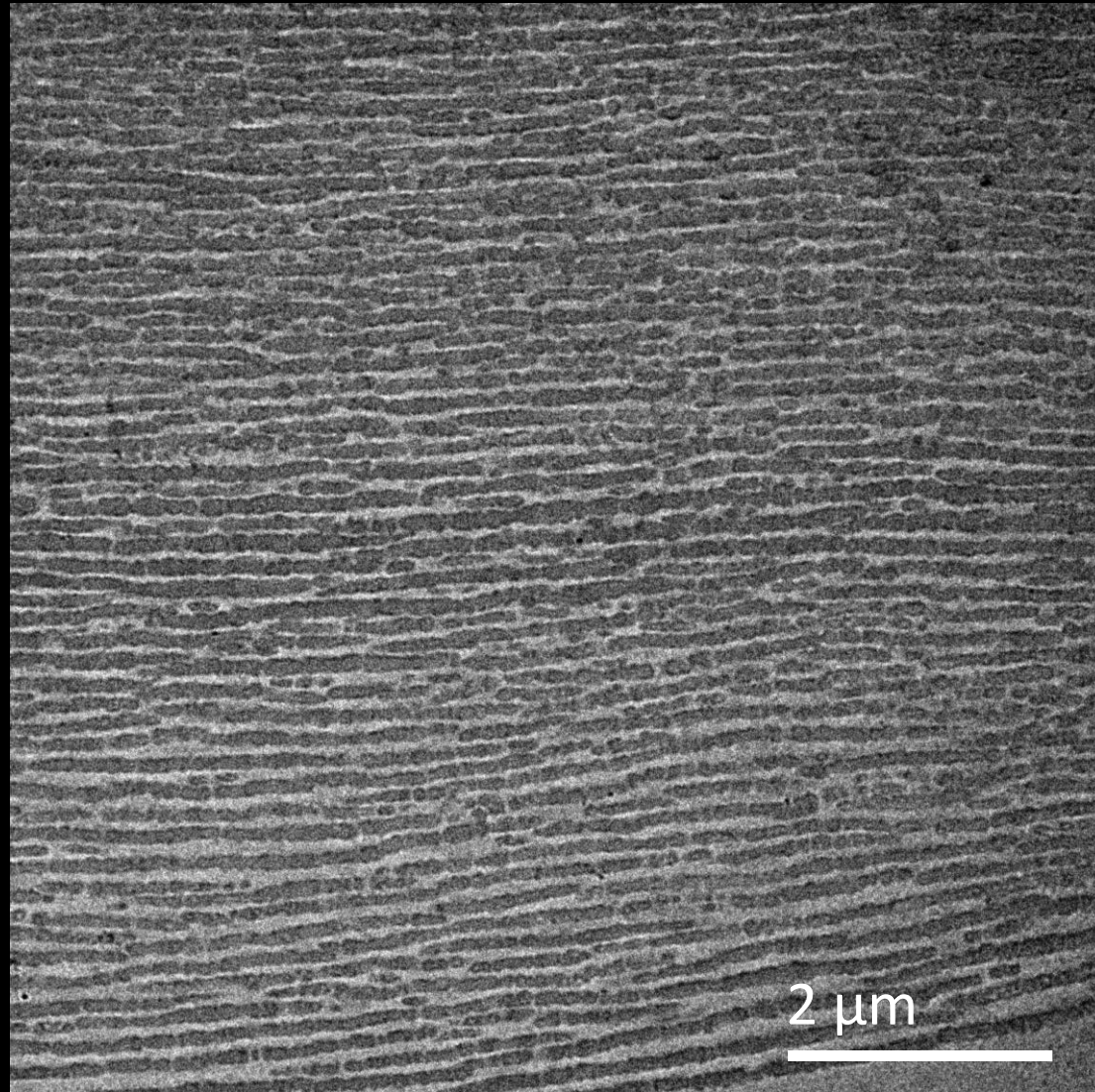
Viburnum tinus



Viburnum tinus

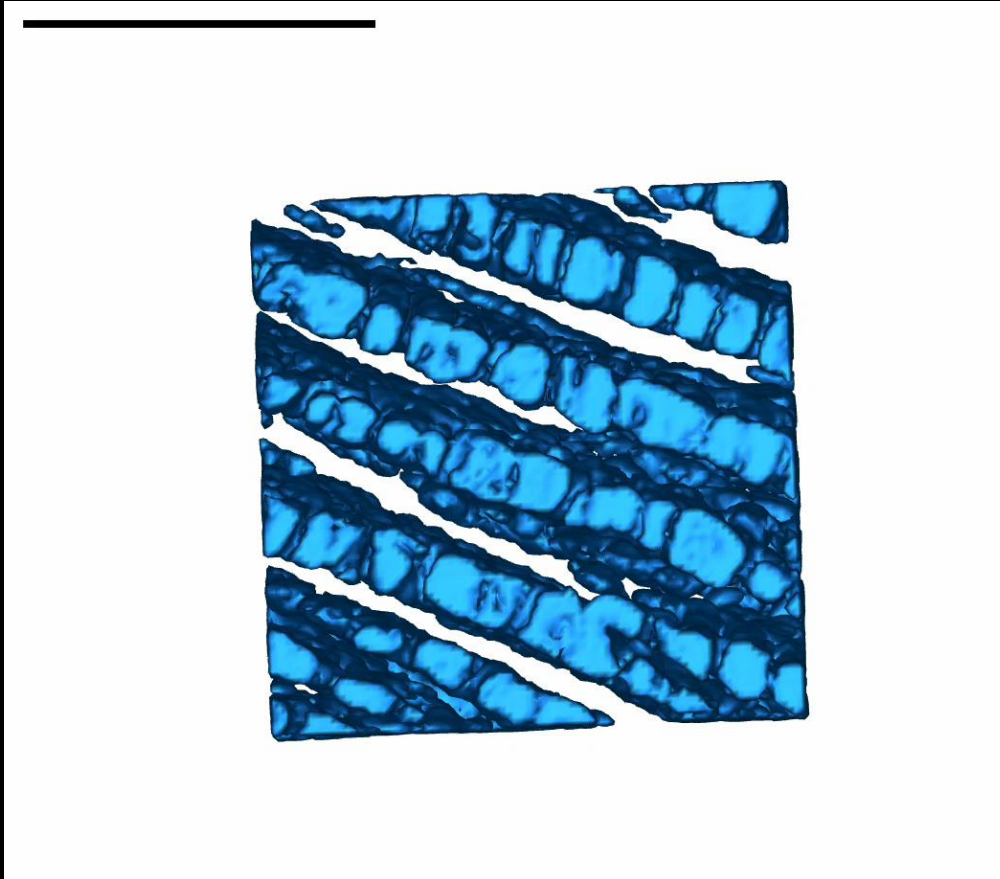


Viburnum tinus



Viburnum tinus

500 nm





Molecular pigment

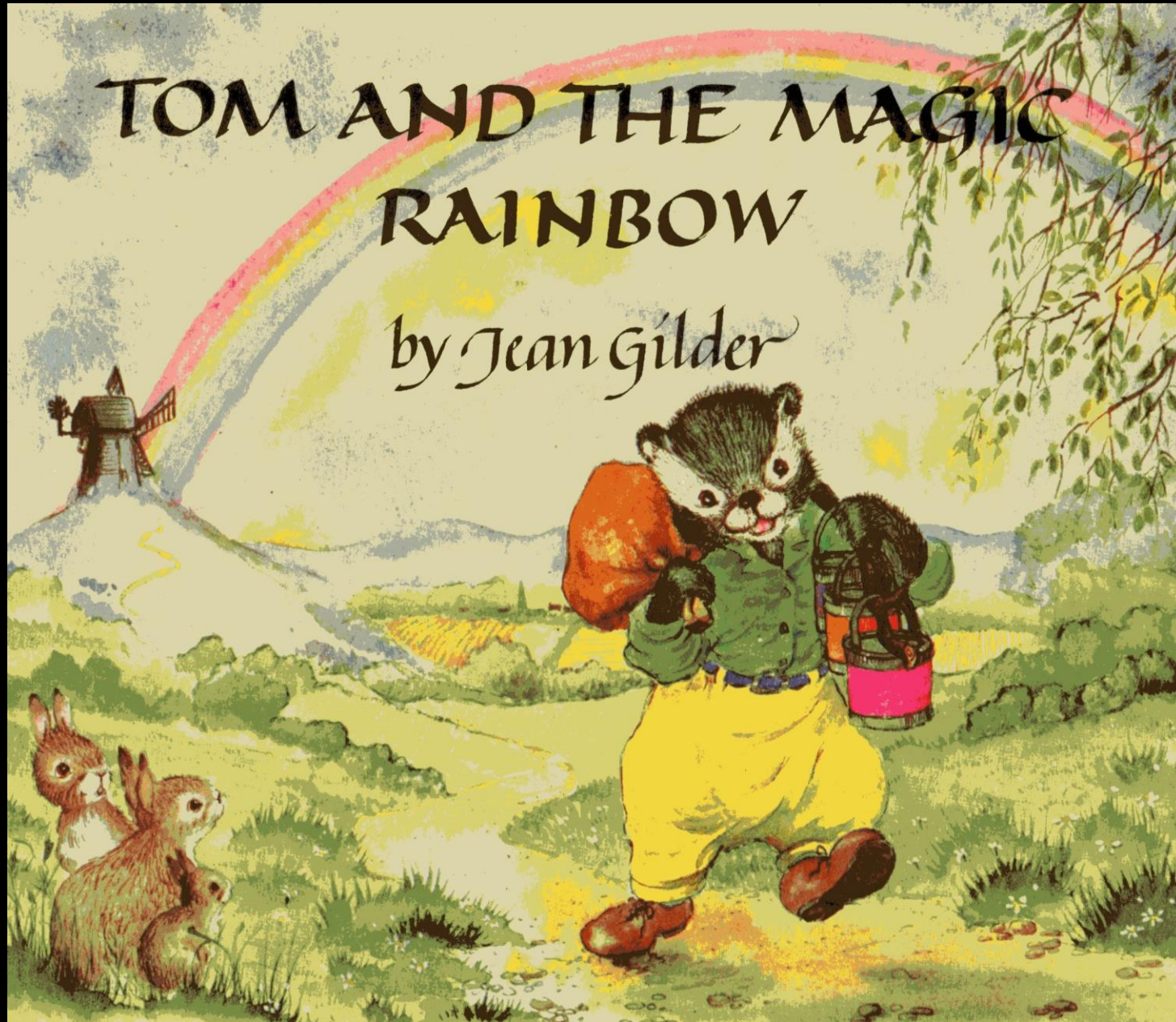


Structural colour



TOM AND THE MAGIC RAINBOW

by Jean Gilder



Polystyrene nanospheres



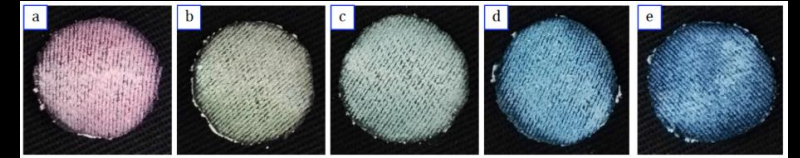
Yang et al. *App. Mat. & Int.*
2016

Silica inverse opal

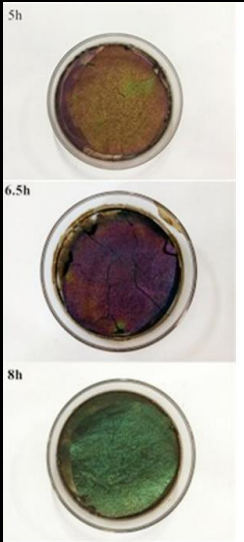


Josephson et al. *Z. Anorg. Allg. Chem.* **2014**

Silica nanoparticles on black cotton fabric



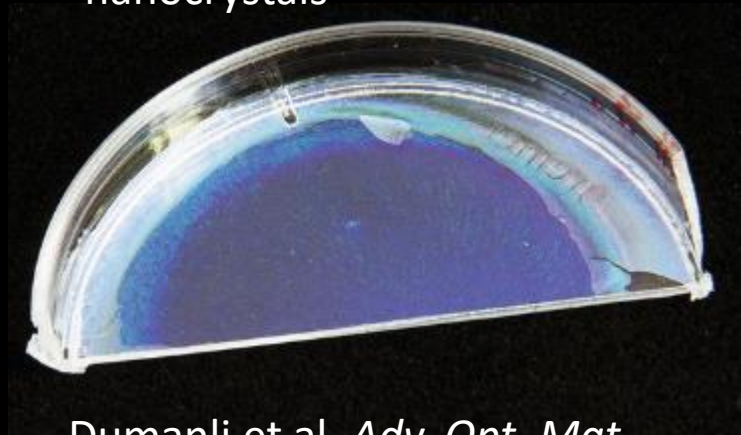
Gao et al. *Opt. Mat. Exp.*
2017



Polydopamine
nanospheres
on silk

Zhu et al. *Progress in Organic Coatings* **2020**

Self-assembled cellulose nanocrystals



Dumanli et al. *Adv. Opt. Mat.*
2014

Hydroxypropylcellulose



Kamita et al. *Adv. Opt. Mat.* **2016**

Chocolate with diffraction grating



Morphotonix **2014**

Benefits of structural colour



- made of any (patternable) material
- non-toxic / biocompatible / biodegradable
- improved colour brightness & saturation
- One material can be used to make any colour!
- responsive, colour-changing sensors



Thank you for listening



Advisors:

Dr Heather Whitney (University of Bristol)

Prof. Silvia Vignolini (University of Cambridge)

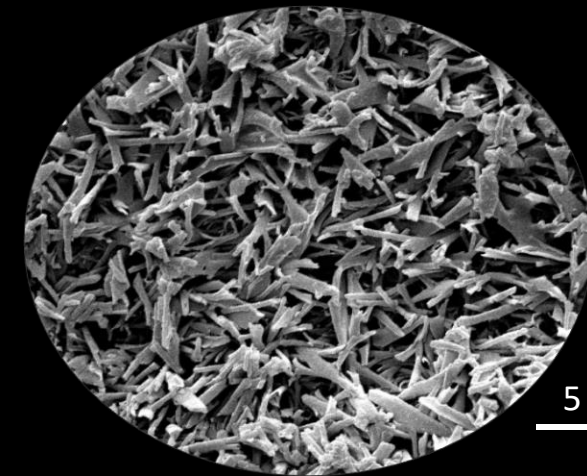
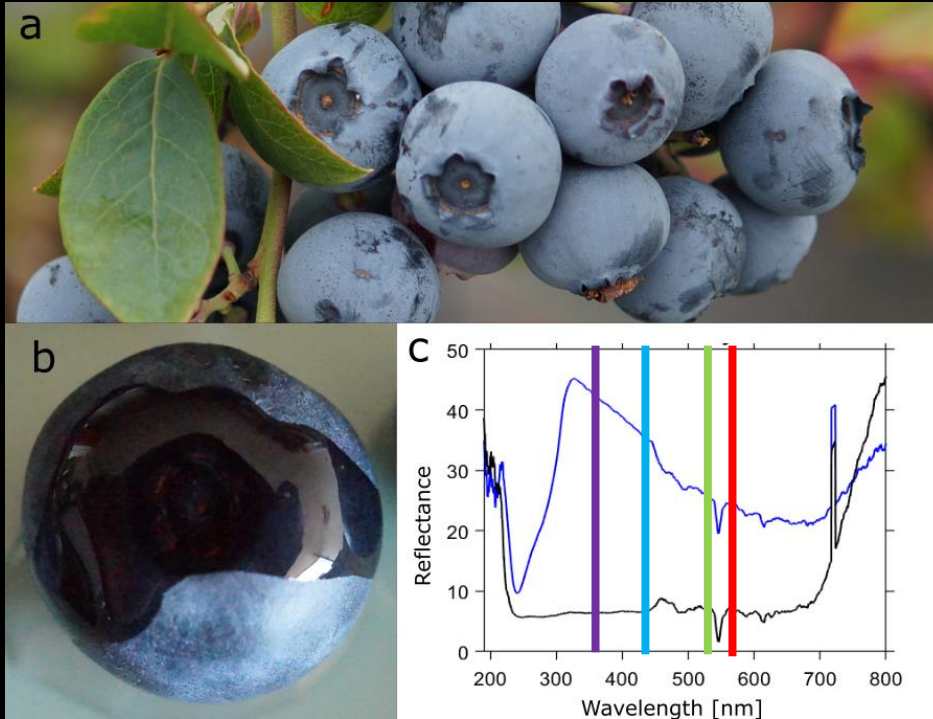
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Caffè-Scienza Firenze
11/06/2021

New Project: Blueberries



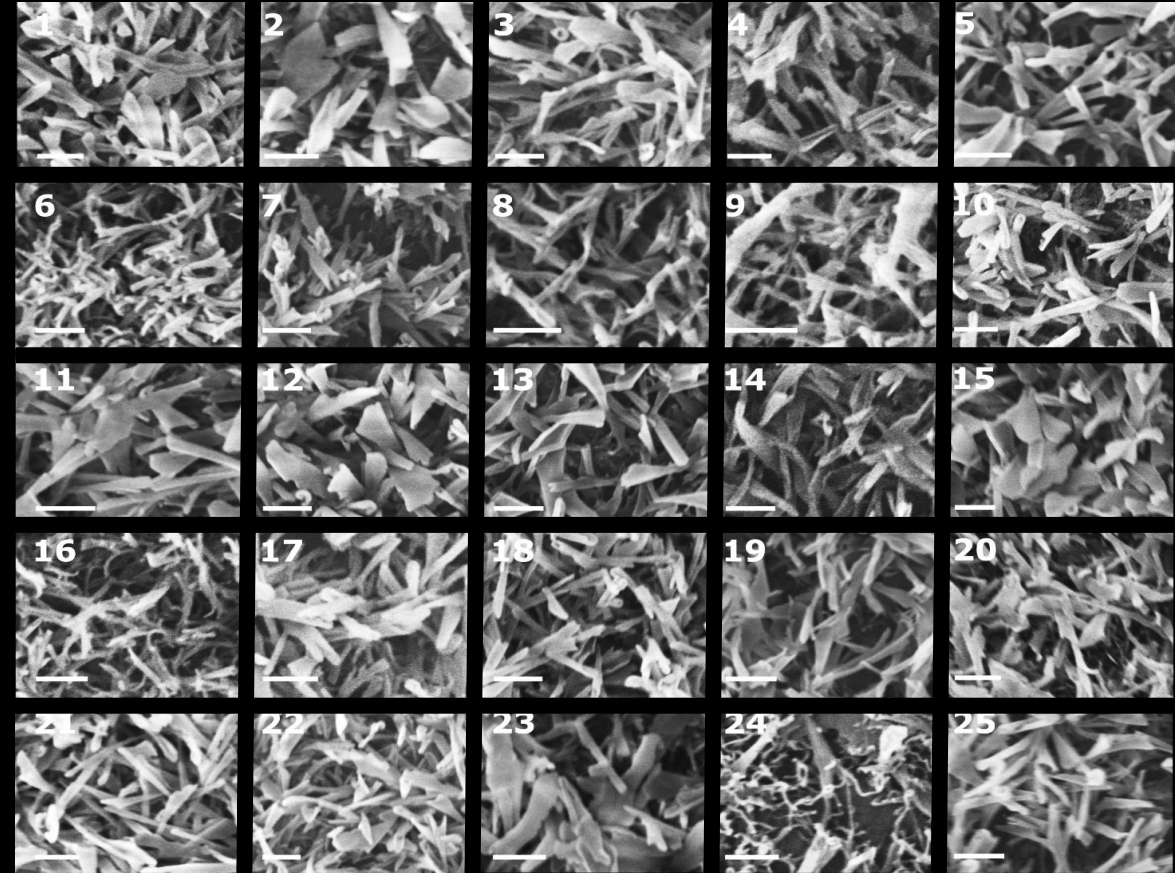
New Project: Blueberries



5 μ m

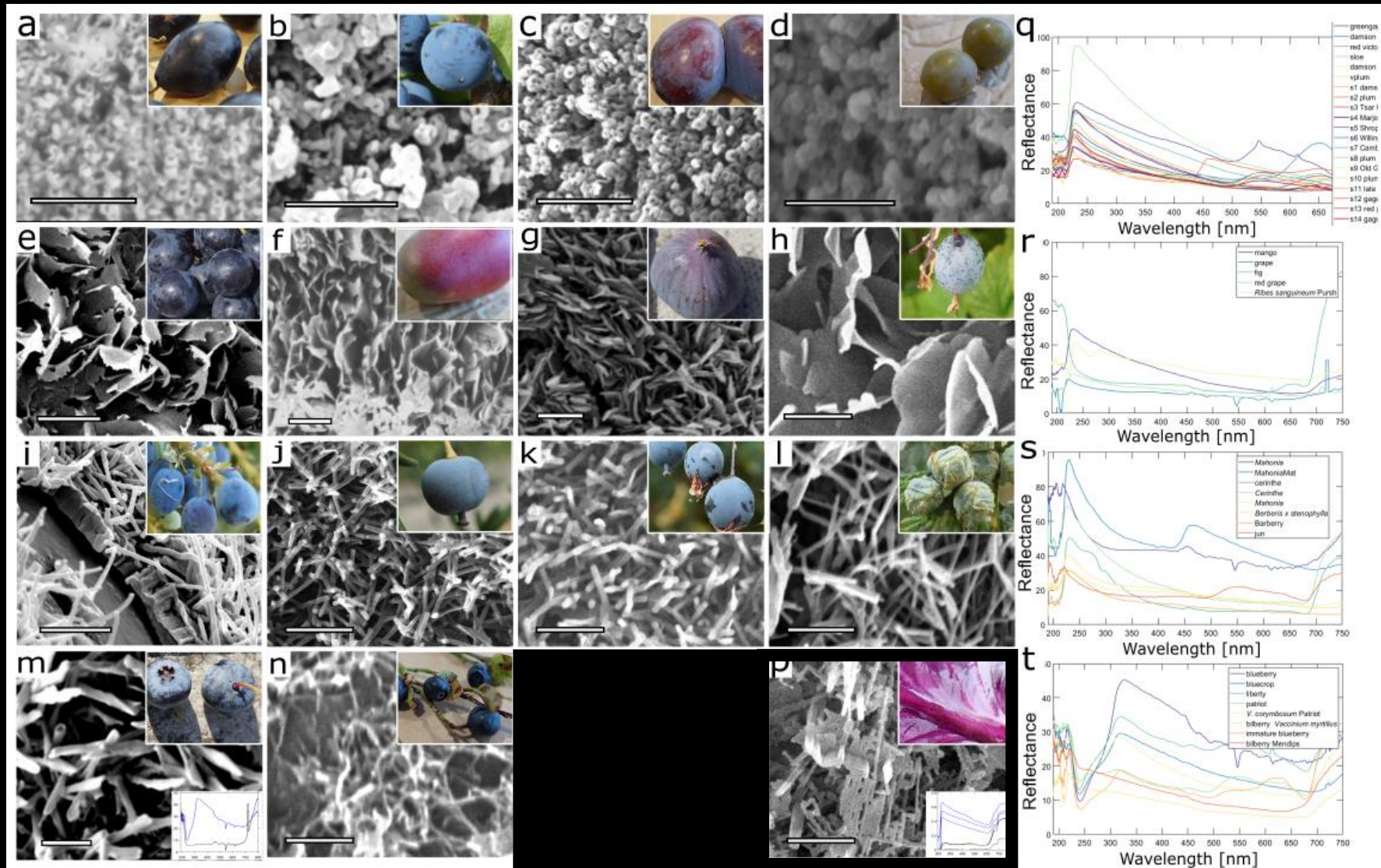
Vaccinium corymbosum

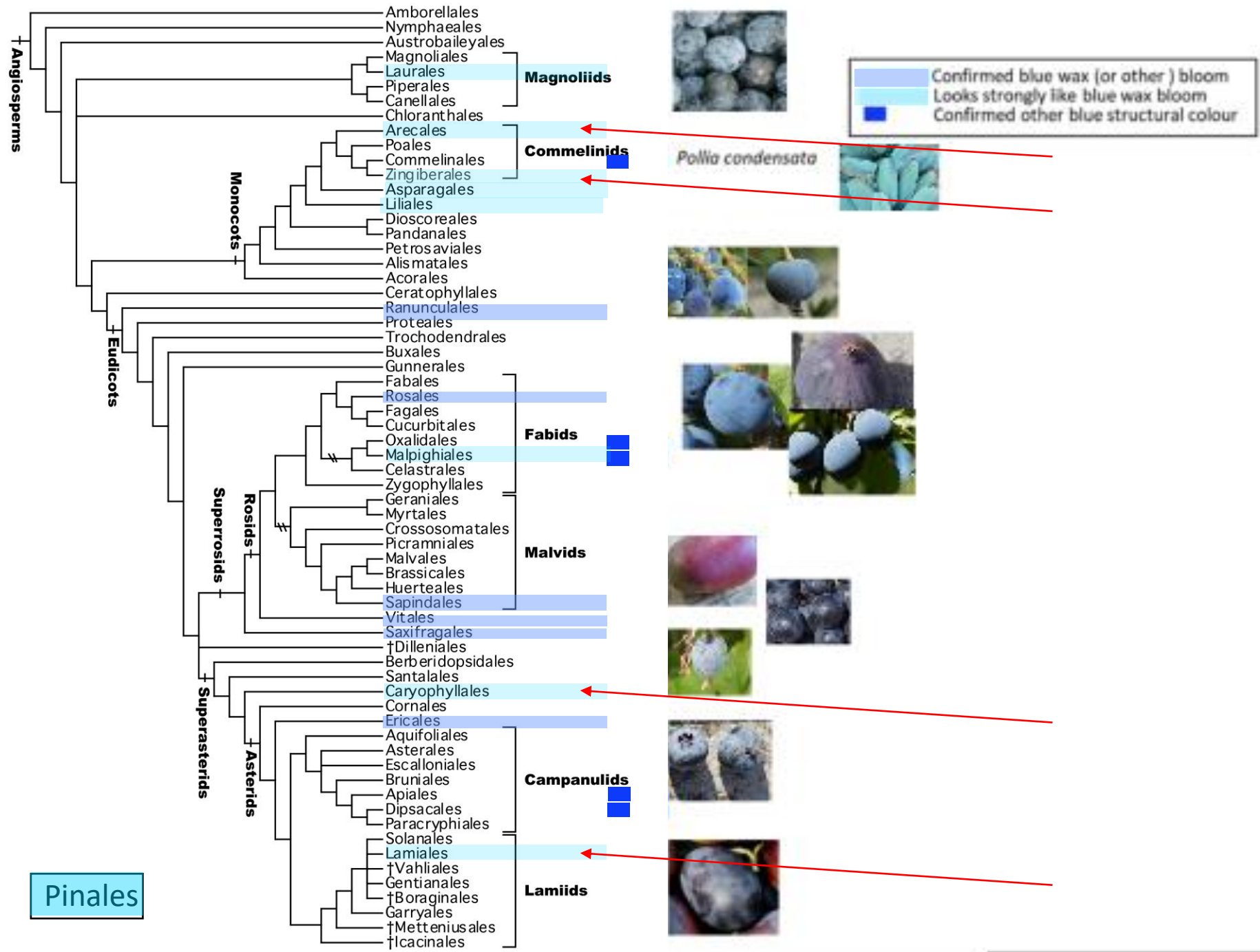
Blueberries



Dr Susan McCallum

Blue bloom fruits





Blue bloom fruits @ RBGE?

Arecales: *Euterpe oleracea* – acai – SOUTH/CENTRAL AMERICA,

Trachycarpus fortunei - Chinese windmill palm

@ RBGE

Oxalidales: *Davidsonia jerseyana* – Mullumbimby plum AUS

Sapindales: *Canarium odontophyllum* – dabai BORNEO

Caryophyllales: *Opuntia violacea* - prickly pear MEX/US

Cornales: *Nyssa sylvatica* – tupelo/ black gum – US/MEX

Bruniales: *Asimina triloba* – Pawpaw US/CAN

OPUNTIA BASILARIS @ RBGE ALSO ENGELMANII

@ RBGE

@ RBGE

Dipsacales: *Viburnum* x US

(CASSINOIDES PROBABLY –@ RBGE)

Lamiales: *Olea europaea* – olive

@RBGE but is it dark?

Zingiberales: *Musa itinerans* Burmese blue banana

@RBGE

Ranunculales: *Disciphania*

Sapindales: *Halfordia kendack* – AUS

Brassicales: *Carica papaya* – Papaya

@RBGE

Pinales: Pine cones, *Juniperus communis* var. *saxatilis* Pall. Juniper

@RBGE

Malpighiales: *Passiflora lutea* yellow passionfruit

Asparagales: *Polygonatum biflorum*, small solomon's seal

@RBGE

Liliales: *Smilax lasioneura*, blue Ridge Carrion

there are other smilaxes @RBGE

Ranunculales: *Caulophyllum thalictroides* blue cohosh

@RBGE looks particularly blue!

Menispermum canadense common moonseed

Laurales: *Sassafras albidum*

@RBGE

Thanks!

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- Phylogeny
- Chemical composition
- Development in vivo
- In vitro blue pigments
- Optical modelling
- New waxes and new morphologies
- Visual signalling and plant-animal interaction
- Non-visual functions of nanostructure

In vitro recrystallisation

