

Solid
Soft Matter

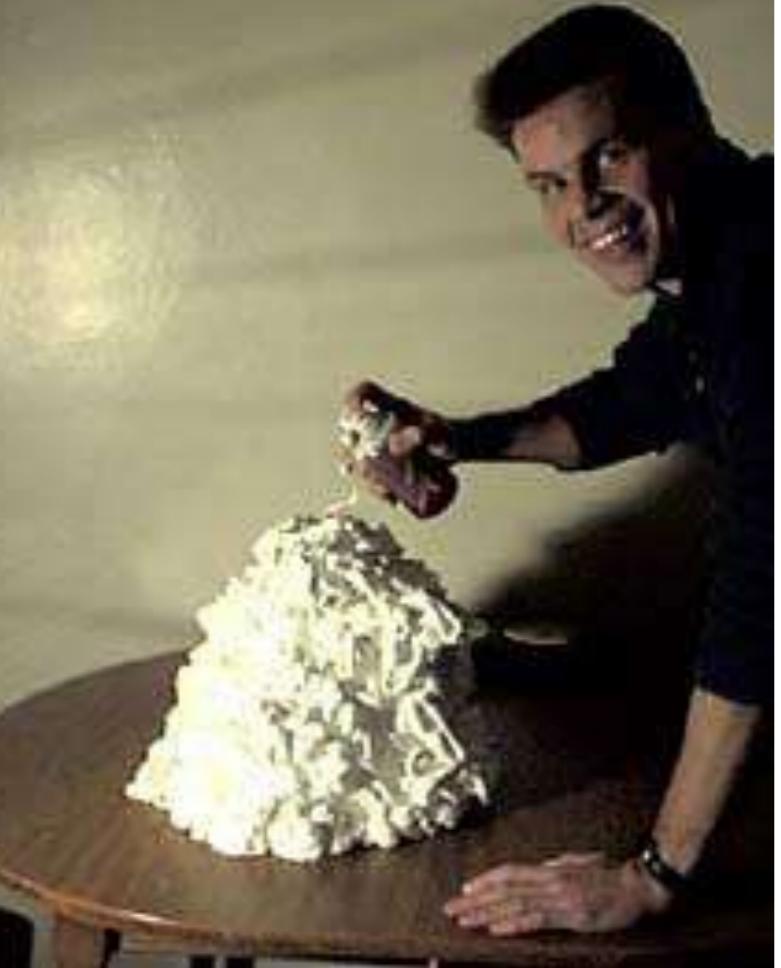
Liquid

GAS

Mechanics of Soft Matter & Application to Evo-Devo



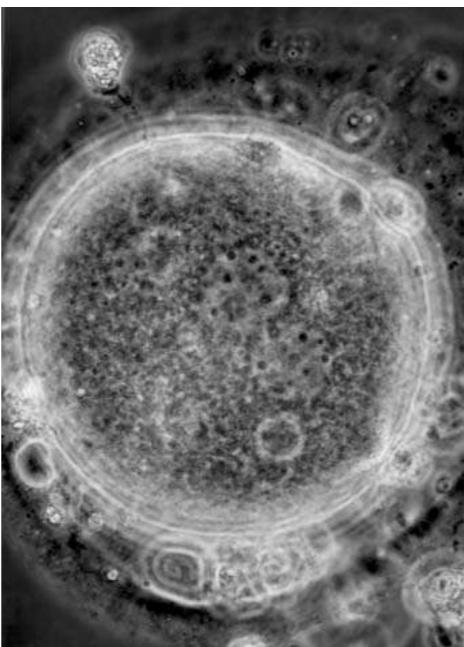
Stephen M. Levin, MD
Ezekiel Biomechanics
Group 8608 Dixie Place
McLean, VA 22102
USA smlevin@biotensegrity.com
[m www.biotensegrity.com](http://www.biotensegrity.com)



foams

Colloids & Emulsions

Pbursariandos



Ovum

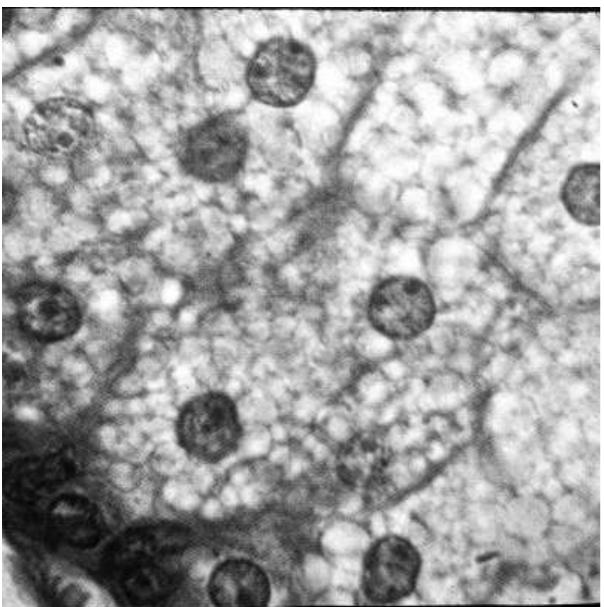


2-day Embryo

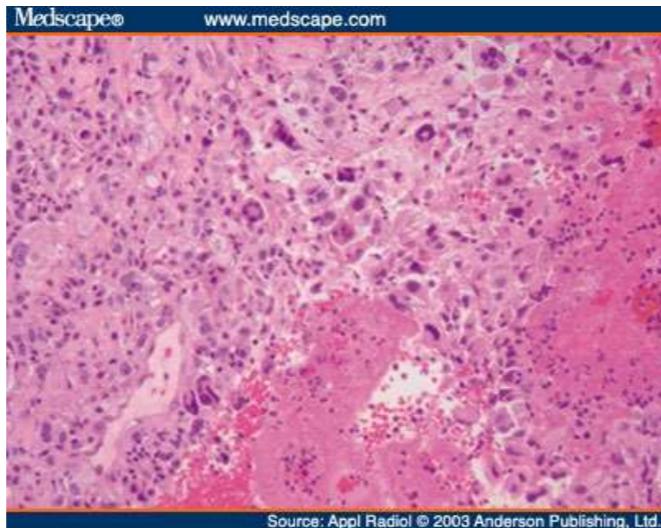


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Cartilage



Fat Cells



Sarcoma

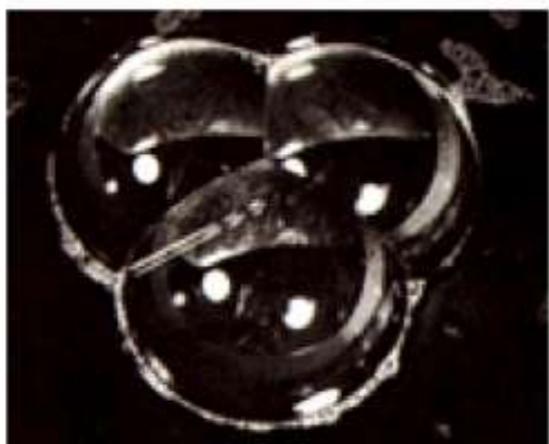


Frogs Eggs



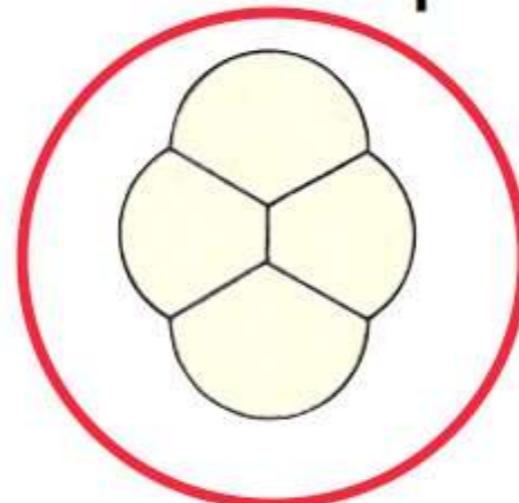
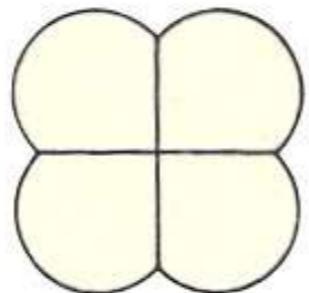
Bone

F O A M S



2-day Embryo

- * Only three films ever meet to form the edge of a bubble
- * Any two adjacent films always meet at an angle of 120°
- * Exactly four edges ever come together to meet at a point

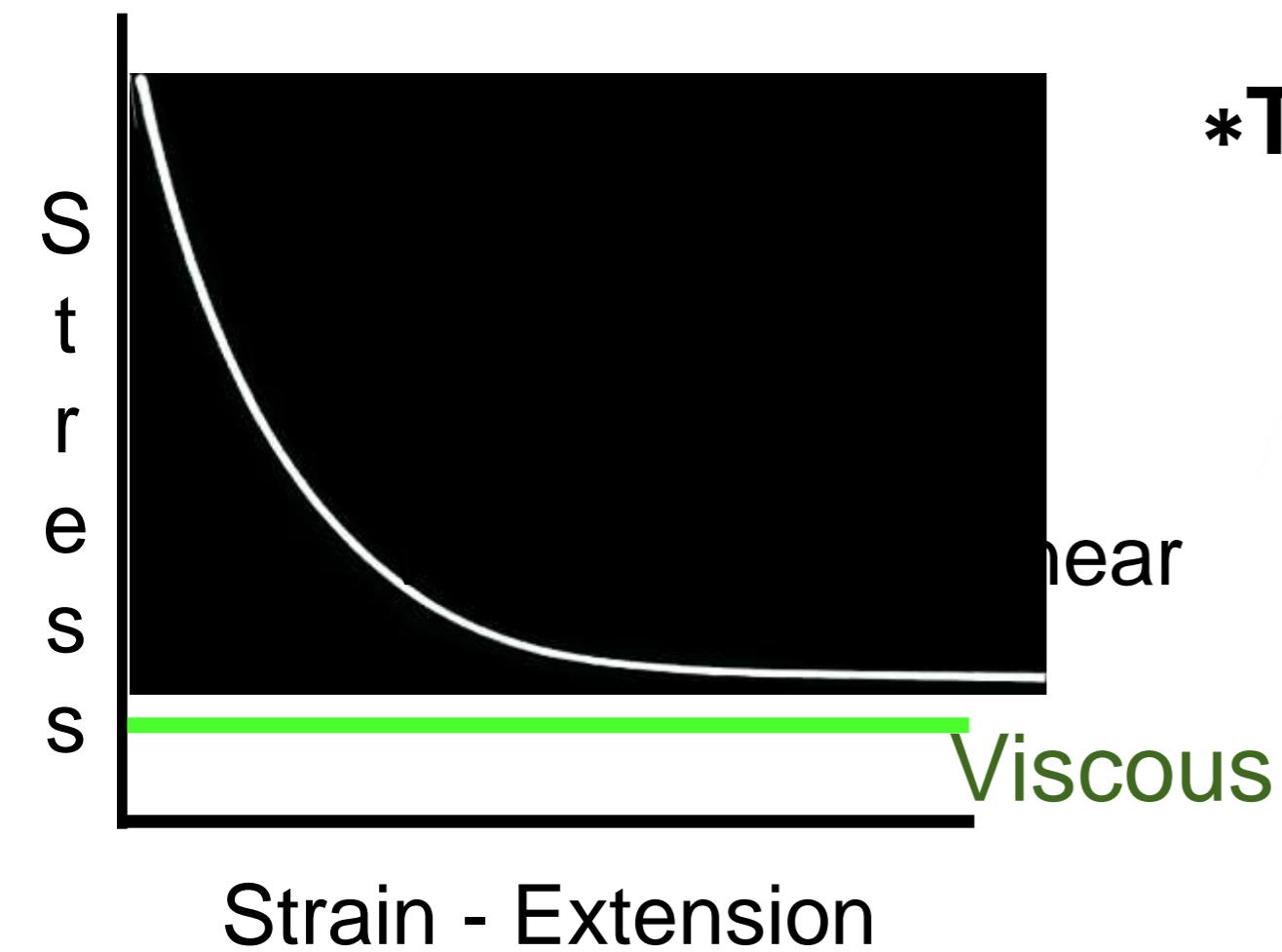


foams



*Spacial Interaction is important
(Mesoscopic Organization-you can't judge a foam by one bubble)

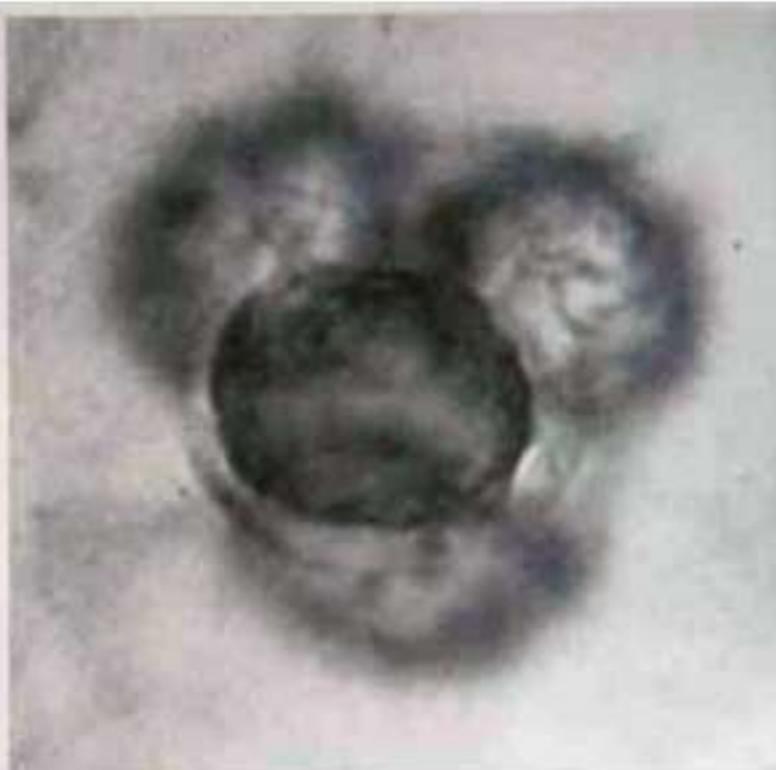
*The systems are in non-equilibrium



*The systems are nonlinear



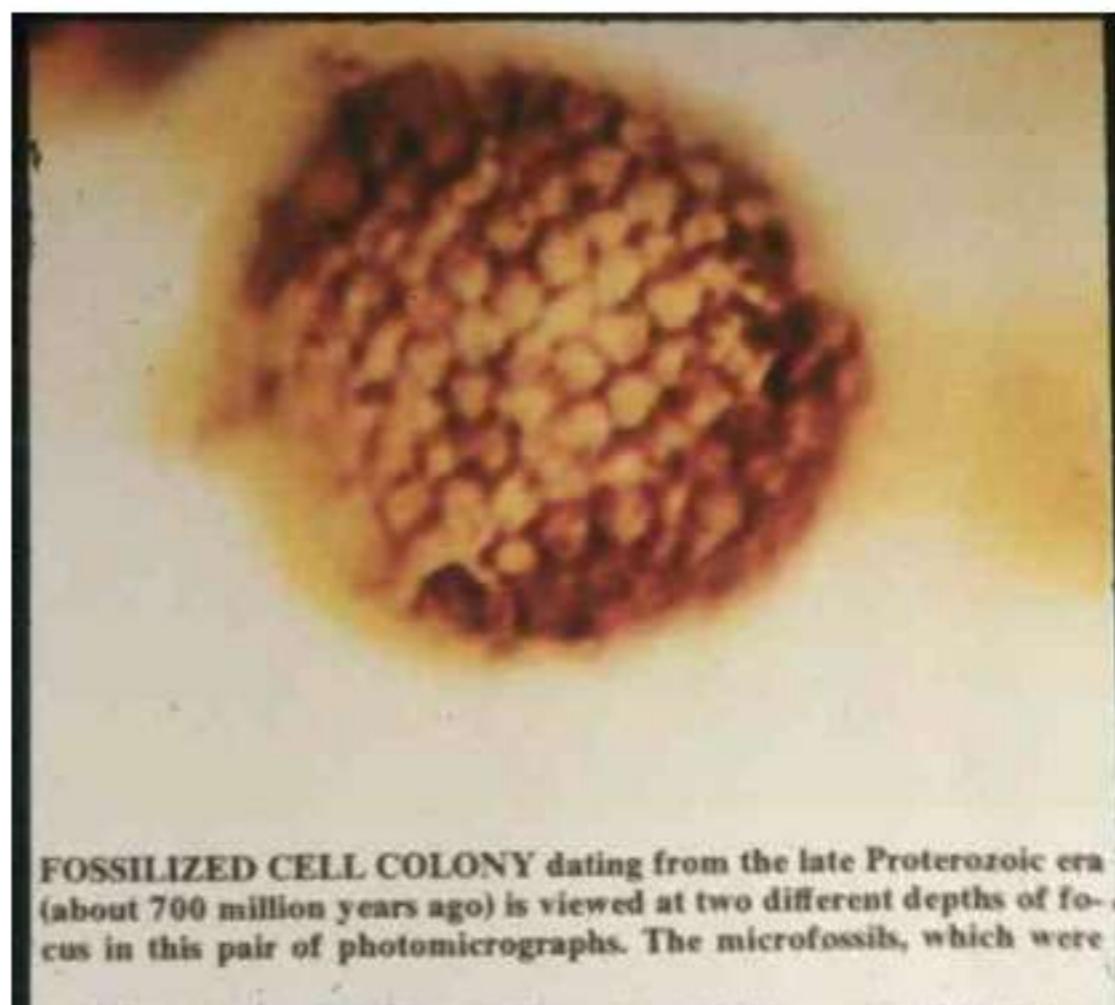
700 million yo fossilized Cell Colony



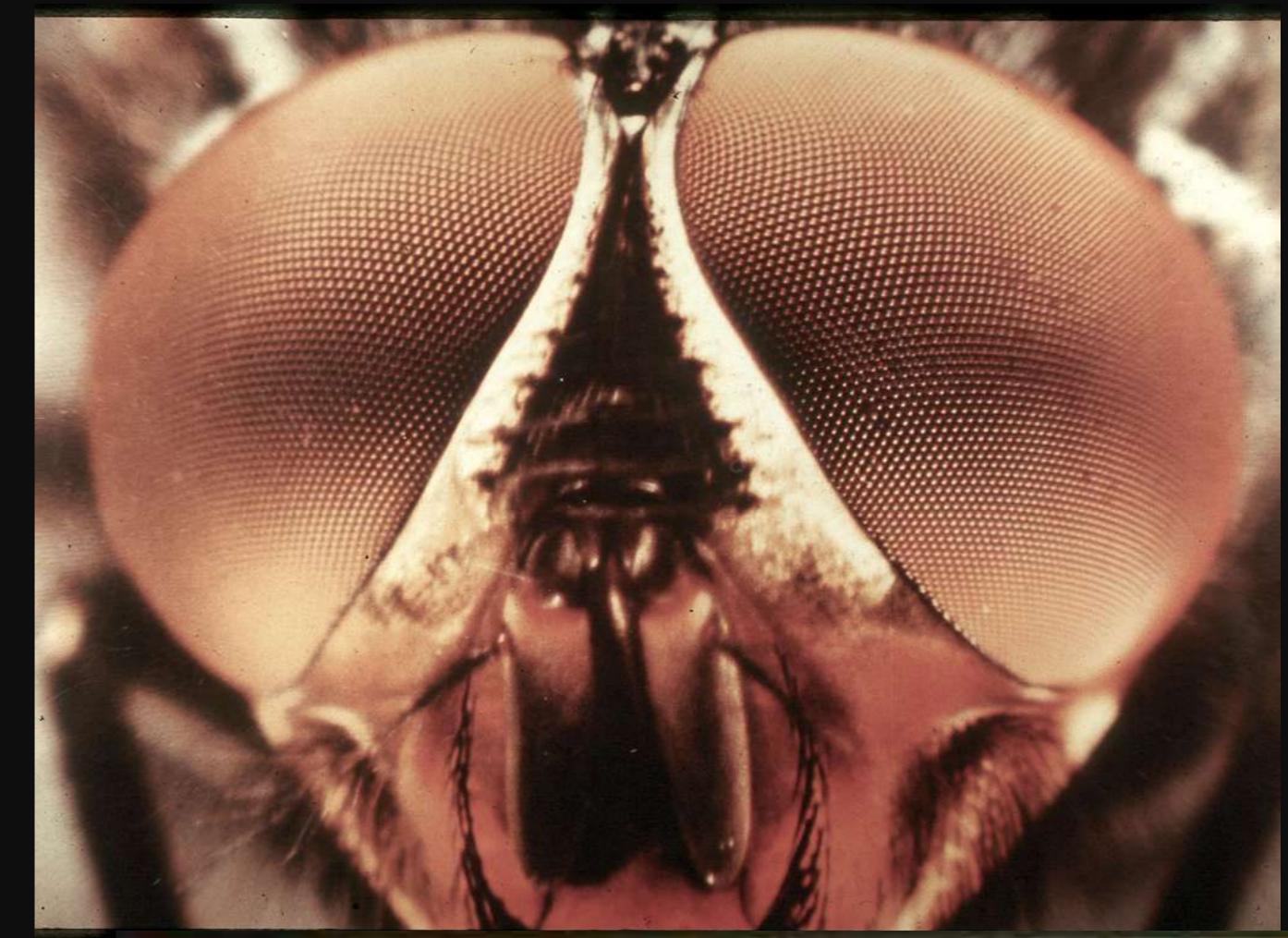
giant spherical prokaryote; it was found in Utah shales 800 million years old. The cluster of cells shown in two views at

850 million years old. The cells are only 10 micrometers across, but their tetrahedral arrangement suggests they formed as a result of mitosis.

800 million yo cells
 10μ
Tetrahedral

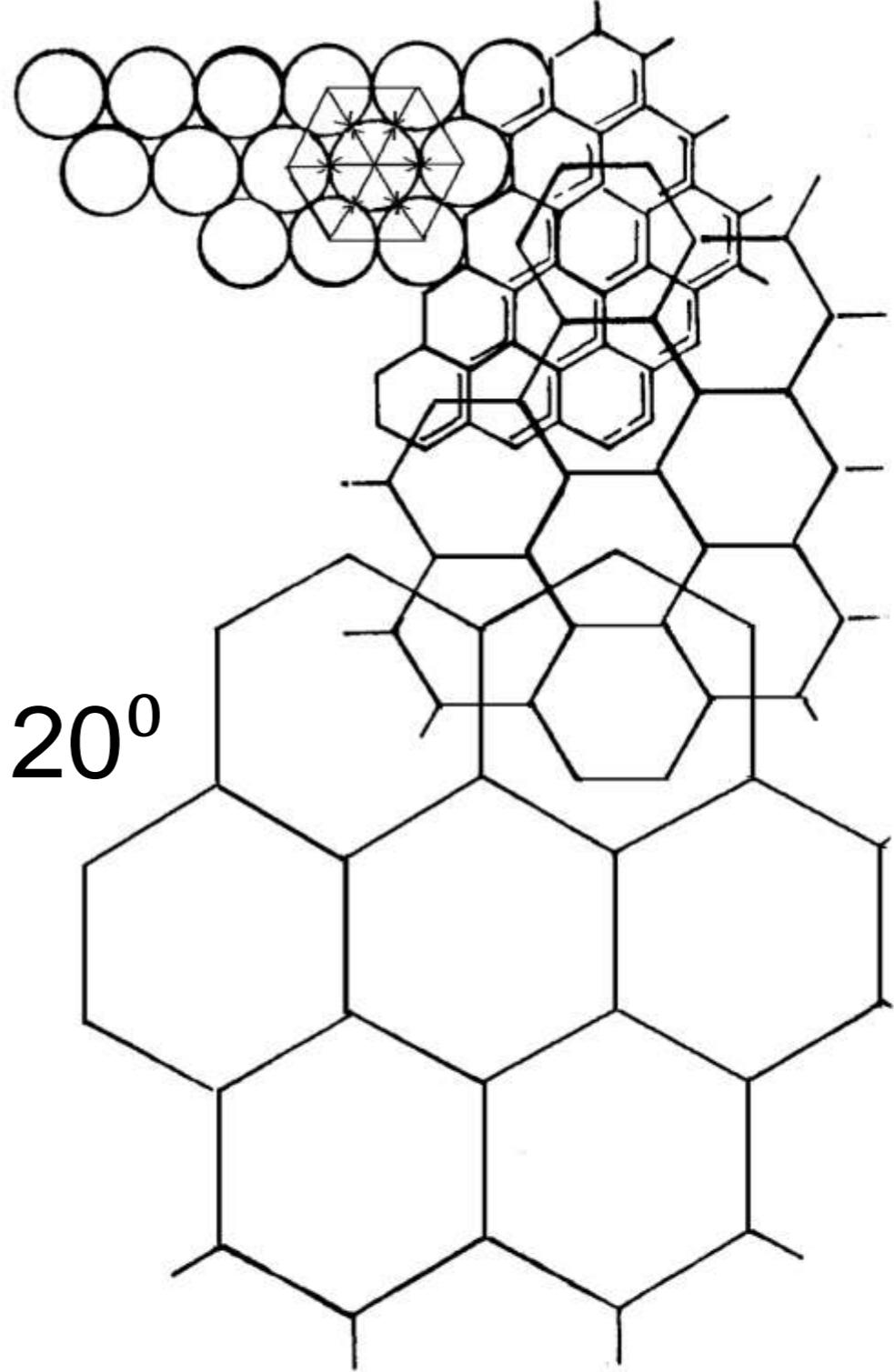
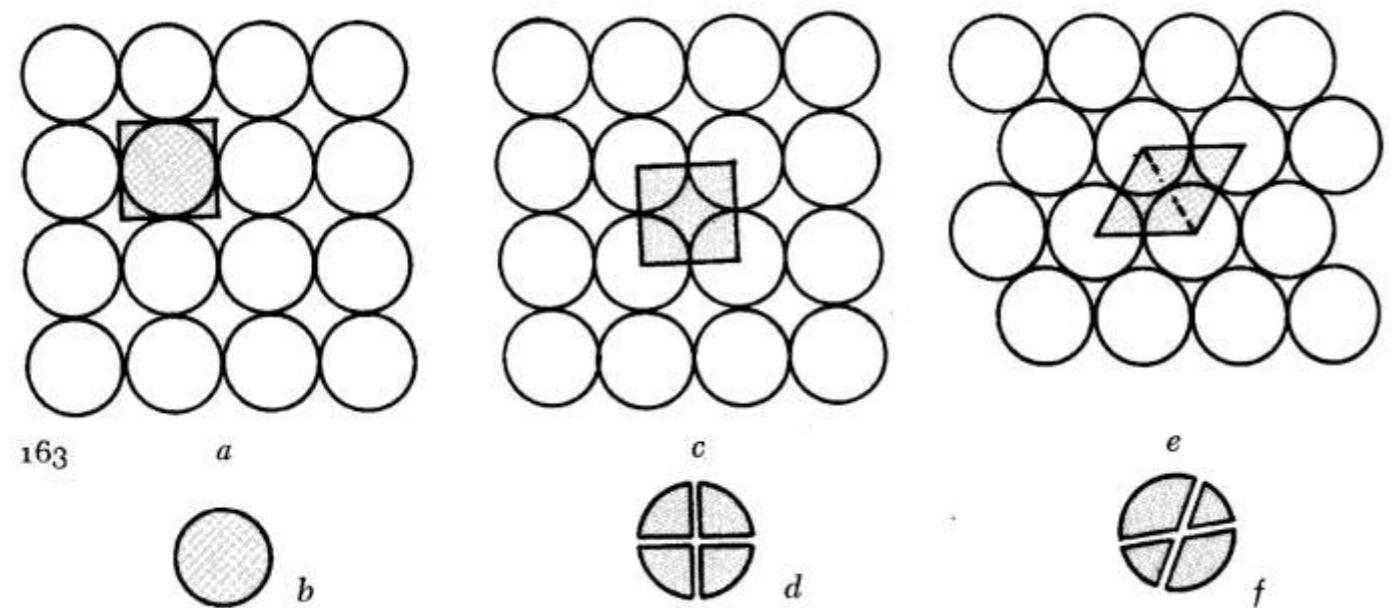


FOSSILIZED CELL COLONY dating from the late Proterozoic era (about 700 million years ago) is viewed at two different depths of focus in this pair of photomicrographs. The microfossils, which were



Closest Packing





Closest Packing

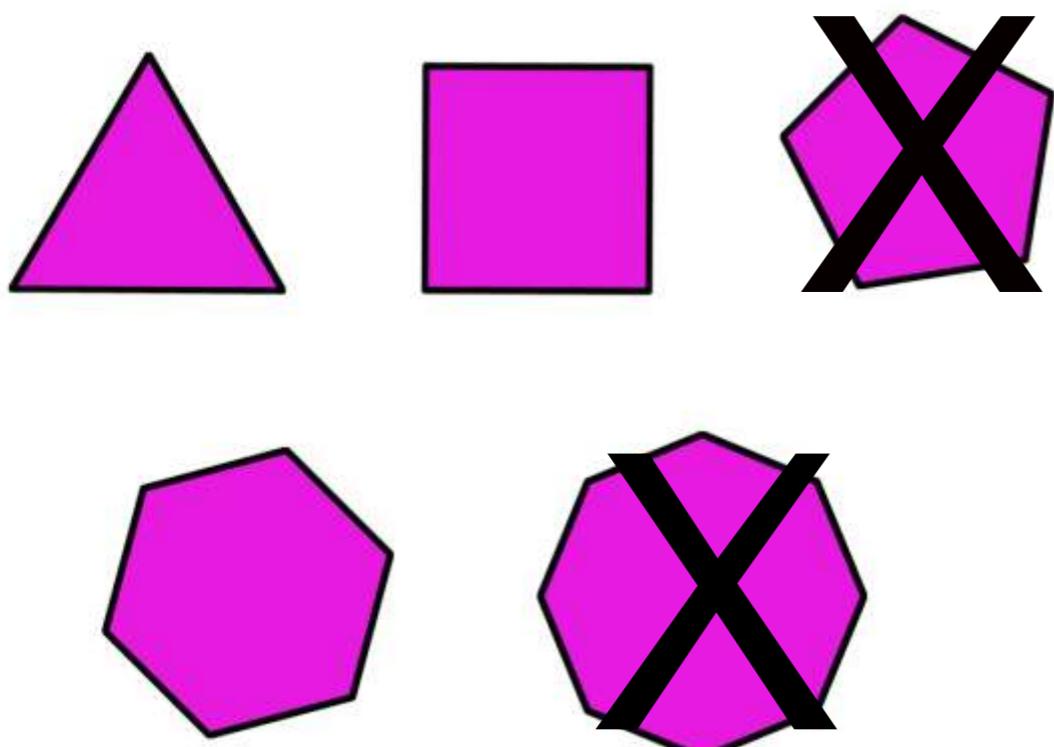
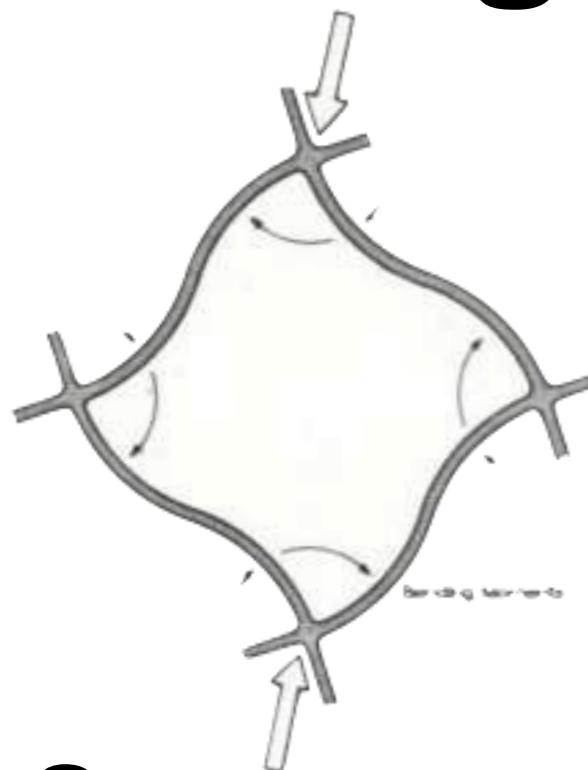
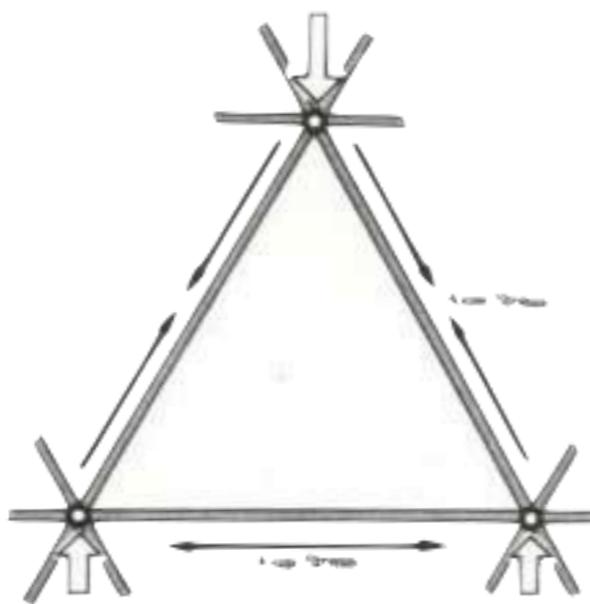
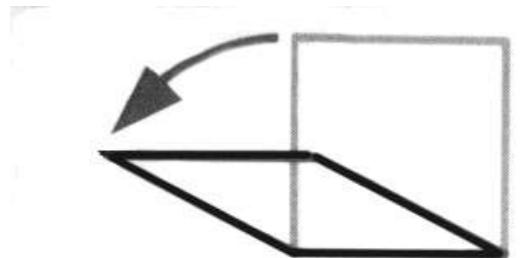


FIGURE 1
HIERARCHICAL CLOSE-PACKING —
CIRCLES TO HEXAGONS
HEXAGONAL BALANCE OF INTRINSIC
AND EXTRINSIC FORCES

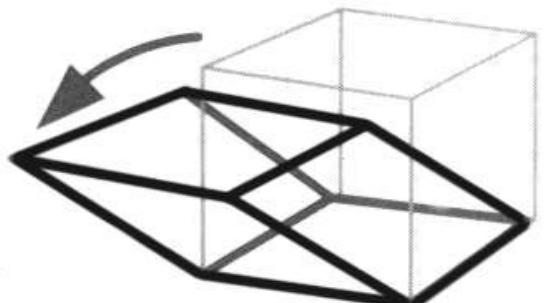
Triangulation



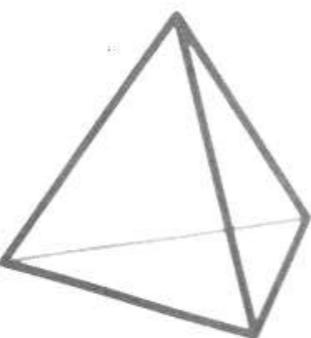
Square



Triangle

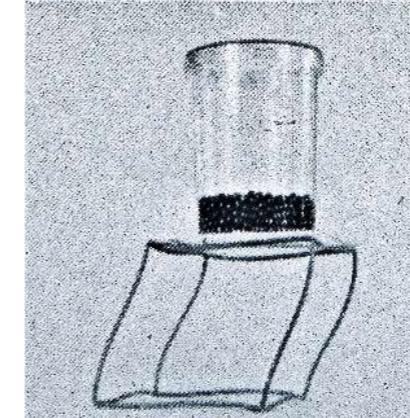
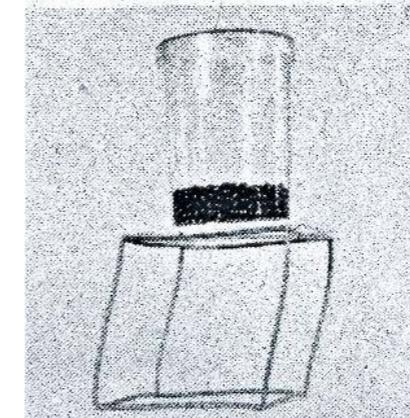
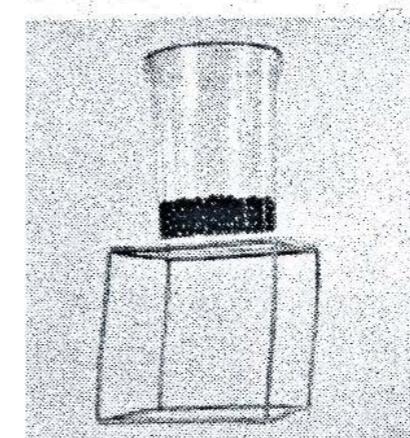
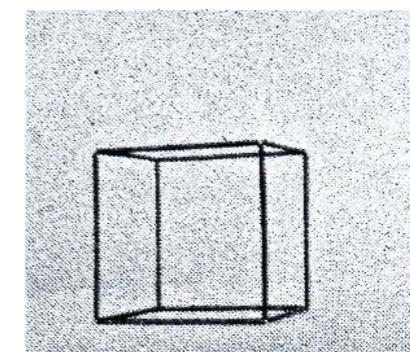


Column A
Unstable Shapes

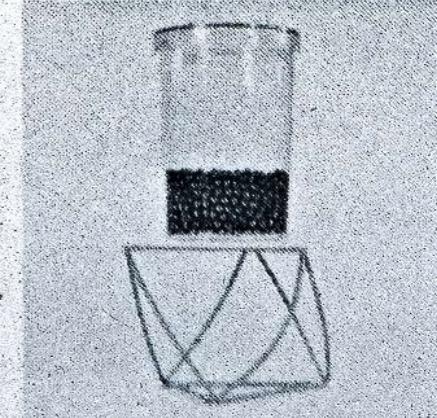
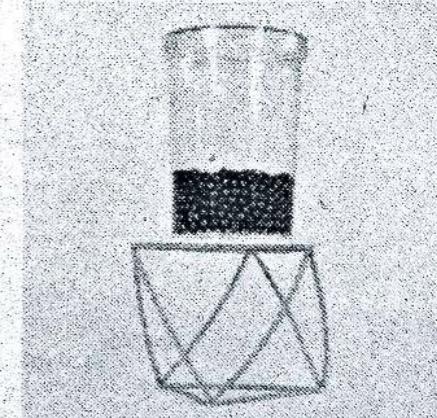
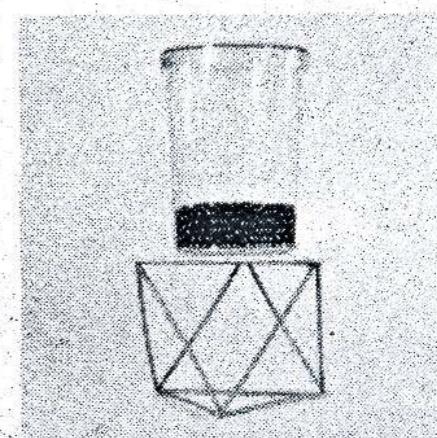
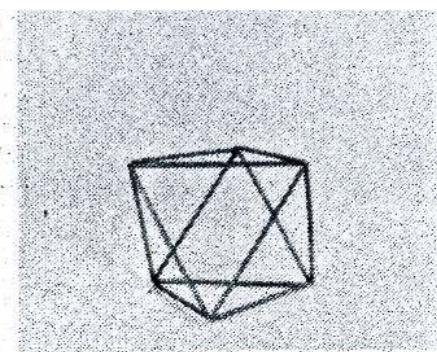


Column B
Stable Shapes

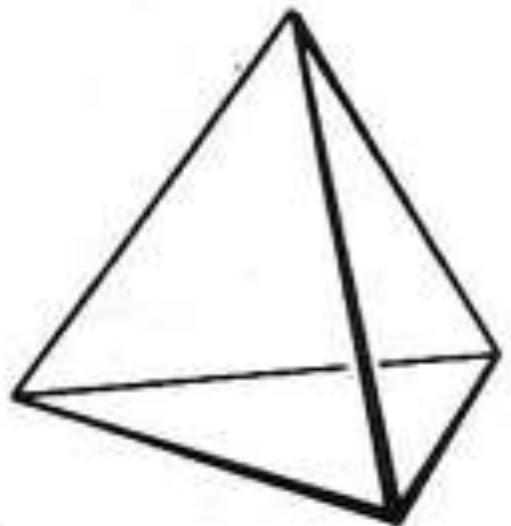
Cube



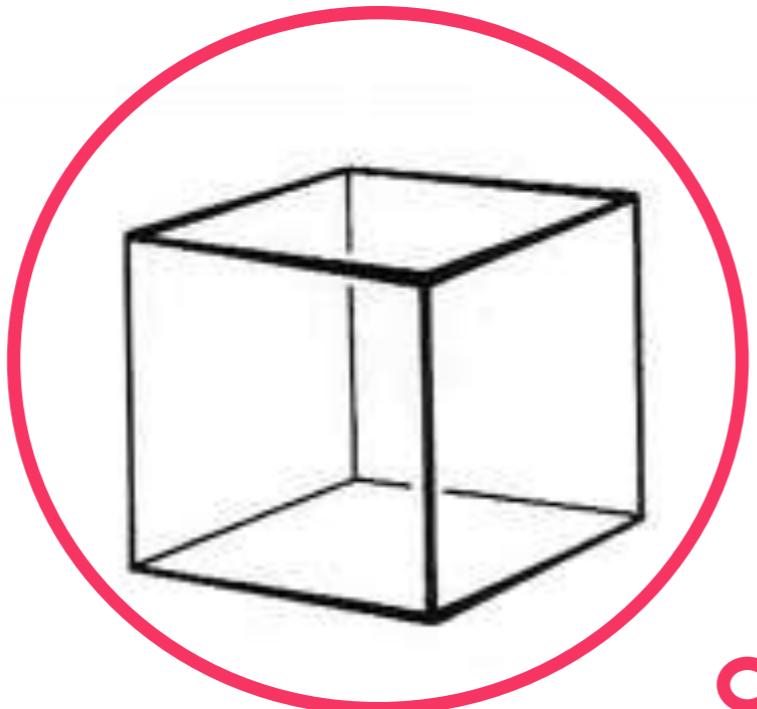
Octahedron



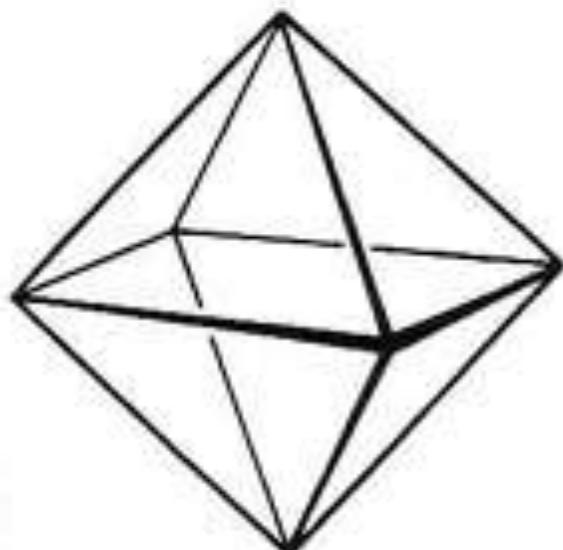
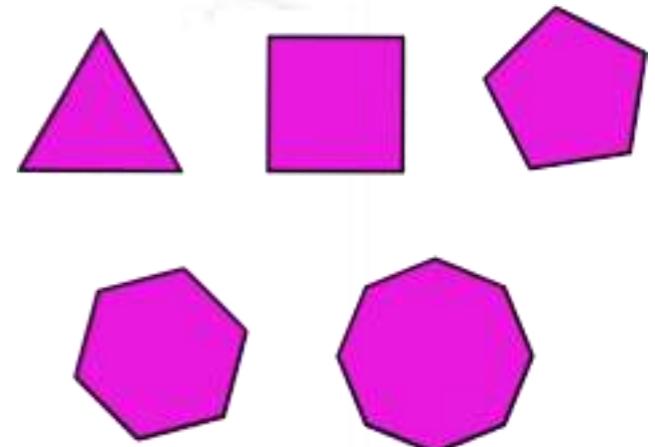
Regular Solids (Polyhedra)



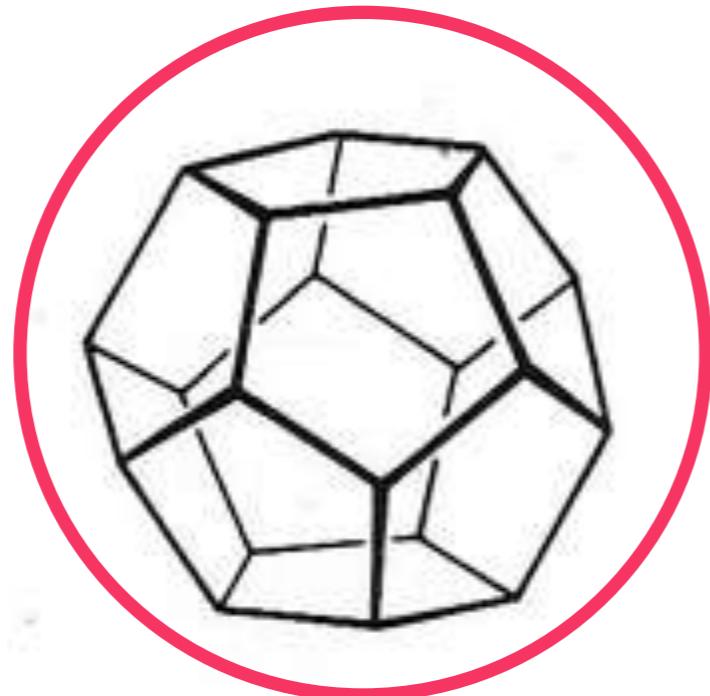
Tetrahedron



Hexa ◎ (Unstable)



Octa

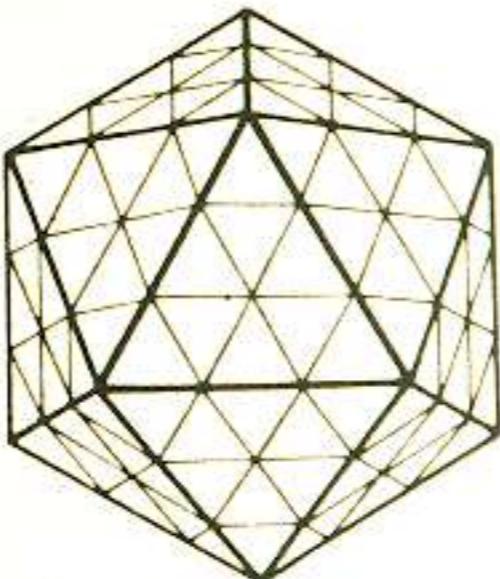
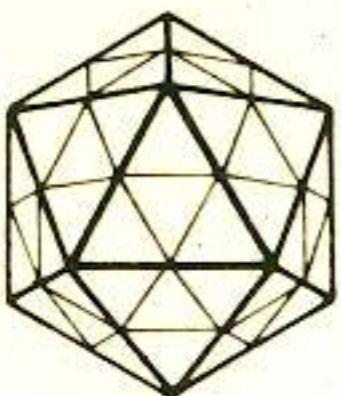


Dodeca



Icosa

icosahedron

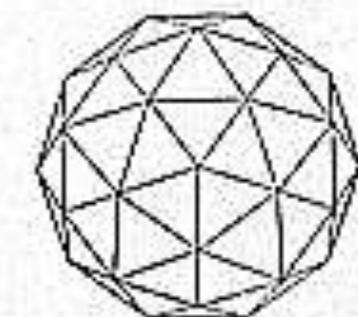


Number of
Vertices:

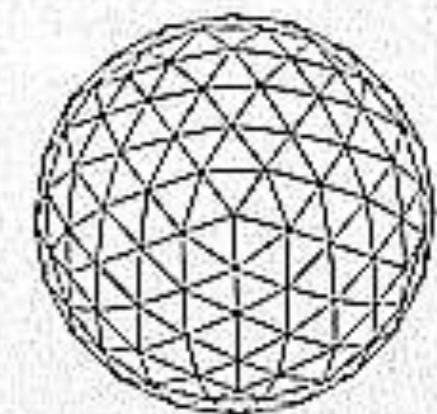
12

42

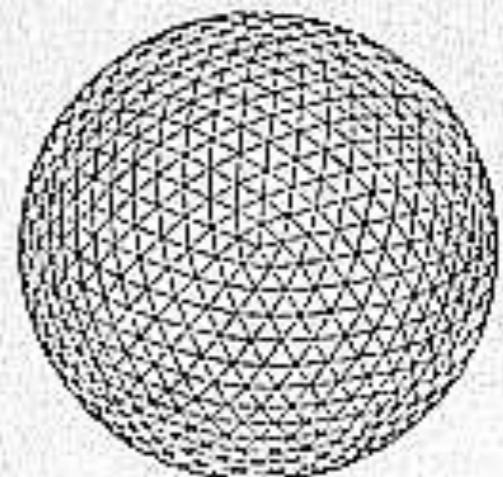
92



Regular Geodesic Two-Frequency Icosahedron



Regular Geodesic Four-Frequency Icosahedron



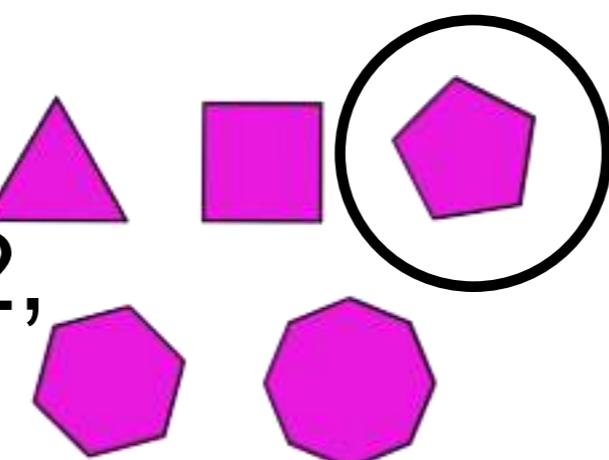
Regular Geodesic Nine-Frequency Icosahedron

Icosahedral Shells

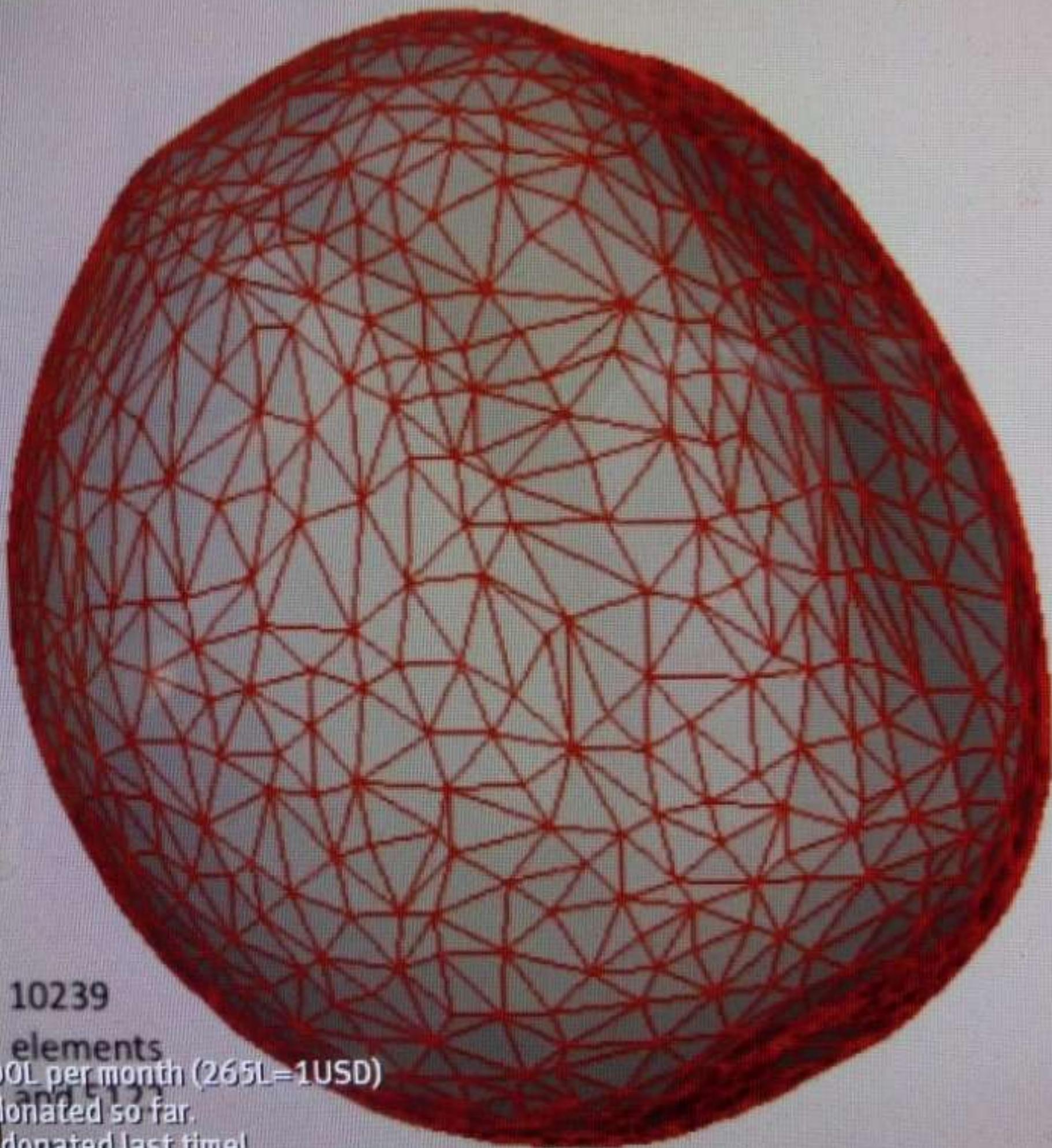
Missing #: 12, 32, 42, 92,

122, 132, 162,

$$10(m-1)^2 + 2$$



Finite Element Grid



10239

elements

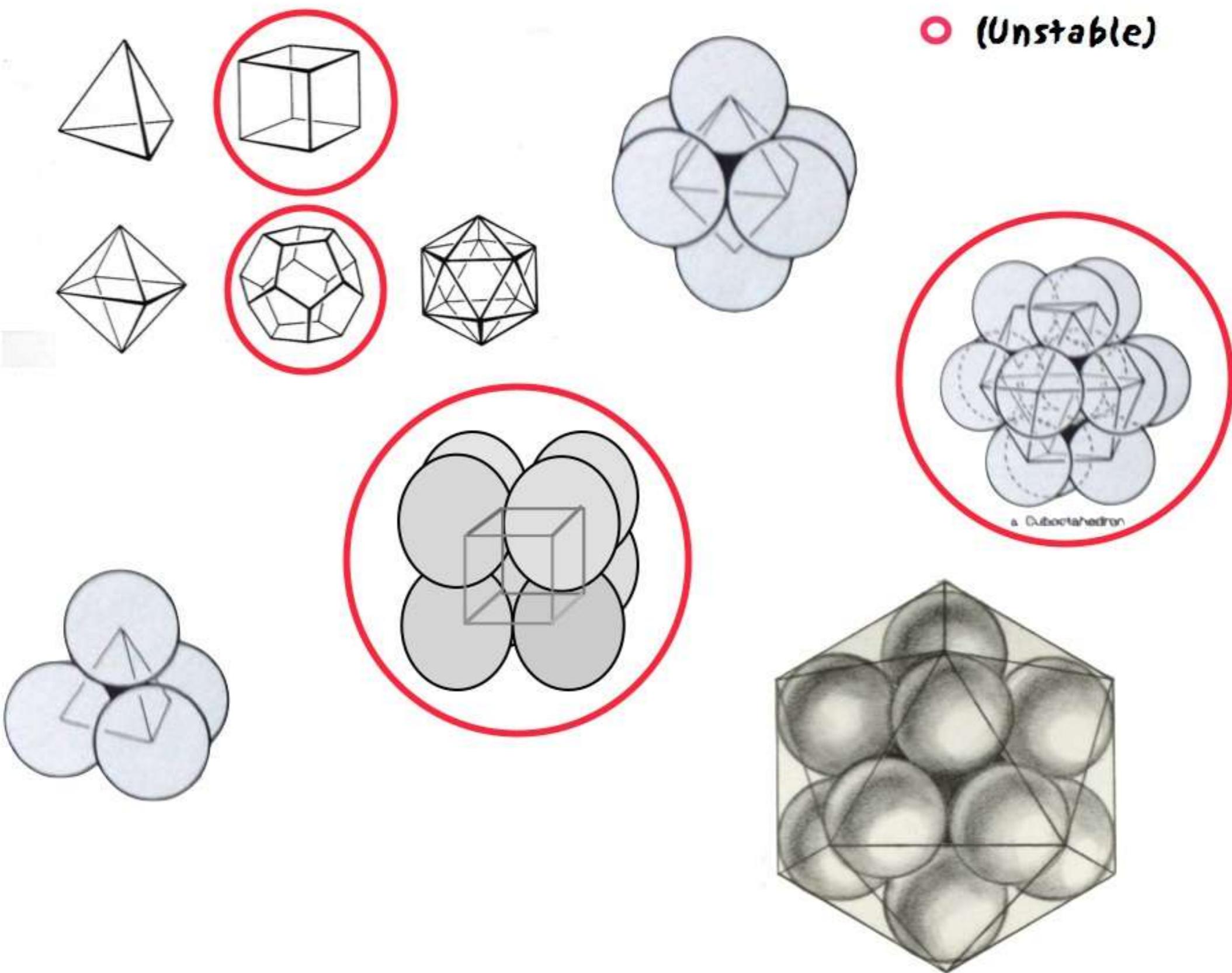
4000L per month (265L=1USD)

L\$ donated so far.

DL\$ donated last time!

40L\$ donated so far

- Chen, X. & G.W. Brodland (2008). **Mechanics of amphibian neurulation** elucidated using a multi-scale finite element model. *Physical Biology*, submitted



Of the Trusses, The Icosahedron is the Most Suitable Because:



Largest Volume for Surface Area



Closest Packing



Omni Directional



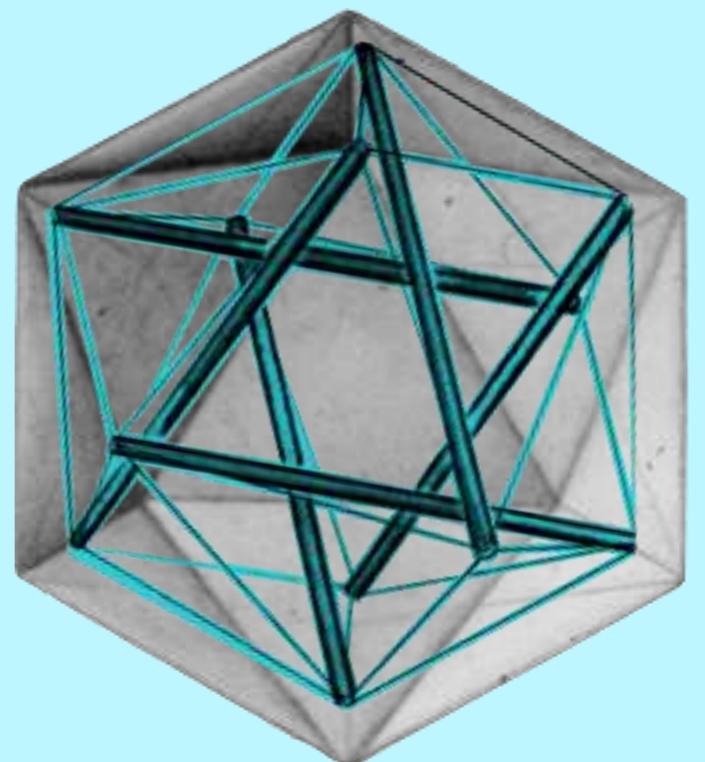
Exo/Endo Skeletal

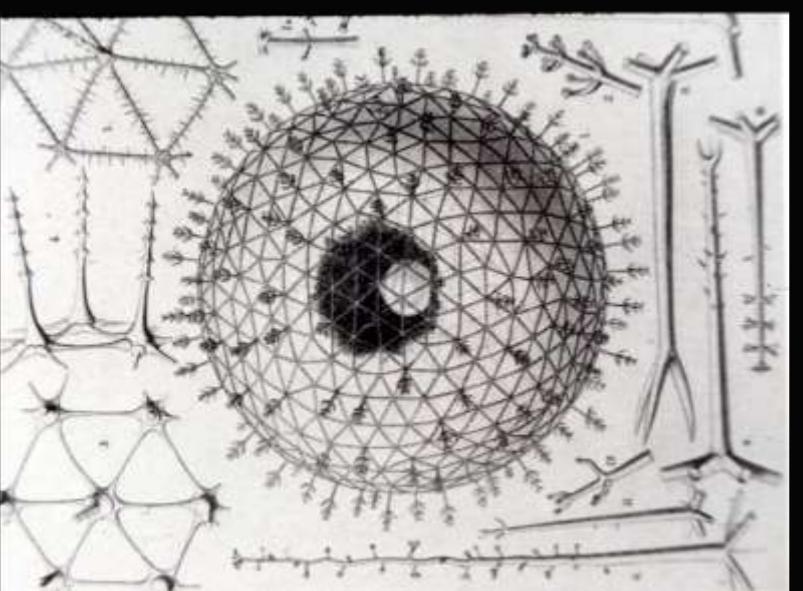


Hierarchical

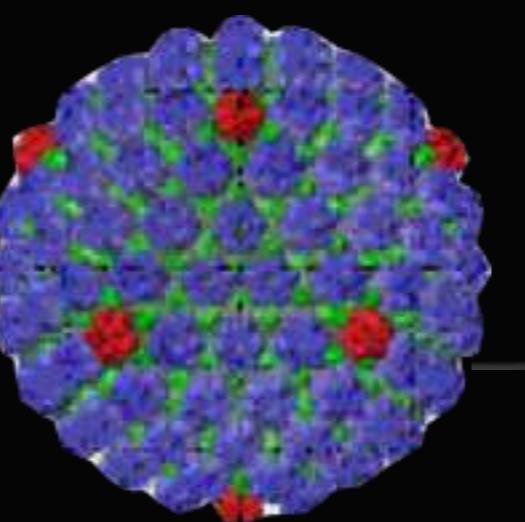


Nonlinear

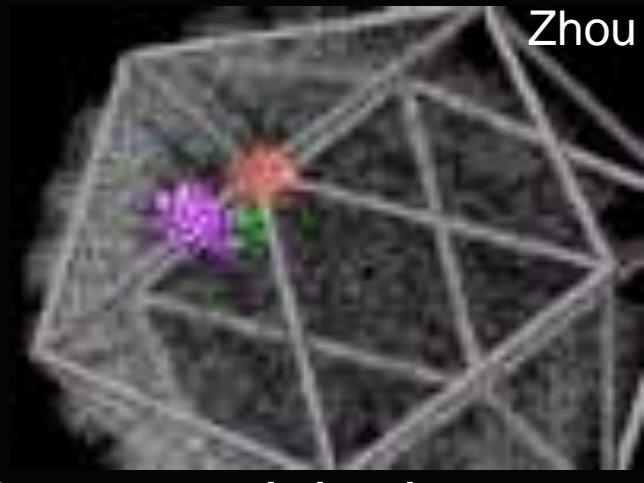




Polio Virus

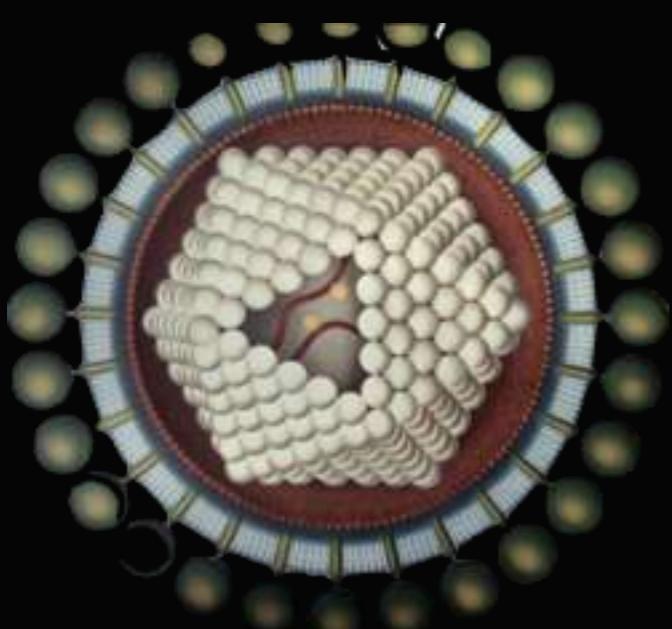


Mold



Pyruvate dehydrogenase

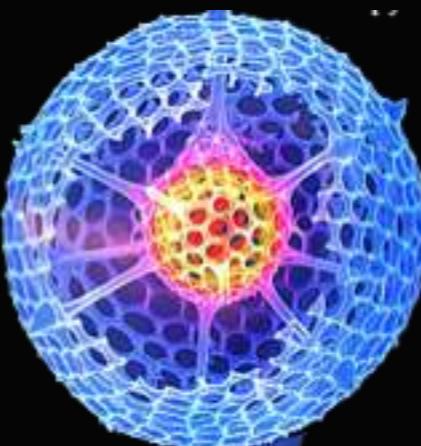
Radiolaria



Virus



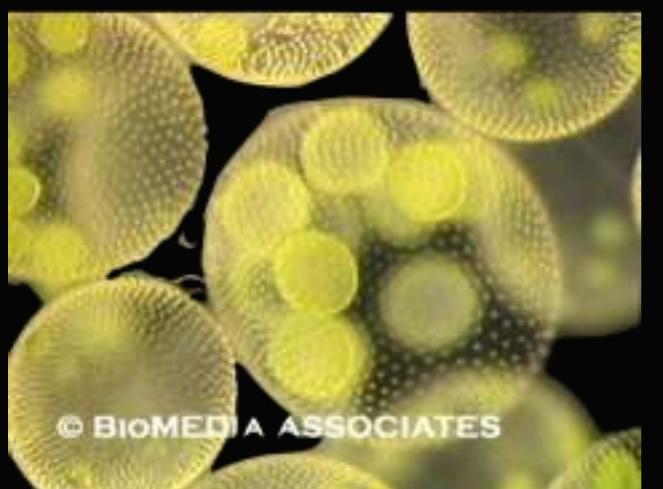
Rice Dwarf Virus



Radiolaria



HIV



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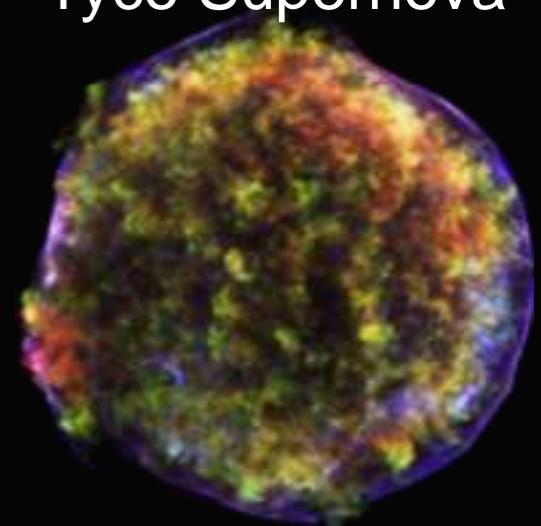
Volvox



Raspberry



Pufferfish

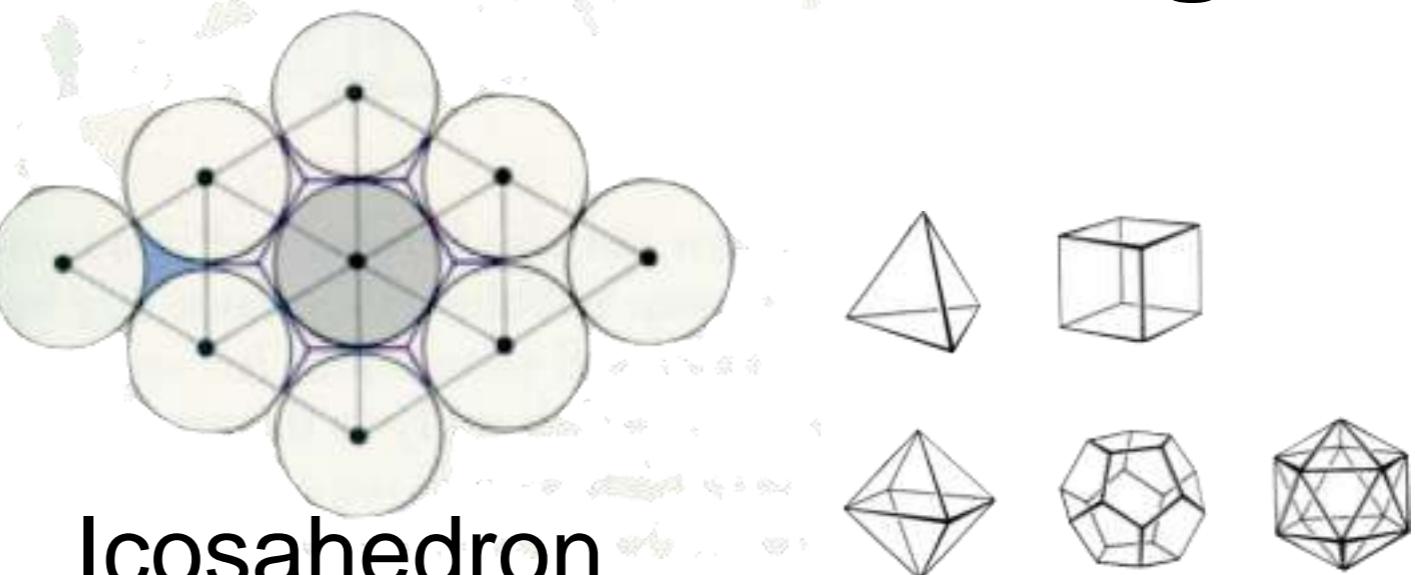


Tyco Supernova

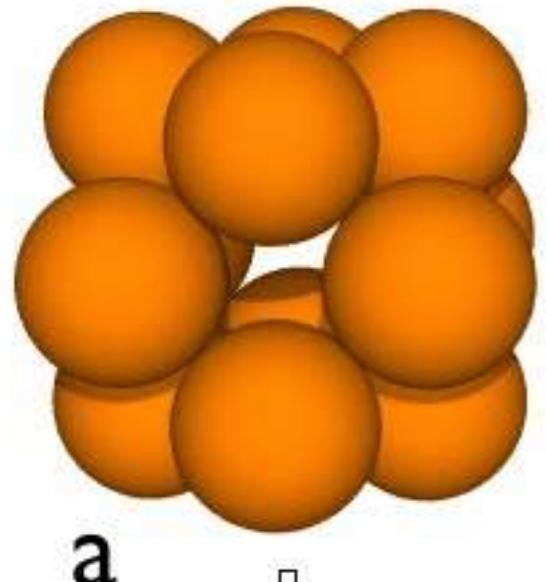




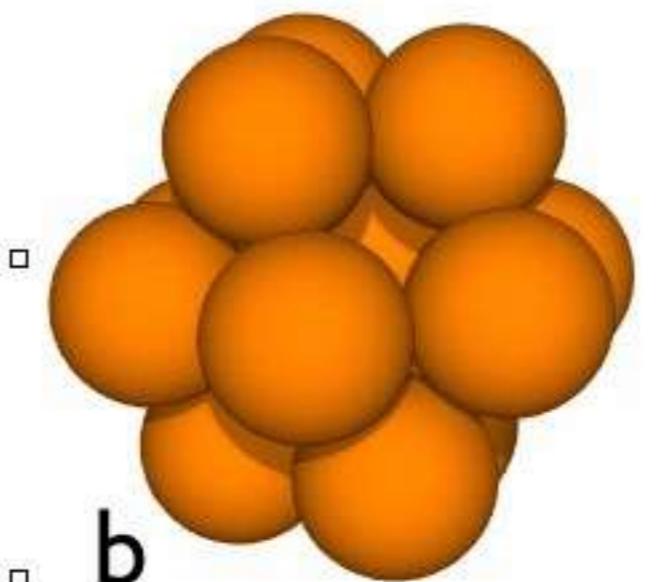
3-D Closest Packing



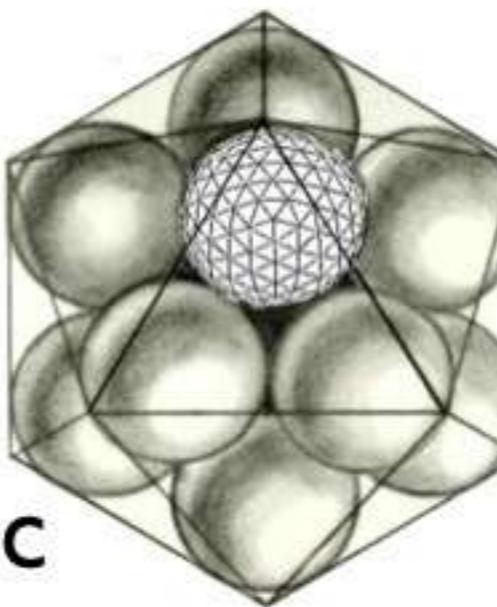
Cuboctahedron



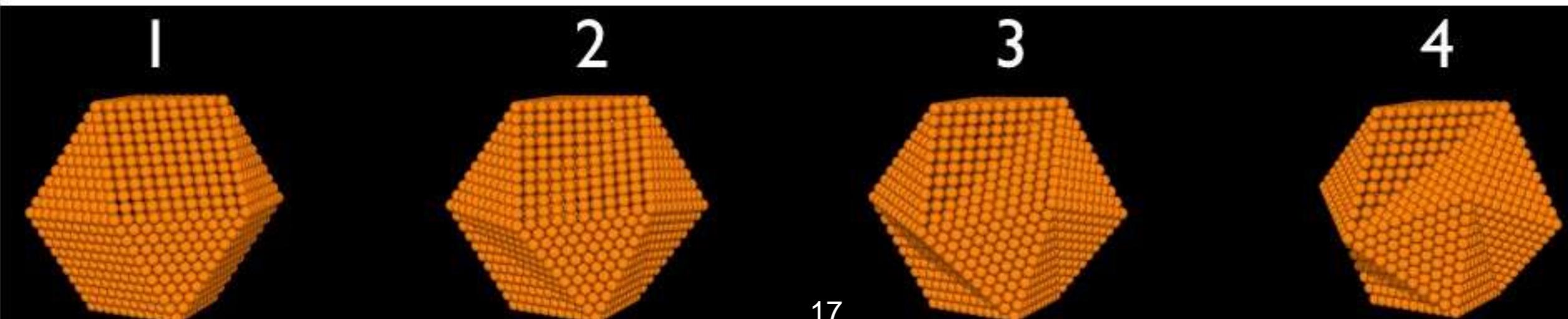
a



b

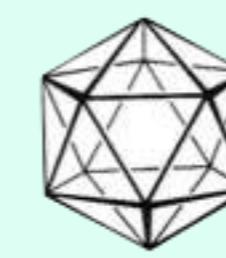
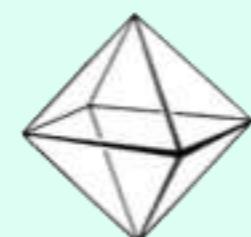
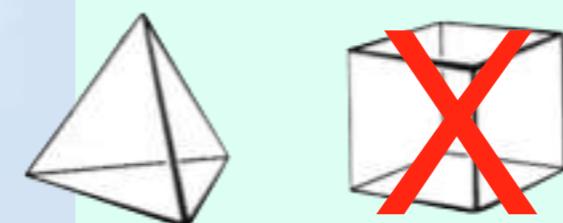
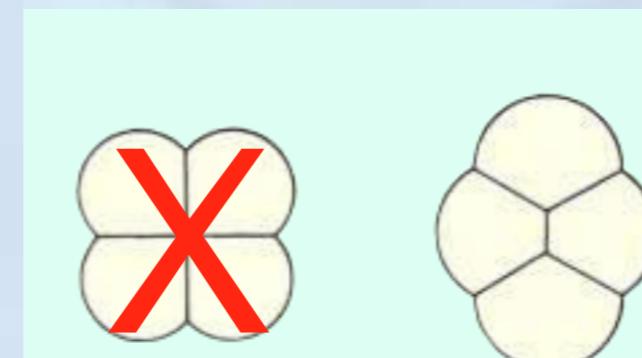


c



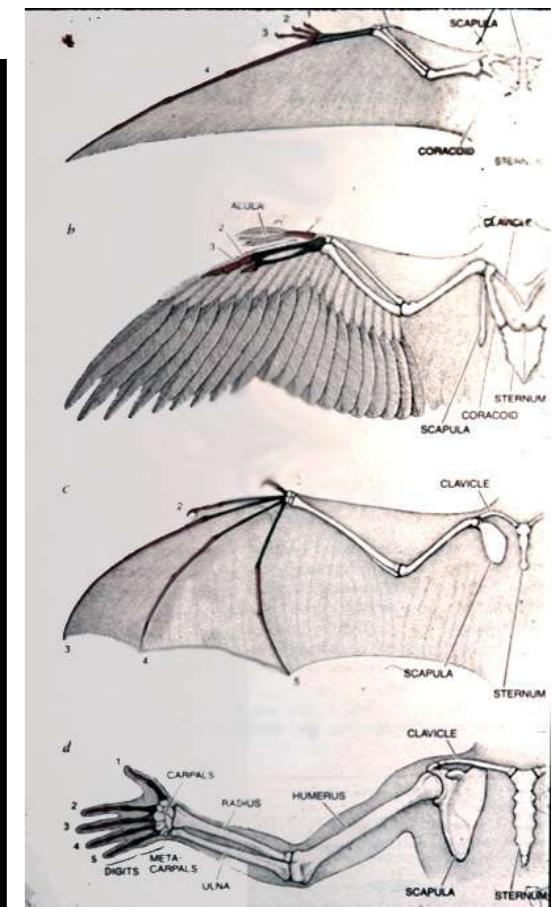
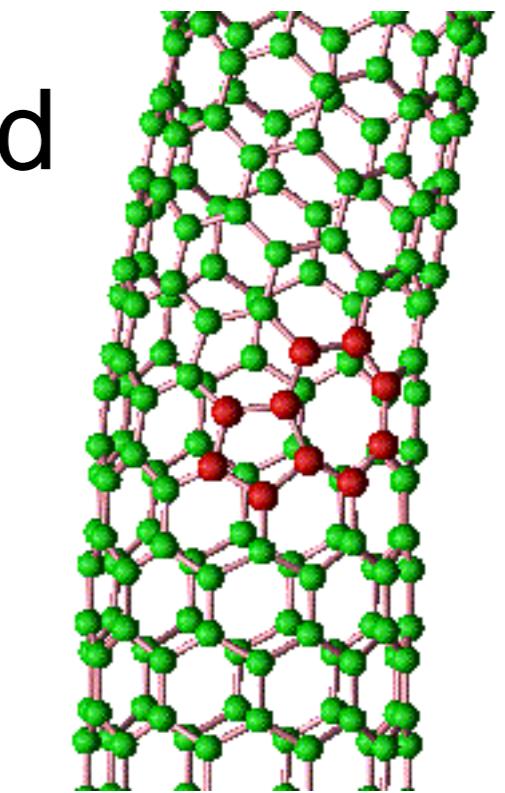
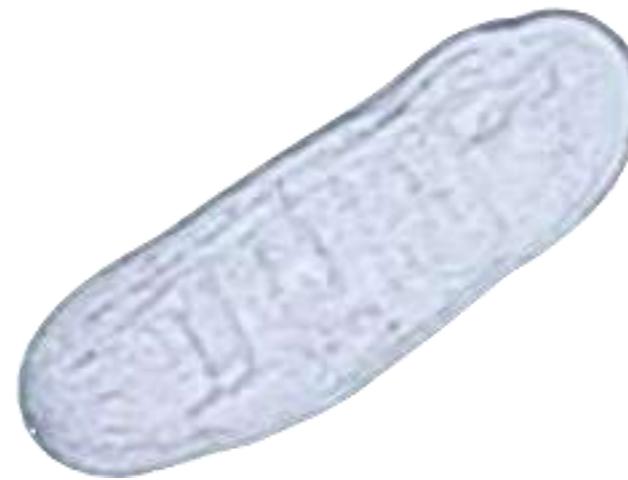
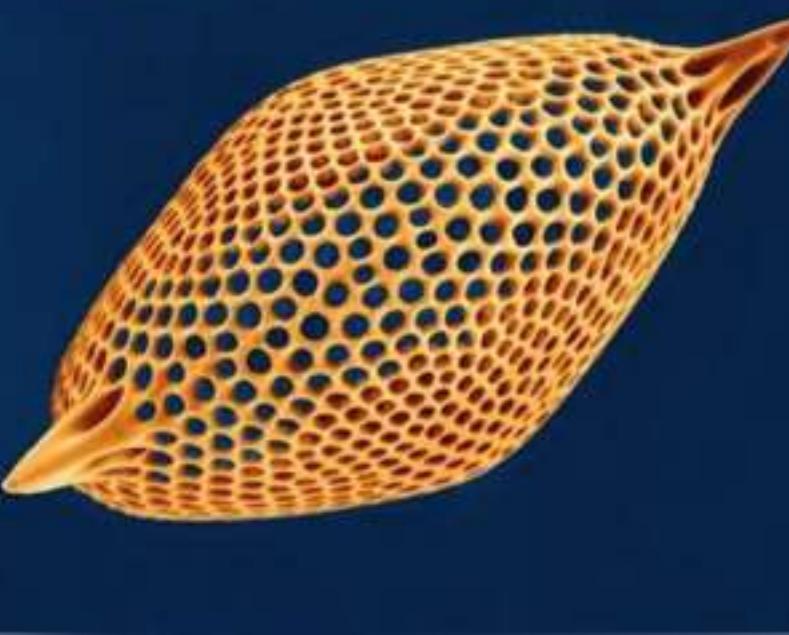
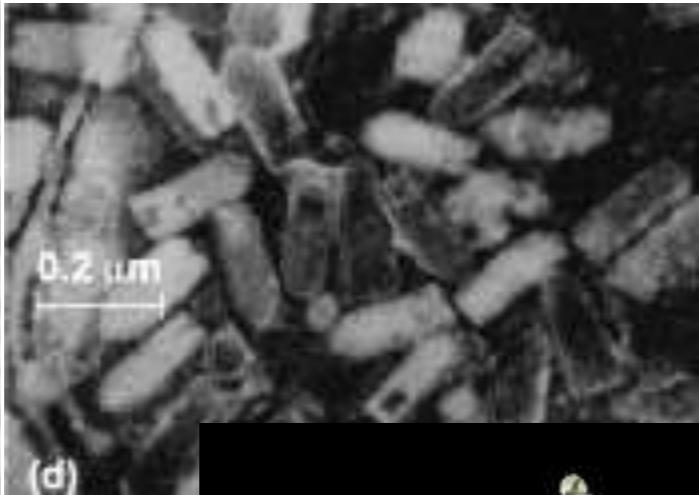
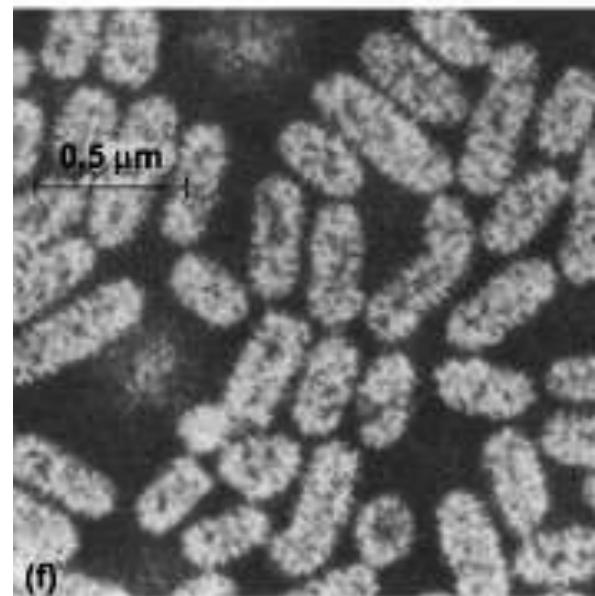
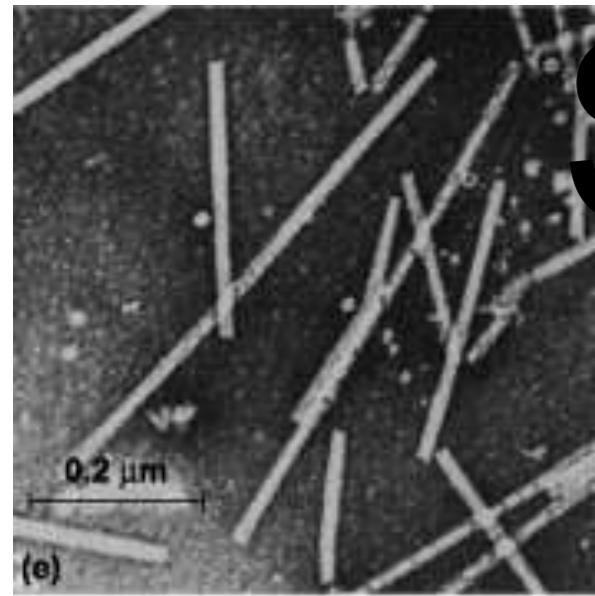
Amphioxus

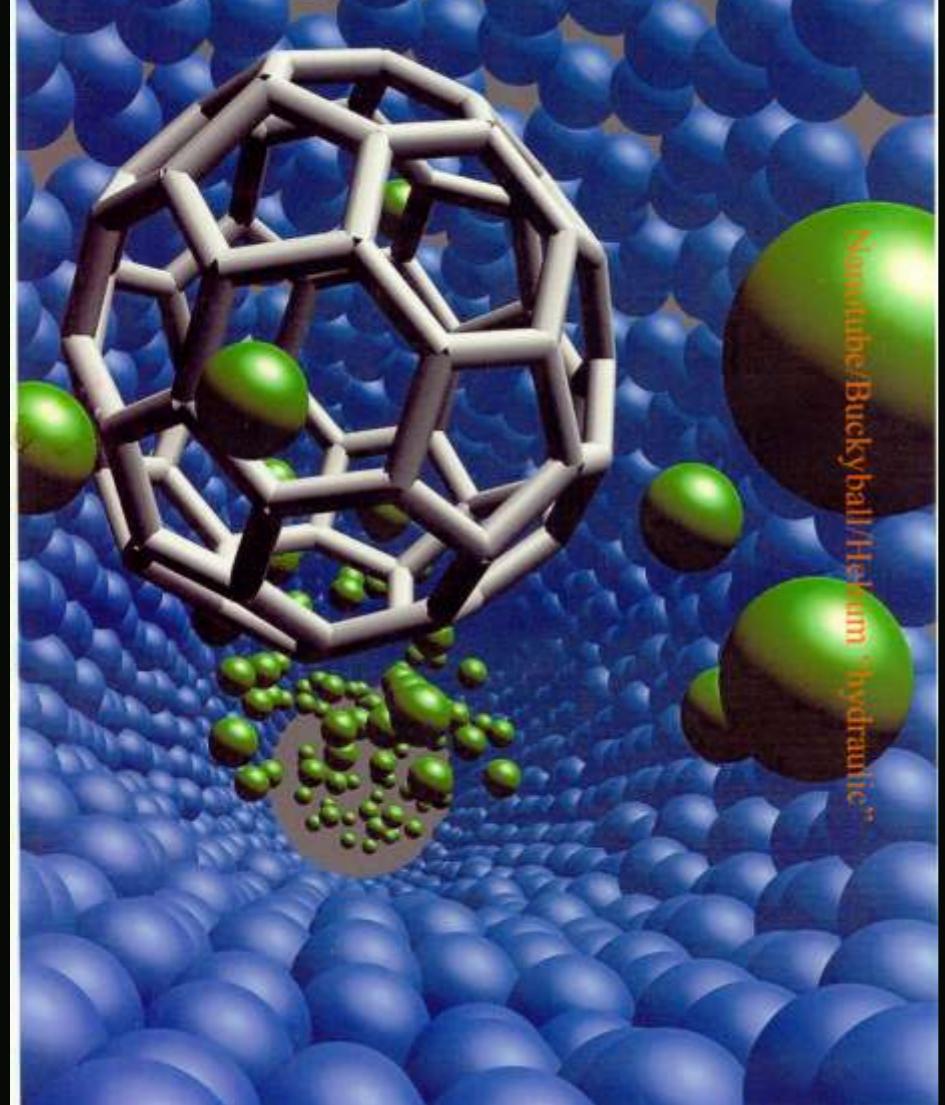
←



Symmetry Breaking

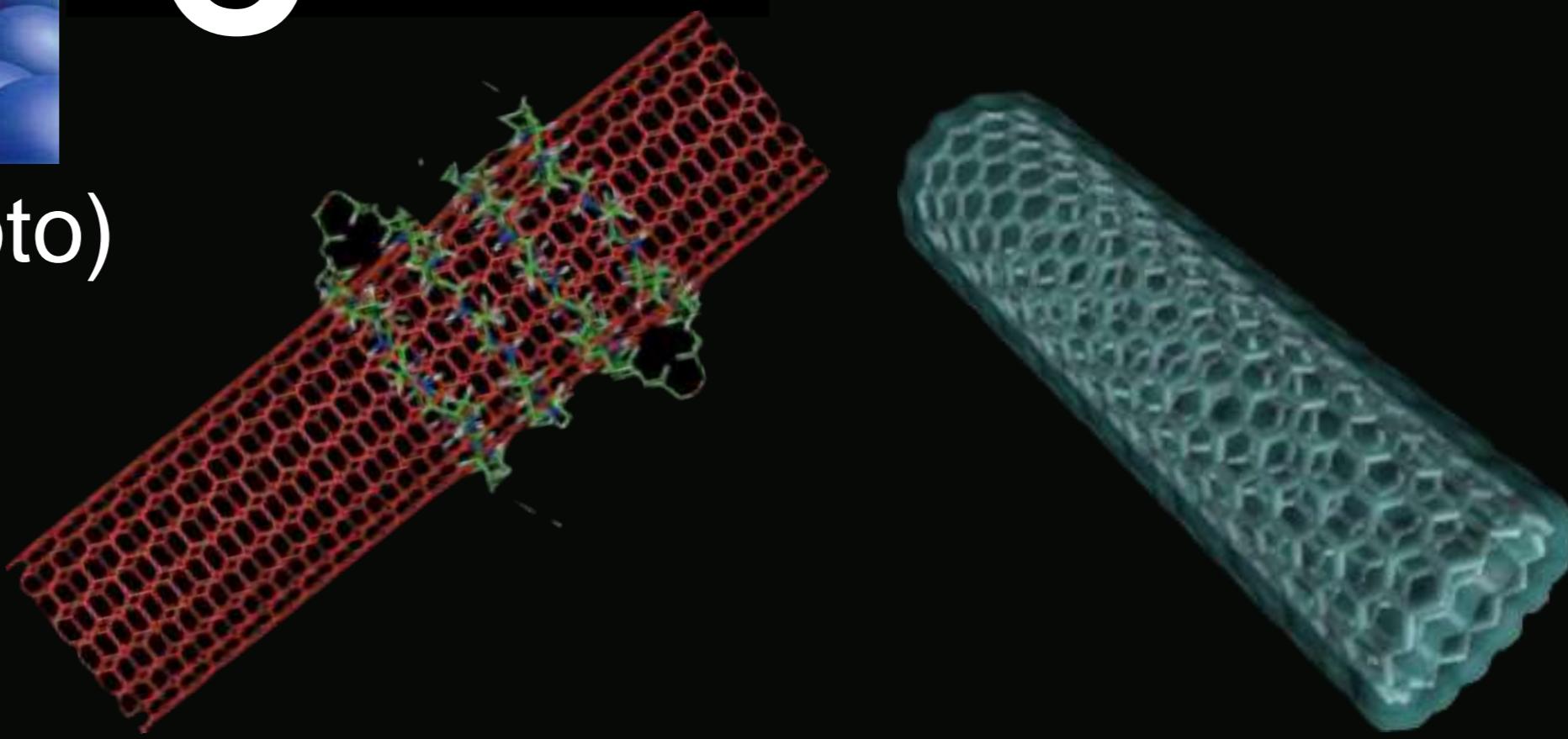
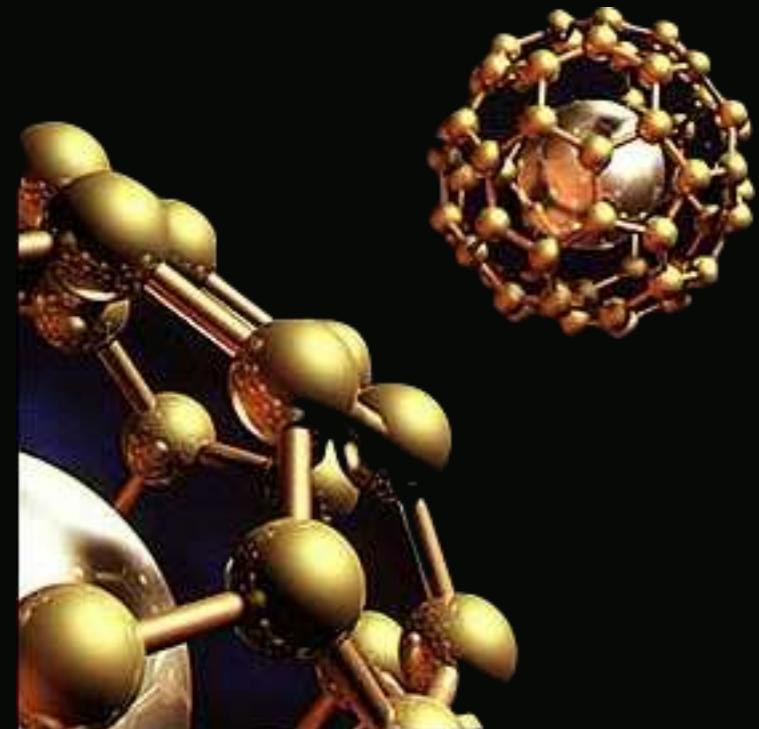
Not Everything is Round

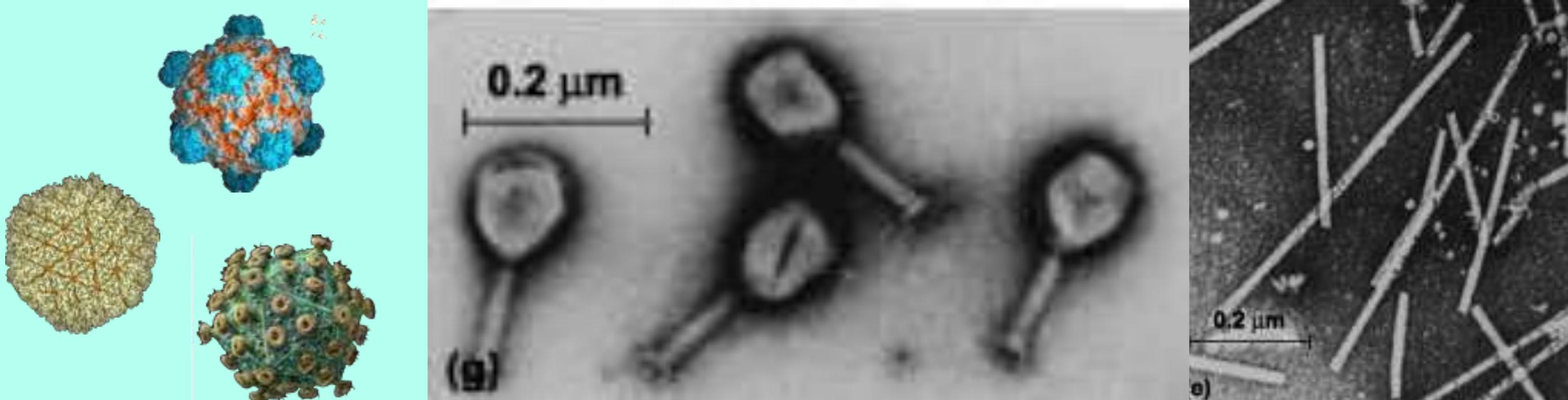




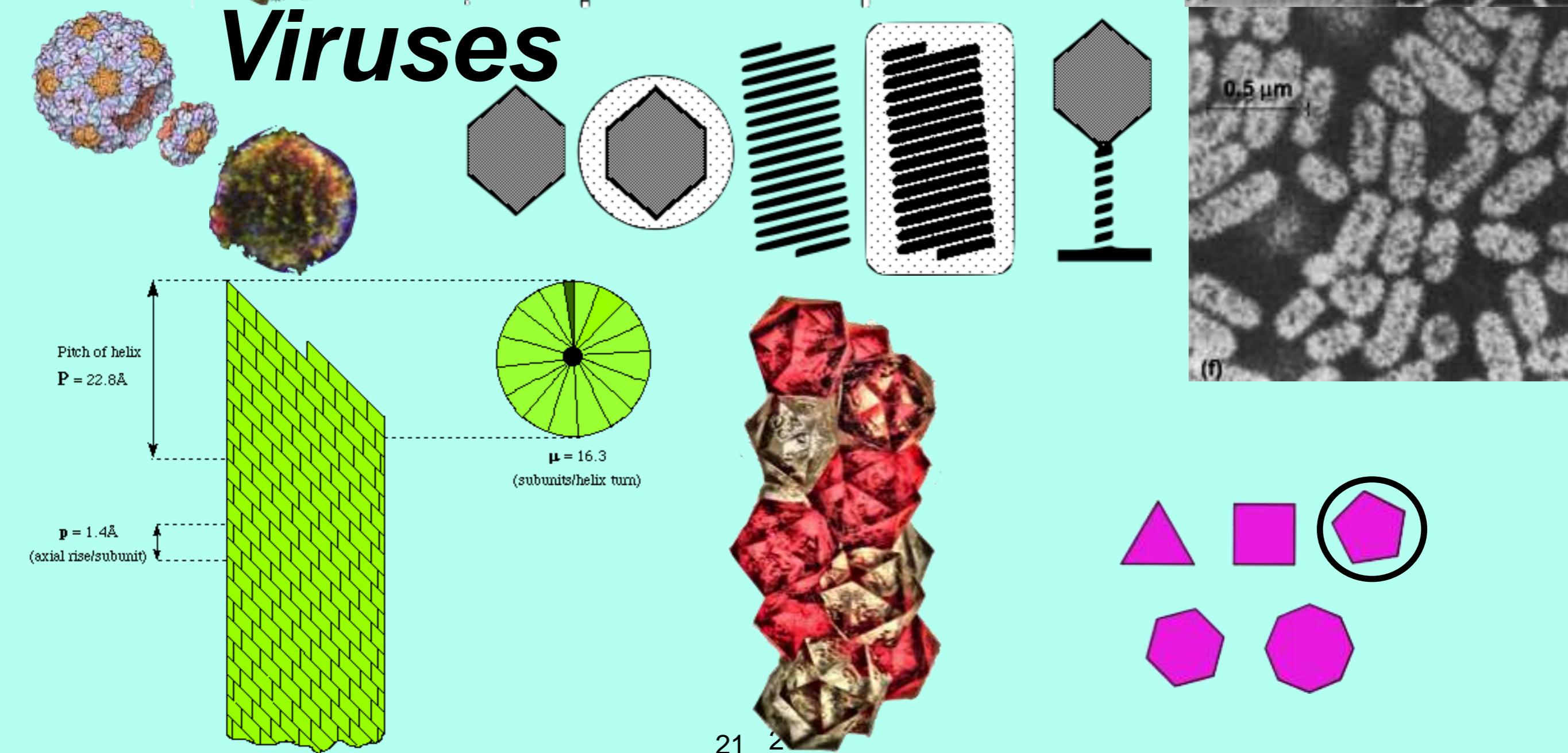
C⁶⁰

Smalley, Curl, Kroto)





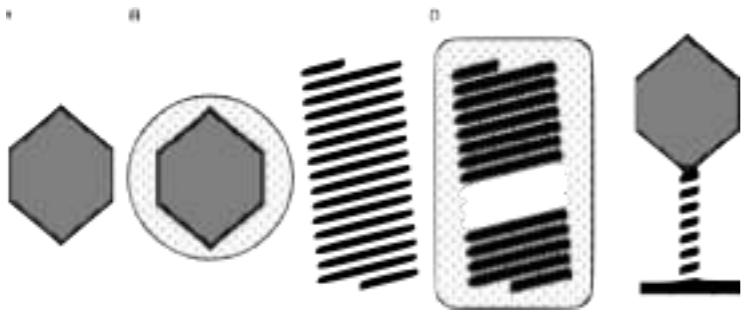
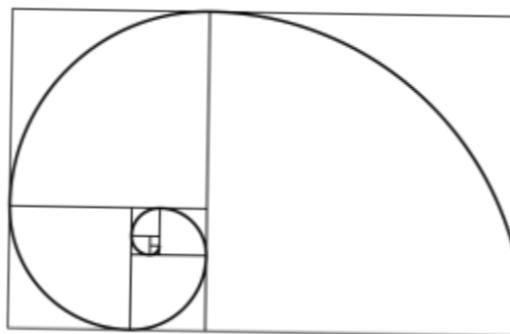
Viruses



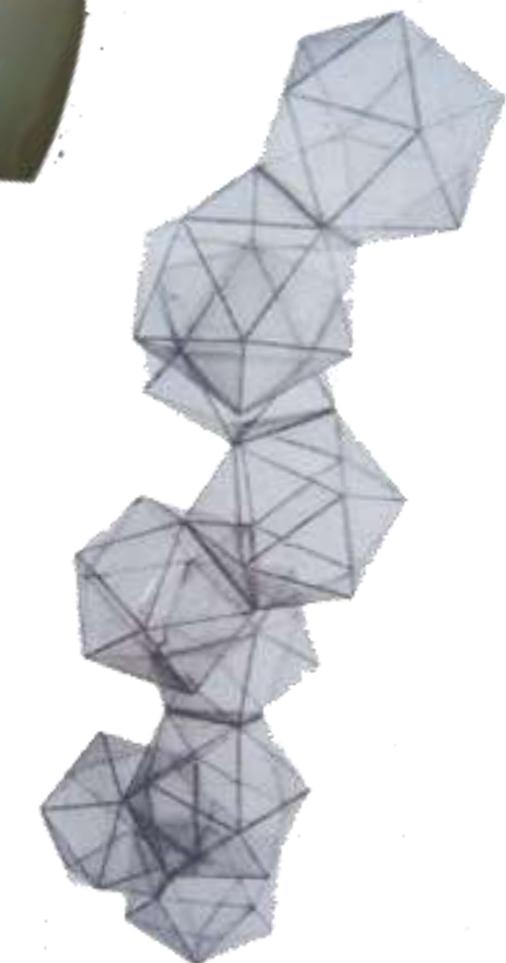
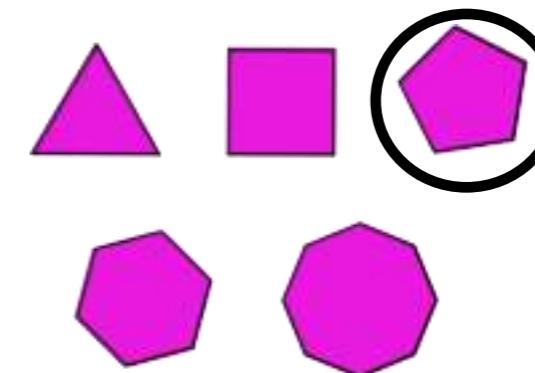
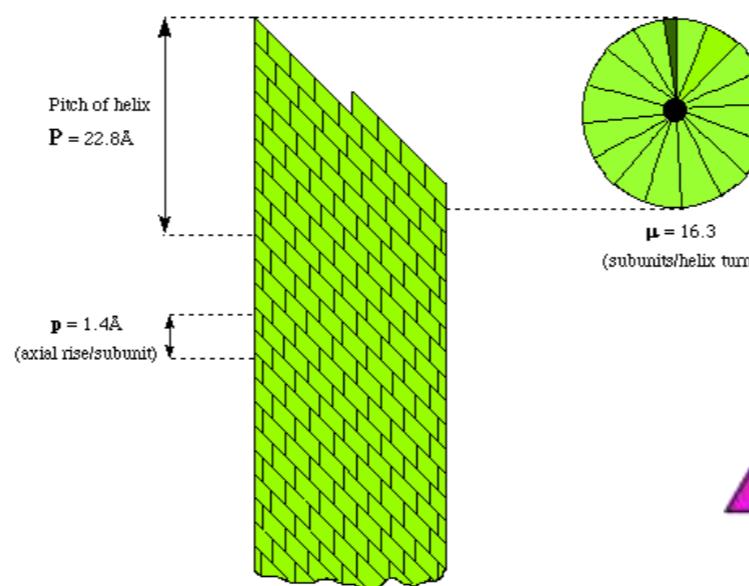
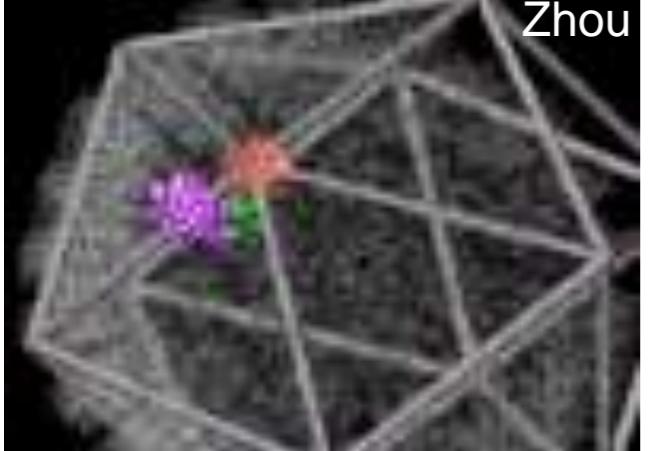


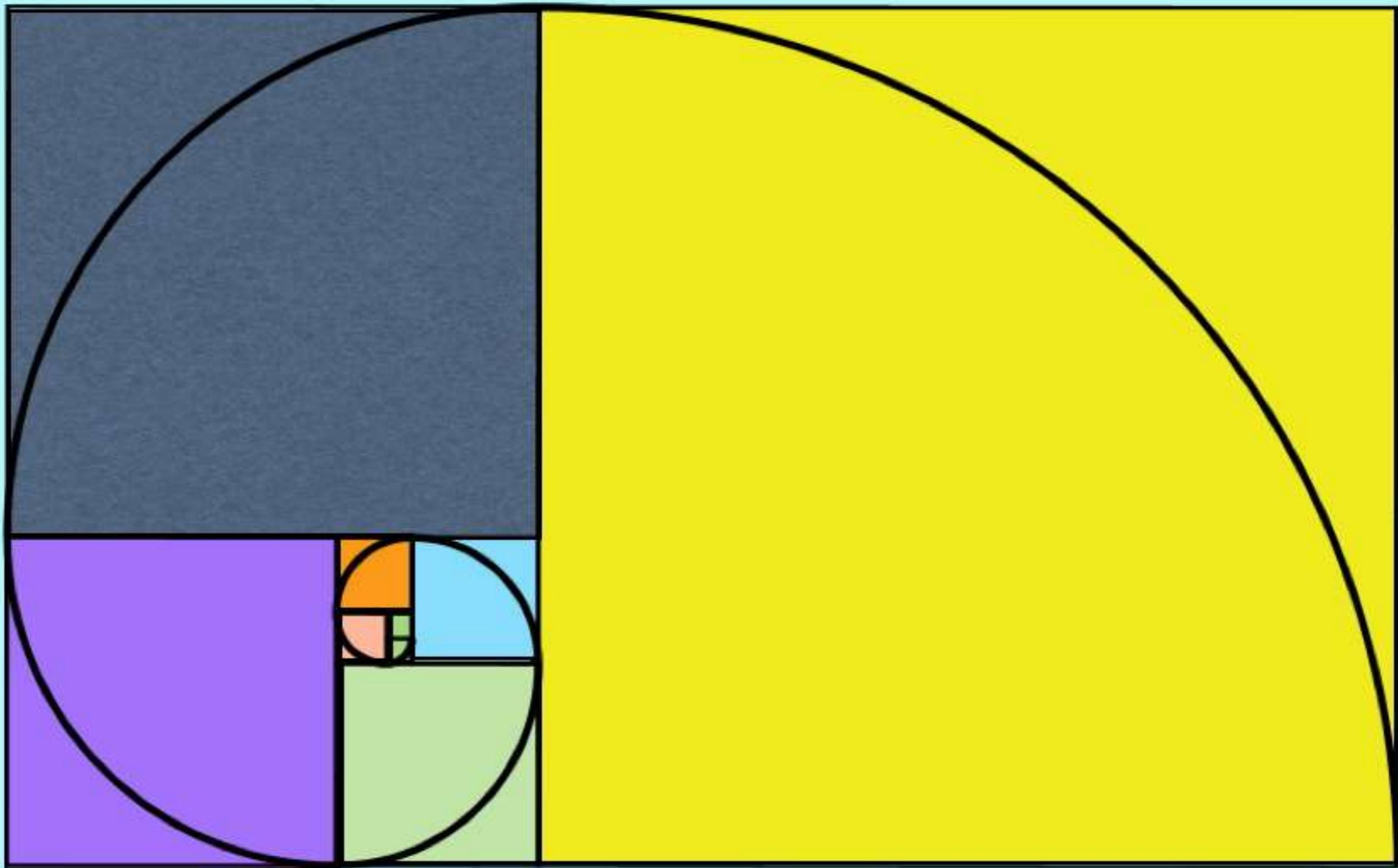
Icospiral-

Kroto



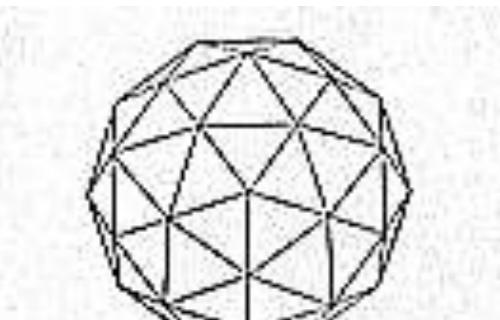
Yruvate Dehydrogenase
Zhou



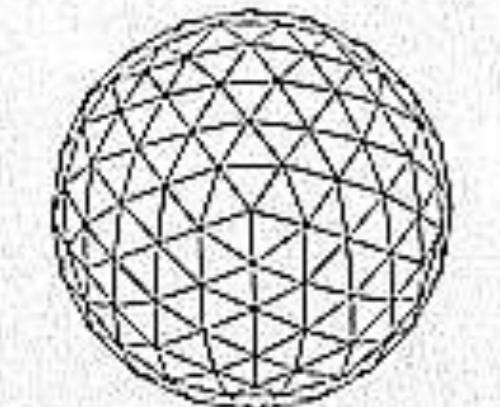


Logarithmic Spiral

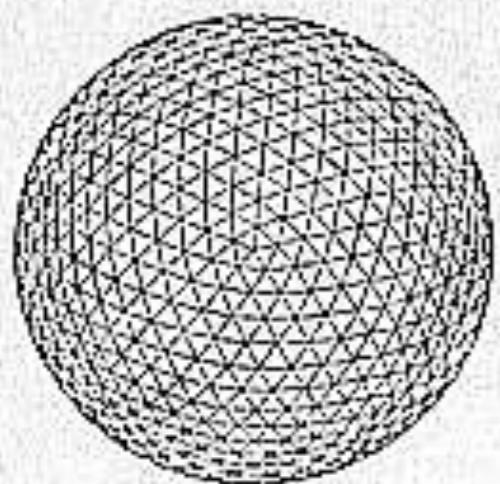
Symmetry Breaking



Regular Geodesic Two-Frequency Icosahedron

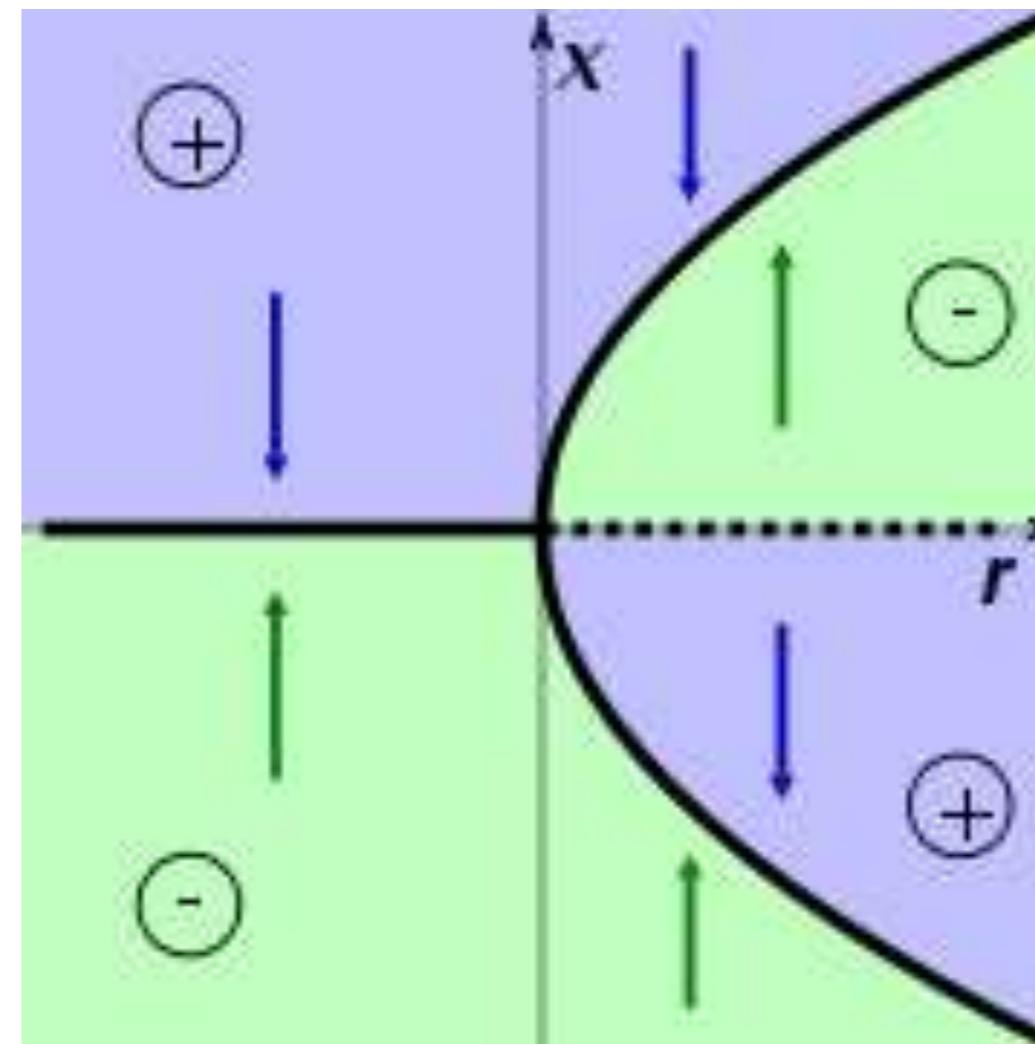
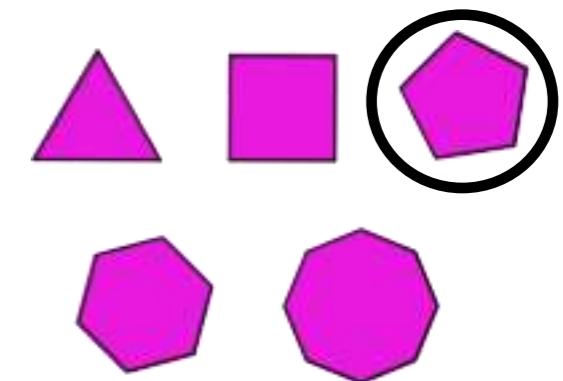


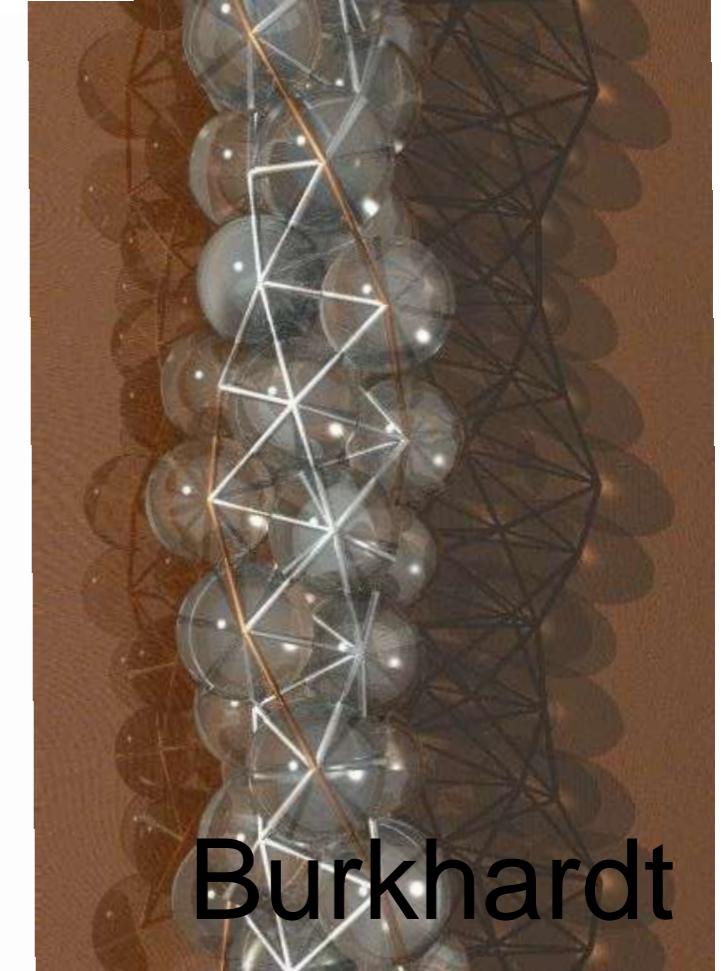
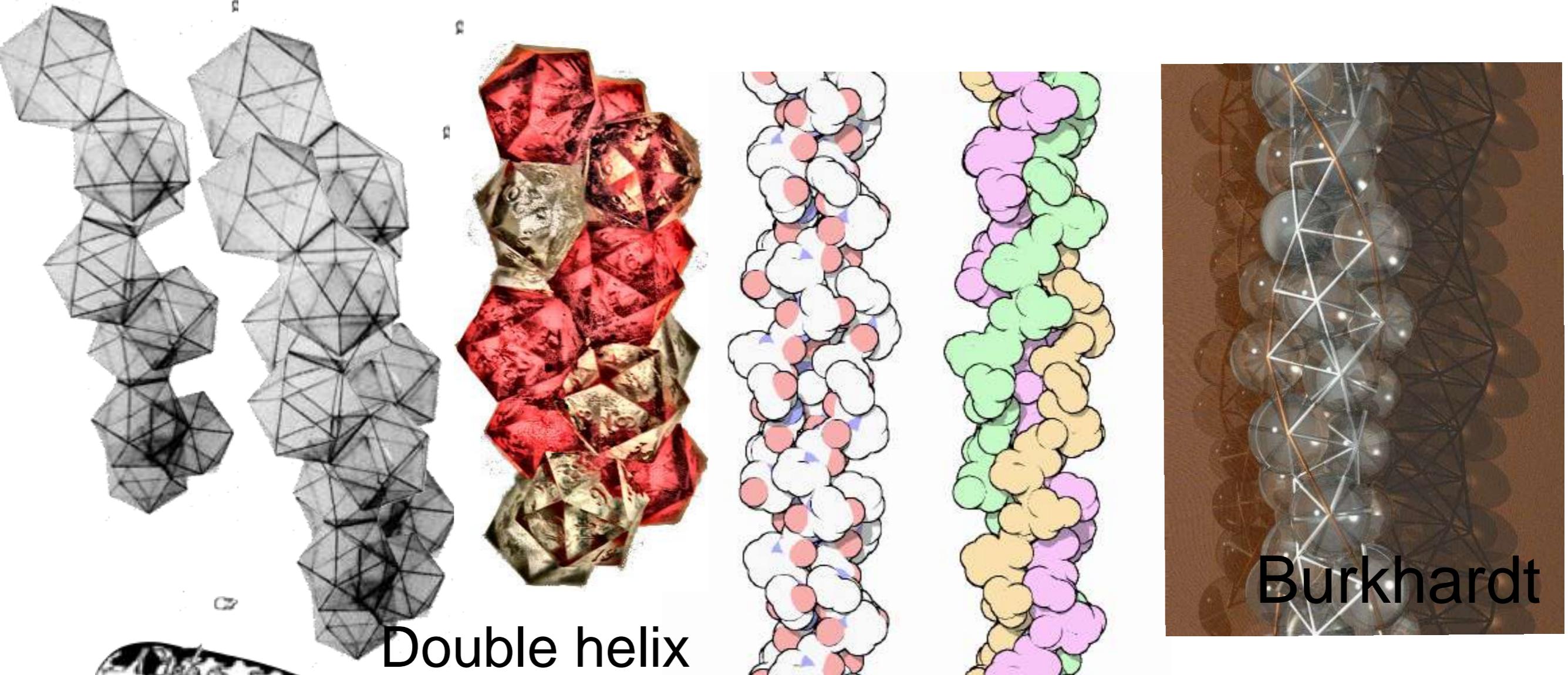
Regular Geodesic Four-Frequency Icosahedron



Regular Geodesic Nine-Frequency Icosahedron

Kissing #: 12, 32, 42, 92,
122, 132, 162,
 $10(m-1)^2+2$

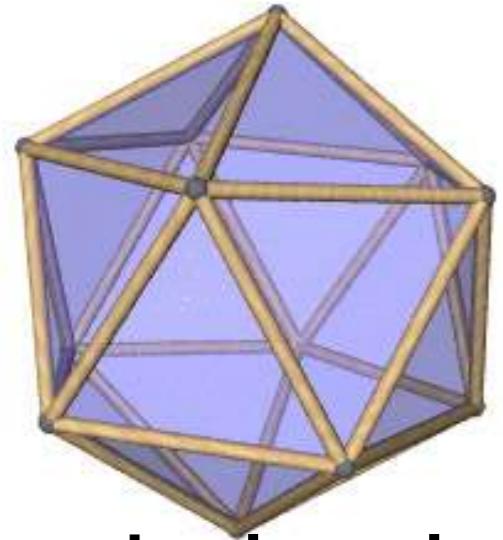




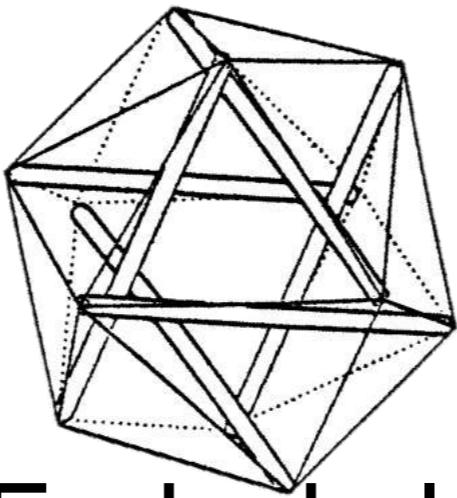
Triple Helix



BioTensegrity



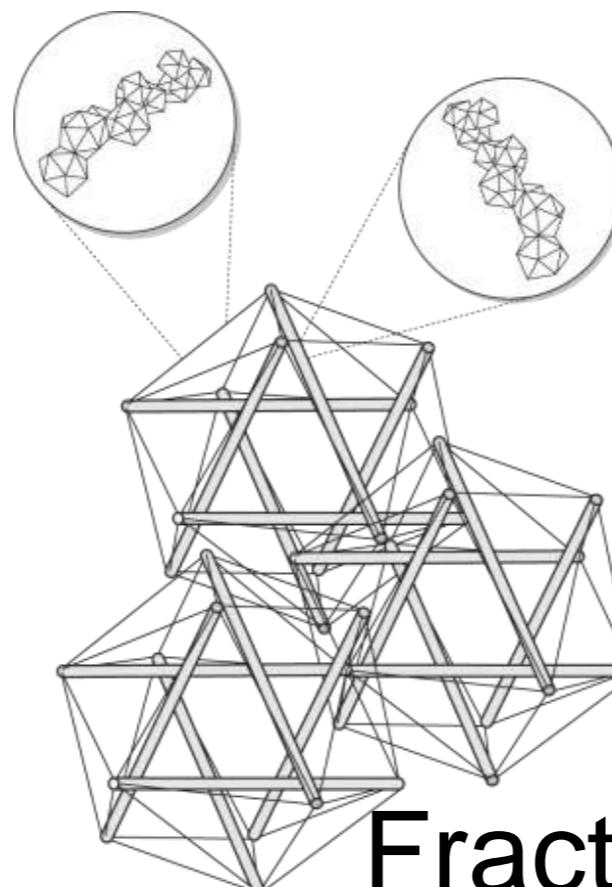
Exoskeletal



Endoskeletal

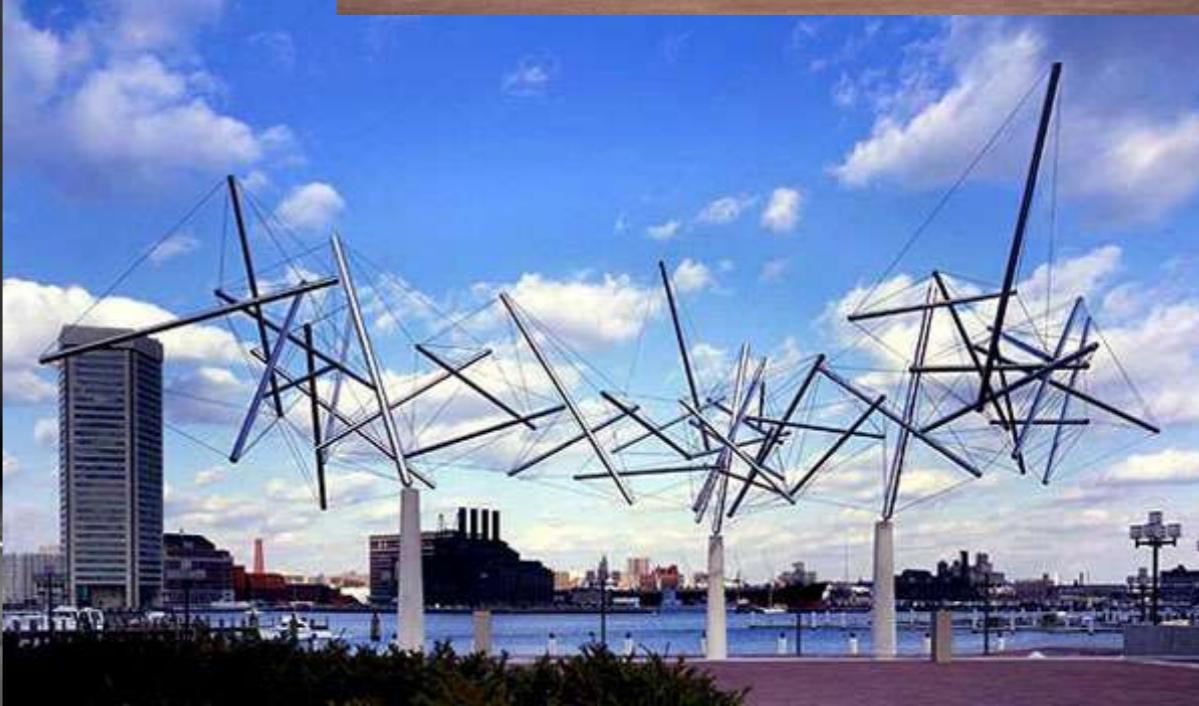
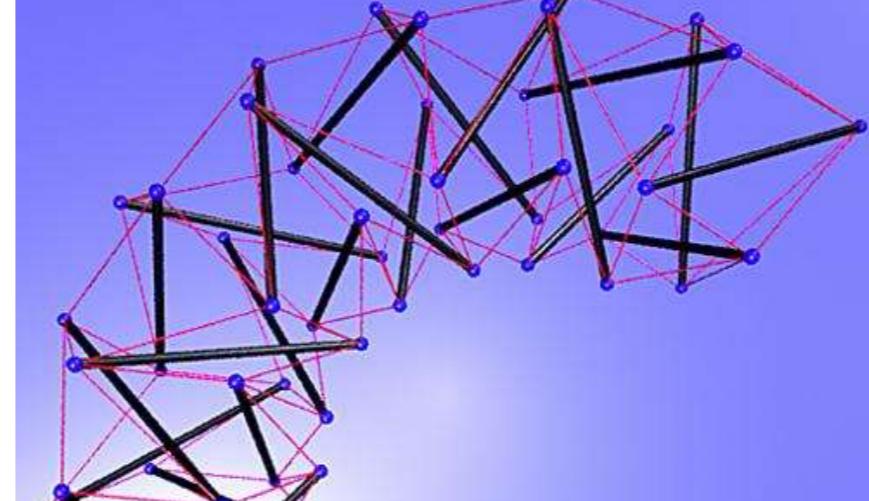


Quasicrystals

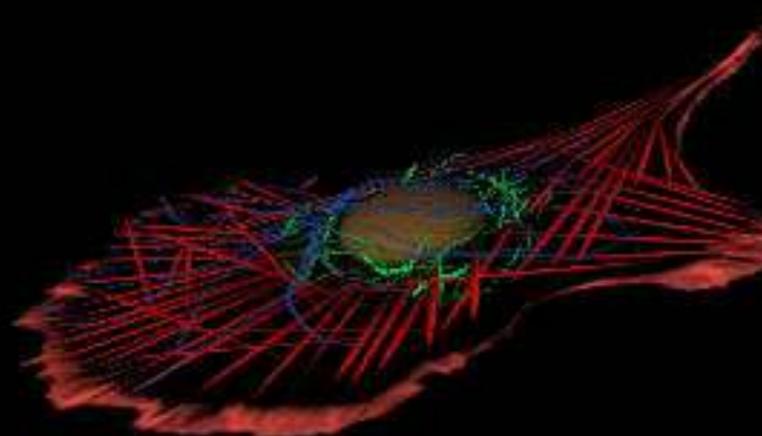


Fractals

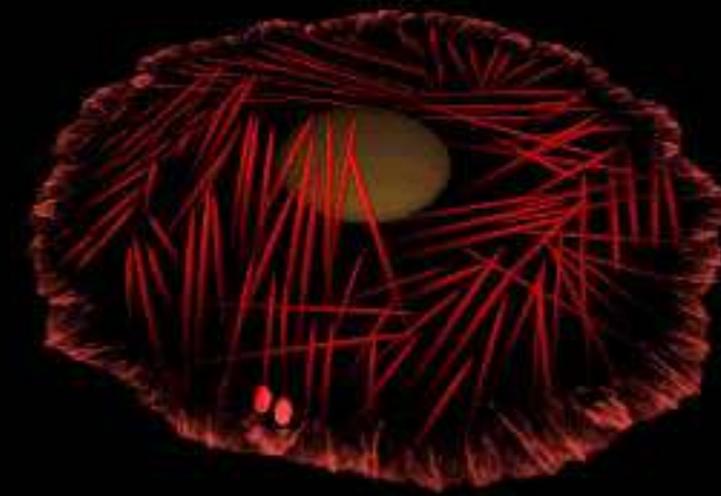




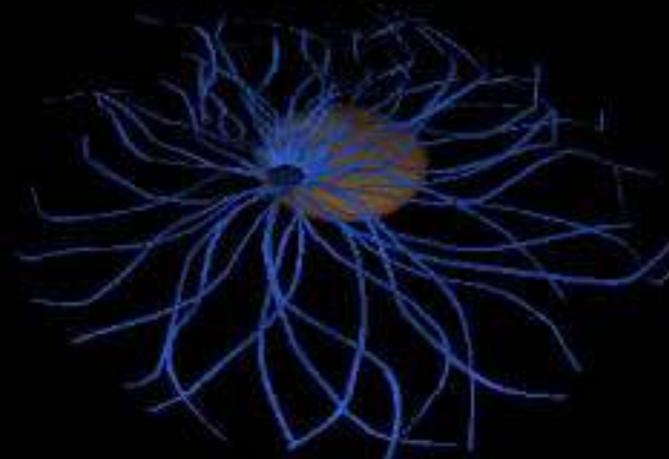
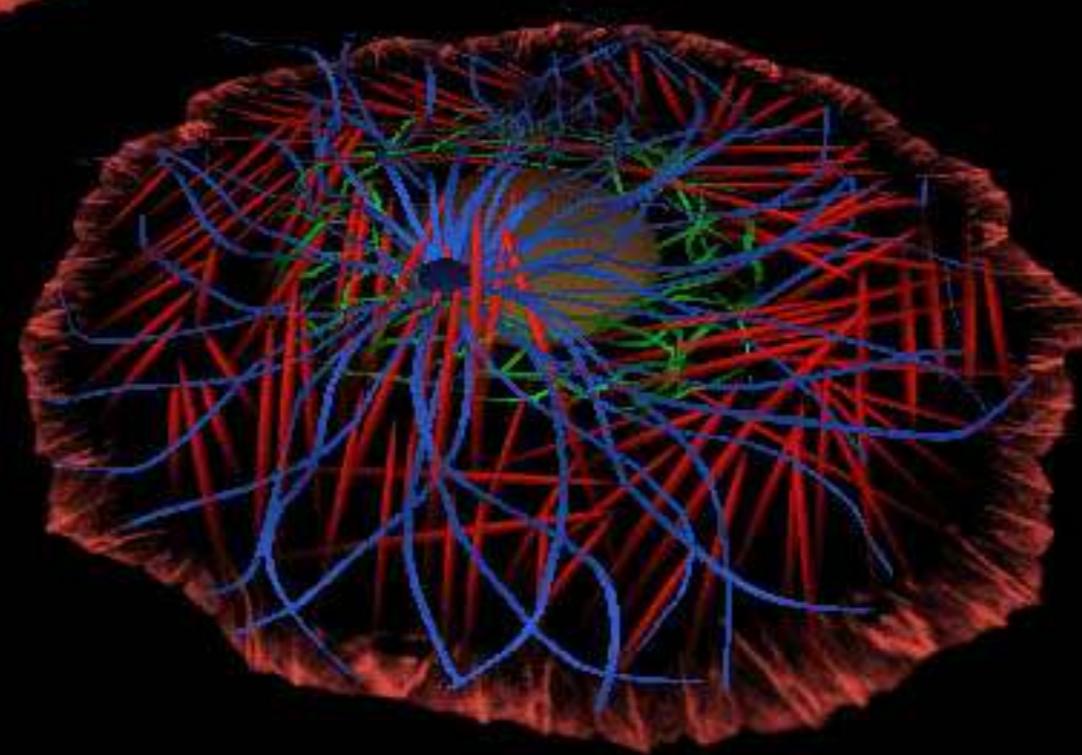
Ingber



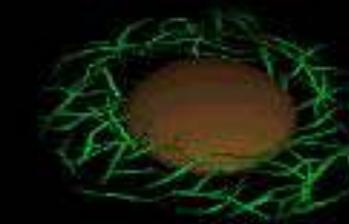
Moving cell



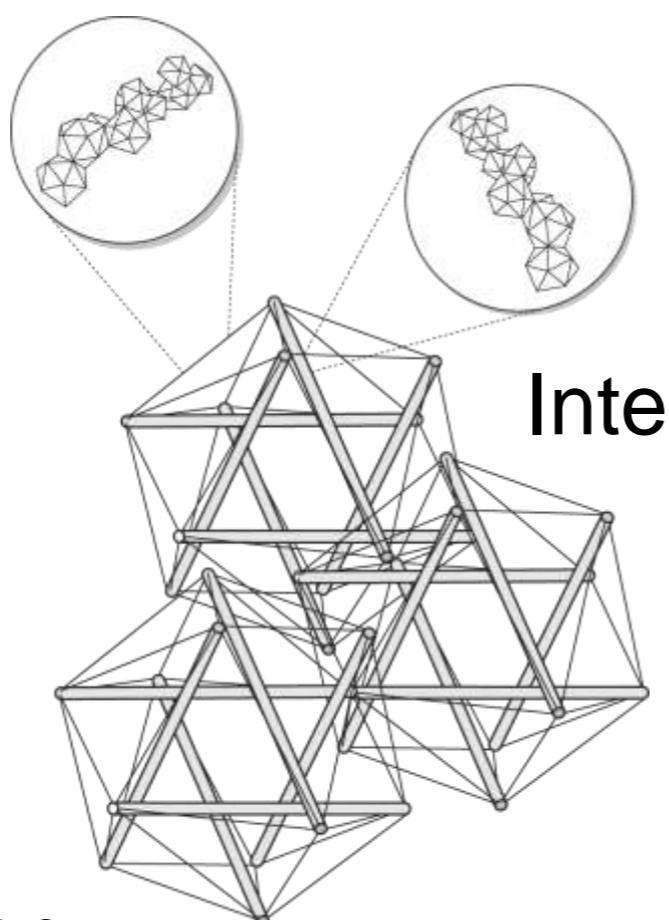
Actin Network



Microtubules

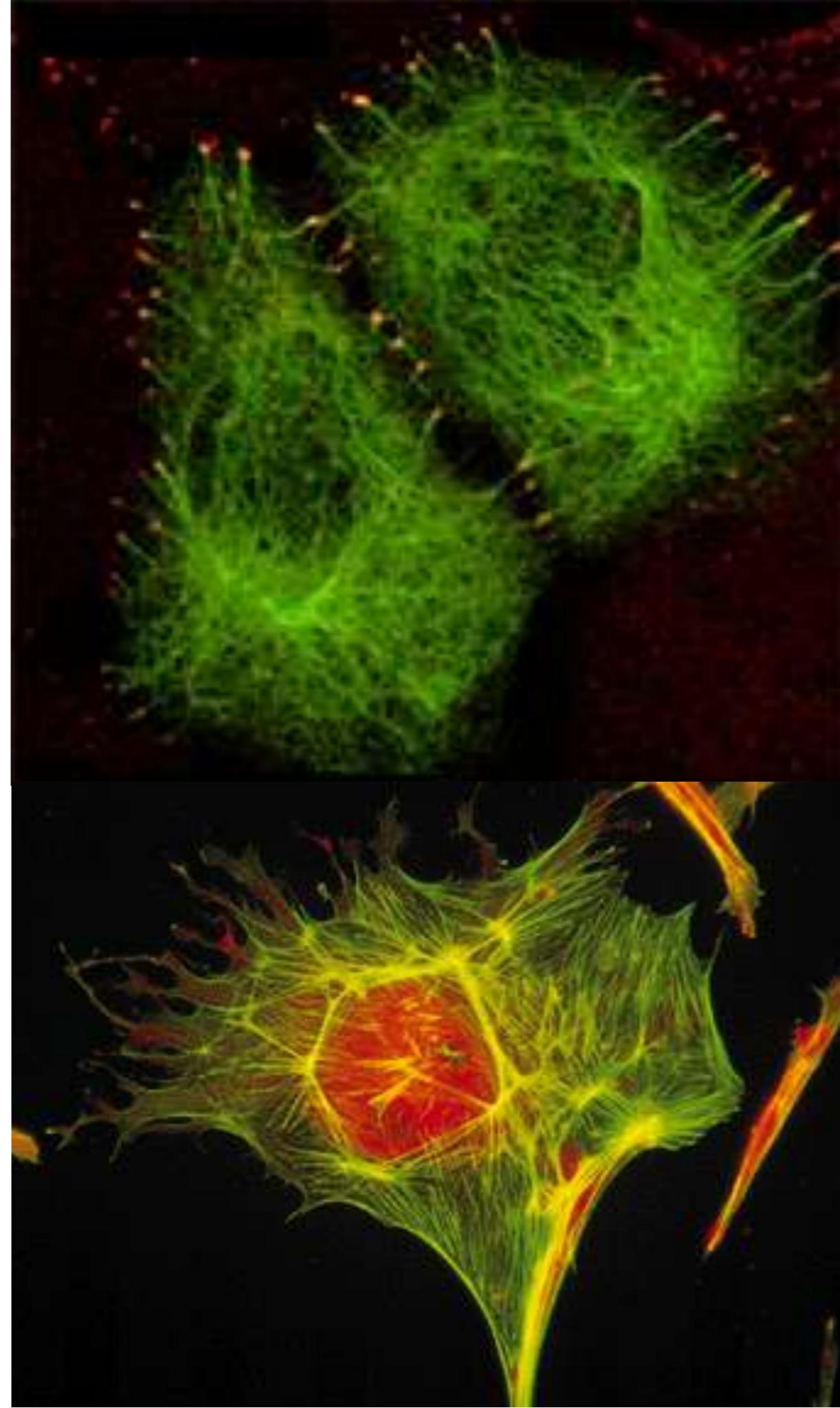
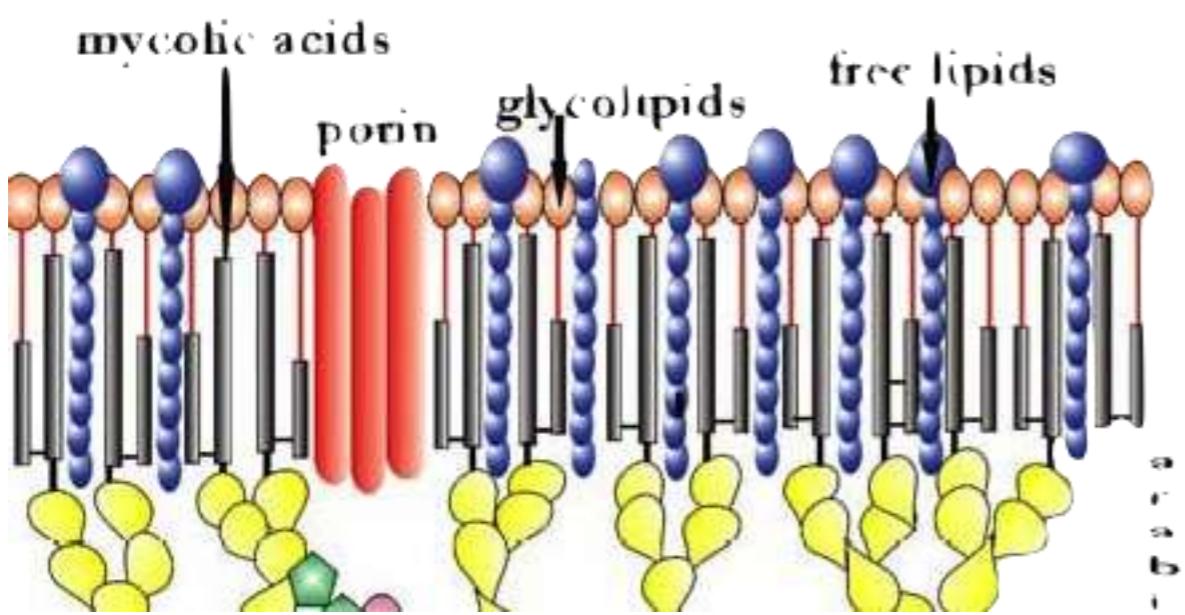


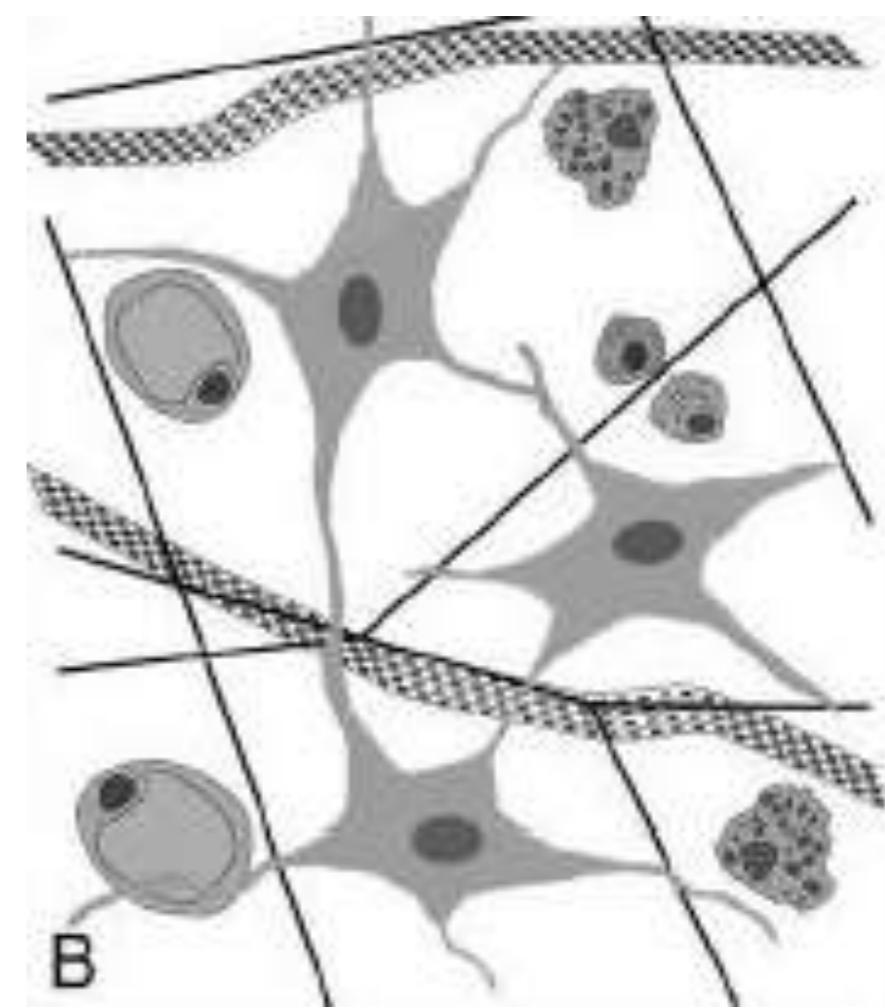
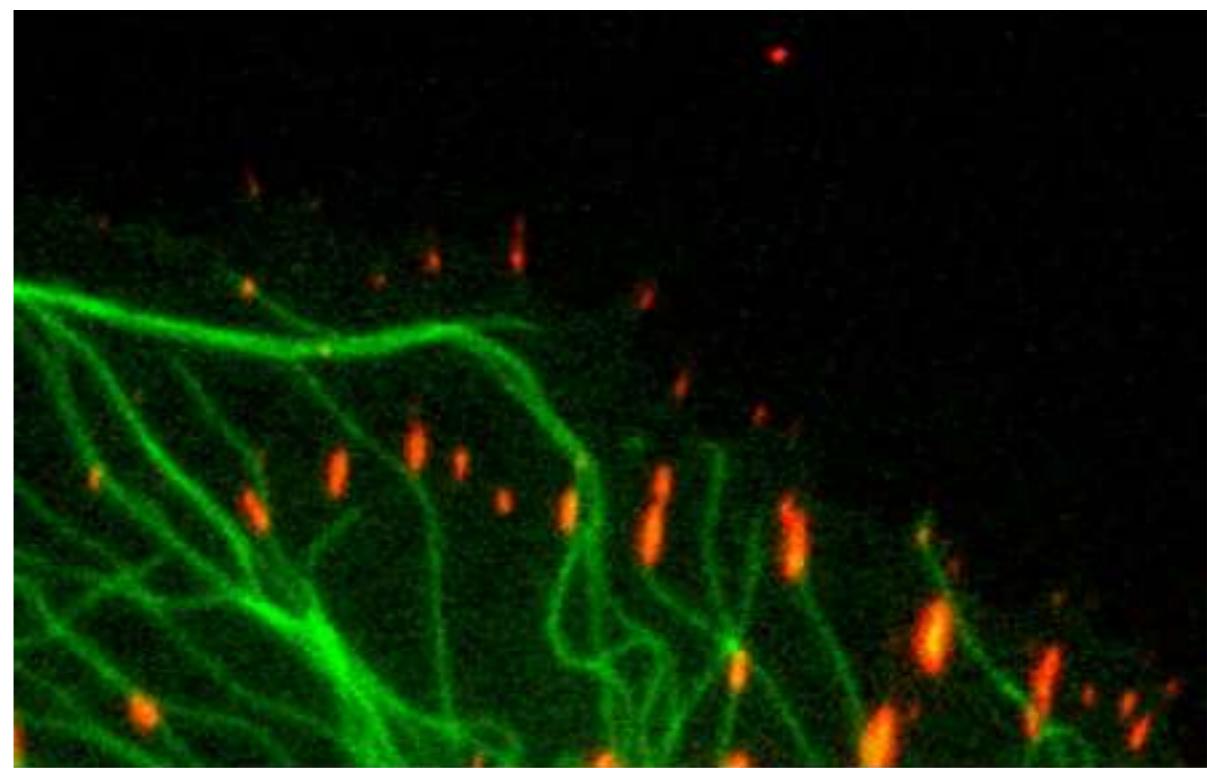
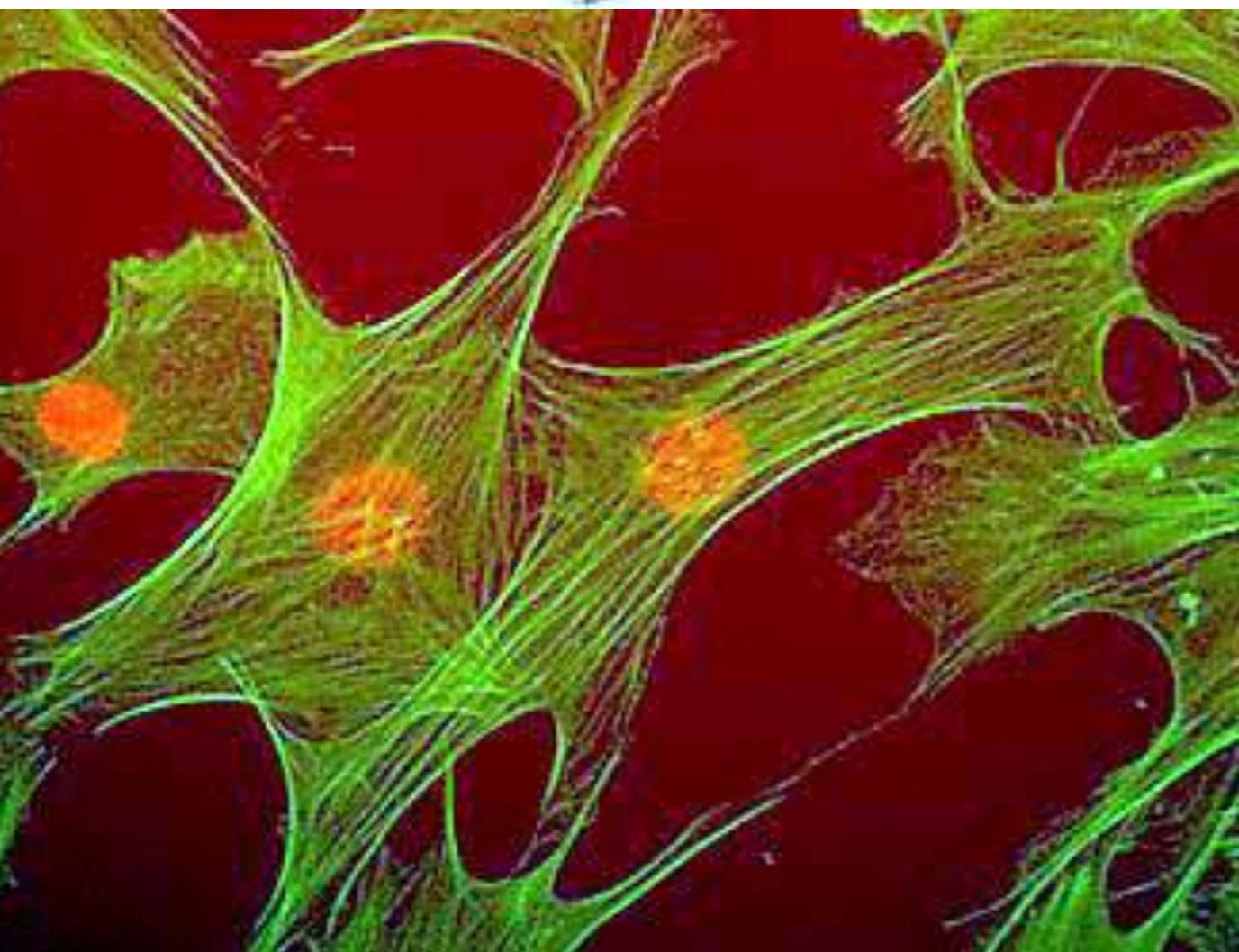
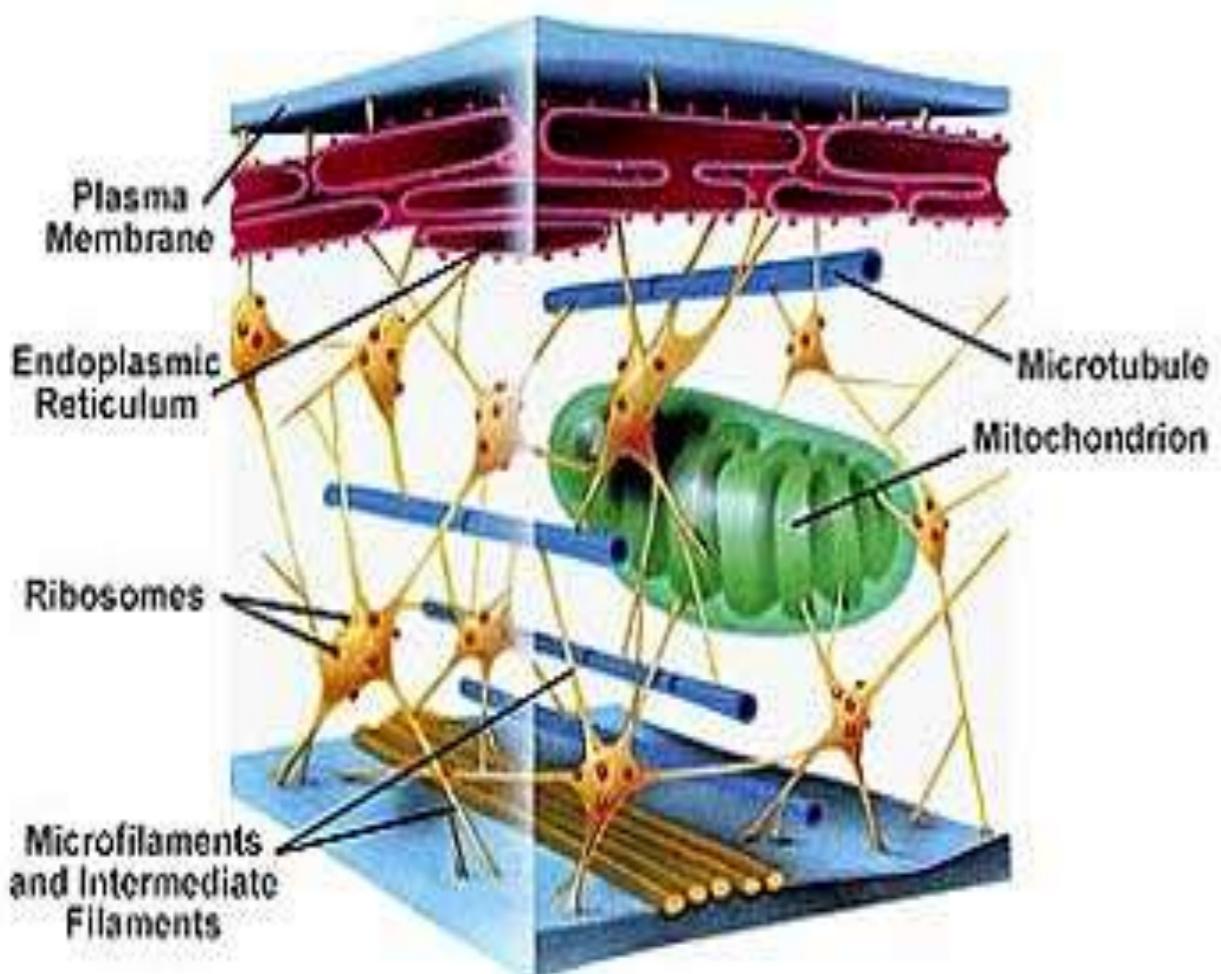
Intermediate Filaments



Integrins

Surface Tension
Soapy Cell Wall



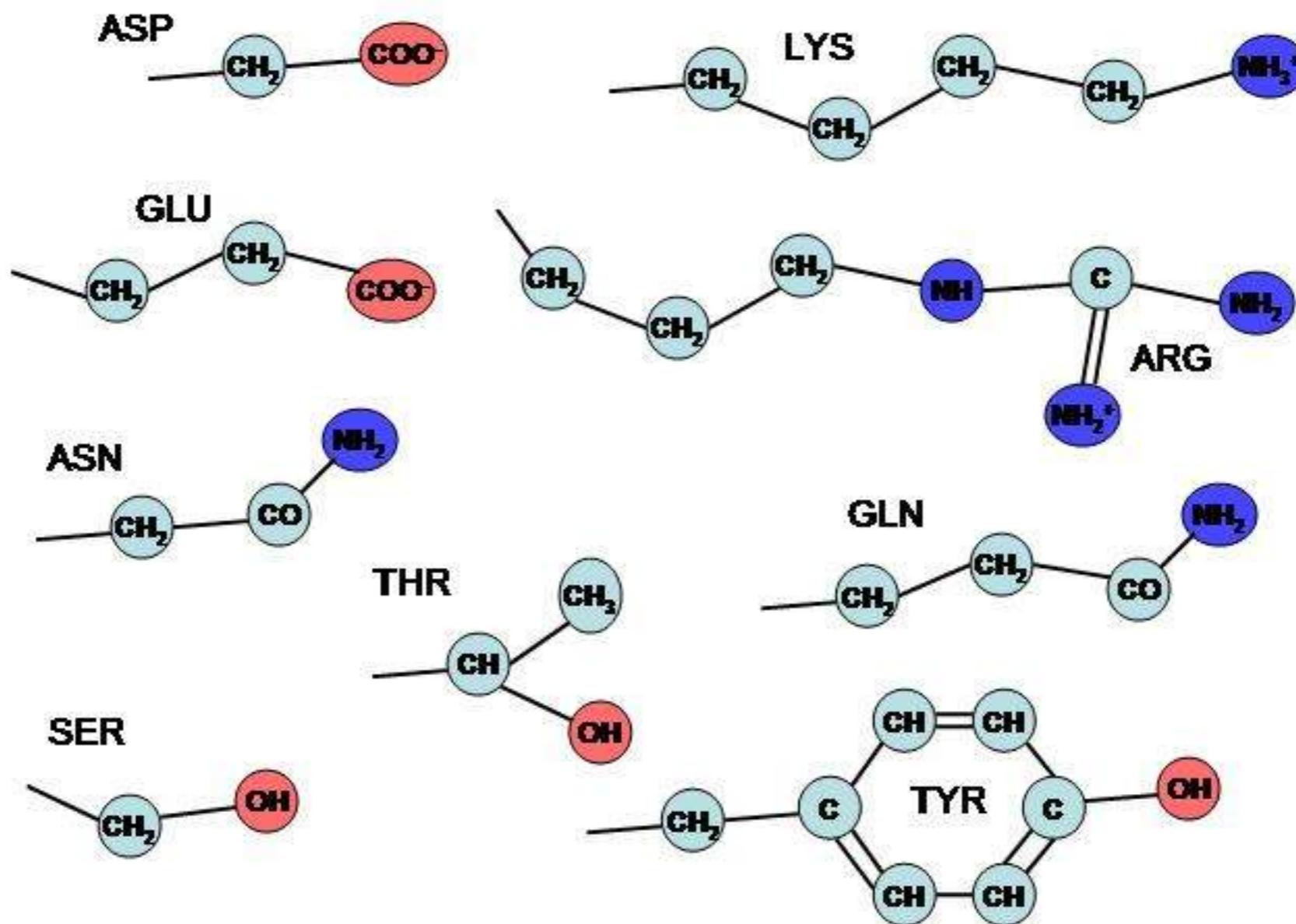


ECM (Langovin)

Water & Soft Matter

The 9 Hydrophilic Amino Acids

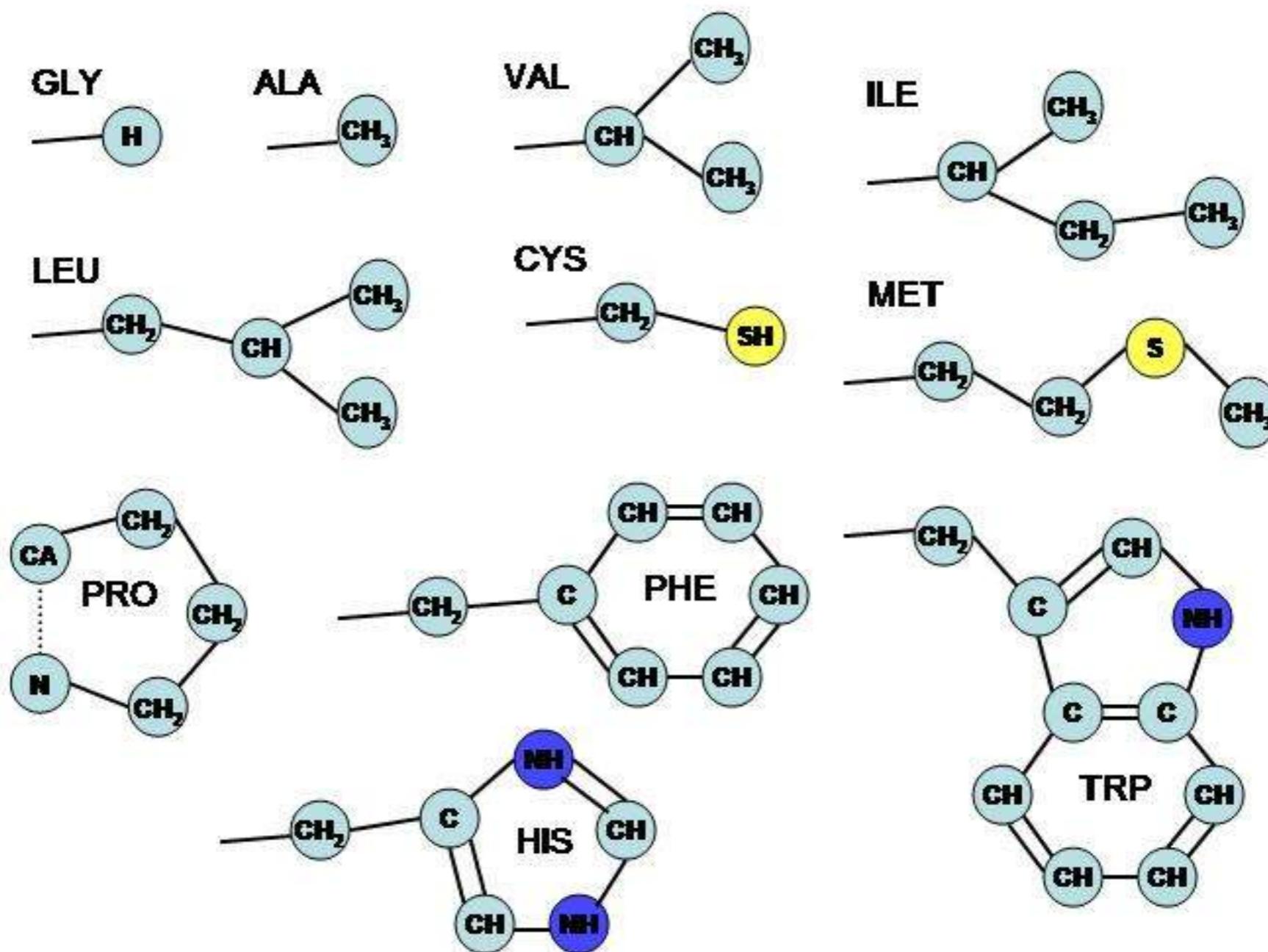
(only R groups are shown)

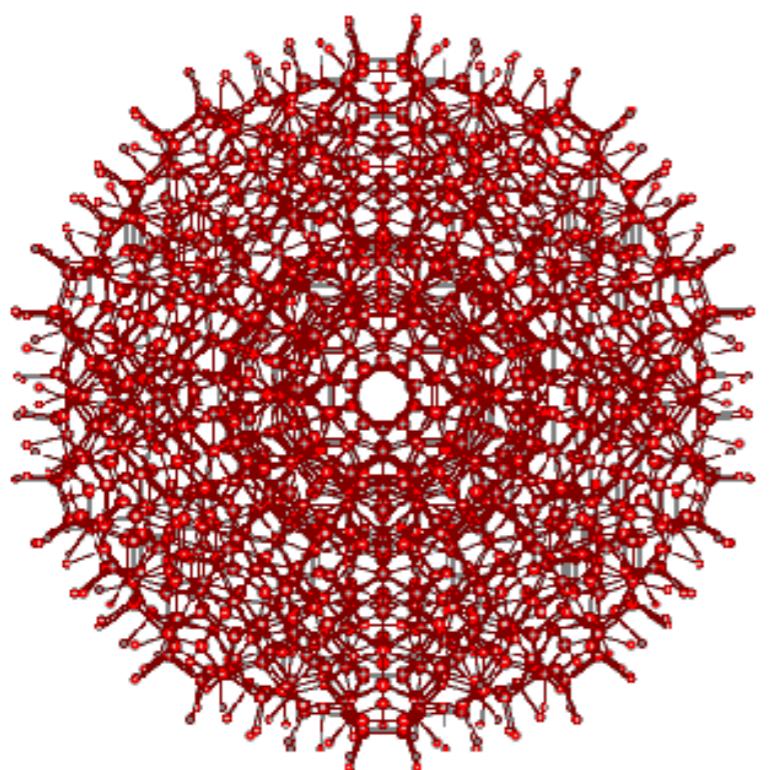
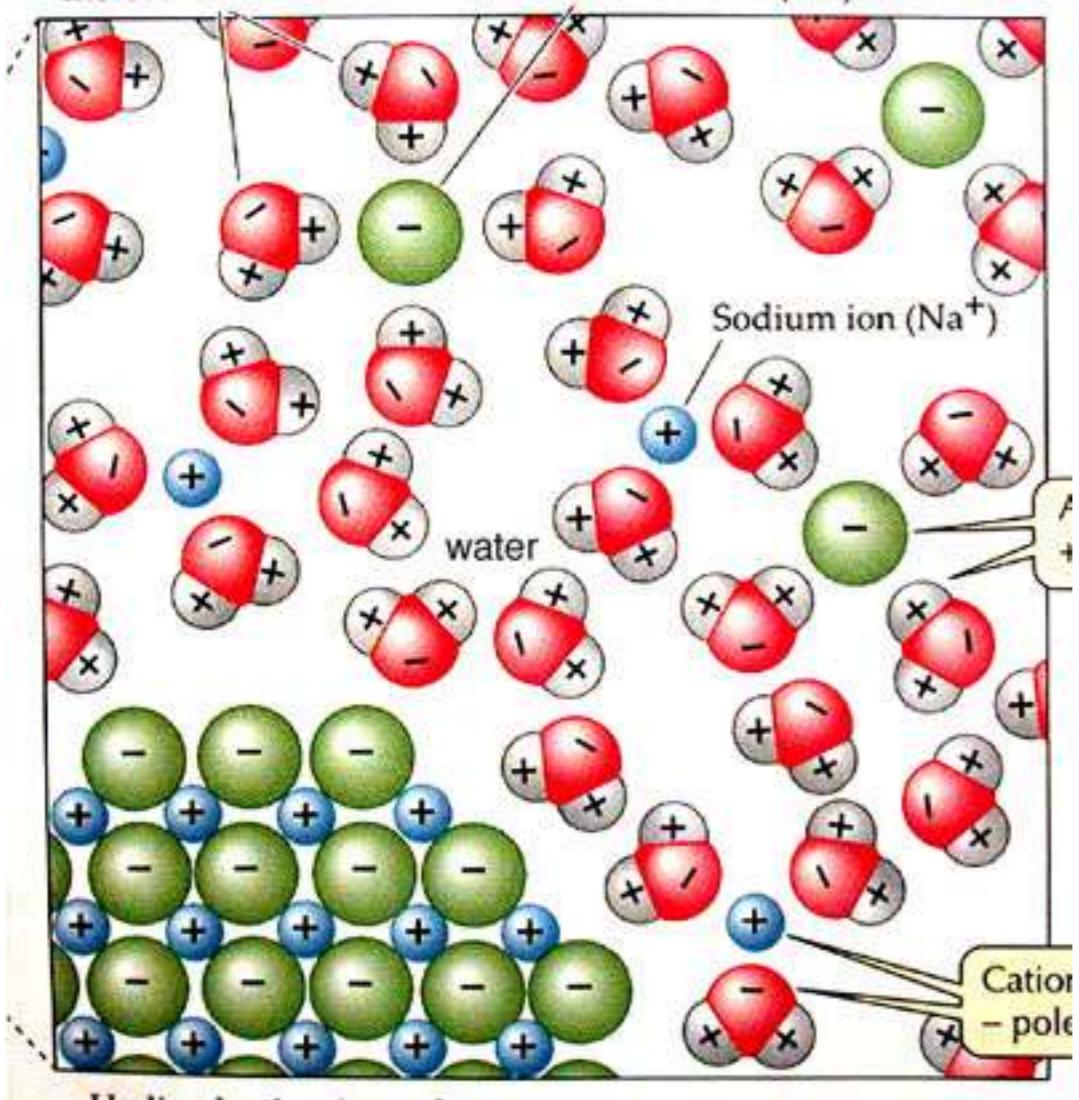


Water & Soft Matter

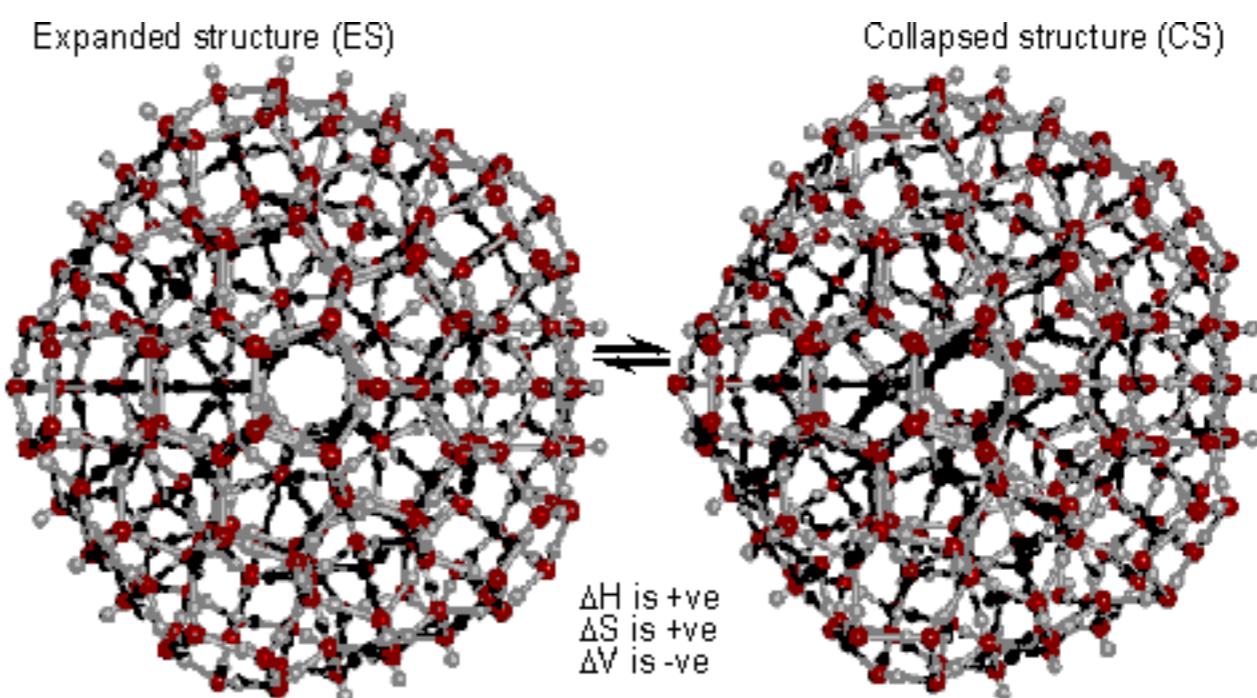
The 11 Hydrophobic Amino Acids

(only R groups are shown)

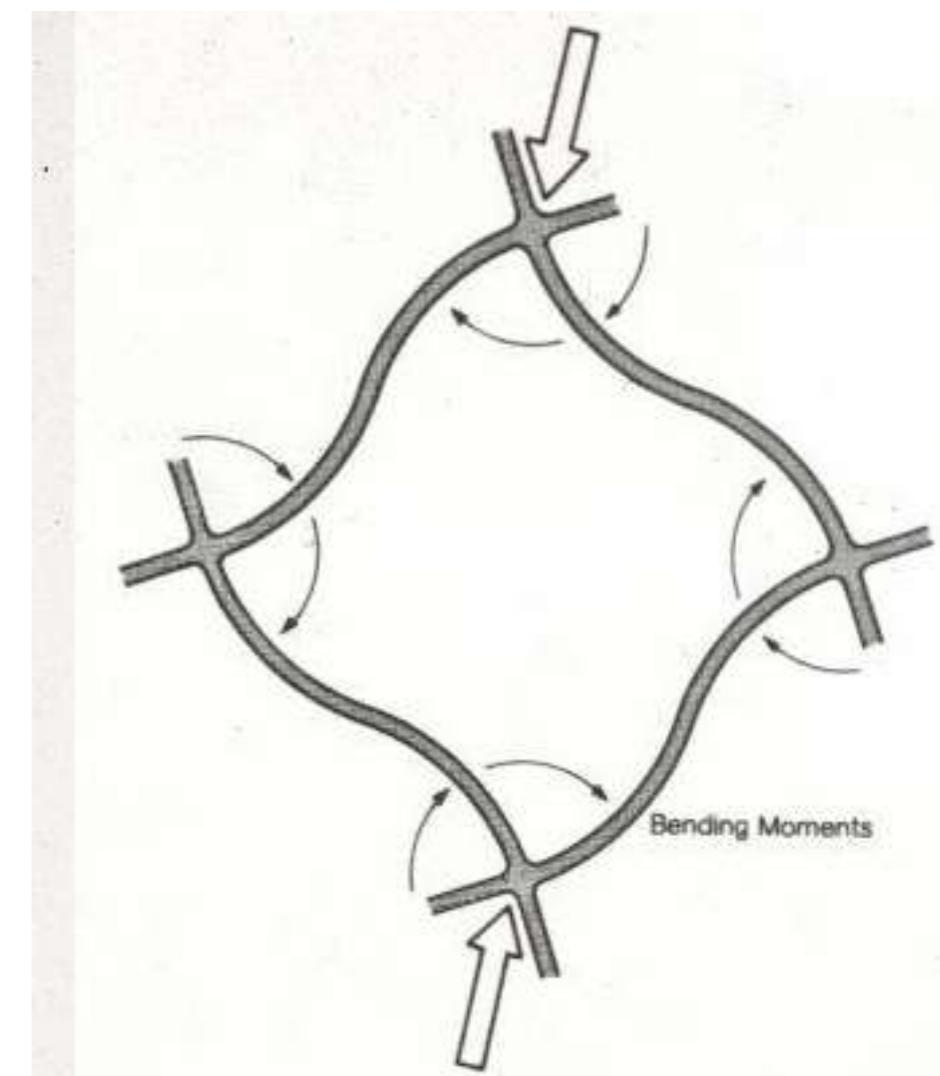
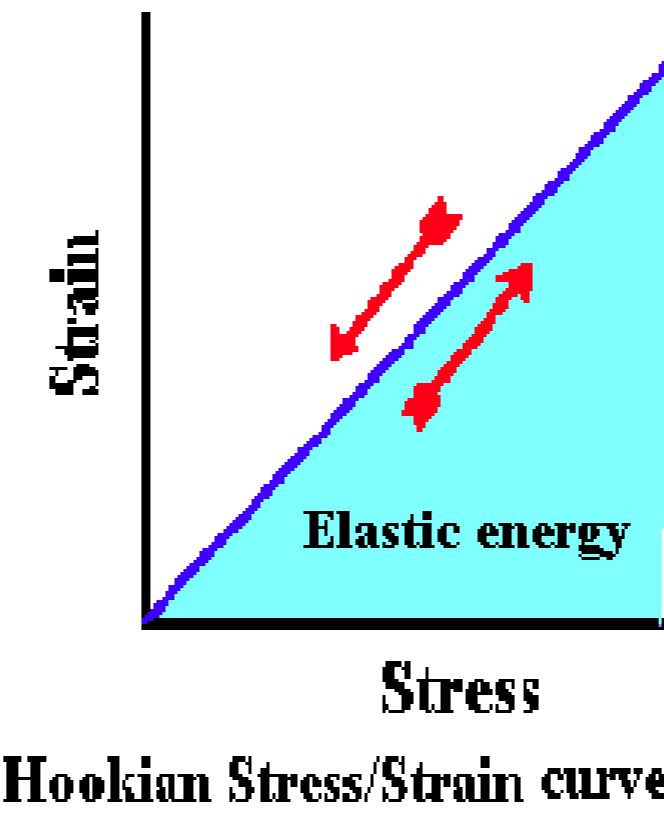
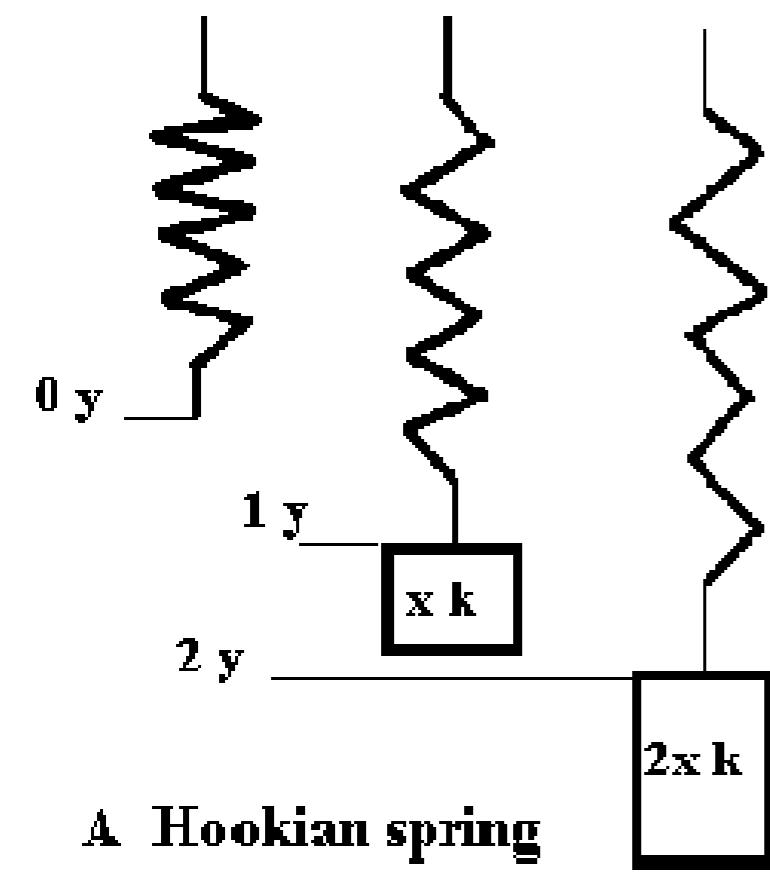
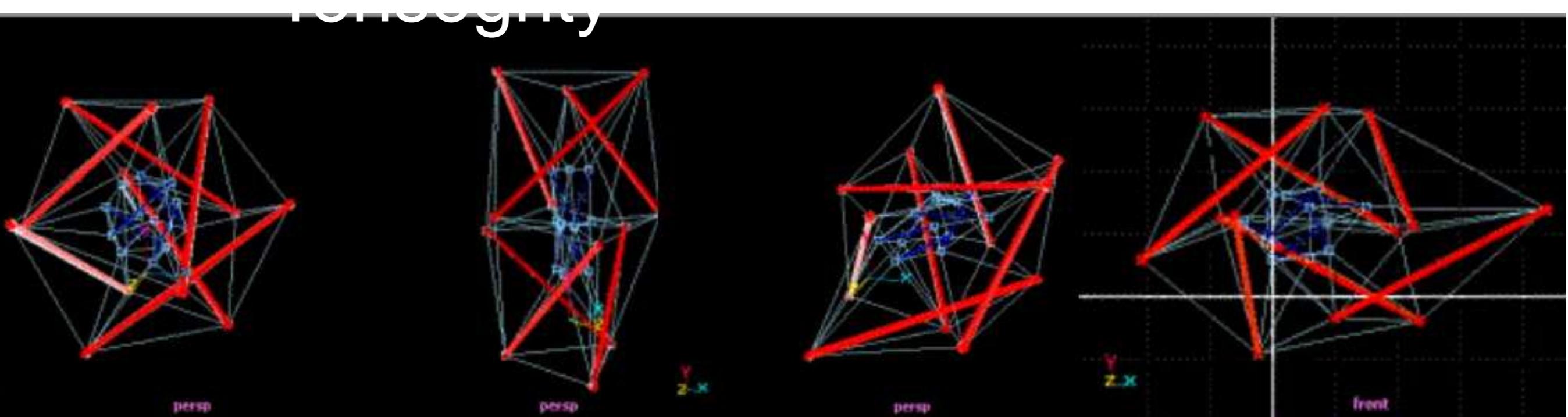


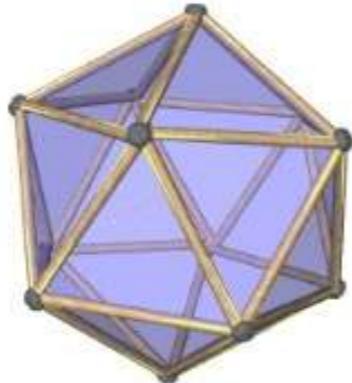
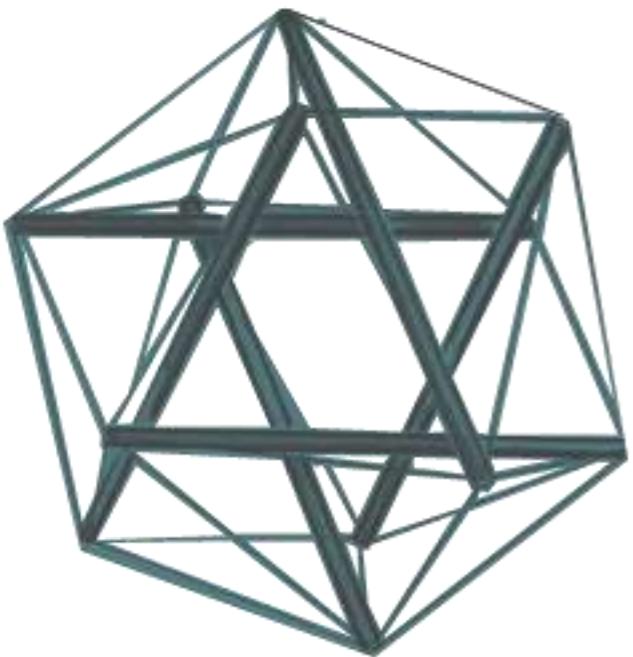


Water Clusters



Icosahedral Water

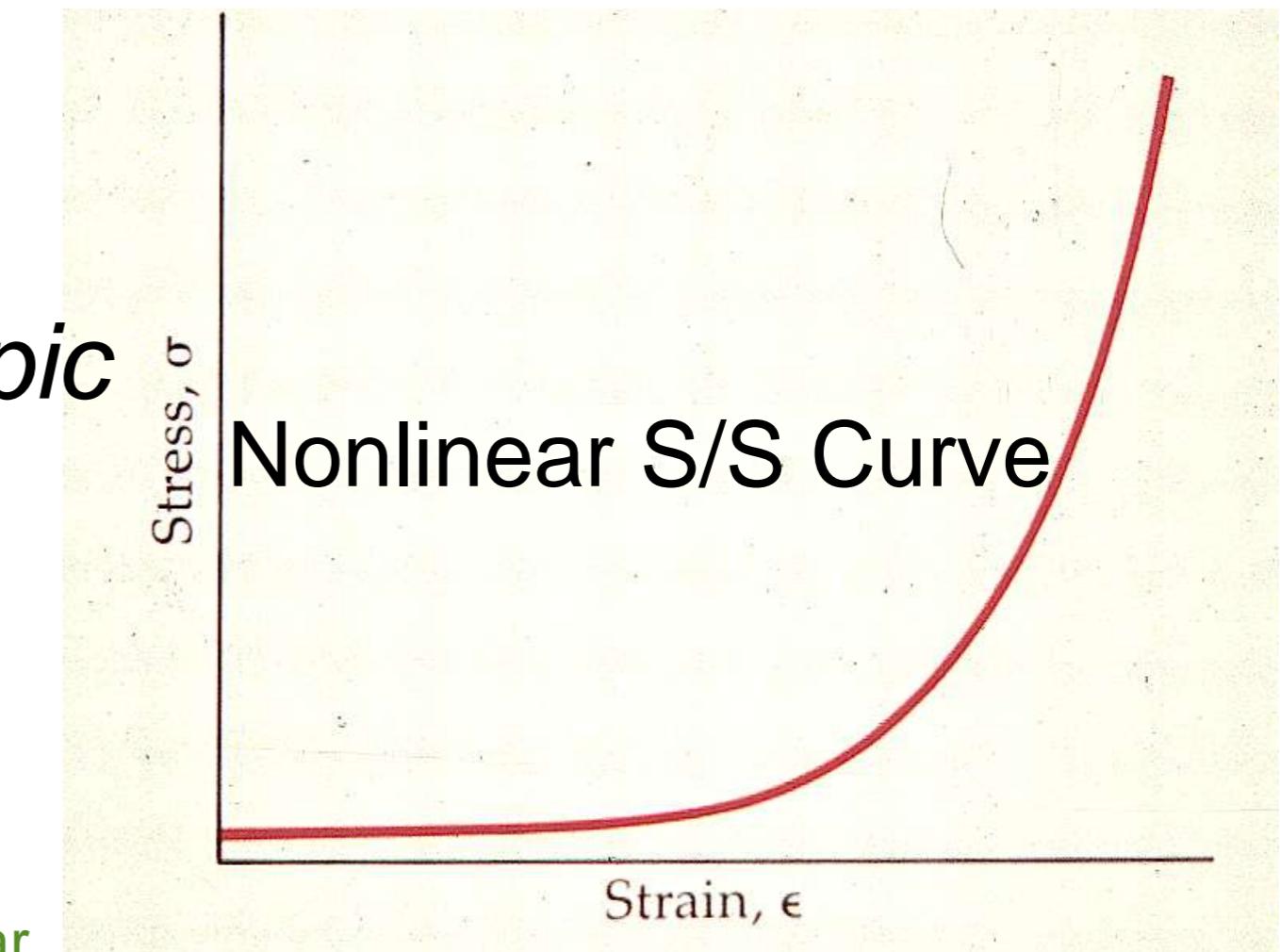
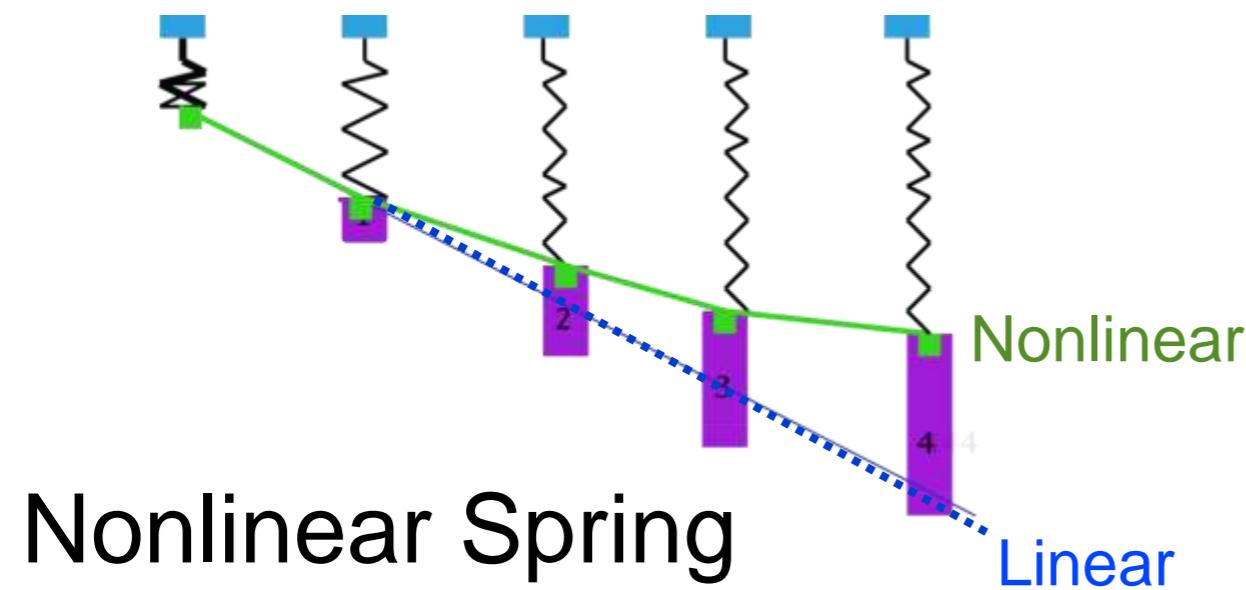




Icosahedron Under Load



Tensegrity Mechanics (As per Fuller) Mesoscopic

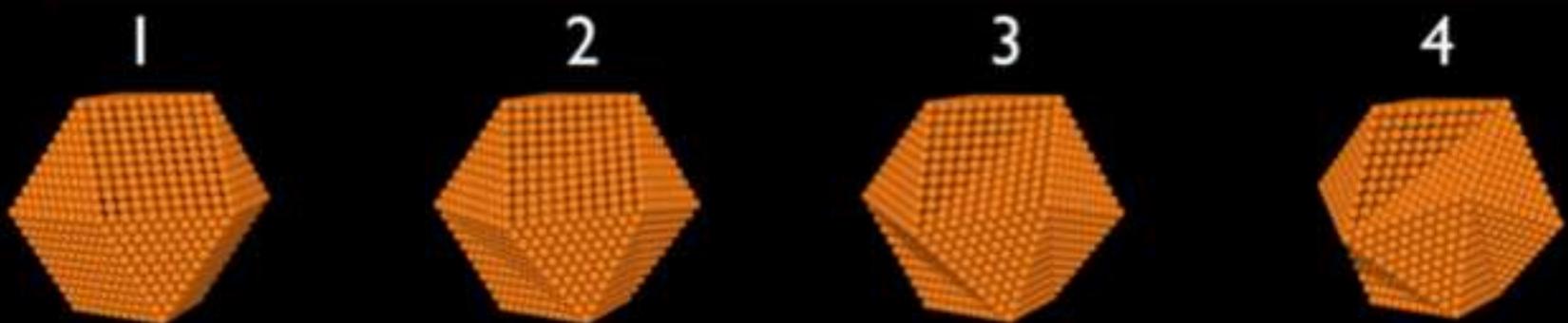
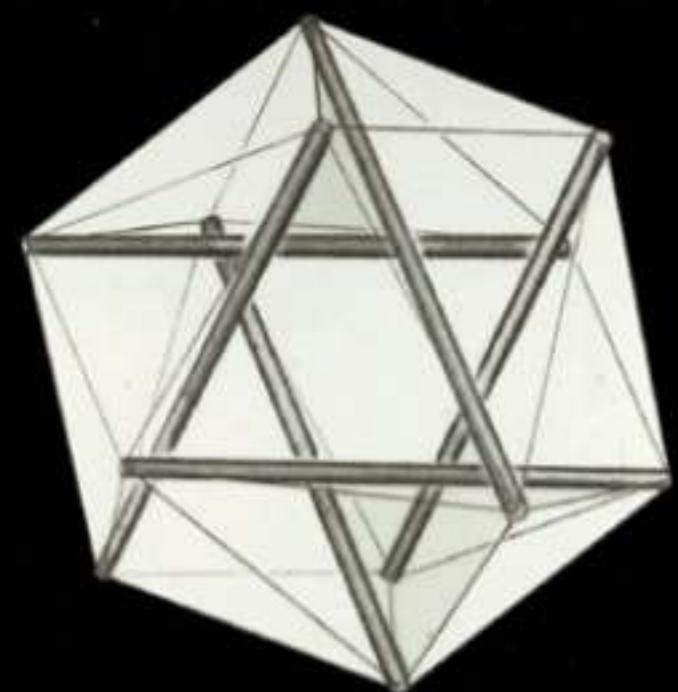


The J-shaped stress-strain curve (or simply J curve) that is typical of nearly all soft animal tissue. It results in mechanical toughness and discourages aneurysms.

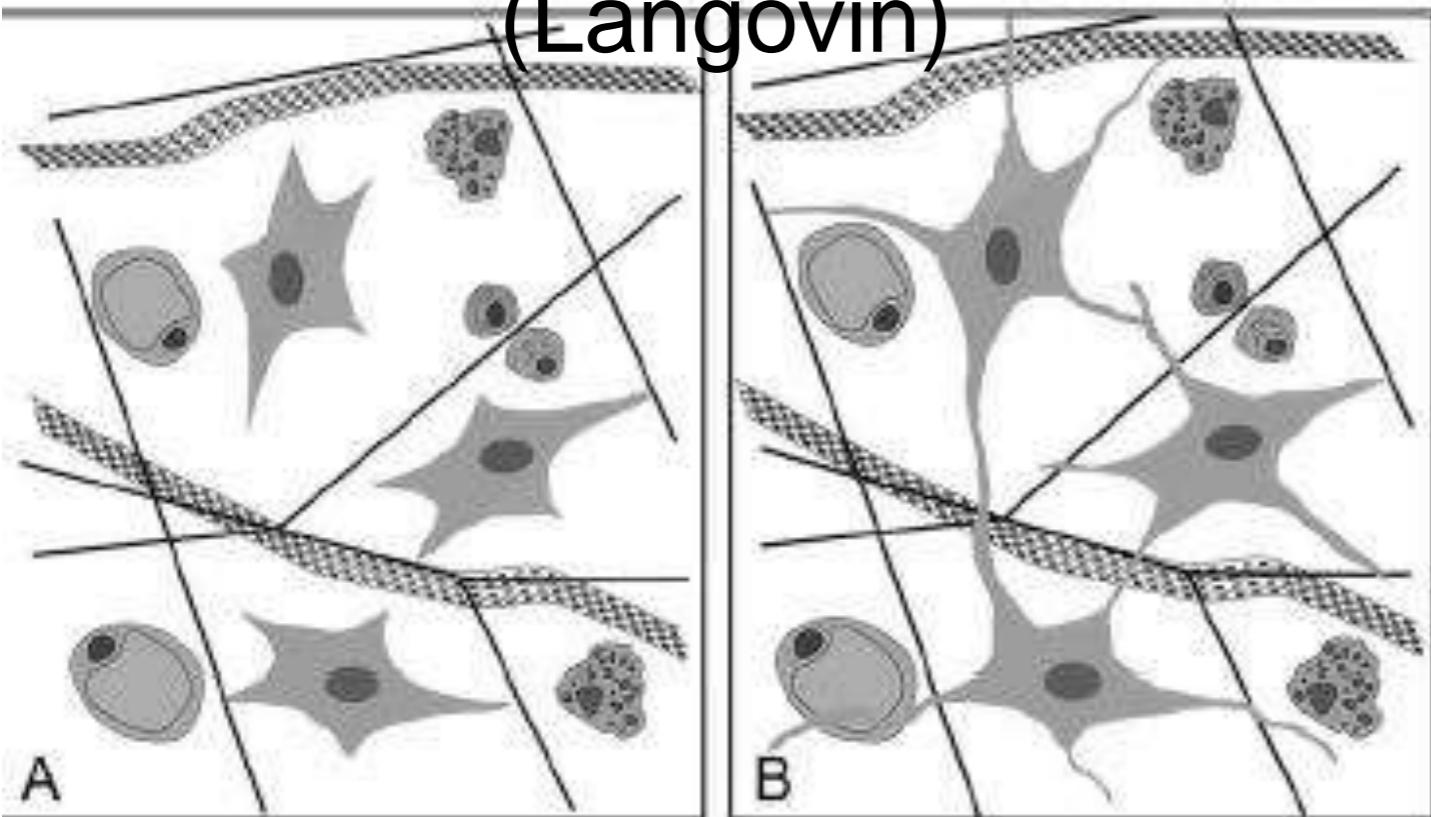
Oscillations Create
Sound
Electromagnetic
Thermal
Energy Transfer
Information

Pumping Action

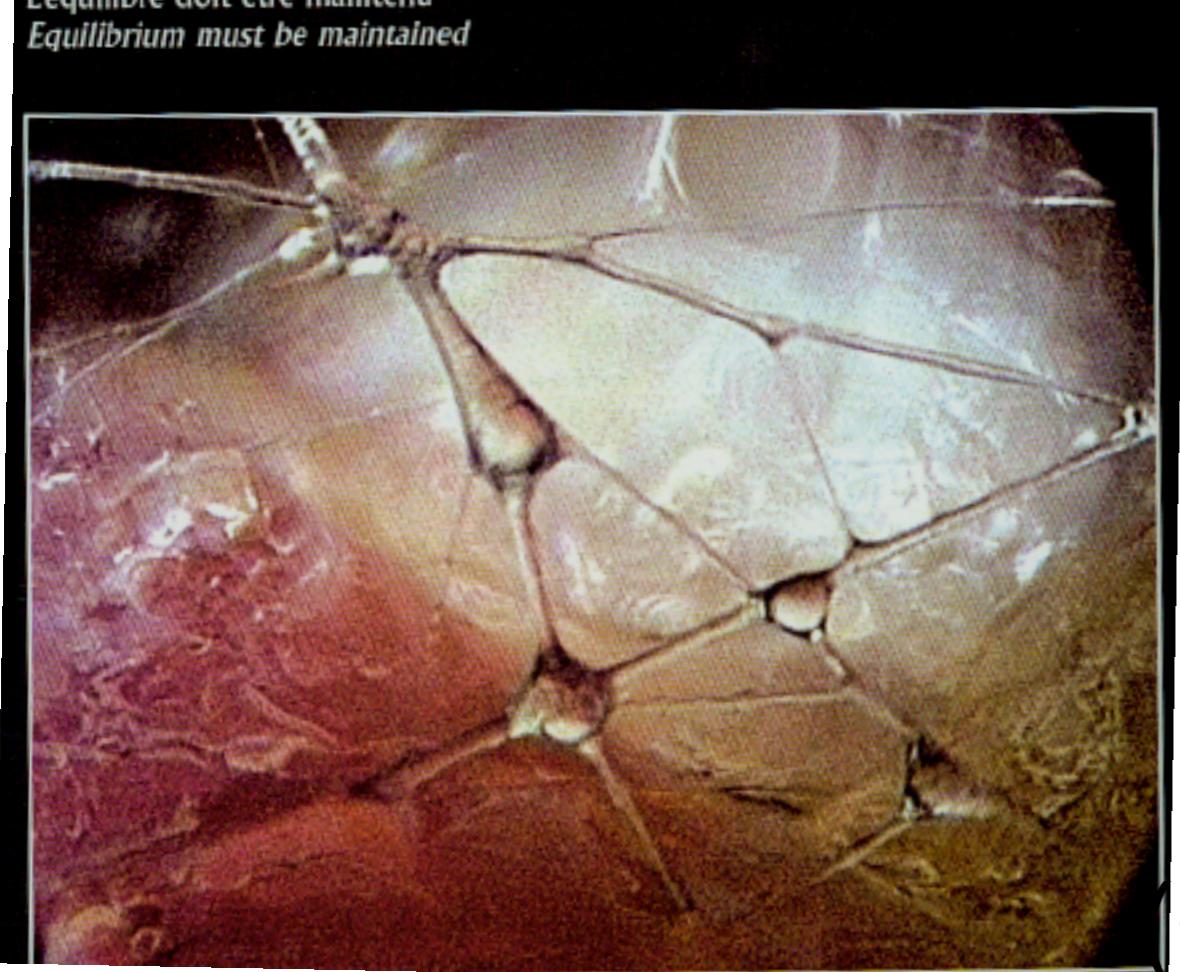
Rossiter



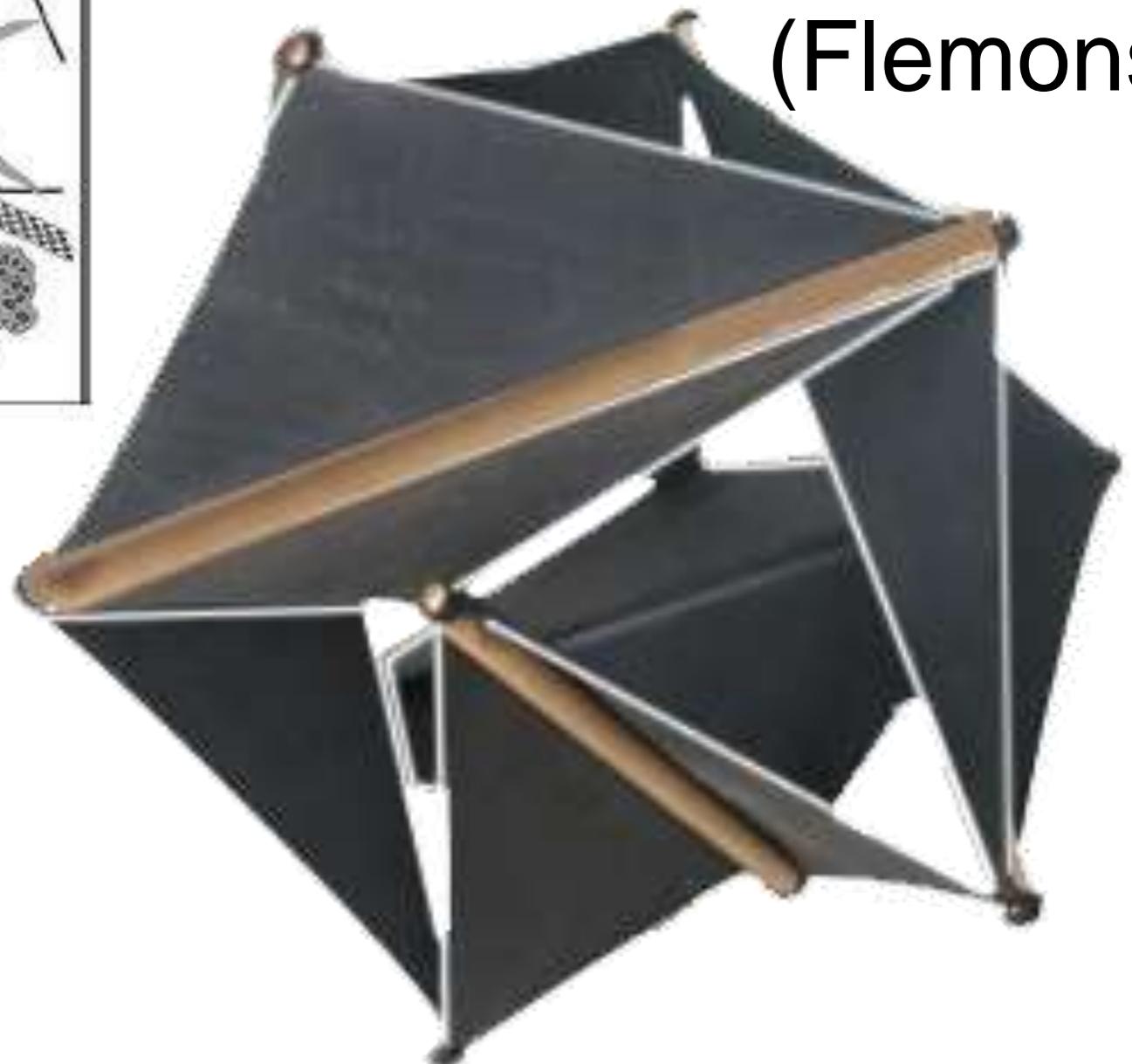
ECM/Fibroblasts/Fascia (Langvin)



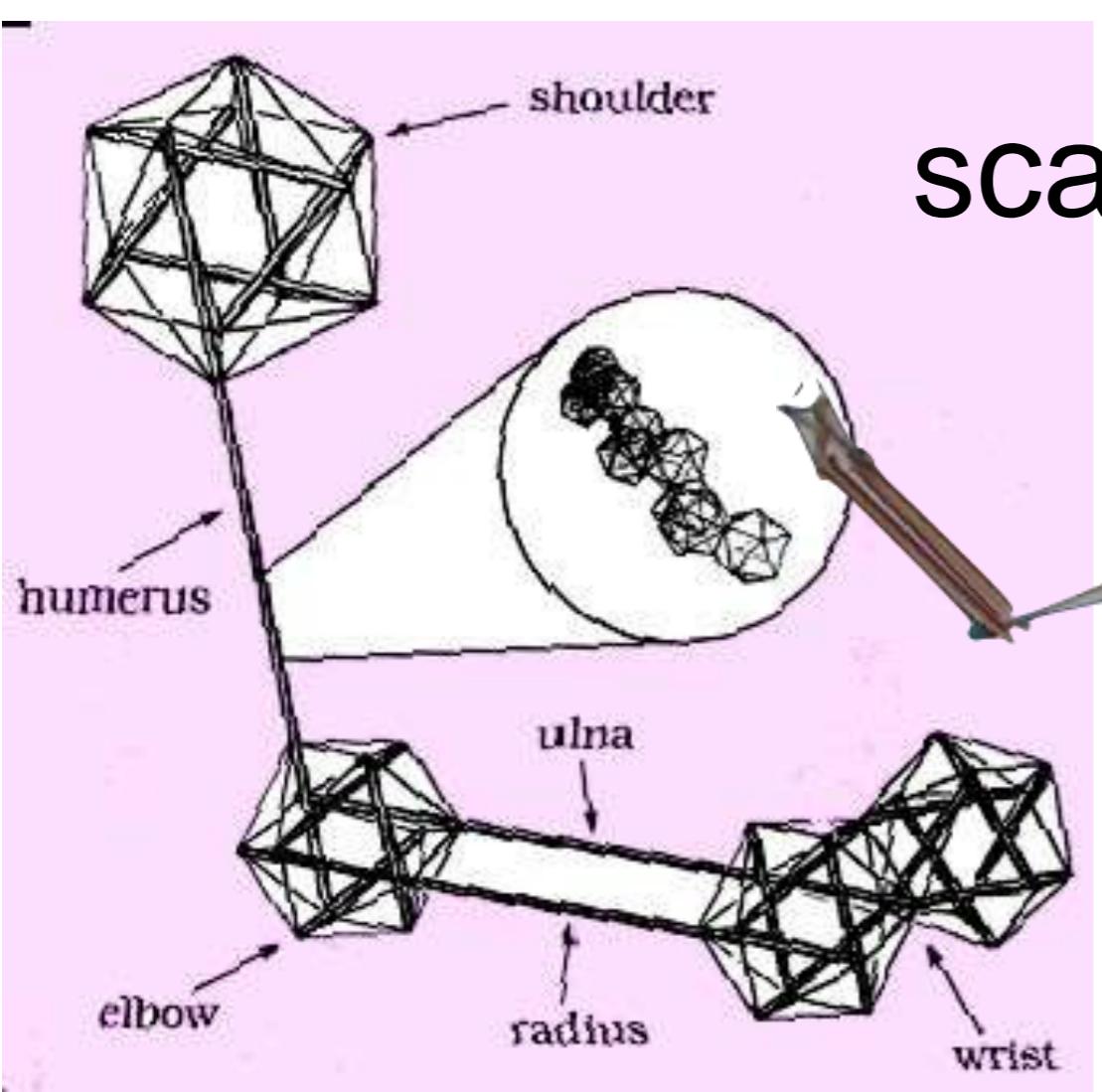
L'équilibre doit être maintenu
Equilibrium must be maintained



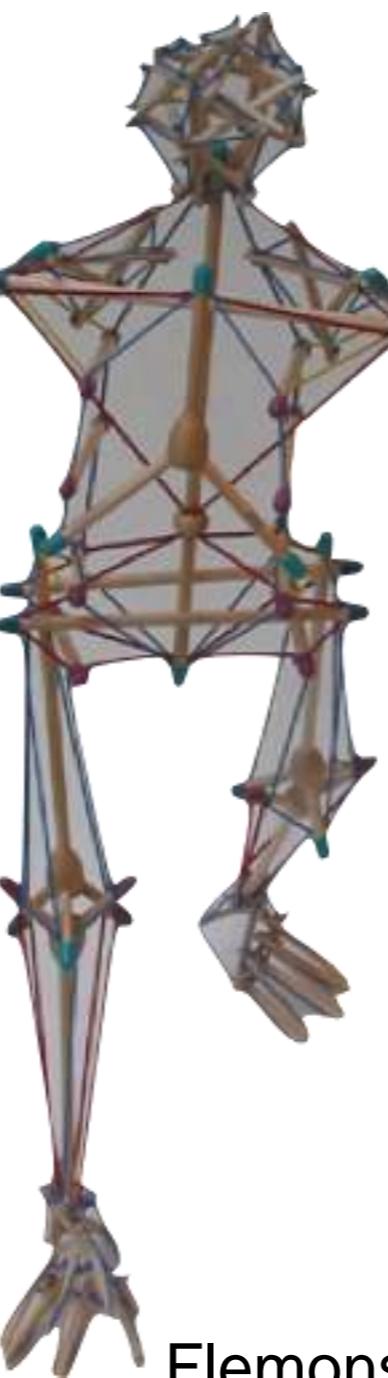
(Flemons)



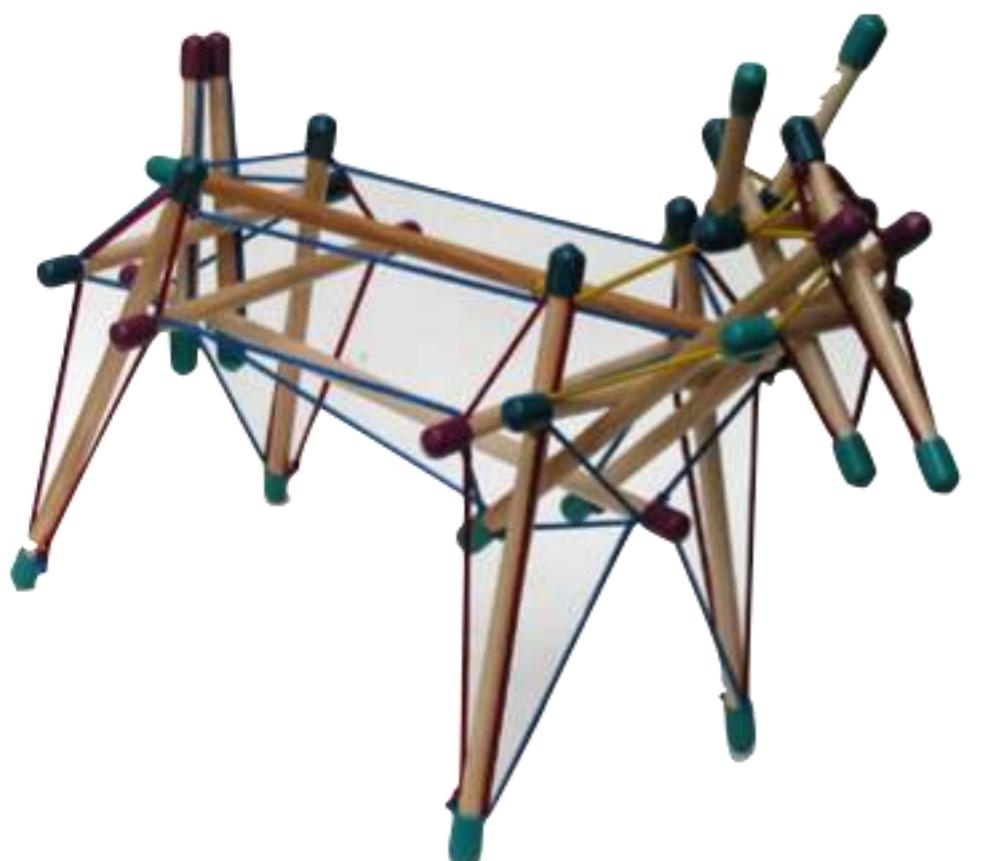
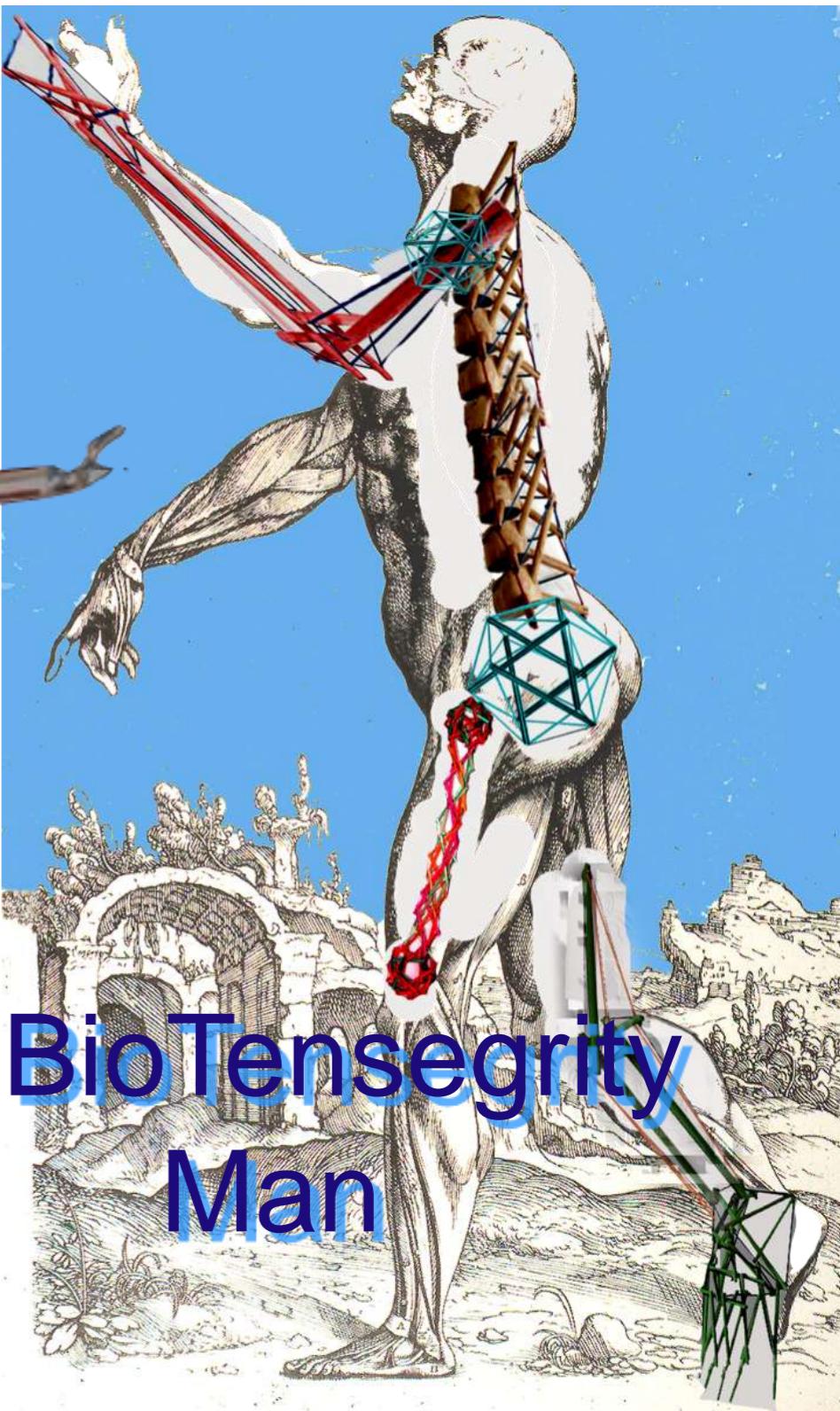
Guimberteau)



scaling up

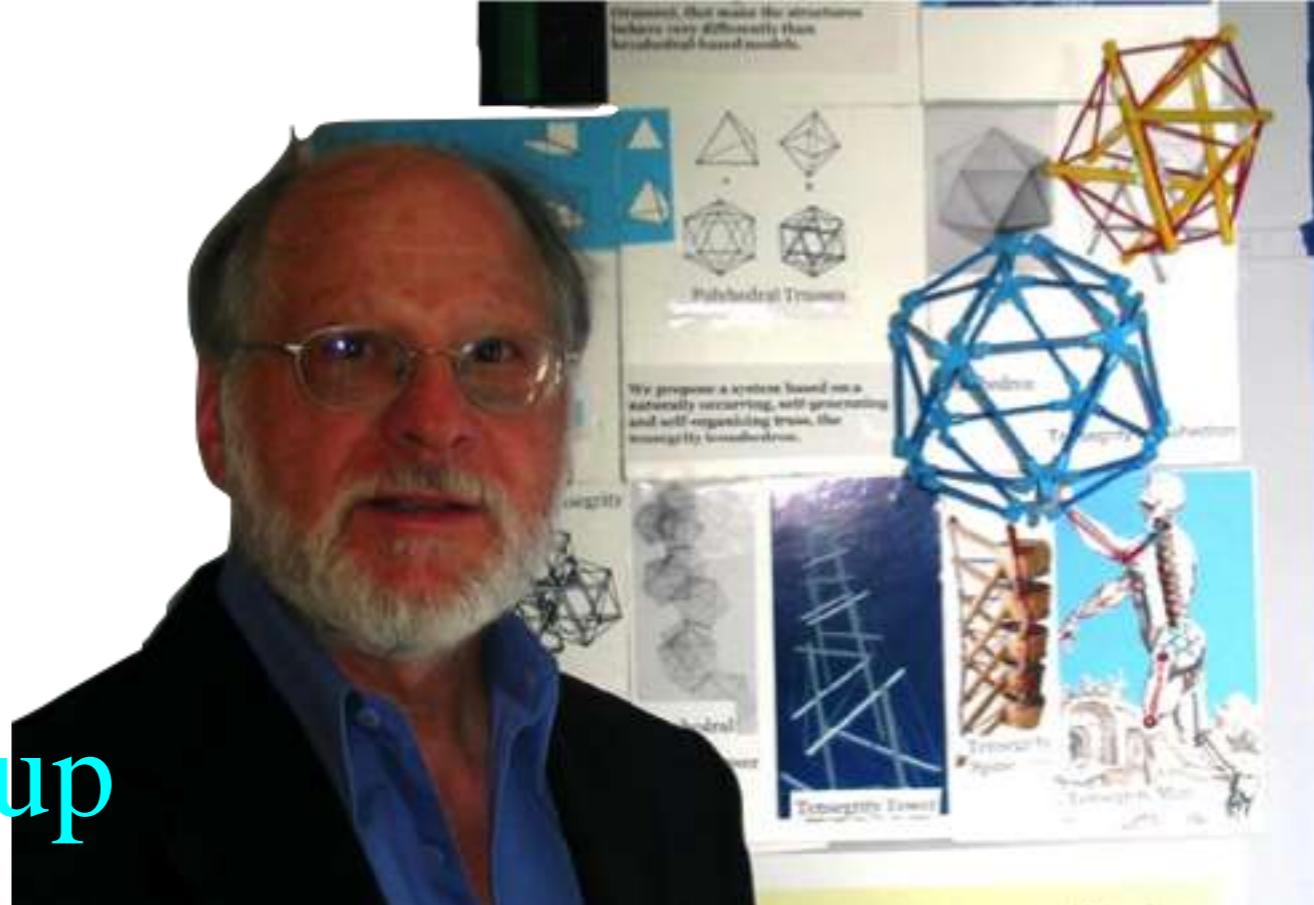


Flemons



Thank you!

Stephen M. Levin, MD
Ezekiel Biomechanics Group
McLean, Virginia 22102



smlevin@biotensegrity.com
www.biotensegrity.com

<http://tinyurl.com/biotensegrity2-embryo>

