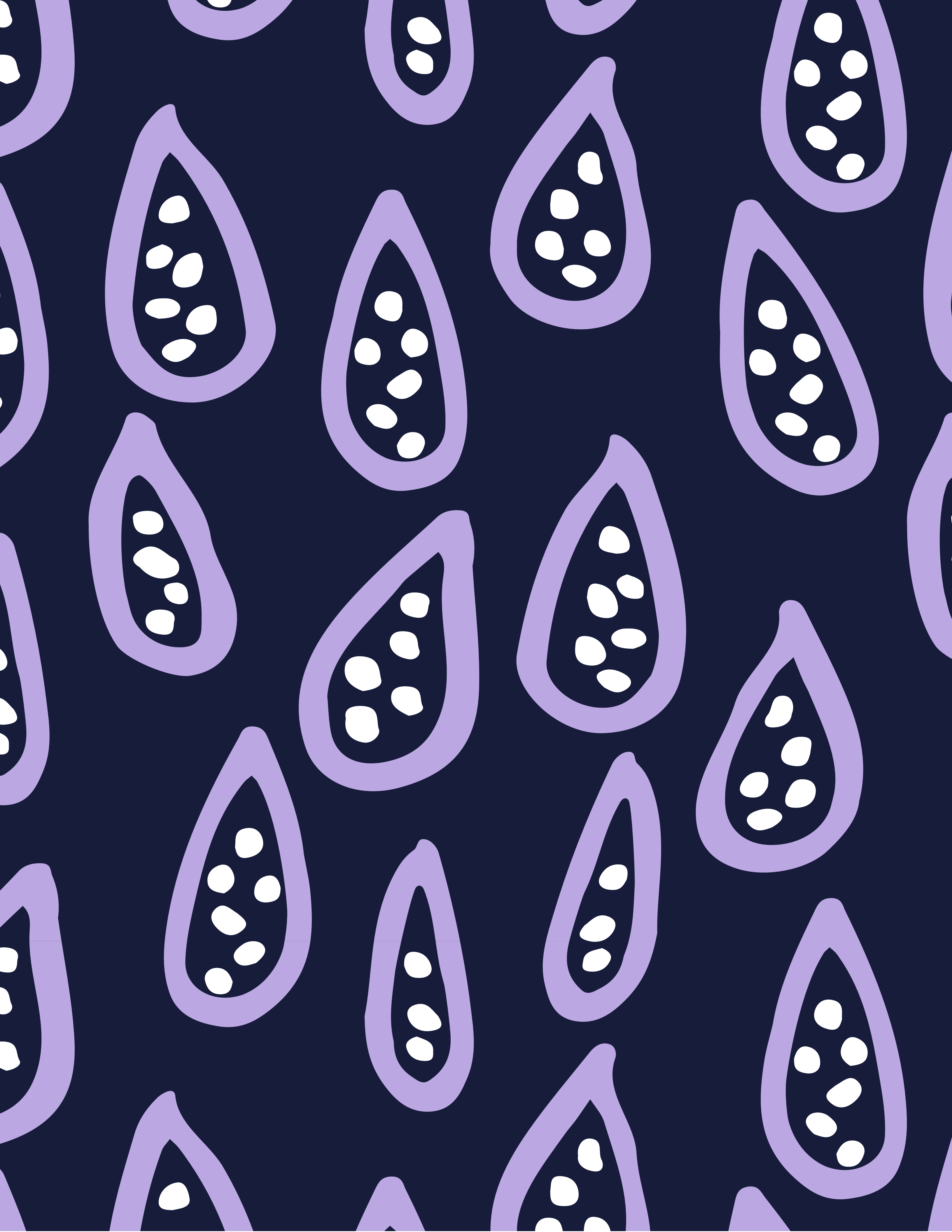


Lessons From Biology: Hierarchical Structures (HS[s])

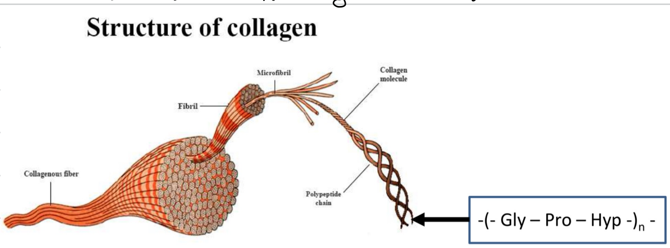
- Hierarchical Structures: Build up of structural layers/components that combine into a larger/scaled phase

↳ Example: Tendons = Tropocollagen → Micro Fibril → Sub fibril → ... → Tendon

- Assemblages of molecular units of their aggregates that are embedded or intertwined with other phases
- Present in practically all complex systems, especially natural ones
- 3 basic principles

1. Scale: Structure is organized in discrete levels or scales
2. Interaction: levels of structural organization held together by specific interaction btwn components
3. Architecture: Levels organized into an oriented hierarchical composite system

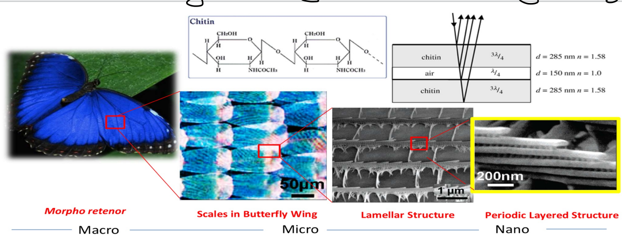
- Uniaxial Mechanical System: Tendon



- Operates reversibly at uniaxial tension
- Hierarchical Structure absorbs energy & protects the tendon as a whole from catastrophic failure

Other examples: Human Hair

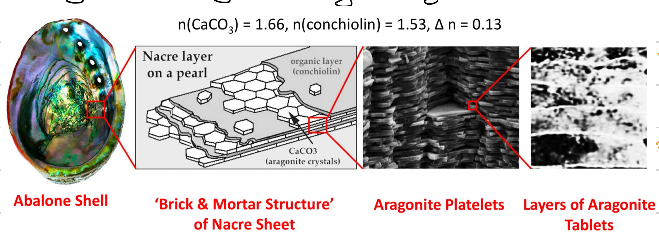
- Photonic Layered Systems: Butterfly Wings



- Periodic Structure creates photonic band gap that gives a brilliant blue color
- Periodicity is different in different butterflies, thus giving color to their wings
- The color is not due to a pigment

Other examples: Elytra of Beetles

- Organic/Inorganic Layered System: Nacre Shells



- Organic cement act as ductile friction preventing crack growth
- (linear slope) Elastic Moduli: 70 GPa in dry, 60 GPa in wet state
- (max pt. lin.) Tensile Strengths: 170 MPa in dry, 130 MPa in wet state
- (3 pt load) Flexural strength (between 100 and 200 MPa) is comparable to many other ceramics

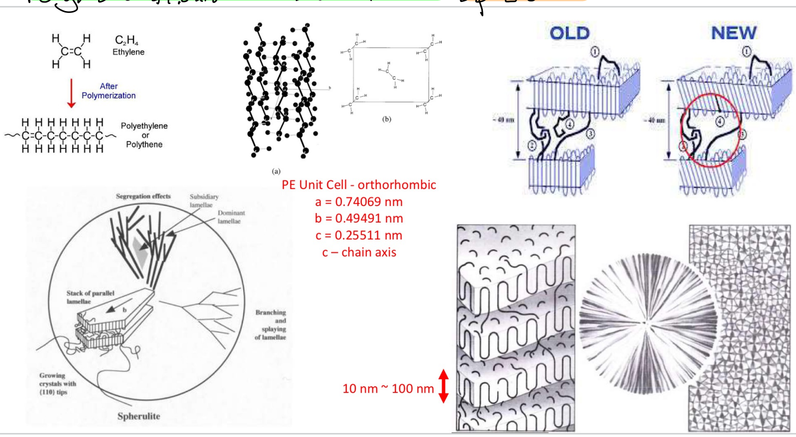
Other Examples: Bone (Young's Modulus btwn 8 and 24 GPa)

- Hierarchical structures in Plants: Wood Cellulose, Bamboo
- Important Concepts in Hierarchical Structures

Scale ← Interaction ← Architecture

Molecular, Nano, micro to macro-scopic — Interfacial interactions — Complex assemblies

- Polymeric Hierarchical Structures: Spherulites



- Hierarchical Structures Elsewhere
  - → The Eiffel Tower
  - → Management Systems → Hierarchical Structures
- Protein HS based on Amino Acid Seq.
  - → A linear seq. of a large number of amino acids forms primary protein structure
  - → The Intramolecular interactions among specific segments of the amino acids in the primary structure forms the Secondary structure

Polystyrene and Styrofoam

Vinyl Polymers   Not to be confused with PVC materials

- Most common type of polymers derived from "vinyl-type" monomers: $CH_2=CHR$
- Olefin polymers are a subgroup of vinyl monomers produced from alkenes having a C_nH_{2n} monomer struct.

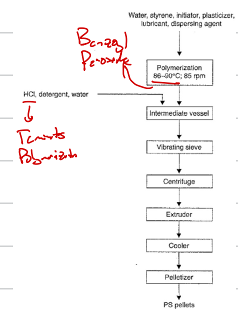
Vinyl Polymers
polystyrene – R = C_6H_5
polyvinyl chloride – R = Cl
polyvinyl acetate – R = O_2CCH_3
polyacrylonitrile - R = CN

Olefin Polymers
polyethylene – R = H => $CH_2 = CH_2$; (n = 2) => C_2H_4
polypropylene – R = CH_3 => CH_2 = CH-CH_3; (n = 3) => C_3H_6
polybutylene – R = CH_2-CH_3 => CH_2 = CH-CH_2-CH_3; (n=4) => C_4H_8

Polystyrene

- $T_g = 102°C$, can be increased by forming a copolymer
- Polymerized by free radical polymerization

Flow Diagram for suspension polymerization of PS



Rand. • Atactic: $T_g \approx 100°C$
Alt • Syndiotactic: rapidly semi-crystalline $T_g = 100°C$, $T_m = 270°C$ can crystallize, but weaker crystal domain
Same • Isotactic: slowly semi-crystalline $T_g = 100°C$, $T_m = 240°C$
↳ None have crystallization temperature!

Recall
- Amorphous = without structure, no repeat ordering
- Semi-crystalline = regions of both crystalline & amorphous

- Crankshaft motion of chains @ $T > T_g$ but frozen @ $T < T_g$
  ↳ Phenyl group spinning on the backbone

Unmodified Polystyrene is quite brittle

- Thermally insulative, XPS for insulation, and EPS for coolers and packaging
  ↑ Extruded   ↳ Expanded