Building College-University Partnerships for Nanotechnology Workforce Development

NACK CENTER

Properties of Nanomaterials

January 29, 2021

PennState

Welcome

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Welcome

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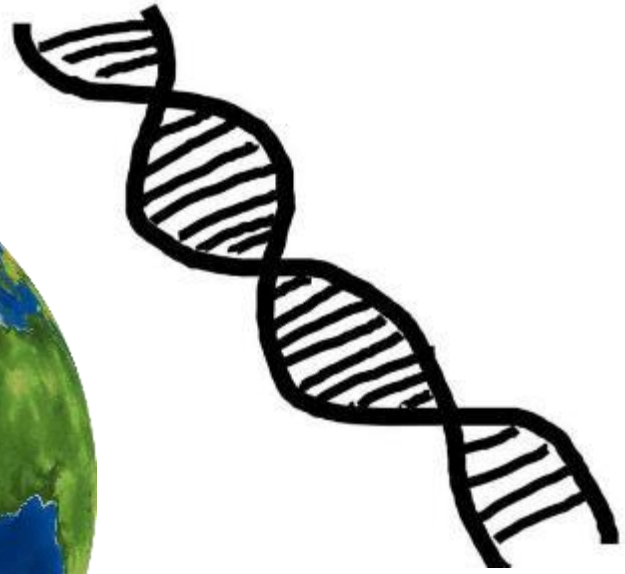
Portland, OR
peter.kazarinoff@pcc.edu

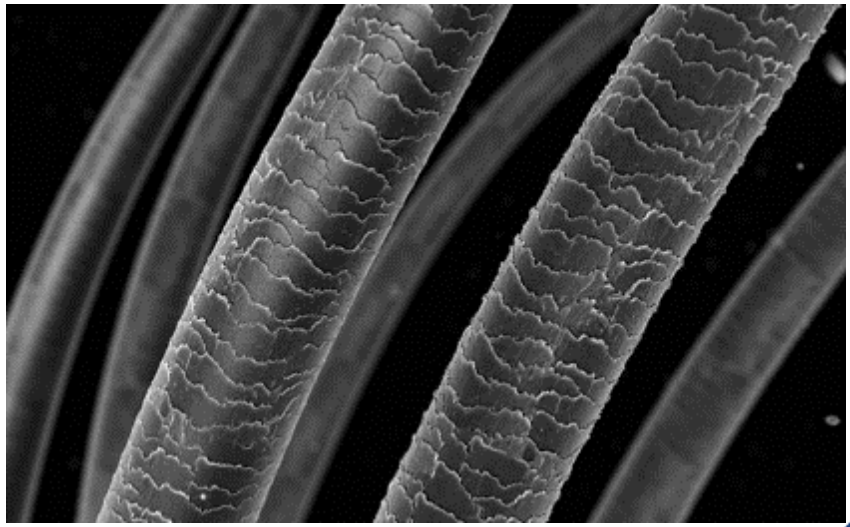
How small is the nanoscale?

Pop quiz!

How small is one billionth?

How do you explain one nanometer?





Properties change with scale

Scale, Proportion and Quantity
Crosscutting Concept, NGSS

"The large idea is that ***the way in which things work may change with scale*.** Different aspects of nature change at different rates with changes in scale, and so the relationships among them change, too."

Source: A framework for K-12 science education: Practices, crosscutting concepts, and core ideas, p. 89

Property changes with scale

- Light-matter interactions change
- Gravity becomes insignificant, intermolecular forces dominate
- Surface effects become important due to large surface area
- Motion becomes complicated
- Quantum effects dominate

Is it blue or is it nanotechnology?

Light-matter interactions at the nanoscale

Mother Nature has trouble making blue

stock photo ID: 70621789
https://www.boredpanda.com/autumn-rainbow-nature-photography/?utm_source=google&utm_medium=organic&utm_campaign=organic

So where does blue come from?

Not one of these organisms has a speck of blue pigment.

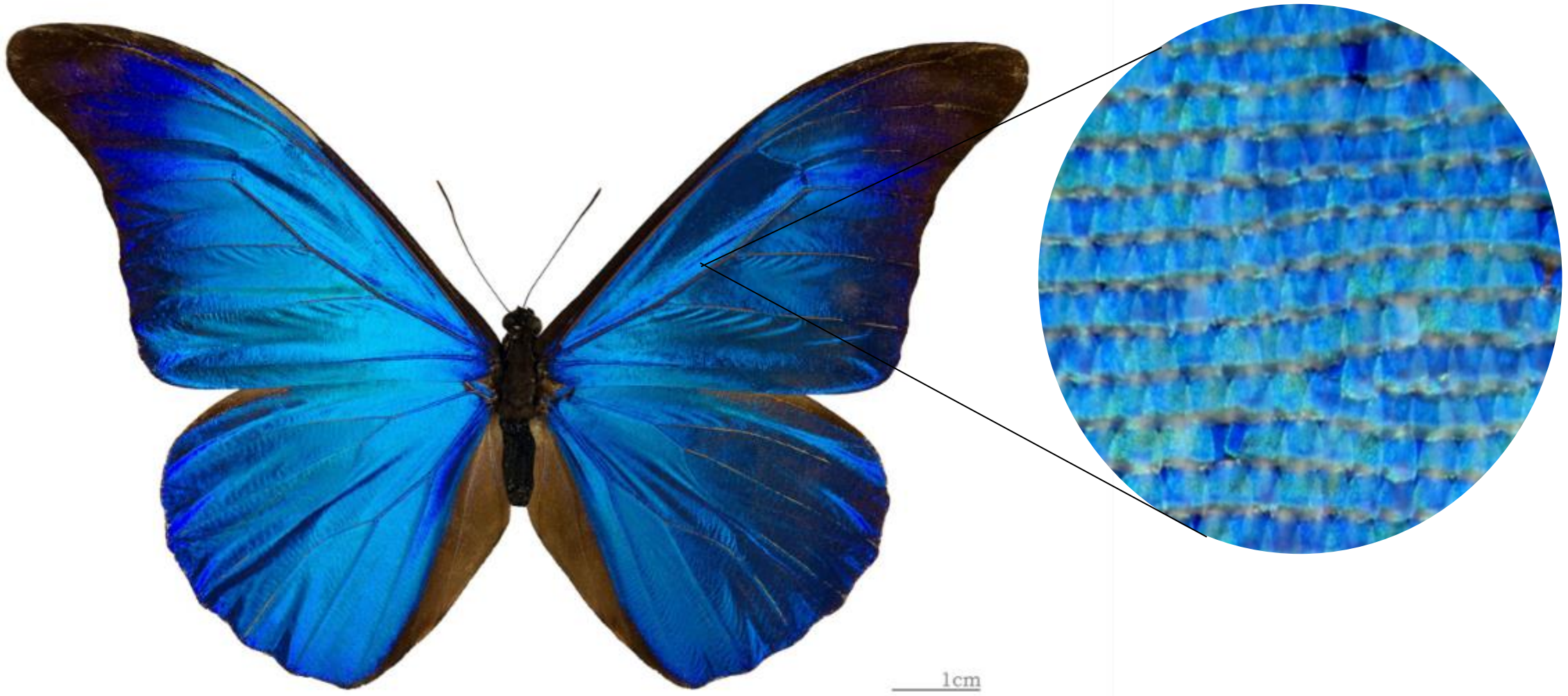
Evan Leeson/Bob Peterson/lowjumpingfrog/Look Into My Eyes/Flickr

Structural color

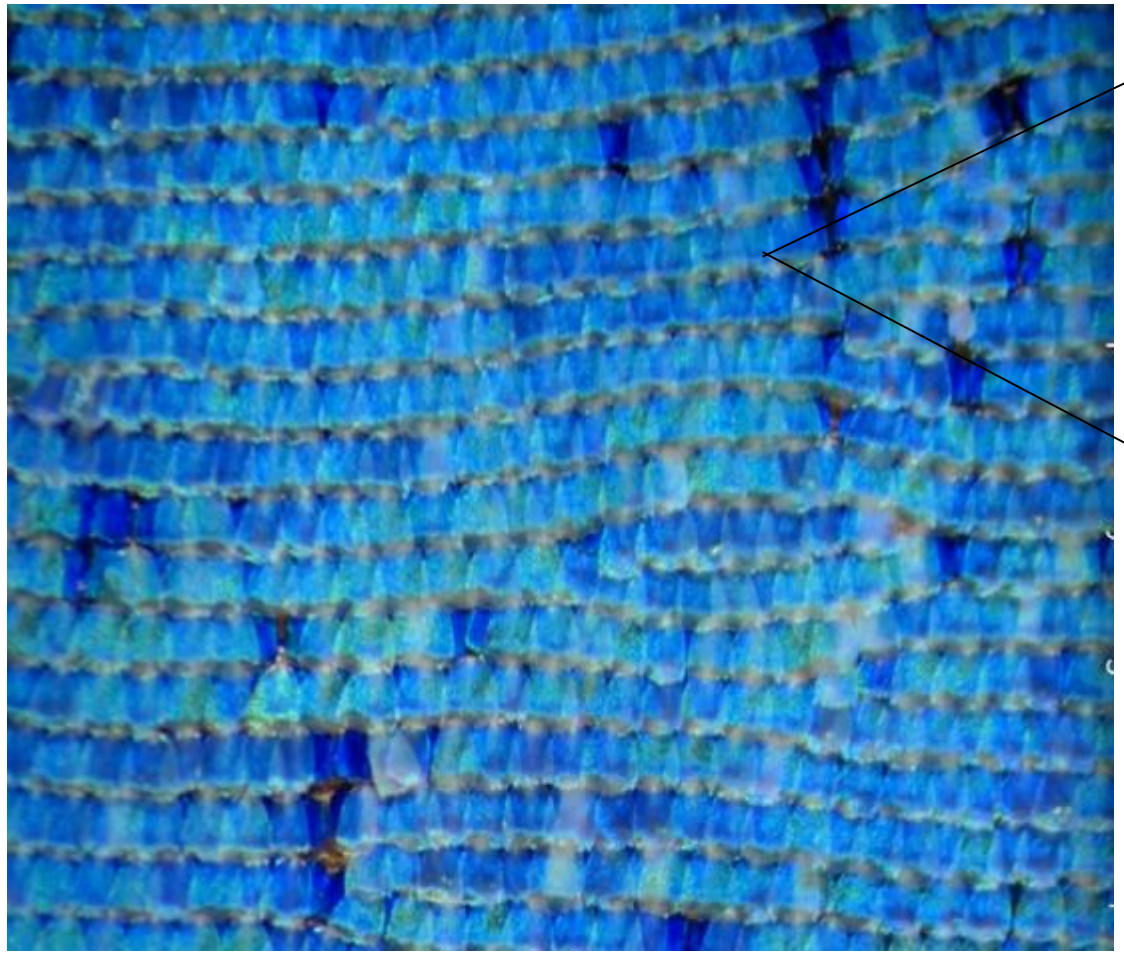
Unlike red, yellow and brown pigments, it is incredibly difficult for nature to assemble blue pigments through chemistry.

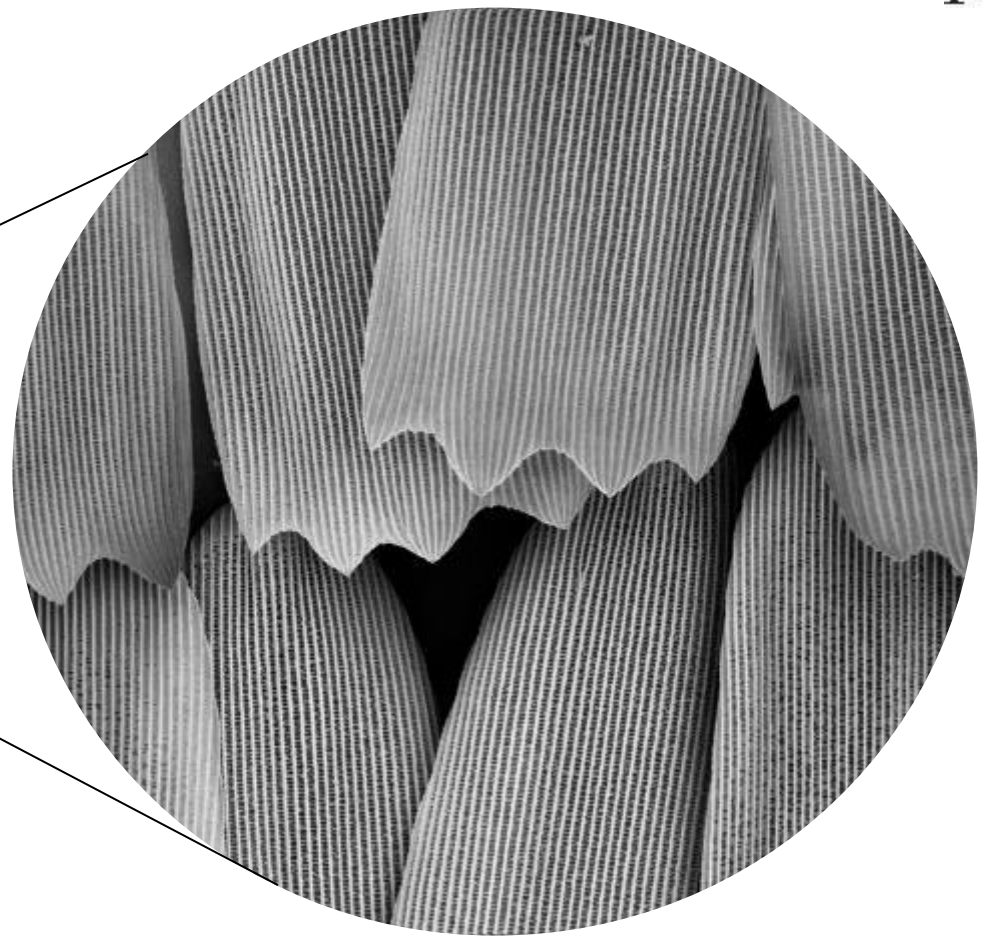
By Peter Stubley https://www.pbase.com/image/147485517

Structural color



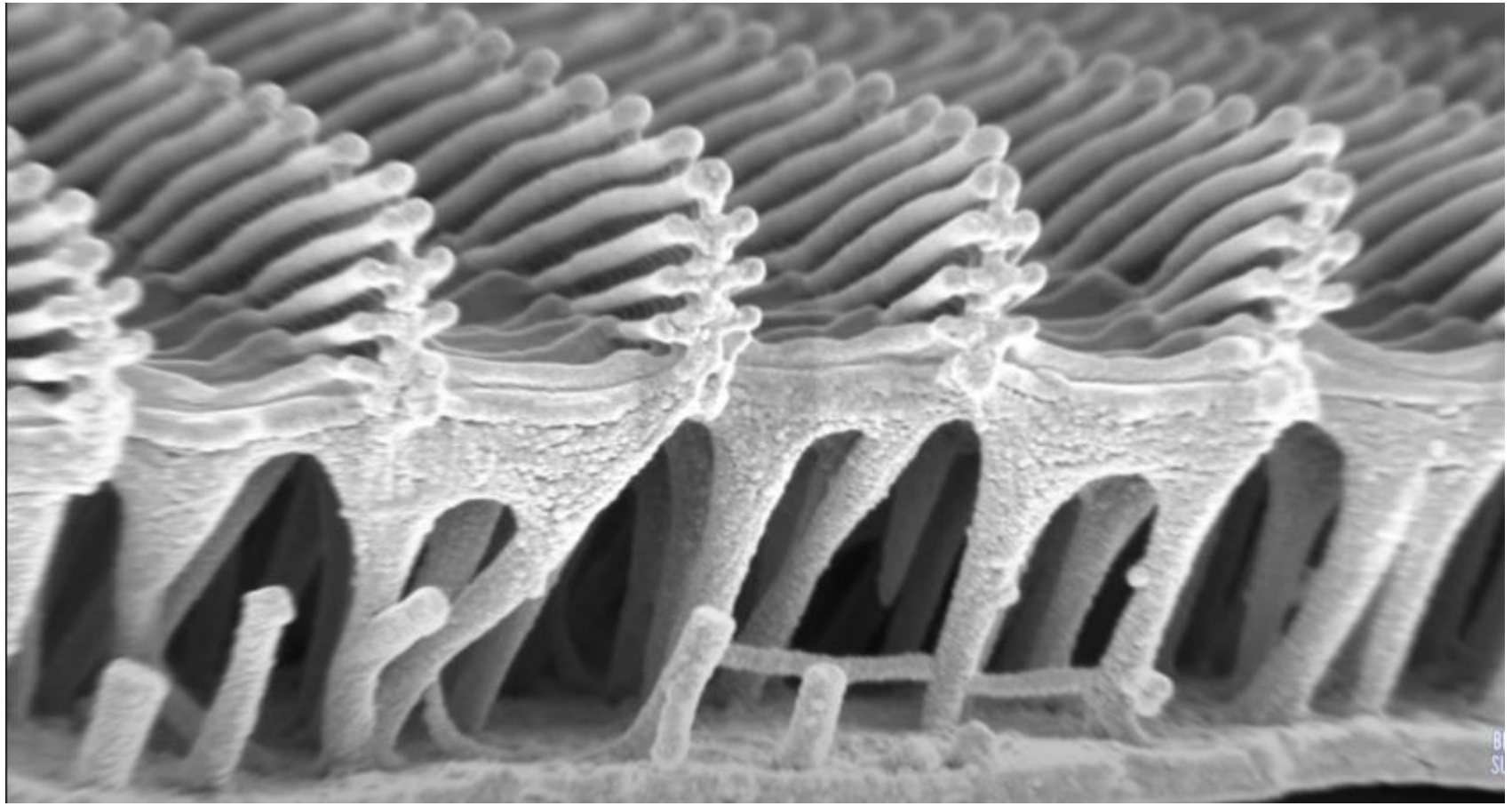
Structural color





NISE Network, https://www.nisenet.org/catalog/scientific-image-overlapping-scales-blue-morpho-butterfly-wing

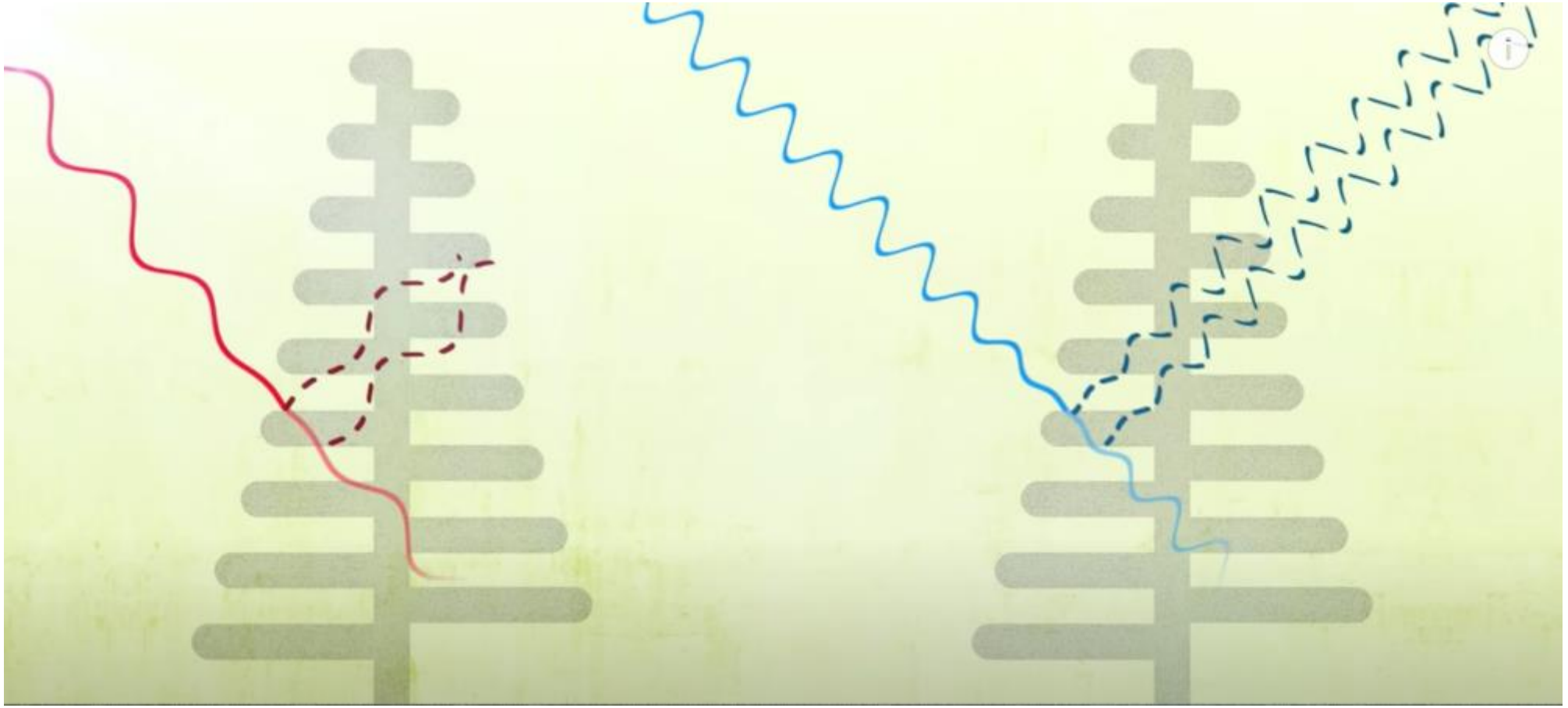
Structural color



Each “tree” in the 400 – 700 nanometer range…
why is that significant?

Why is blue so rare in nature? Video: https://youtu.be/3g246c6Bv58

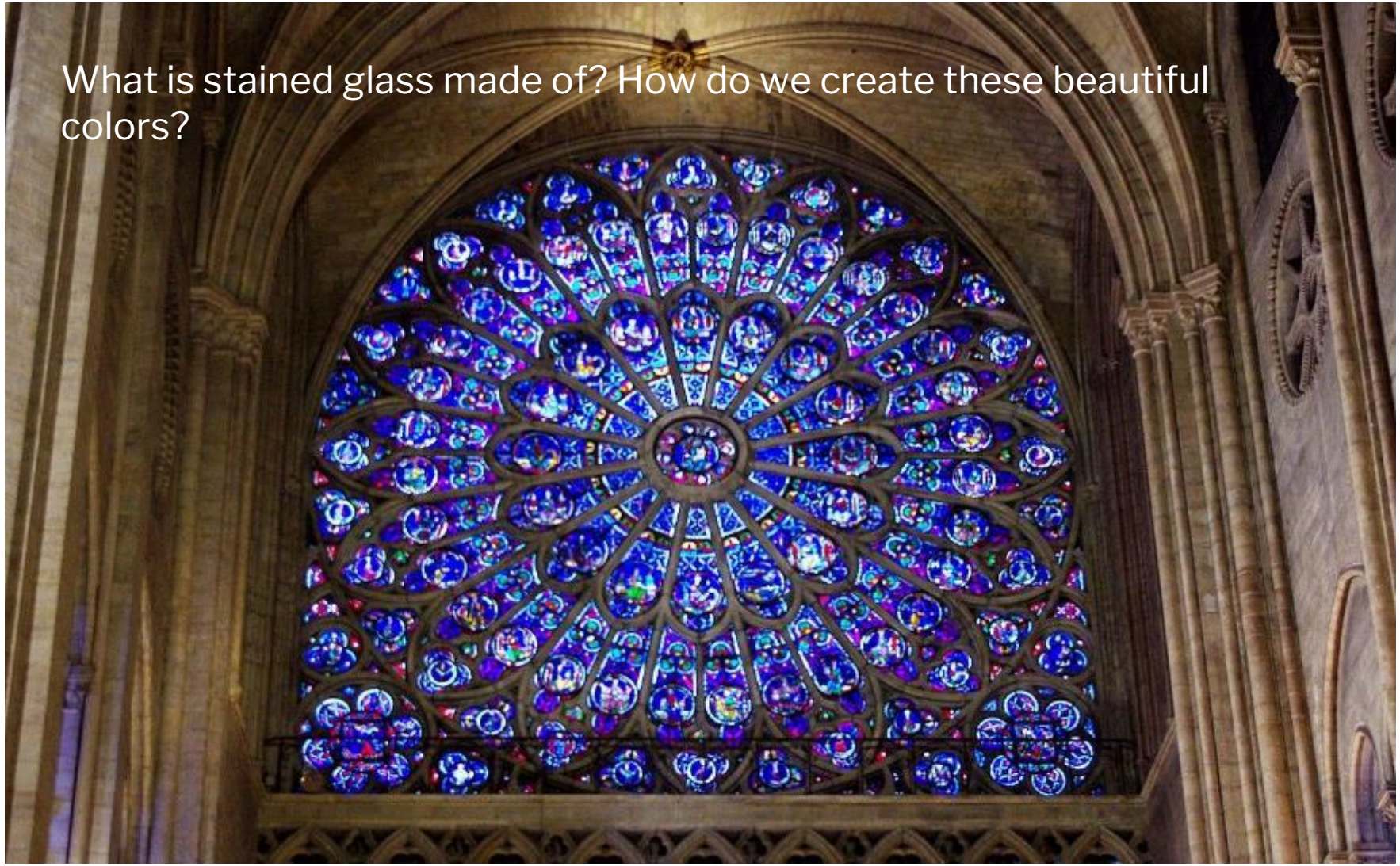
Structural color



What kinds of wave interference are responsible?

Why is blue so rare in nature? Video: https://youtu.be/3g246c6Bv58

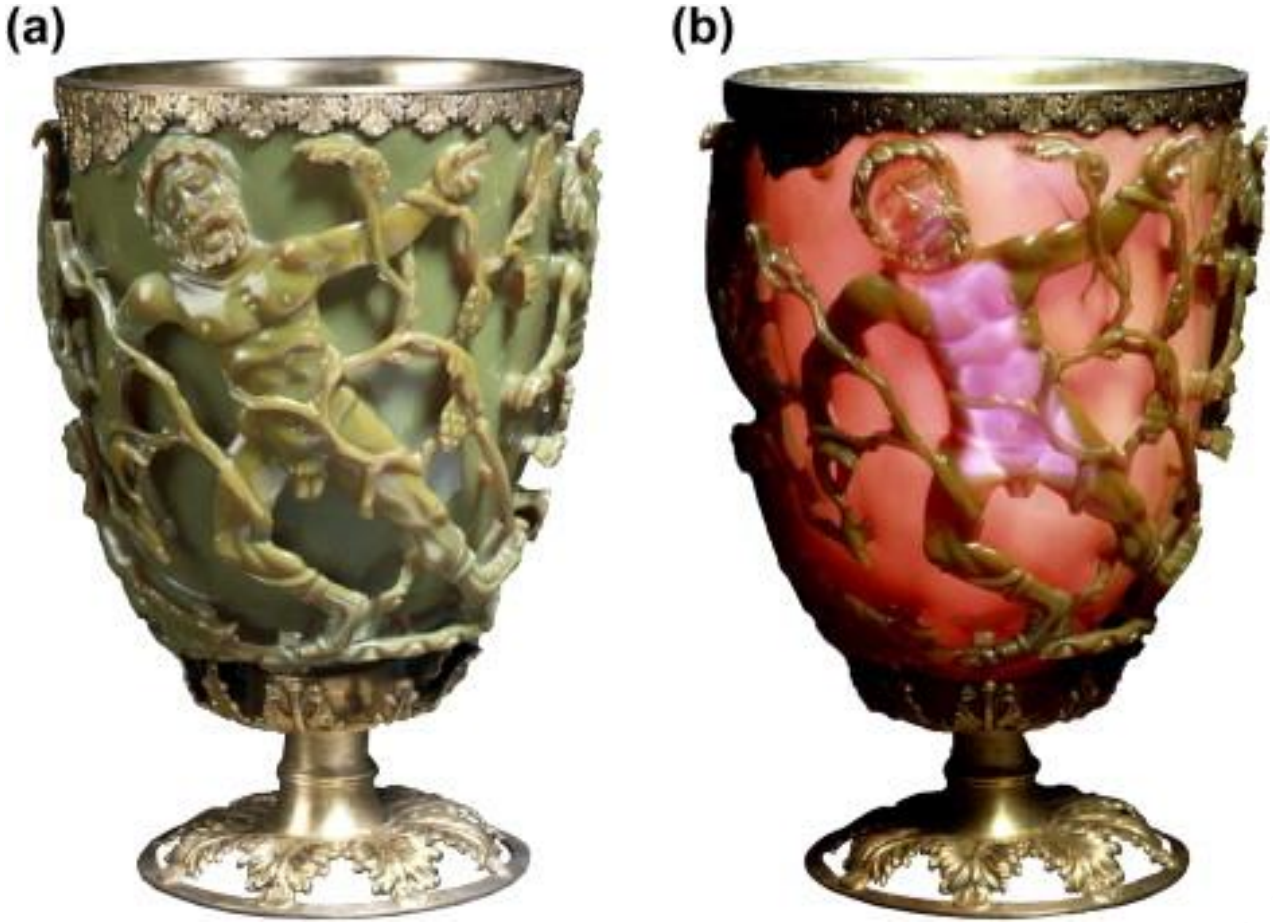
Nanoparticles create color



Nanoparticles create color

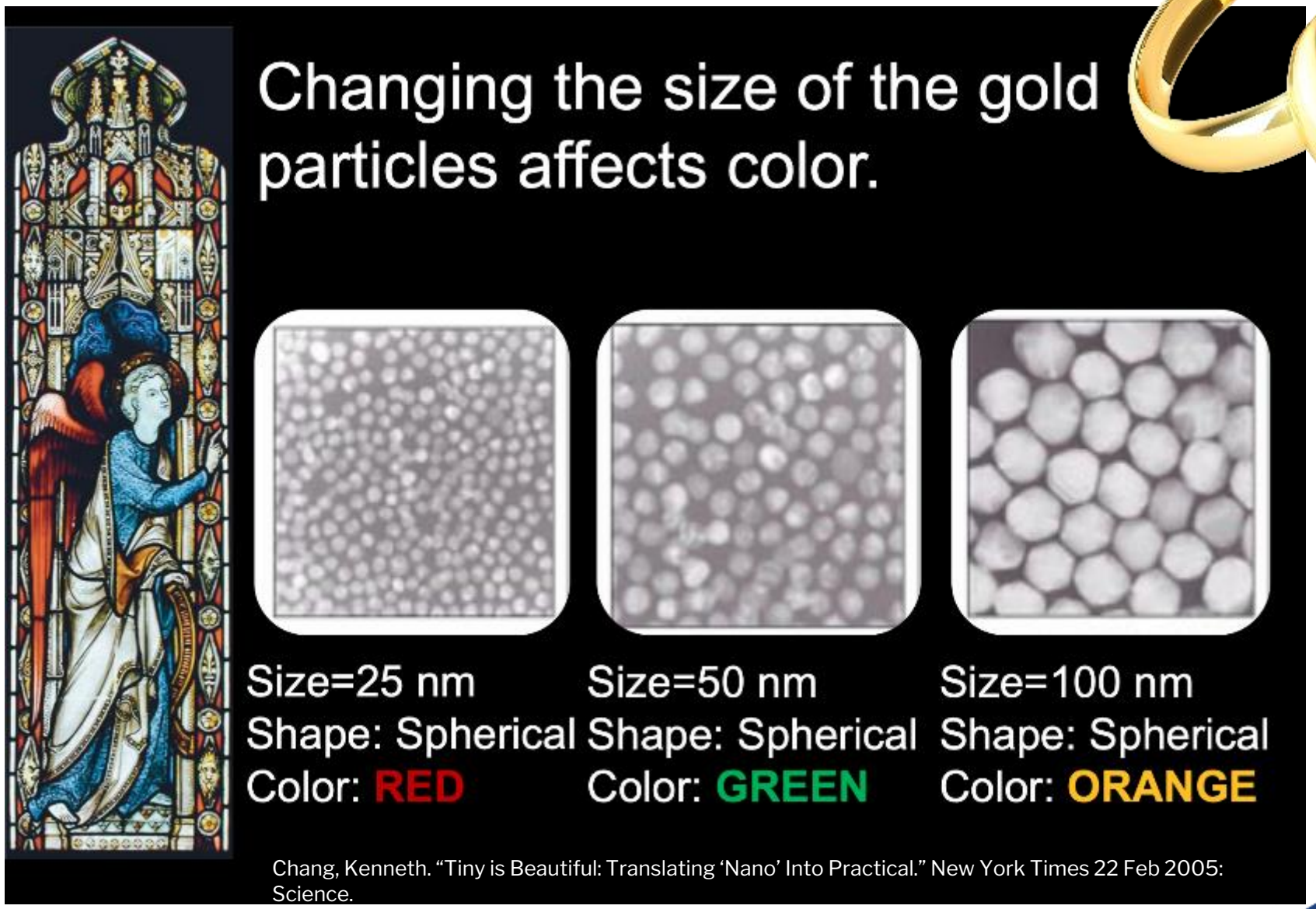
The Lycurgus Cup

- *Roman glasswork from the 5th century CE.*
- *Contains gold, silver and copper nanoparticles up to 100 nm.*



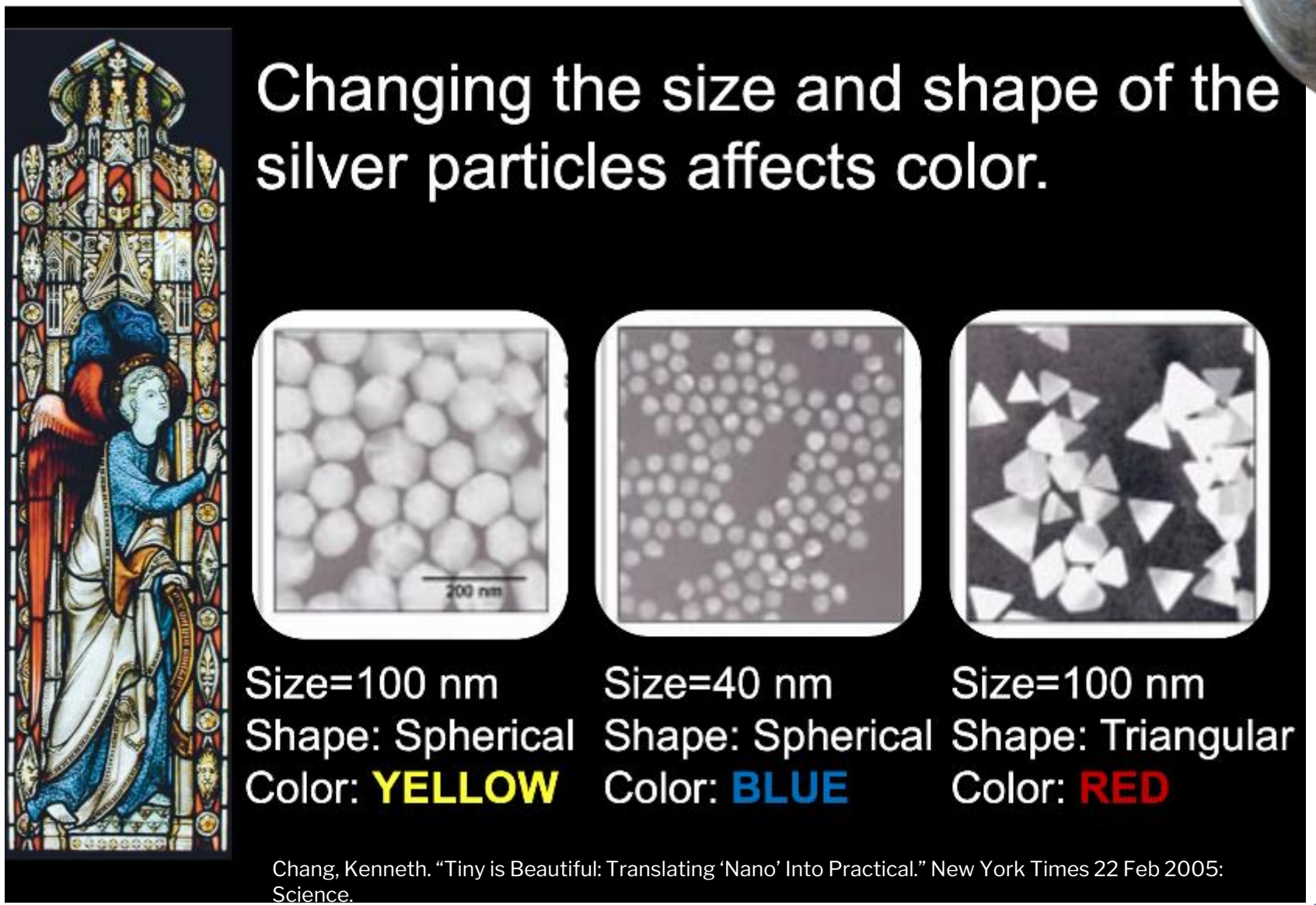
https://www.sciencedirect.com/topics/engineering/lycurgus-cup

Nanoparticles create color



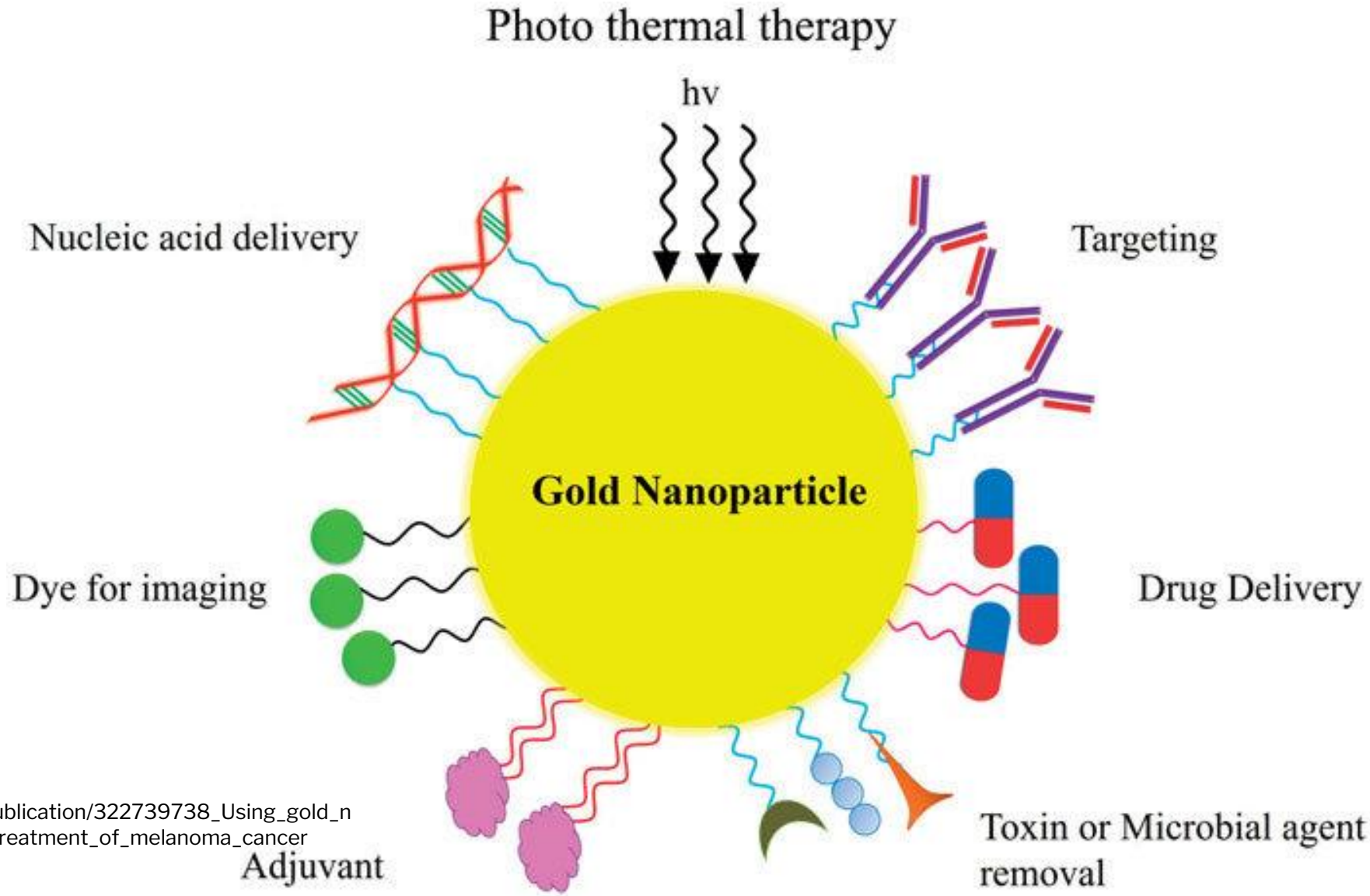
Chang, Kenneth. “Tiny is Beautiful: Translating ‘Nano’ Into Practical.” New York Times 22 Feb 2005: Science.

Nanoparticles create color



Chang, Kenneth. "Tiny is Beautiful: Translating 'Nano' Into Practical." New York Times 22 Feb 2005: Science.

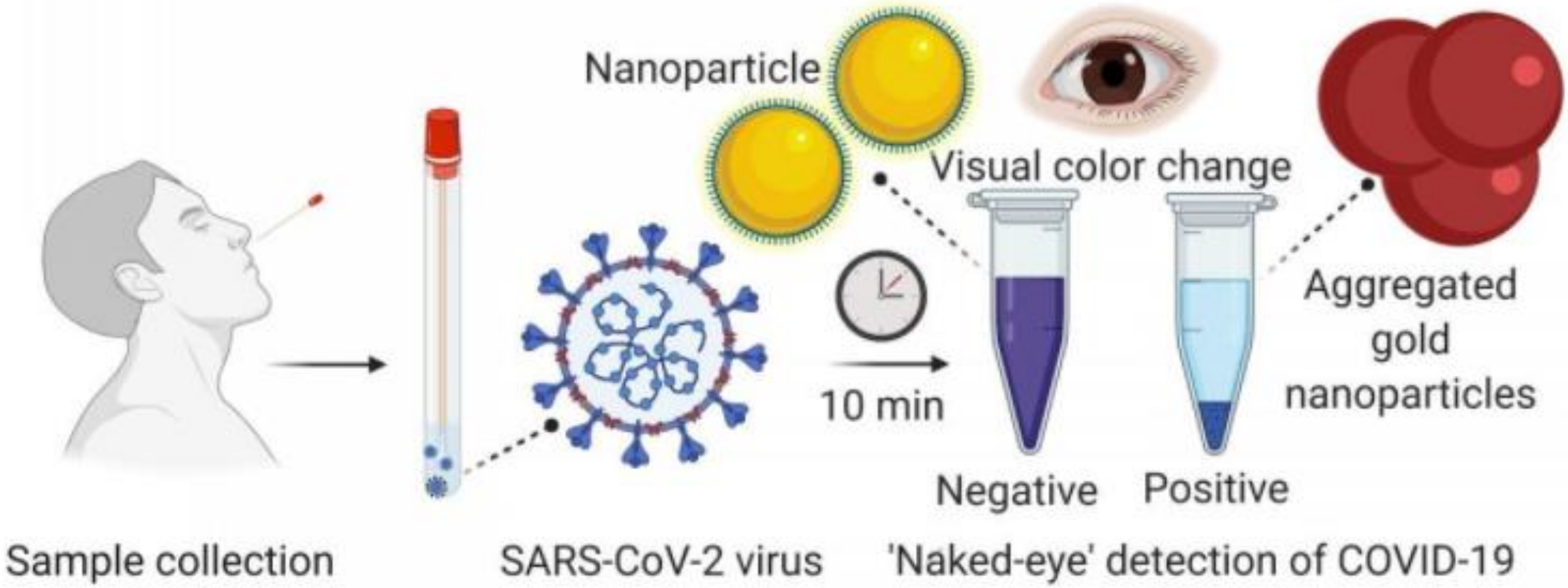
Nanoparticles in medicine



https://www.researchgate.net/publication/322739738_Using_gold_nanoparticles_in_diagnosis_and_treatment_of_melanoma_cancer

Nanoparticles in medicine

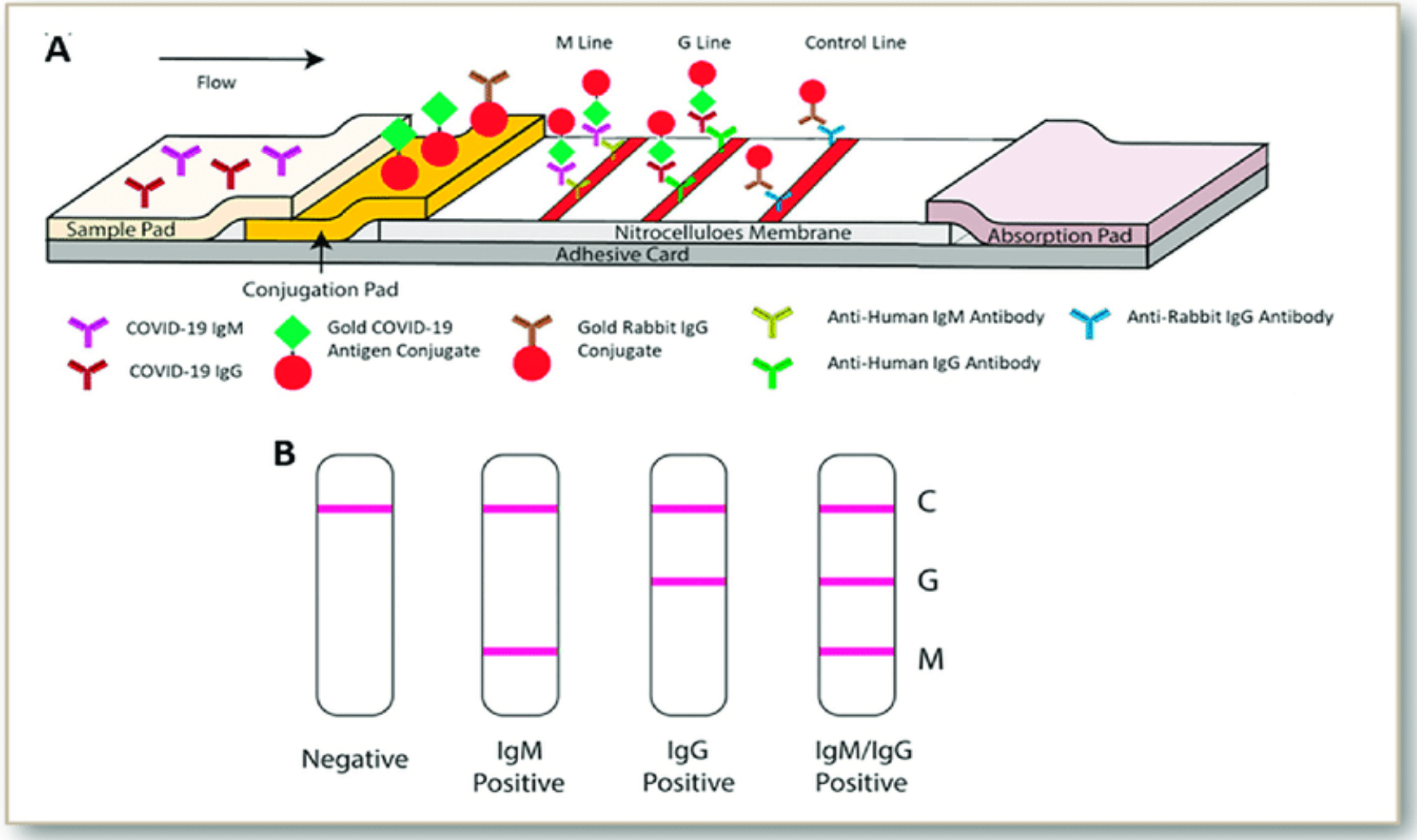
Institute for Genome Sciences at UMSOM
Rapid COVID-19 Test



https://catalystmag.umaryland.edu/on-the-front-lines/

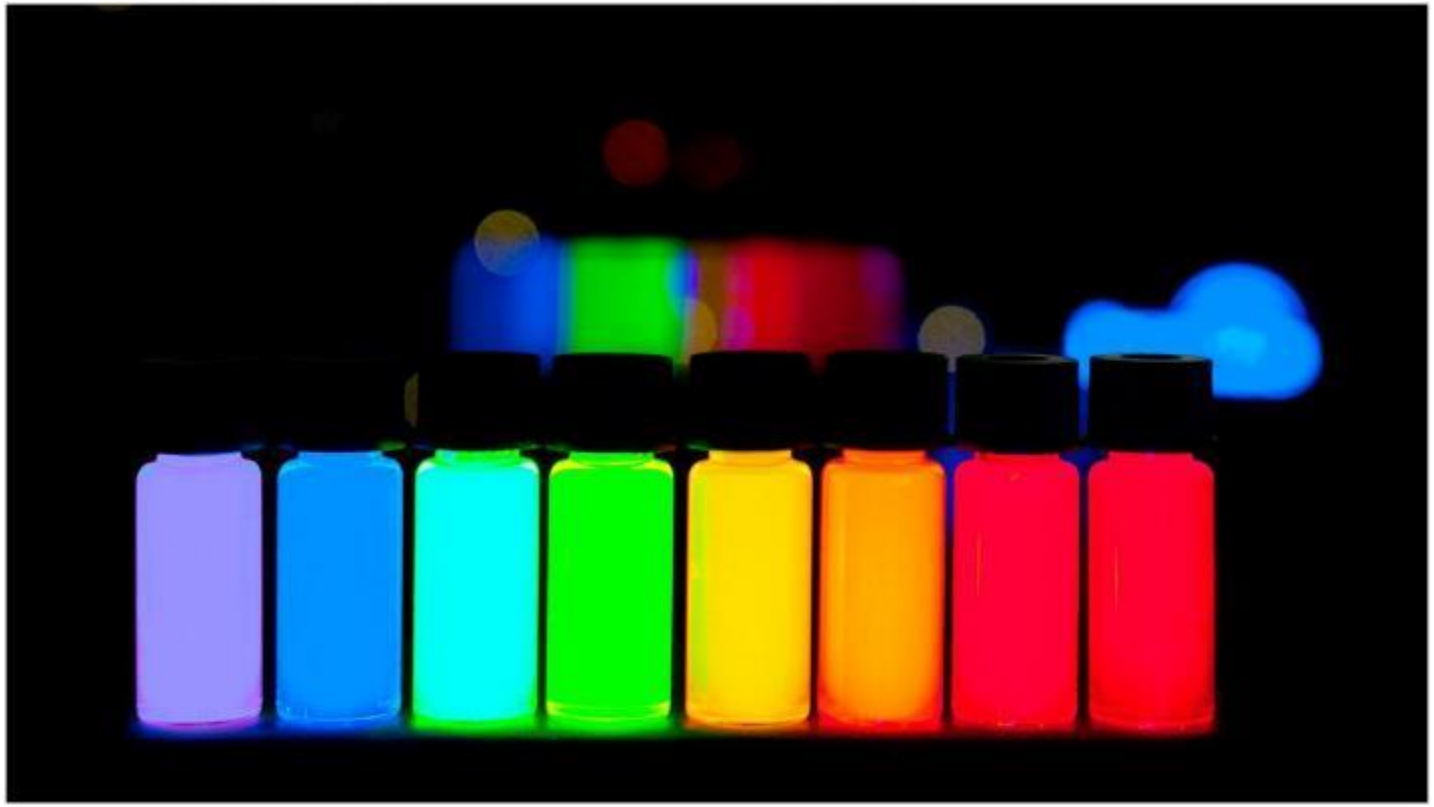
Nanoparticles in medicine

Gold nanoparticle enabled Rapid SARS-CoV-2 IgM-IgG combined antibody test by GaDia SA.



https://www.researchgate.net/publication/344815070_Rapid_Antibody-Based_COVID-19_Mass_Surveillance_Relevance_Challenges_and_Prospects_in_a_Pandemic_and_Post-Pandemic_World

Quantum dots



https://www.pnas.org/content/113/11/2796

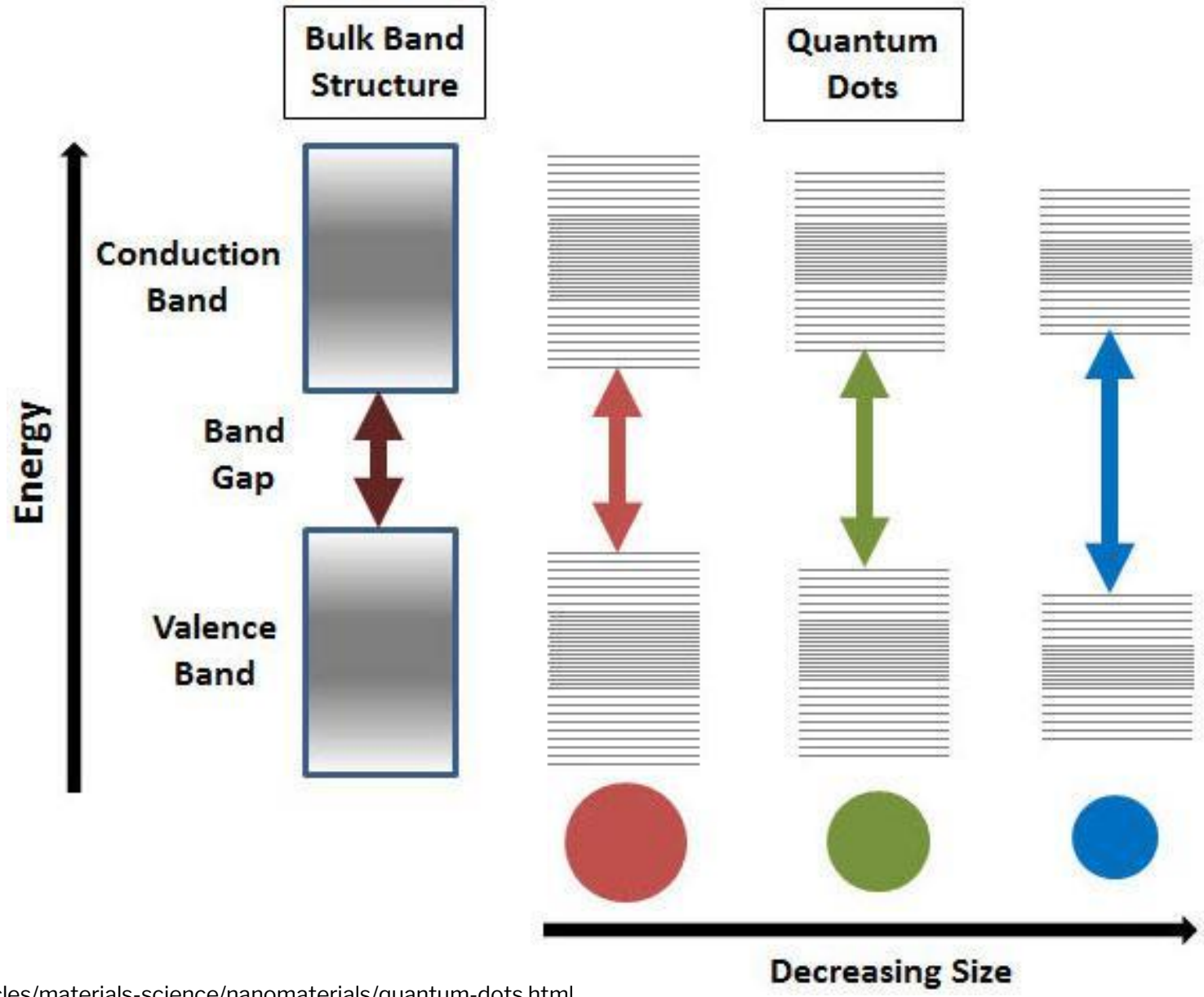
Quantum dots

Quantum dots are light-emitting devices with electroluminescence that is ***tunable*** over the entire visible spectrum.

https://www.nanowerk.com/what_are_quantum_dots.php

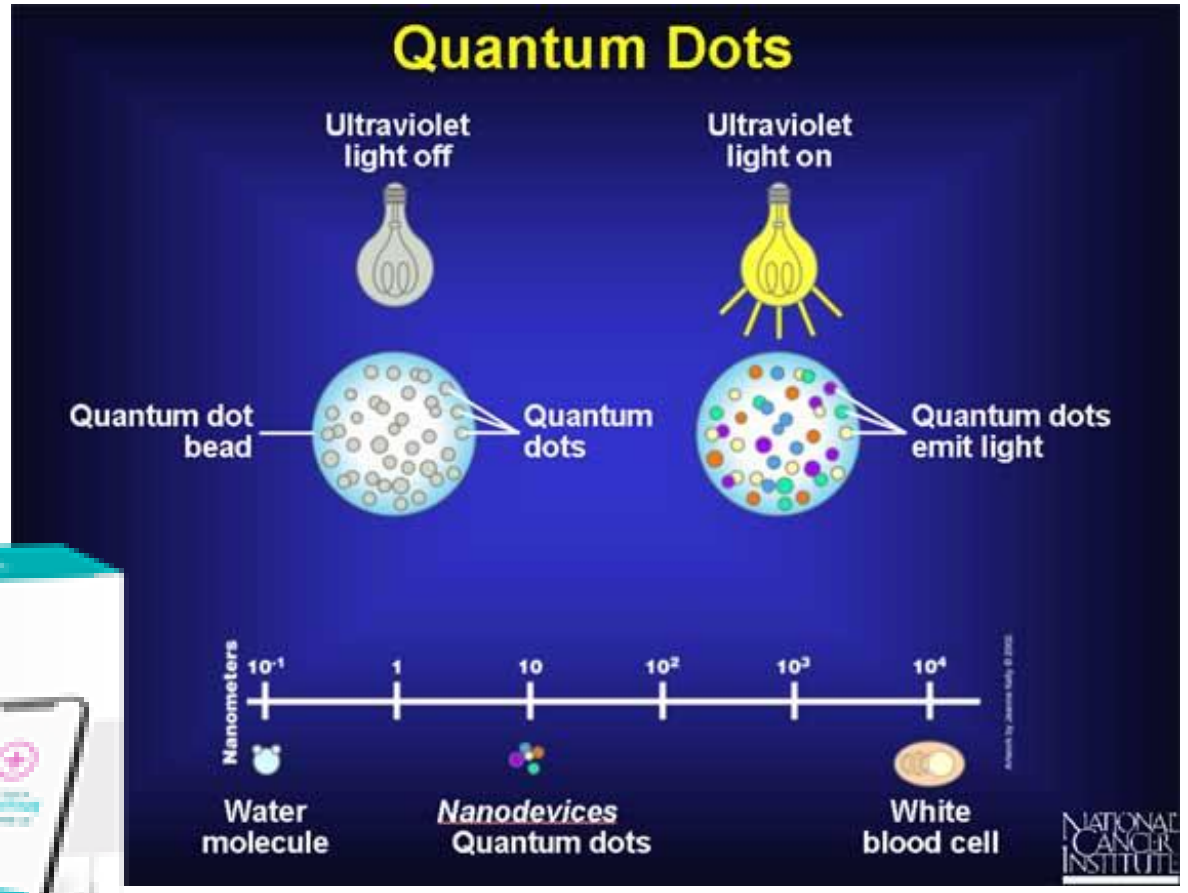
Quantum dots

Excitation of electrons inside the nanoparticles cause QDs to glow in specific colors



https://www.sigmaaldrich.com/technical-documents/articles/materials-science/nanomaterials/quantum-dots.html

Quantum Dots



http://www.ubooks.pub/Books/ON/B0/E20R2020/14MB20.html
https://www.nanosysinc.com/news/2019/8/15/tcl-brings-quantum-dots-to-us-market-with-new-6-and-8-series-qled-tvs
https://www.globenewswire.com/news-release/2020/12/15/2145612/0/en/FDA-Authorizes-Ellume-COVID-19-Home-Test-as-First-Over-the-Counter-Fully-At-Home-Diagnostic-Test.html

May the Force be with you

Force interactions are different at the nanoscale

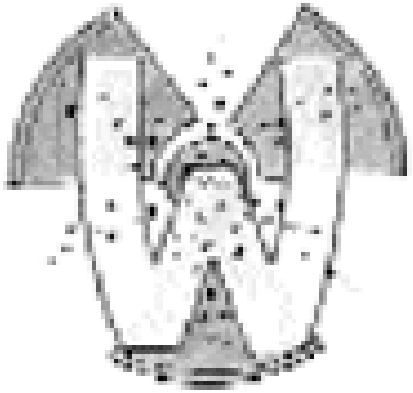
The four forces in nature

gravity

Mass is so small for nano-sized objects that gravity becomes insignificant

strong force

Electrostatic force between molecules dominates at the nanoscale



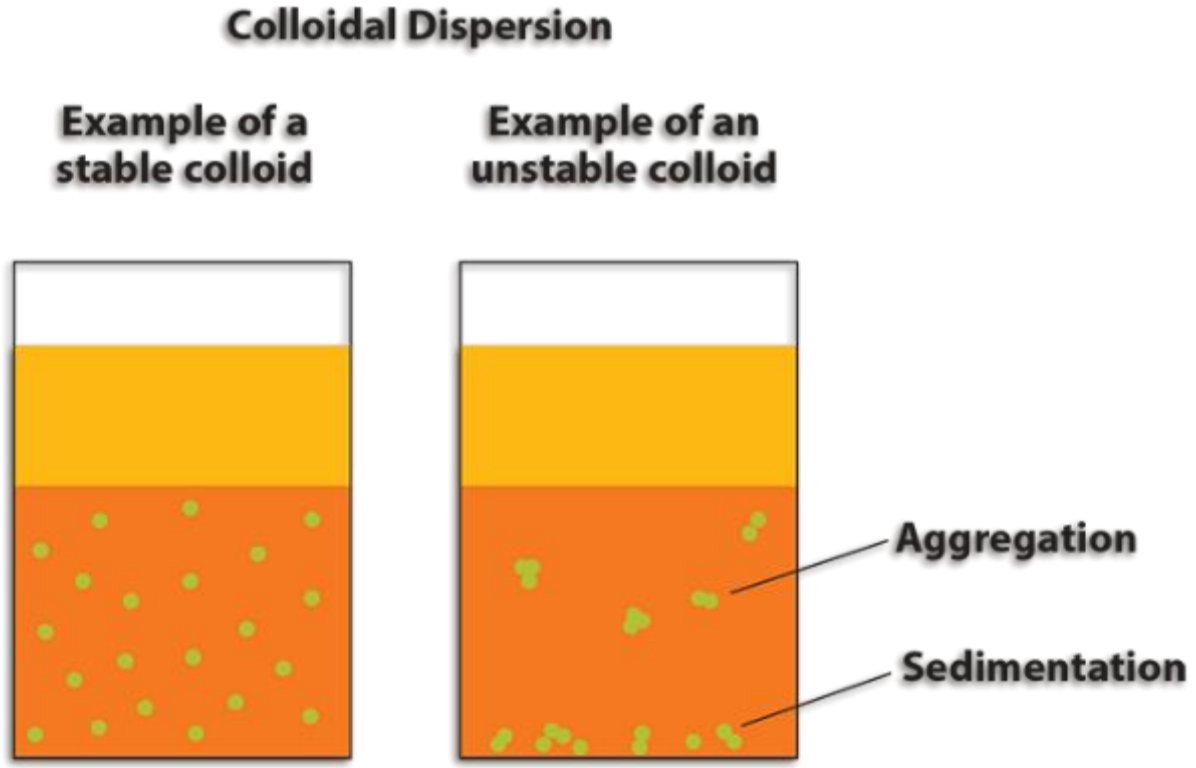
weak force

electromagnetism

https://www.pbs.org/wgbh/nova/teachers/activities/3012_elegant_09.html

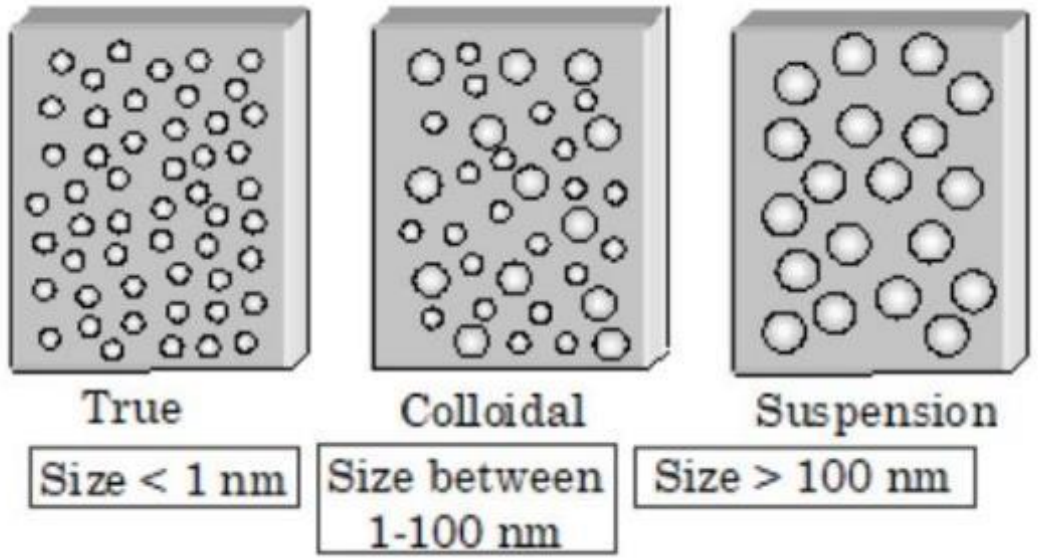
Colloids and gravity

Why don't colloidal particles settle?



https://agclassroom.org/matrix/lesson/576/

Colloids and gravity

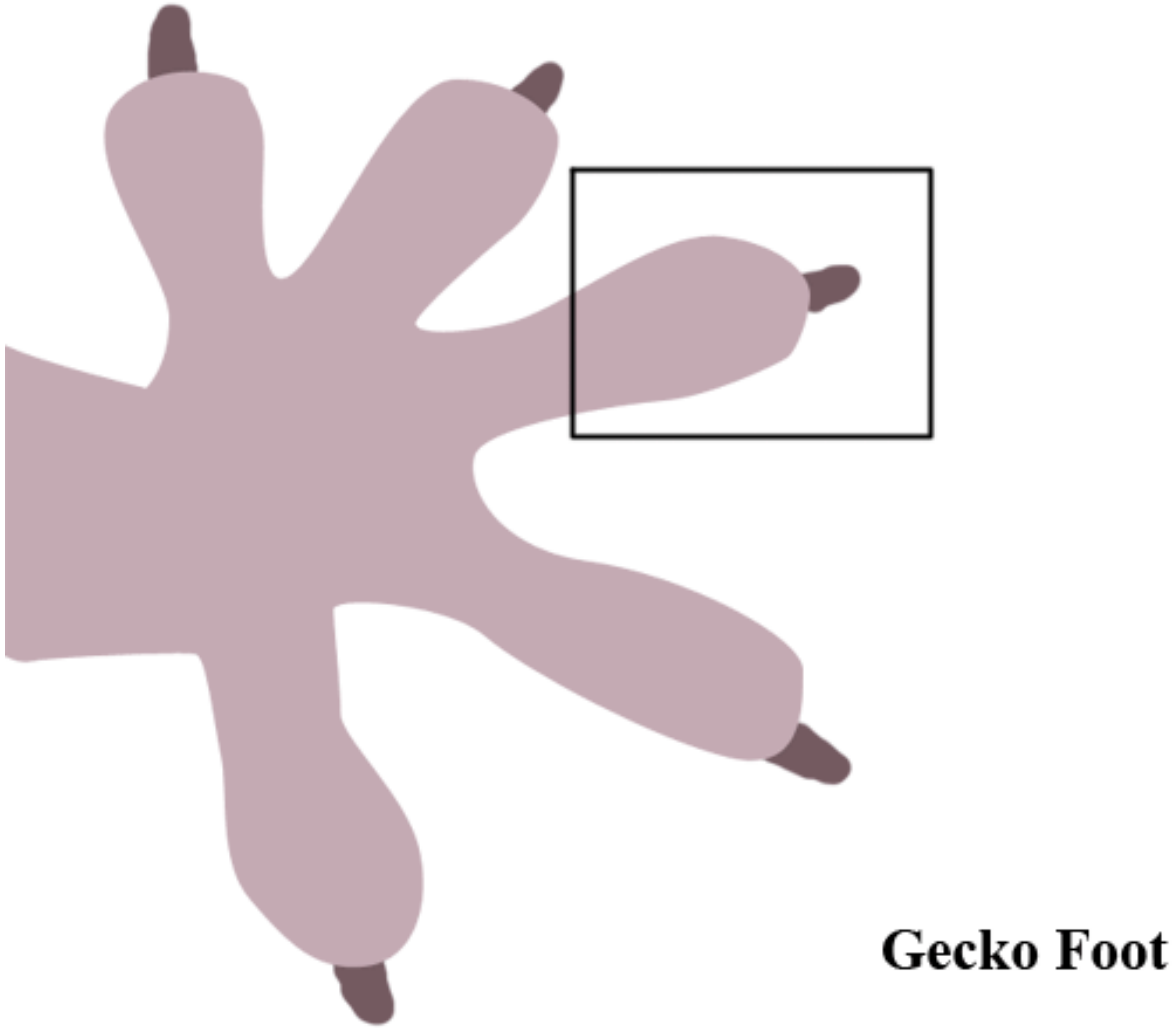


https://classnotes.org.in/class12/chemistry12/surface-chemistry/colloidal-state/

Geckos and gravity

https://allyouneedisbiology.wordpress.com/2019/01/04/animals-walking-walls/

Intermolecular forces conquer gravity

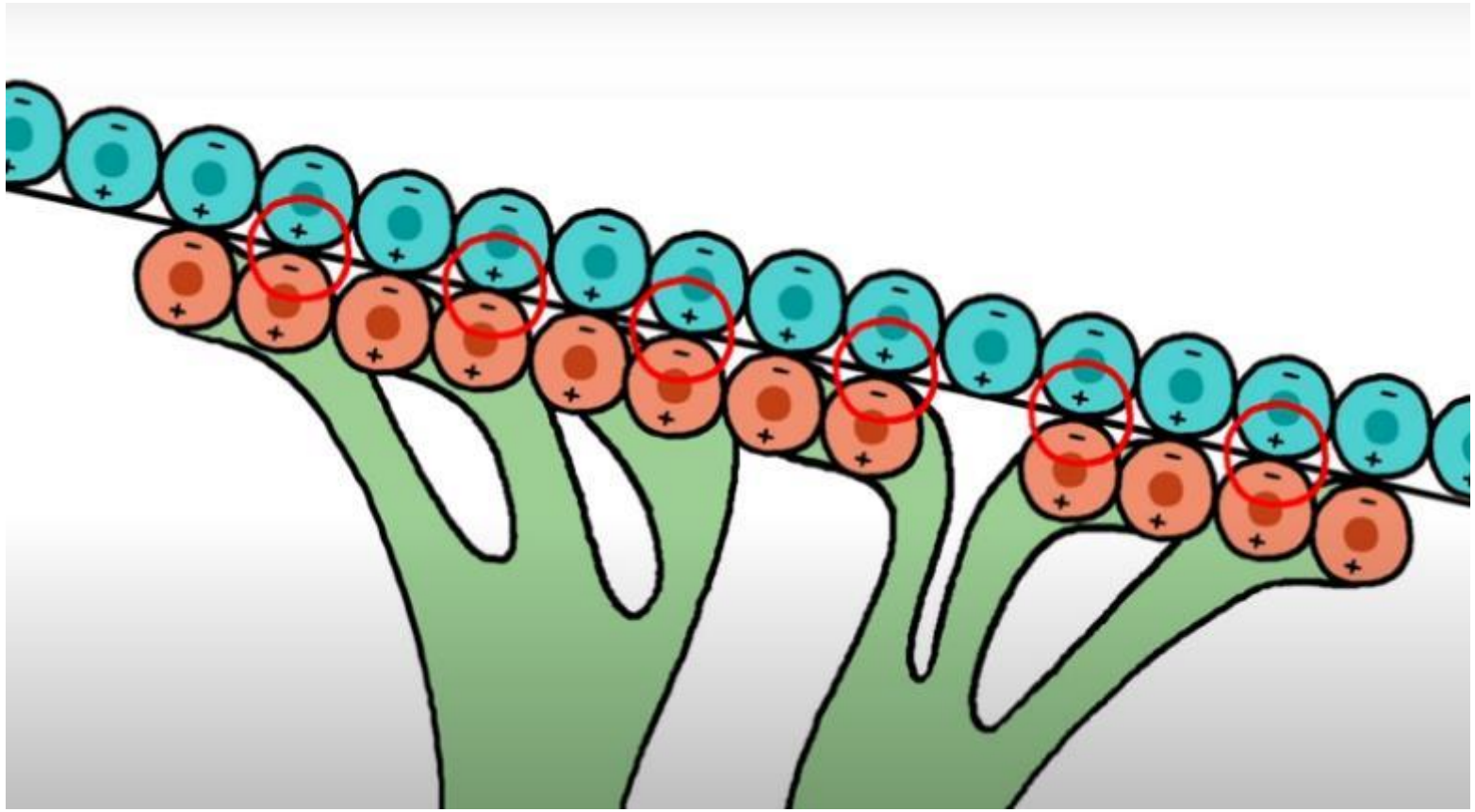


Gecko Foot

https://web.stanford.edu/group/mota/education/Physics%2087N%20Final%20Projects/Group%20Gamma/gecko.htm

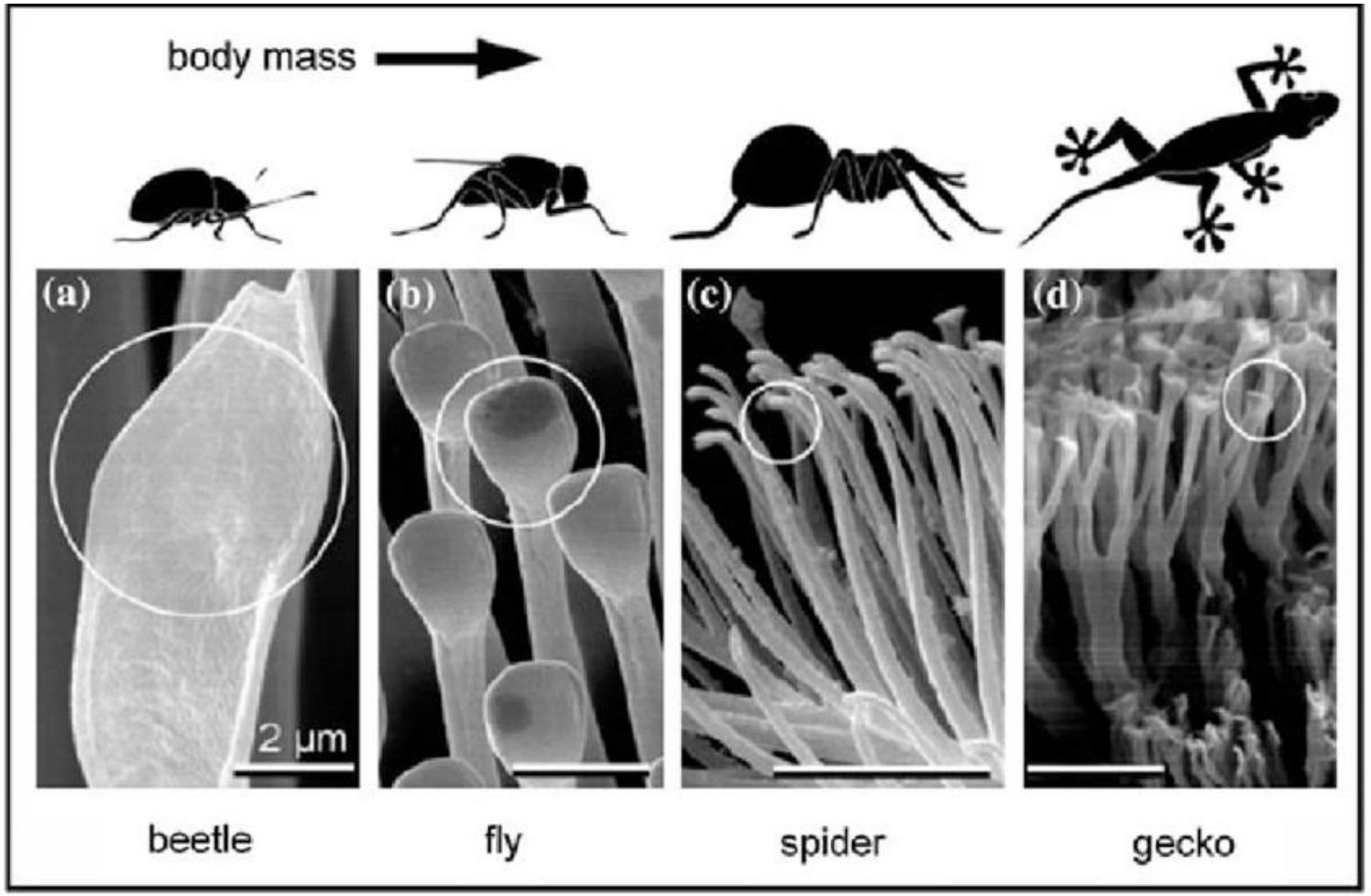
Intermolecular forces conquer gravity

Geckos have mastered the art of harnessing electrostatic forces on a macro scale



https://www.youtube.com/watch?v=YeSuQm7KfaE&feature=emb_logo

Intermolecular forces conquer gravity



https://www.researchgate.net/publication/275771737_Bio-inspired_Studies_on_Adhesion_of_a_Thin_Film_on_a_Rigid_Substrate

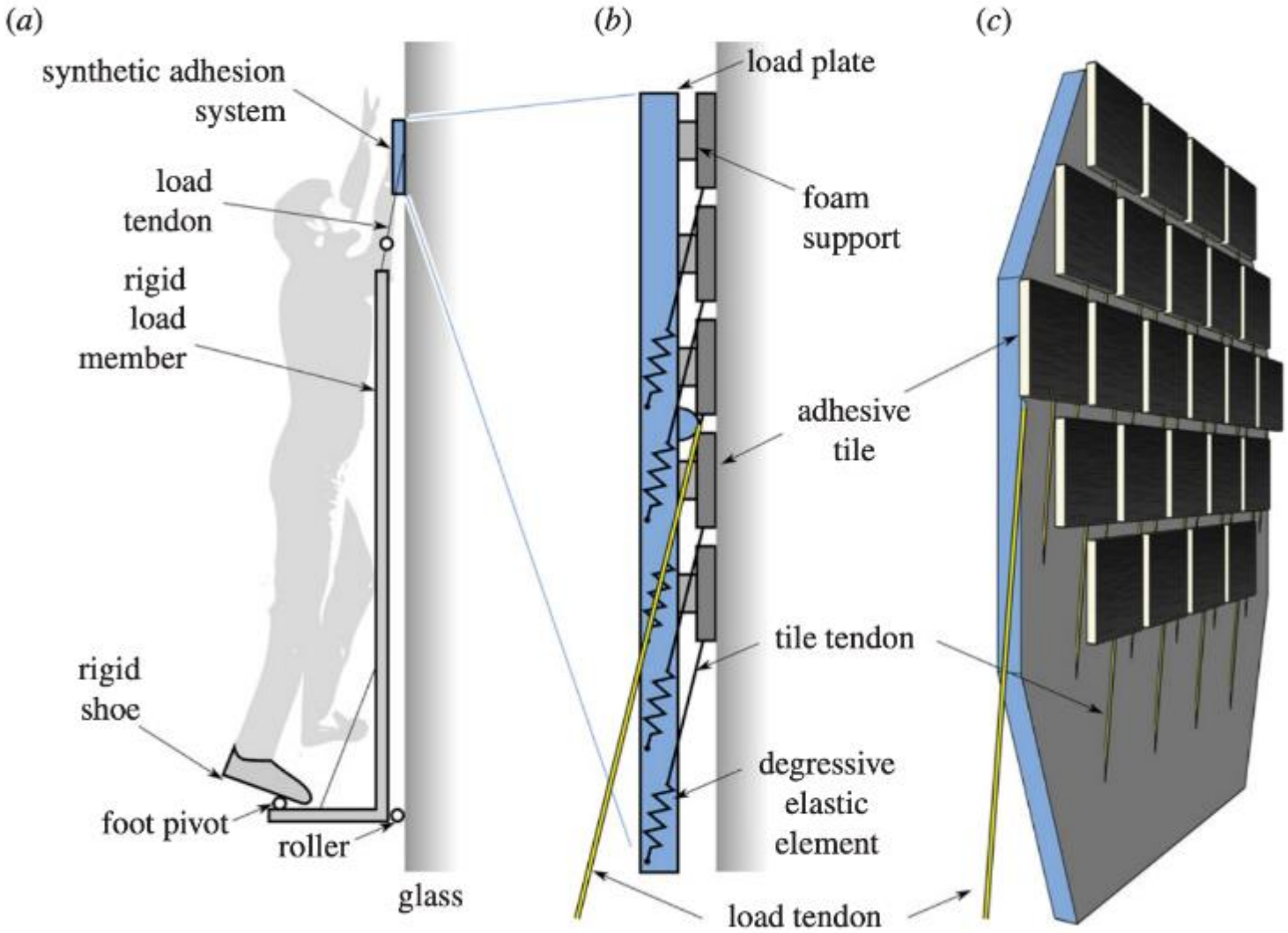
Breakout groups

A Tokay Gecko weighing 0.875 lb can be suspended by just one of its feet, a surface area of 0.008 m^2. If you weigh 180 lb, how big does your one hand have to be, in m^2, to hold you up?

How big is that, as measured in cookie sheets? A standard cookie sheet is 0.15 m^2.

Alternately or in addition, discuss with your group the potential uses for mastering this natural nanotechnology.

Gecko-inspired dry adhesive



Human climbing with efficiently scaled gecko-inspired dry adhesives

Elliot W. Hawkes[1], Eric V. Eason[2], David L. Christensen[1] and Mark R. Cutkosky[1]

[1]Department of Mechanical Engineering, and [2]Department of Applied Physics, Stanford University, Stanford, CA 94305, USA

https://royalsocietypublishing.org/doi/pdf/10.1098/rsif.2014.0675

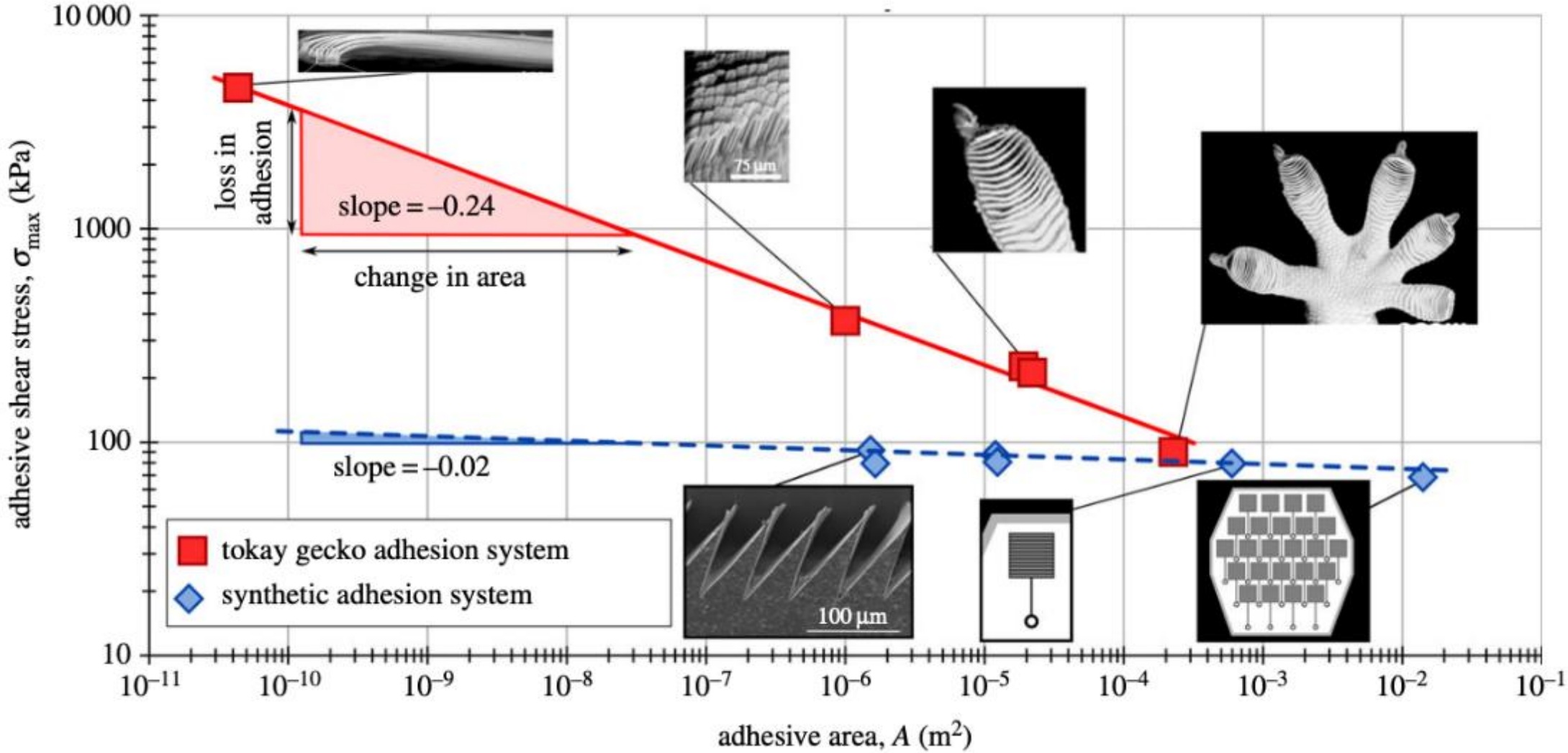
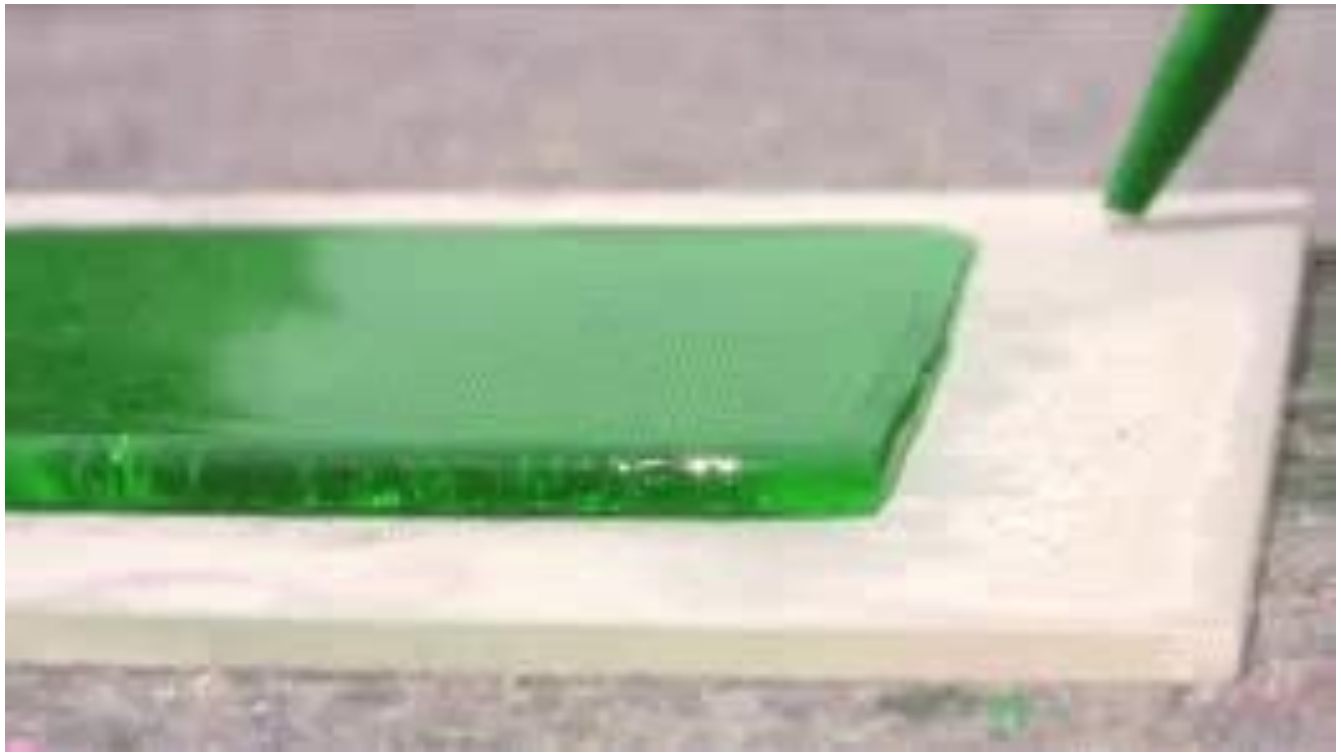


Figure 1. The red squares ($n = 5$) indicate the maximum adhesive shear stress σ_{max} that can be achieved on a flat, smooth surface by tokay gecko adhesion systems as the adhesive area A increases [6]. From left, these data correspond to a single seta, a setal array, a toe and two feet. The red line shows the least-squares power law fit to the data ($\log \sigma_{max} = -0.24 \log A + 1.1$). Similarly, for the PDMS microwedge synthetic adhesion system, the blue diamonds ($n = 6$) represent the maximum adhesive stress produced by a 1.5 mm^2 patch, a 12 mm^2 patch, a 6.5 cm^2 tile and a 24-tile system. The least-squares power law is plotted as a blue dashed line ($\log \sigma_{max} = -0.02 \log A + 1.8$).

Superhydrophobicity

http://blog.markmanalaysay.com/post/130273194285/water-dancing-on-a-lotus-leaf-x

Superhydrophobicity



https://wifflegif.com/tags/77192-hydrophobic-gifs

Superhydrophobicity

https://www.neverwet.com/
https://wifflegif.com/tags/77192-hydrophobic-gifs

Lotus effect

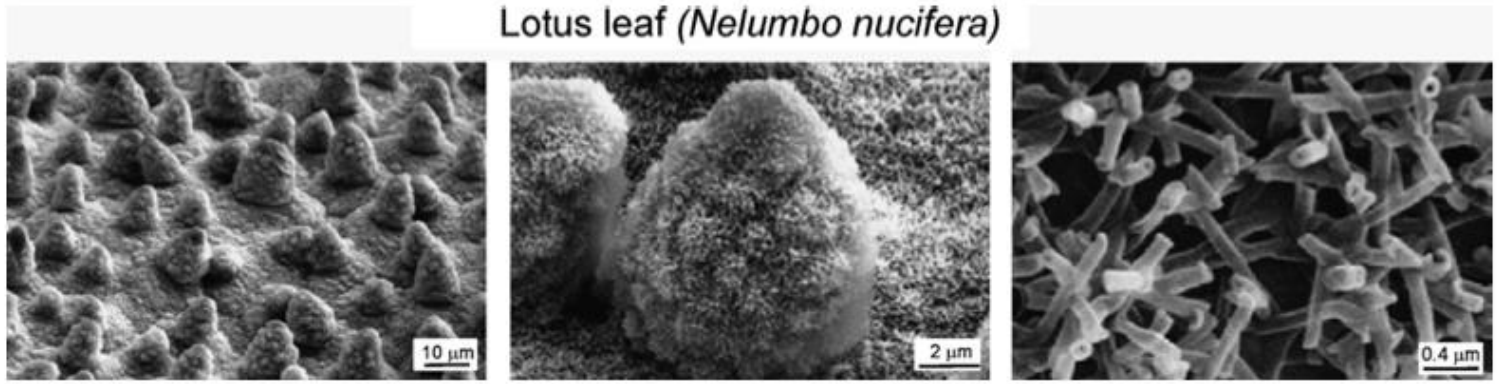
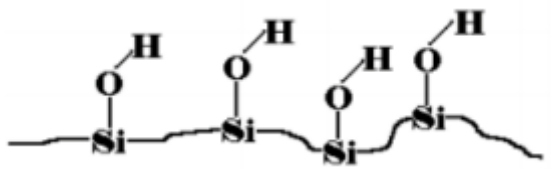
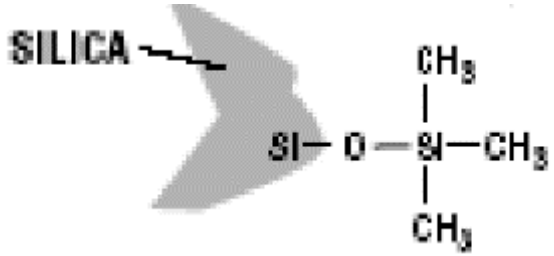


Fig. 1 SEM micrographs (shown at three magnifications) of the Lotus (*Nelumbo nucifera*) leaf surface, which consists of a microstructure formed by papillose epidermal cells covered with epicuticular wax tubules on surface, which create a nanostructure.

https://en.wikipedia.org/wiki/Lotus_effect#:~:text=The%20lotus%20effect%20refers%20to,droplet's%20adhesion%20to%20that%20surface.

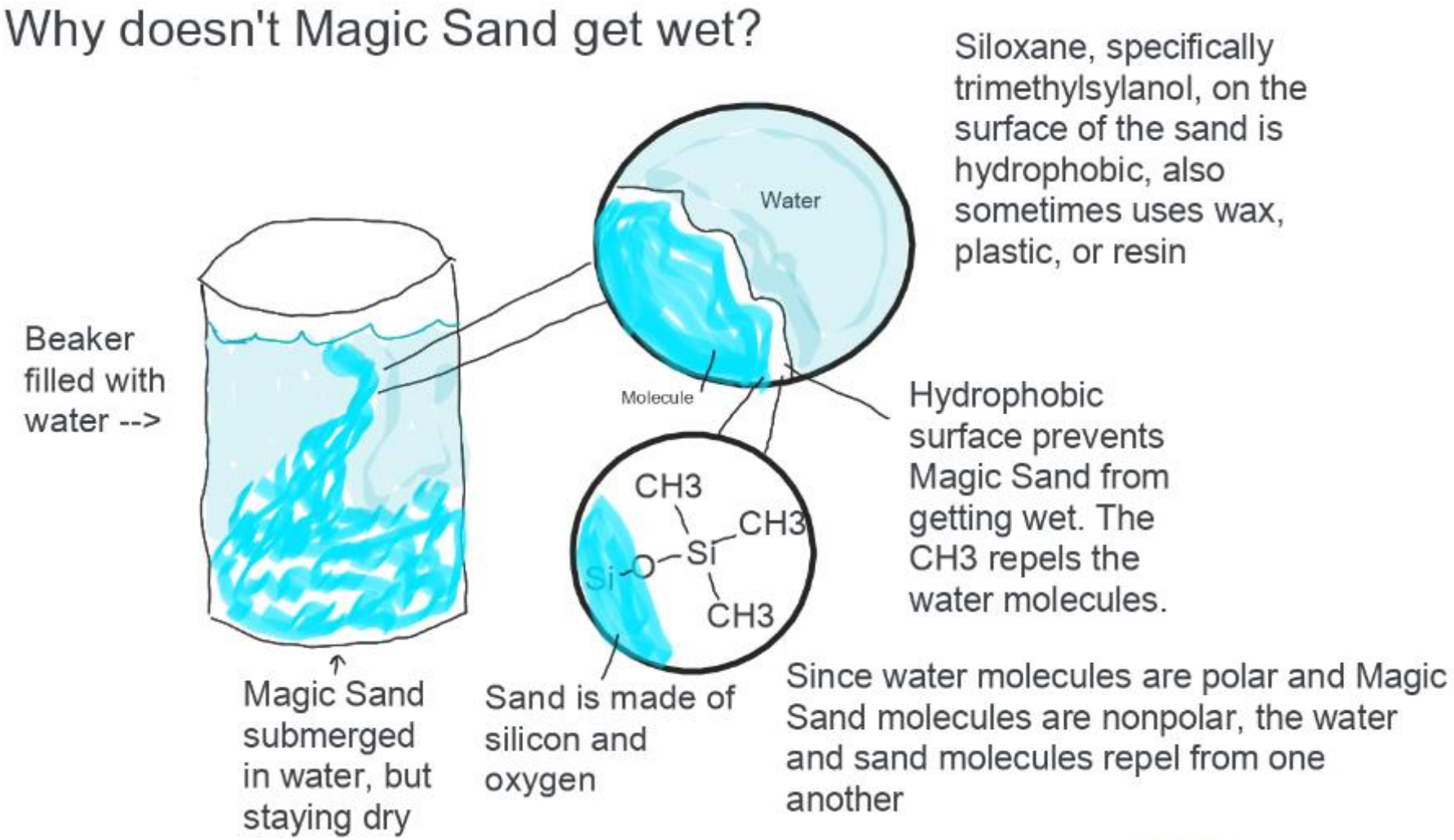
Hydrophobicity





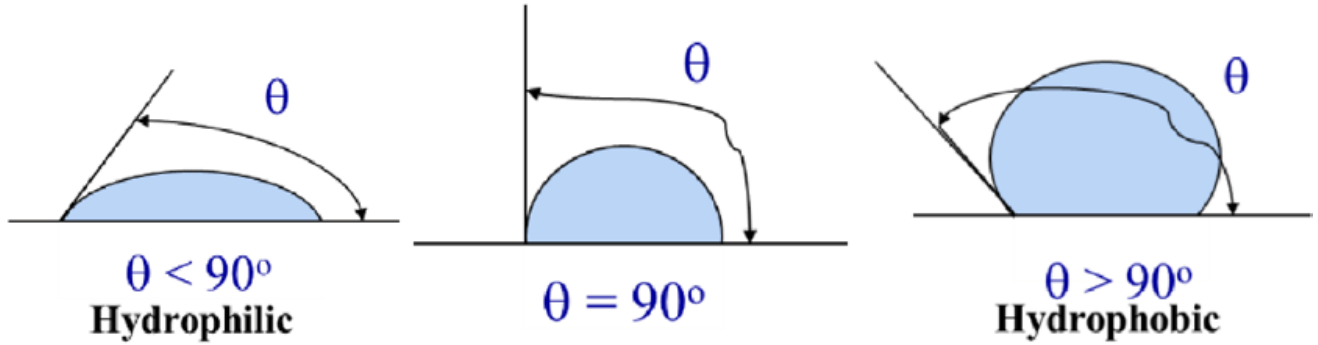
https://www.amazon.com/Educational-Innovations-Magic-Sand-Blue/dp/B009P8ARHY
https://www.sciencesource.com/archive/Beaker-with-Sand-and-Water-SS2811363.html

Student explanatory modeling



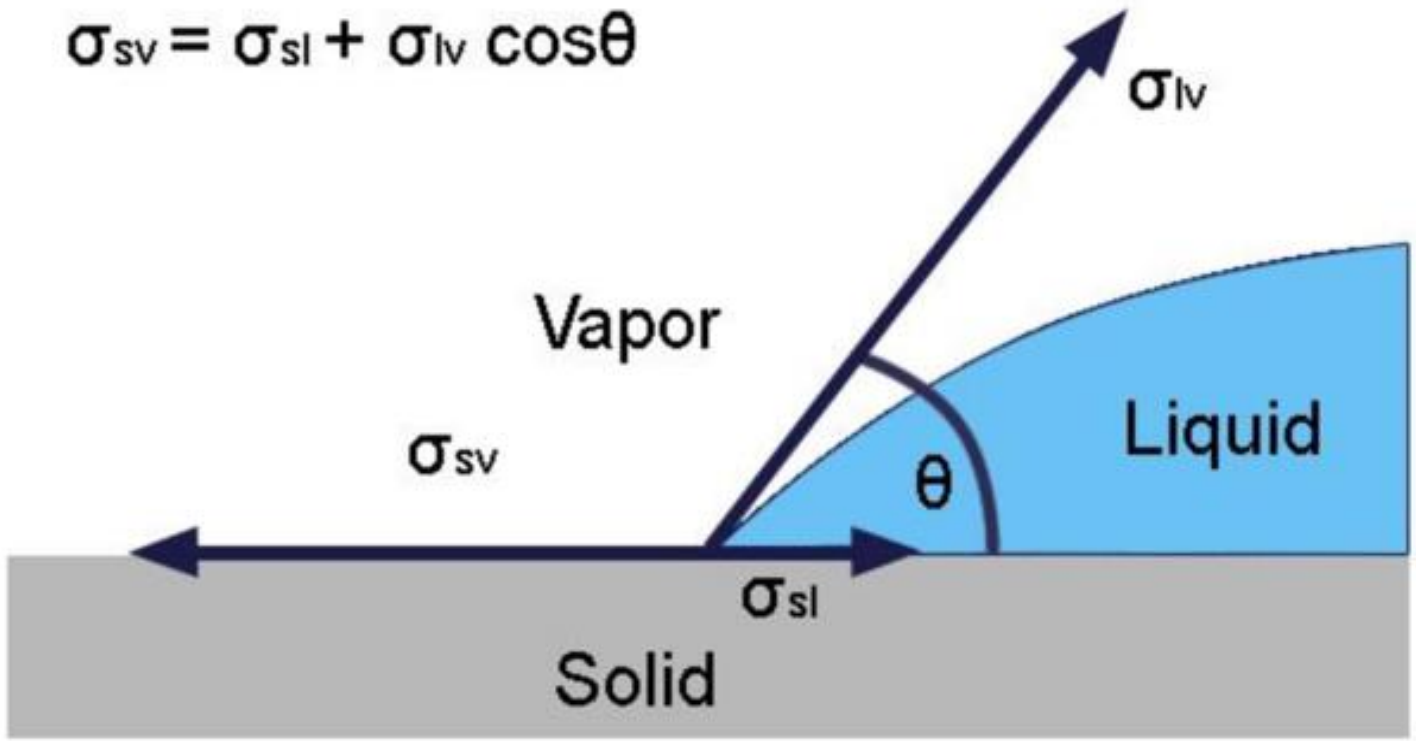
Student model. (2020) Nanoscale Science & Engineering course, Morristown High School. Morristown, NJ.

Contact angle



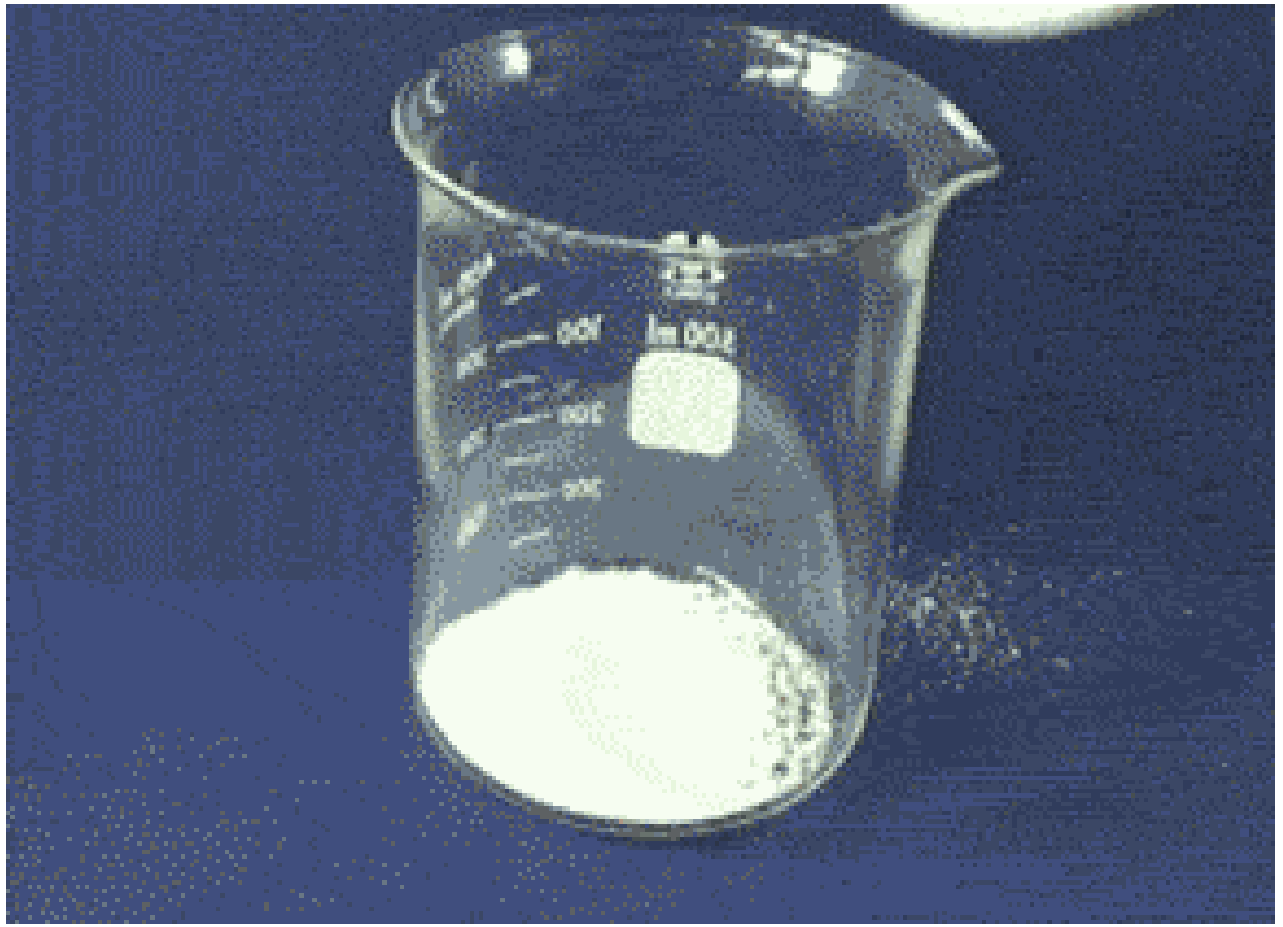
https://www.researchgate.net/figure/Force-diagram-of-Youngs-equation-and-associated-Contact-Angle-measurement_fig1_280115341

A competion of energy terms



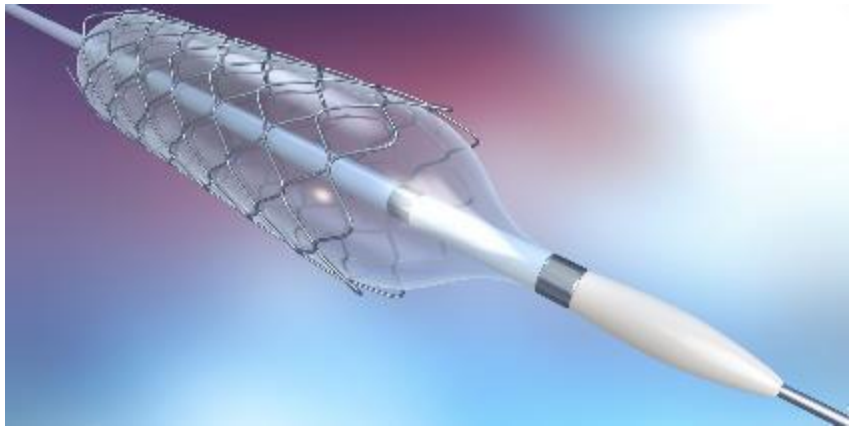
L A Leonova, E L Boytsova, A A Pustovalova. The study of titanium oxynitride coatings solubility deposited by reactive magnetron sputtering. Conference Series Materials Science and Engineering 135(1):012026, June 2016. DOI: 10.1088/1757-899X/135/1/012026

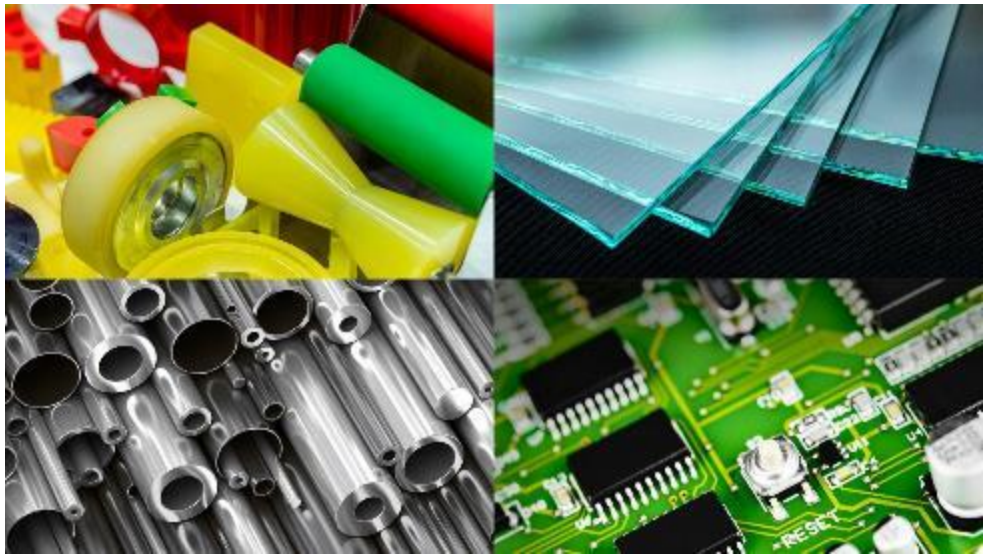
Hydrophilicity



https://gifer.com/en/74bl

Applications



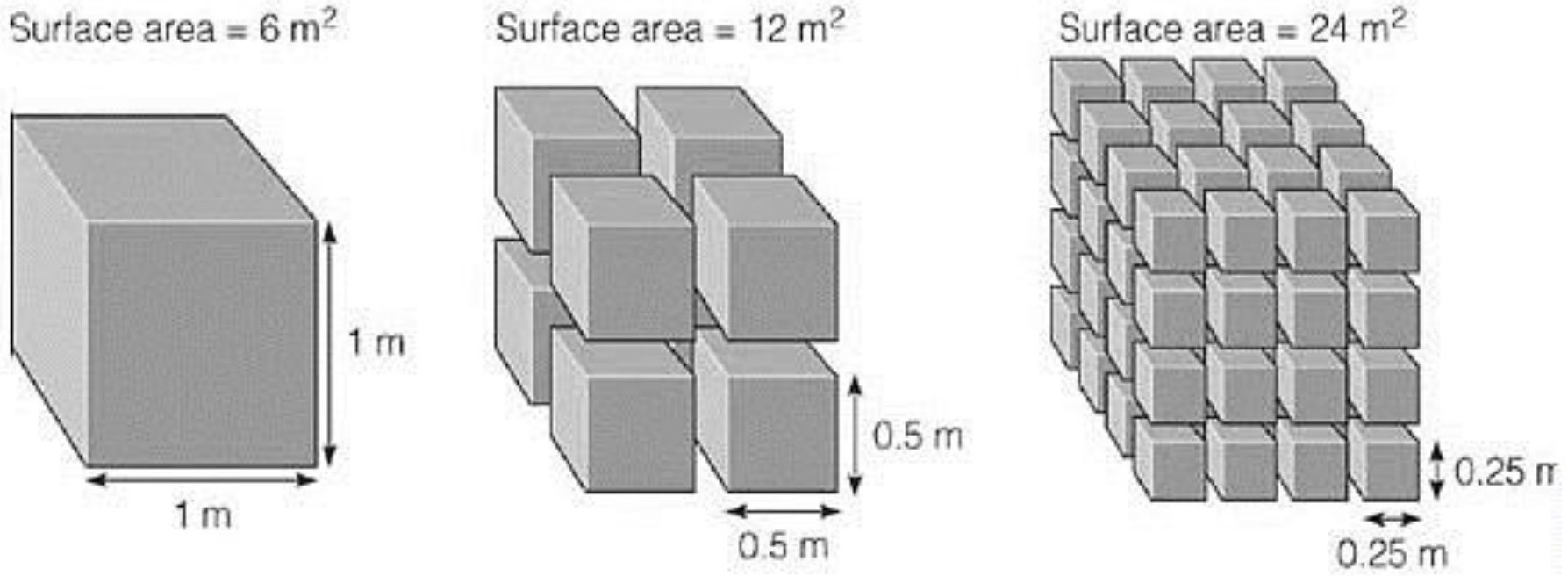


https://parenting.firstcry.com/articles/diapers-usage-how-many-will-your-baby-need/
https://www.wired.co.uk/article/now-your-phone-can-swim
https://www.aculon.com/hydrophobic/

On the surface of things

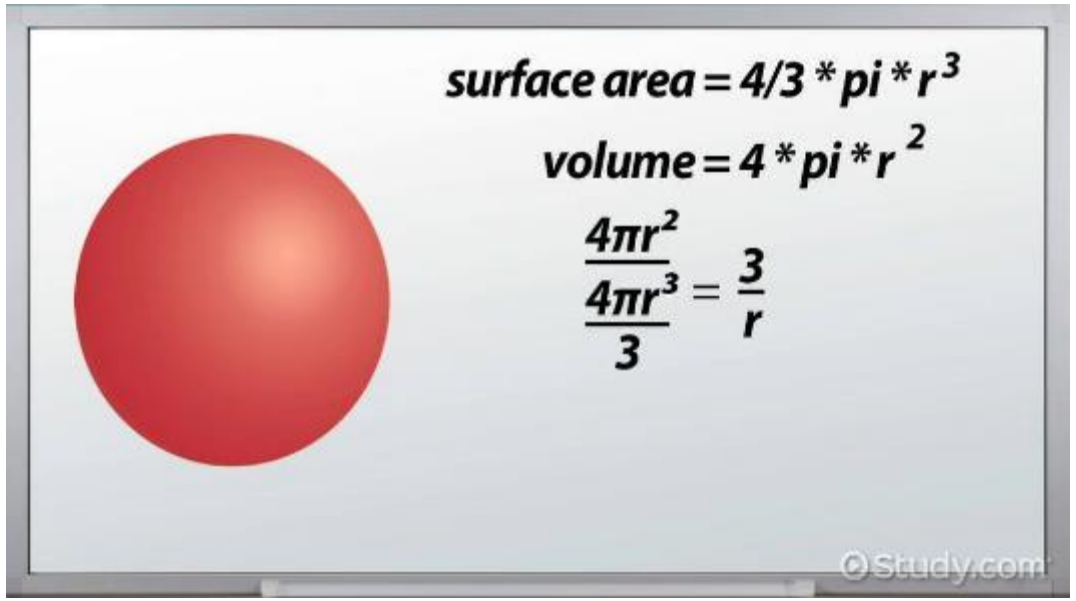
Surface Area to Volume ratio

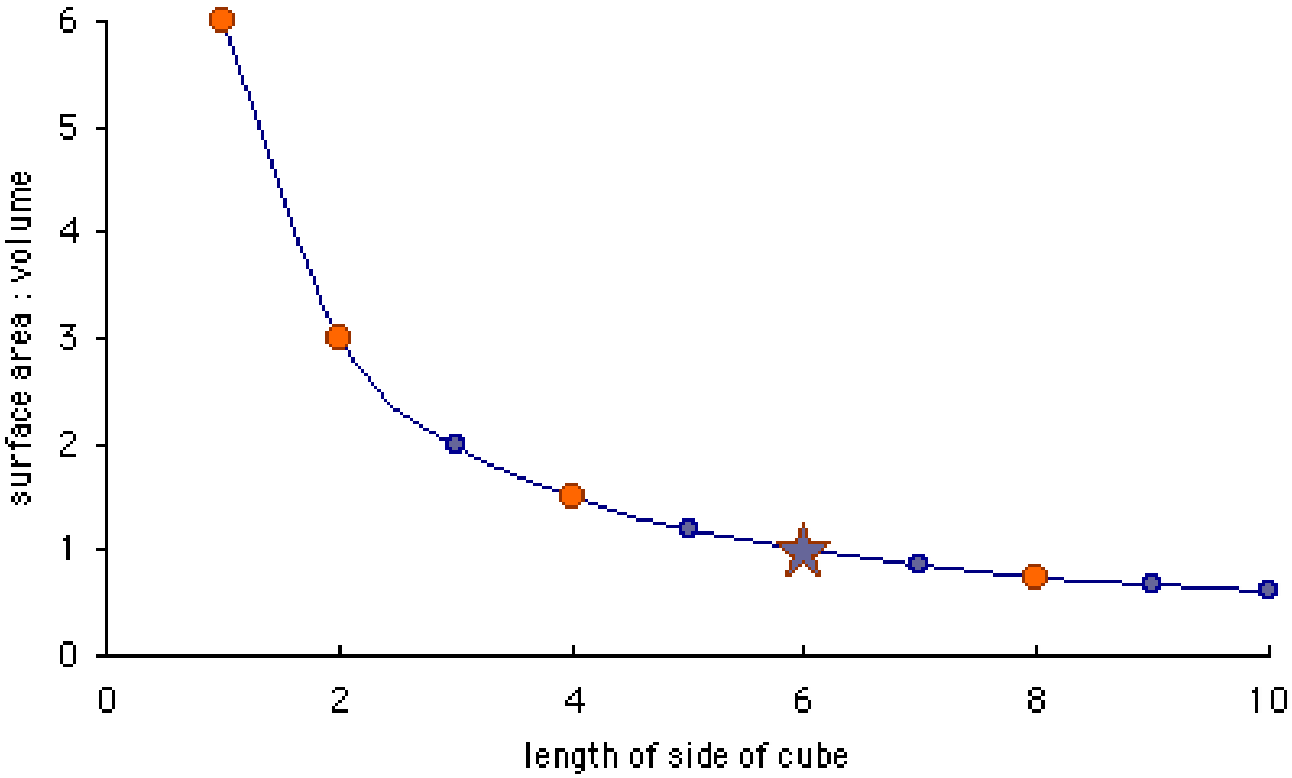
Surface Area to Volume ratio



https://www.researchgate.net/publication/325396498_A_Literature_Review_and_Transport_Modelling_of_Nanoparticles_for_Enhanced_Oil_Recovery

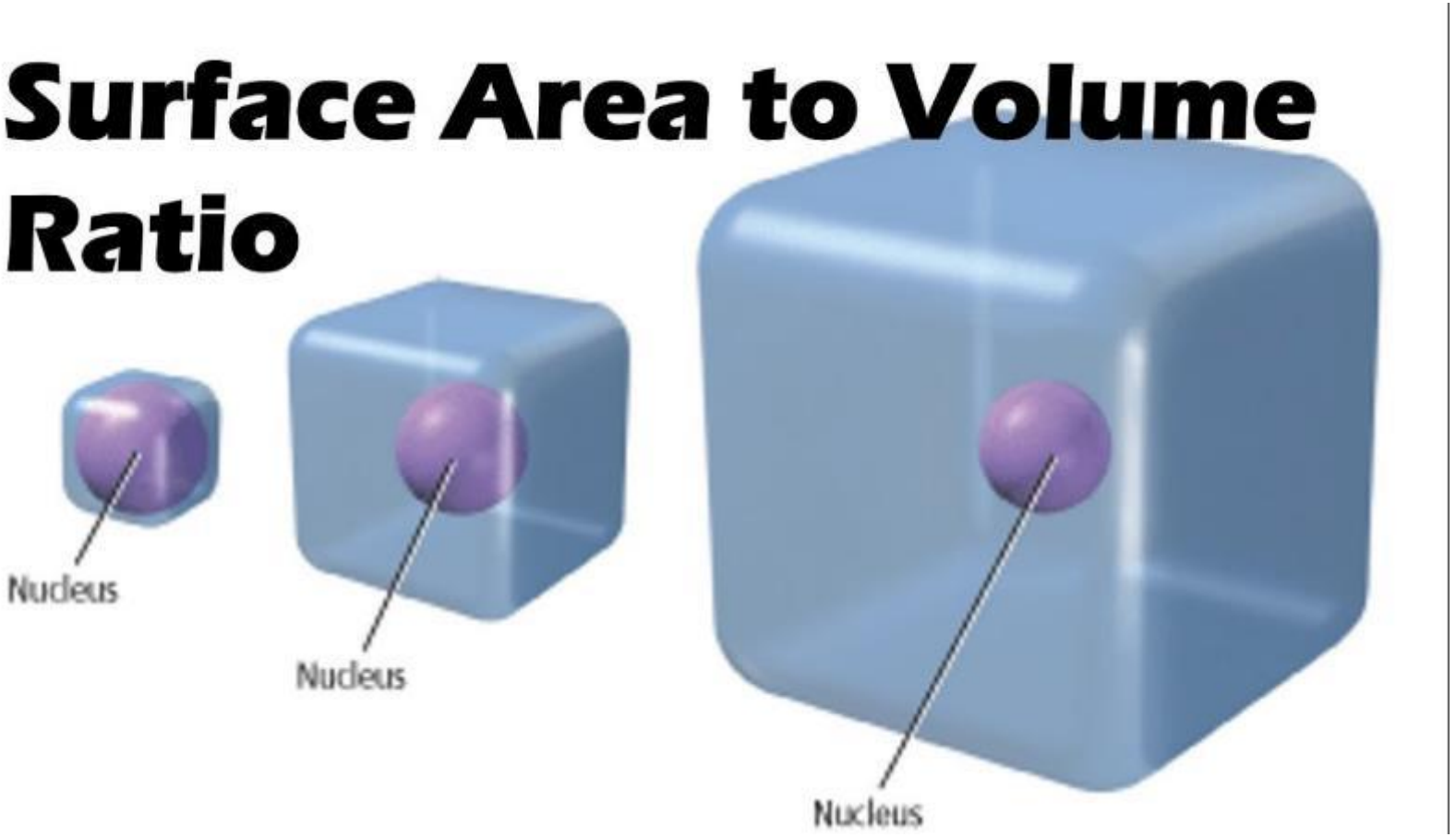
Surface Area to Volume Ratio





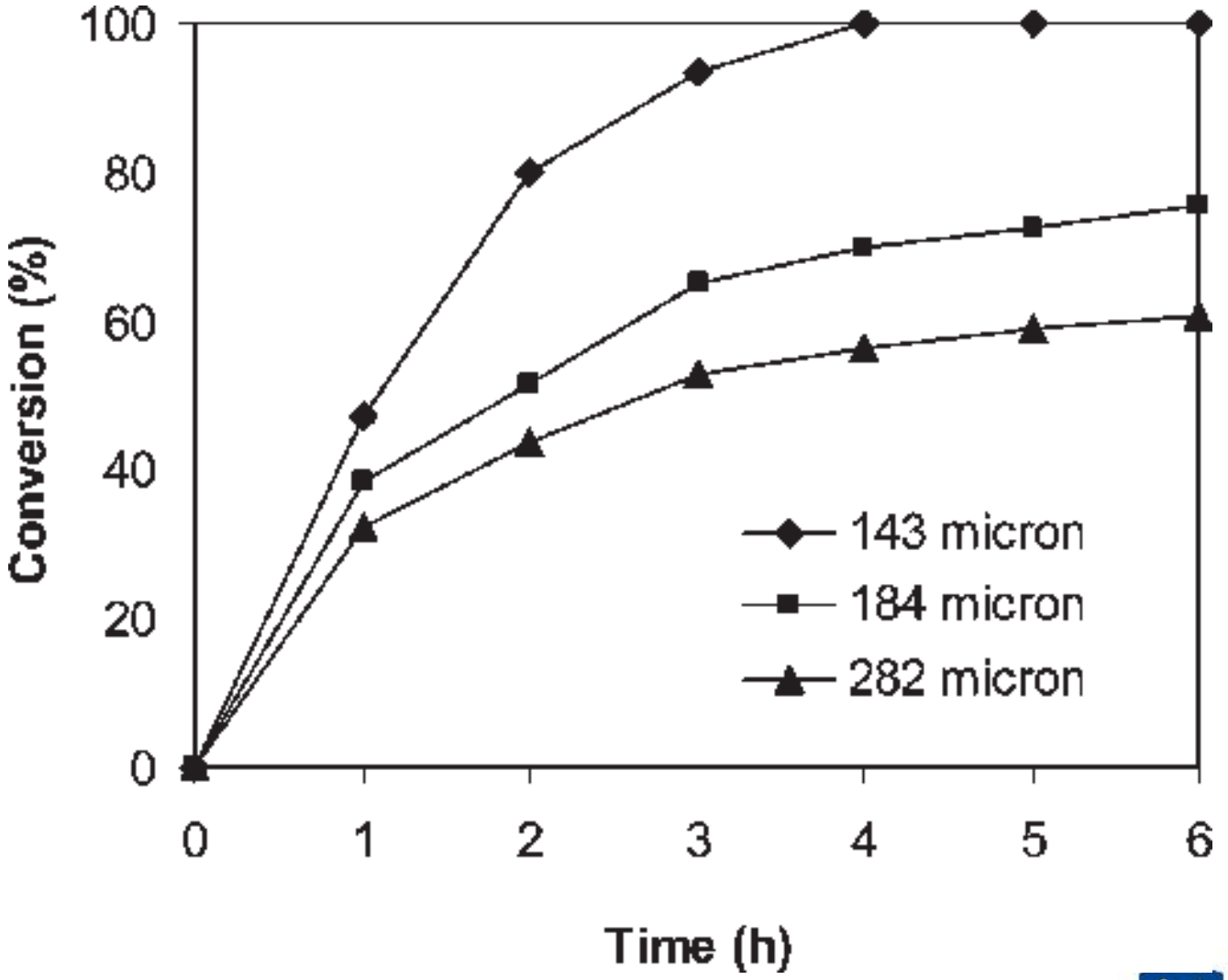
http://www.tiem.utk.edu/~gross/bioed/bealsmodules/area_volume.html
https://study.com/academy/lesson/surface-area-to-volume-ratio.html

SA/V and biology



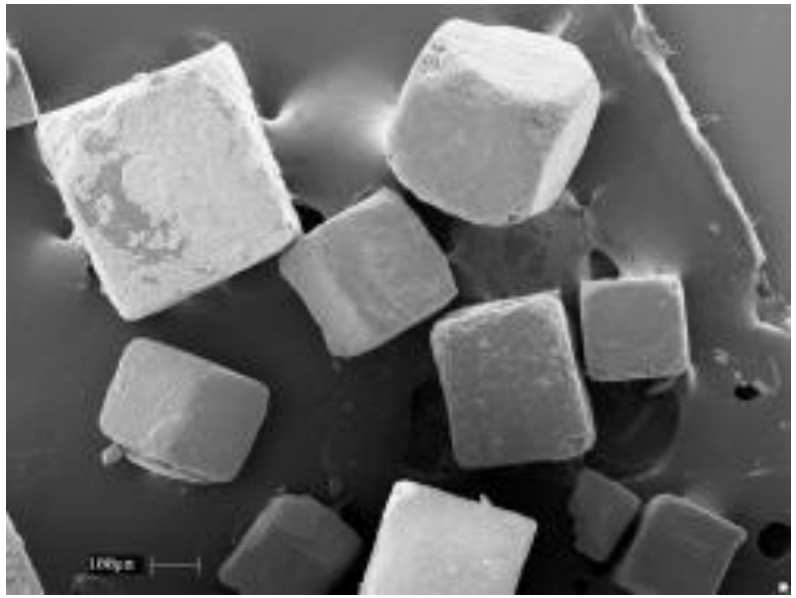
https://www.youtube.com/watch?app=desktop&v=CYaADg5NfEw

SA/V and chemistry



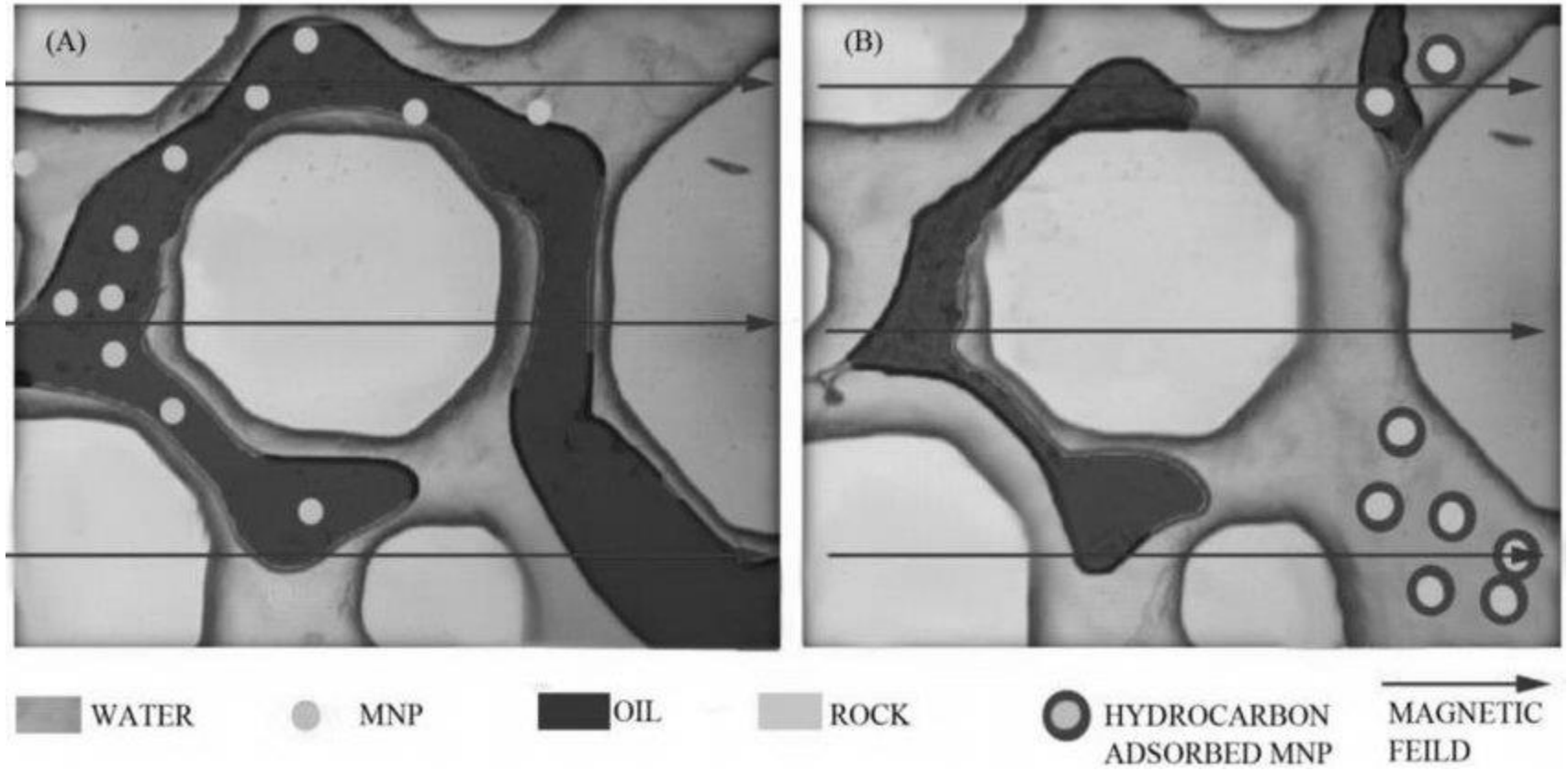
https://www.researchgate.net/publication/231247354_Expanding_Applications_of_Metal-Organic_Frameworks_Zeolite_Imidazolate_Framework_ZIF-8_as_an_Efficient_Heterogeneous_Catalyst_for_the_Knoevenagel_Reaction

SA/V in food science



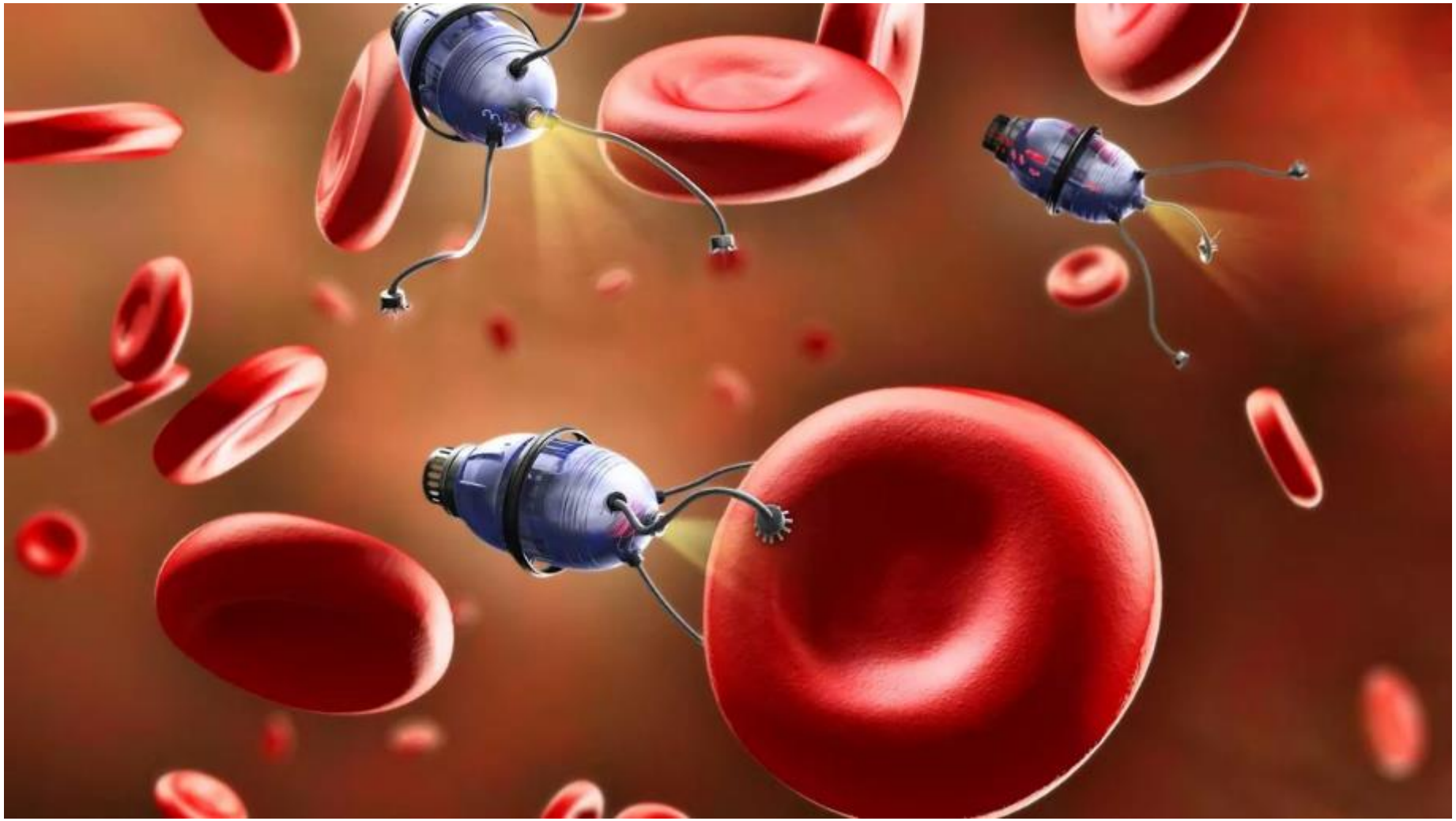
https://www.nisenet.org/catalog/exploring-products-nano-food

SA/V for oil recovery



https://www.researchgate.net/publication/325396498_A_Literature_Review_and_Transport_Modelling_of_Nanoparticles_for_Enhanced_Oil_Recovery

Motion at the nanoscale

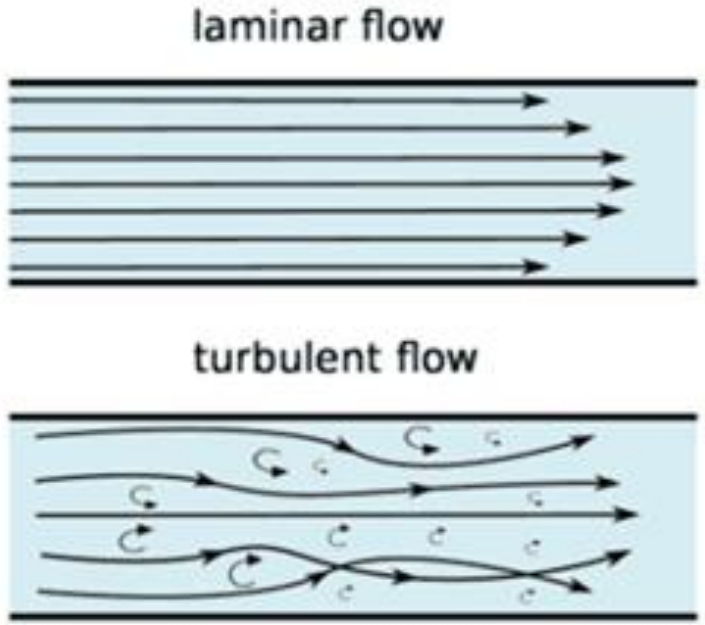


https://www.cnet.com/news/nanobots-can-now-swarm-like-fish-to-perform-complex-medical-tasks/

Reynold's number and viscosity

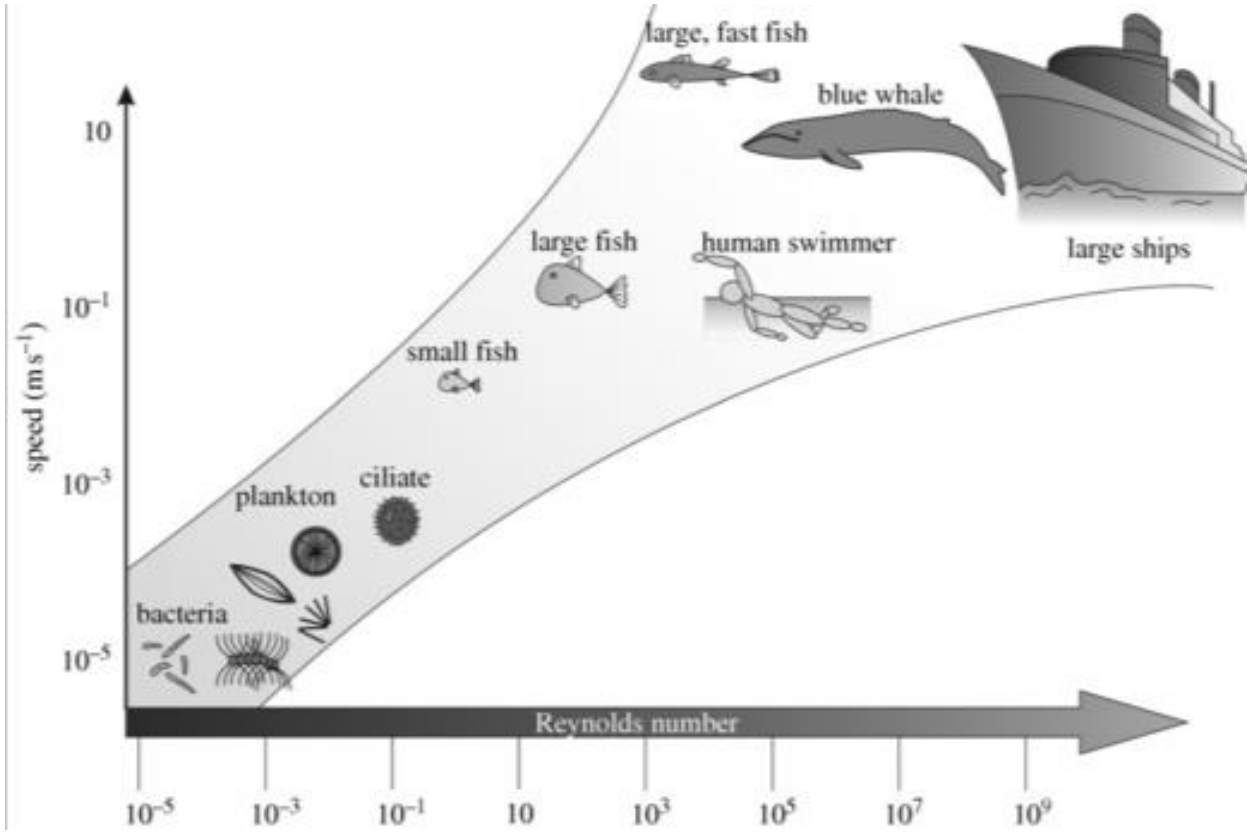
Reynolds number

$$Re = \frac{\rho v_s^2/L}{\mu v_s/L^2} = \frac{\rho v_s L}{\mu} = \frac{v_s L}{\nu} = \frac{\text{Inertial forces}}{\text{Viscous forces}}$$



https://en.ppt-online.org/286821
https://www.nuclear-power.net/nuclear-engineering/fluid-dynamics/reynolds-number/

Reynold's number and viscosty



Laminar Flow

$$\mathrm{Re} = \frac{\rho V L}{\mu} < 10^3$$

Viscous Forces Dominate

Reynold's number and viscosity

http://frederatorstudios.com/costume-quest-episode-coqu193-lucy-downloads-the-mueller-report/

Laminar flow at low Re

https://gfycat.com/edibleconstantgemsbuck
https://www.ks.uiuc.edu/Research/flagellum_growth/

Reynold's number and Stokes' Law

Fluid Mechanics: Stokes' Law and Viscosity

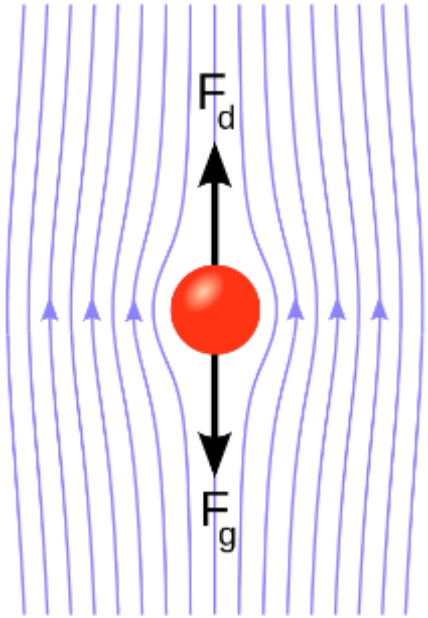
4. Calculate the Stokes' velocities for each radius, and record it in the box below.

$$vStokes = \frac{2}{9}\frac{(\varrho_p - \varrho_f)}{\mu} gR^2 \quad g = 9.8\ m/s^2$$

5. Calculate the Reynolds number for each radius, using the theoretical velocity values. Using this equation, be sure to ***convert radius to diameter*** first, and ***use the density of the fluid not the particle***.

$$R_e = \frac{\varrho\, v\, D}{\mu}$$

Radius (m)	v_{Stokes} (m/s)	Reynolds number	$v_{experimental}$ (m/s)

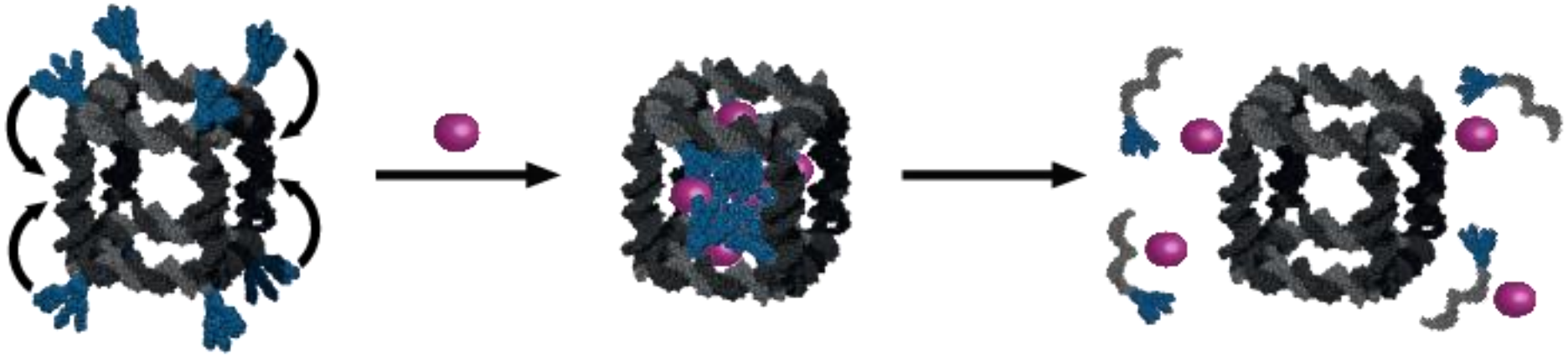


$$F_d = 6\pi\mu R v$$

Kolker, M. (2020). Fluid Mechanics: Stokes' Law and Viscosity. Nanoscale Science and Engineering. Morristown High School, Morristown, NJ.

Motion at low Reynold's number

DNA drug cages… how do scientists deliver them?



A DNA cage (at left), with lipid-like molecules (in blue). The lipids come together in a 'handshake' within the cage (center image) to encapsulate small-molecule drugs (purple). The molecules are released (at right) in response to the presence of a specific nucleic acid.

https://www.mcgill.ca/newsroom/channels/news/dna-cages-may-aid-drug-delivery-230159

Breakout

Which concepts, if any, might fit into your curriculum?

- Size and scale
- Scientific phenomena
- Light
- Forces
- Catalysts
- Polar/nonpolar chemistry
- Band gaps
- Surface area to volume
- Materials
- Colloids
- Medical innovation
- Current scientific research

Groups: High schools / CCs / University

Breakout

As I speak, Renee is putting a link to our Resources doc in the chat.

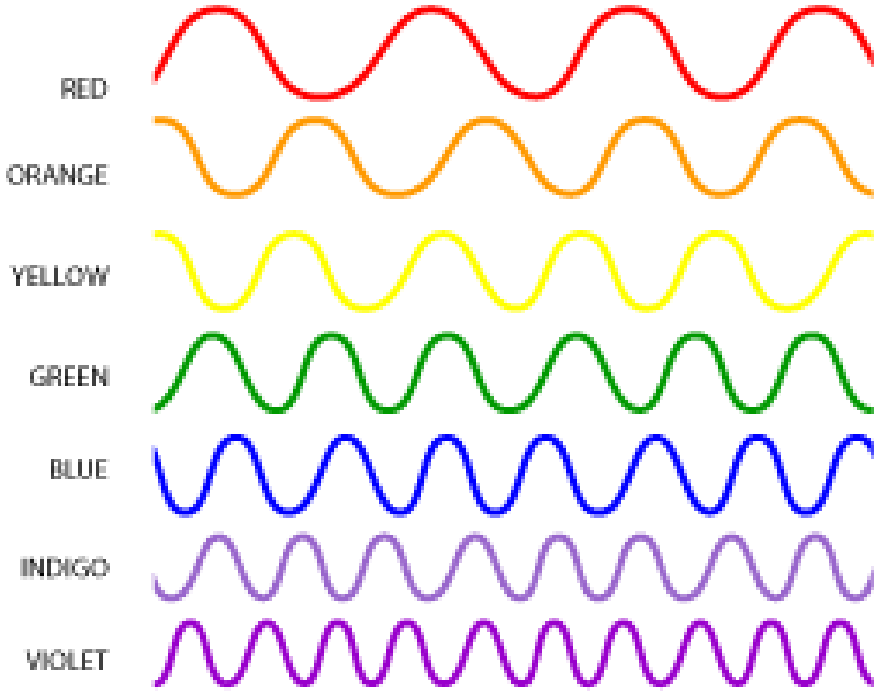
In your group, examine the Changes with Scale section of the doc. Discuss with your partners what could be used in your course.

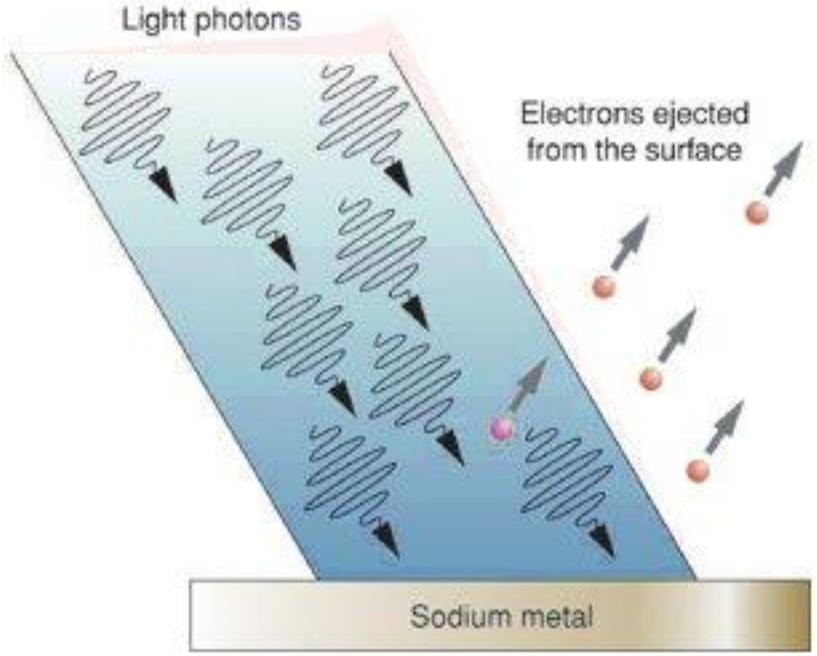
Groups: High schools / CCs / Unis

Playing dice with the universe

Quantum effects

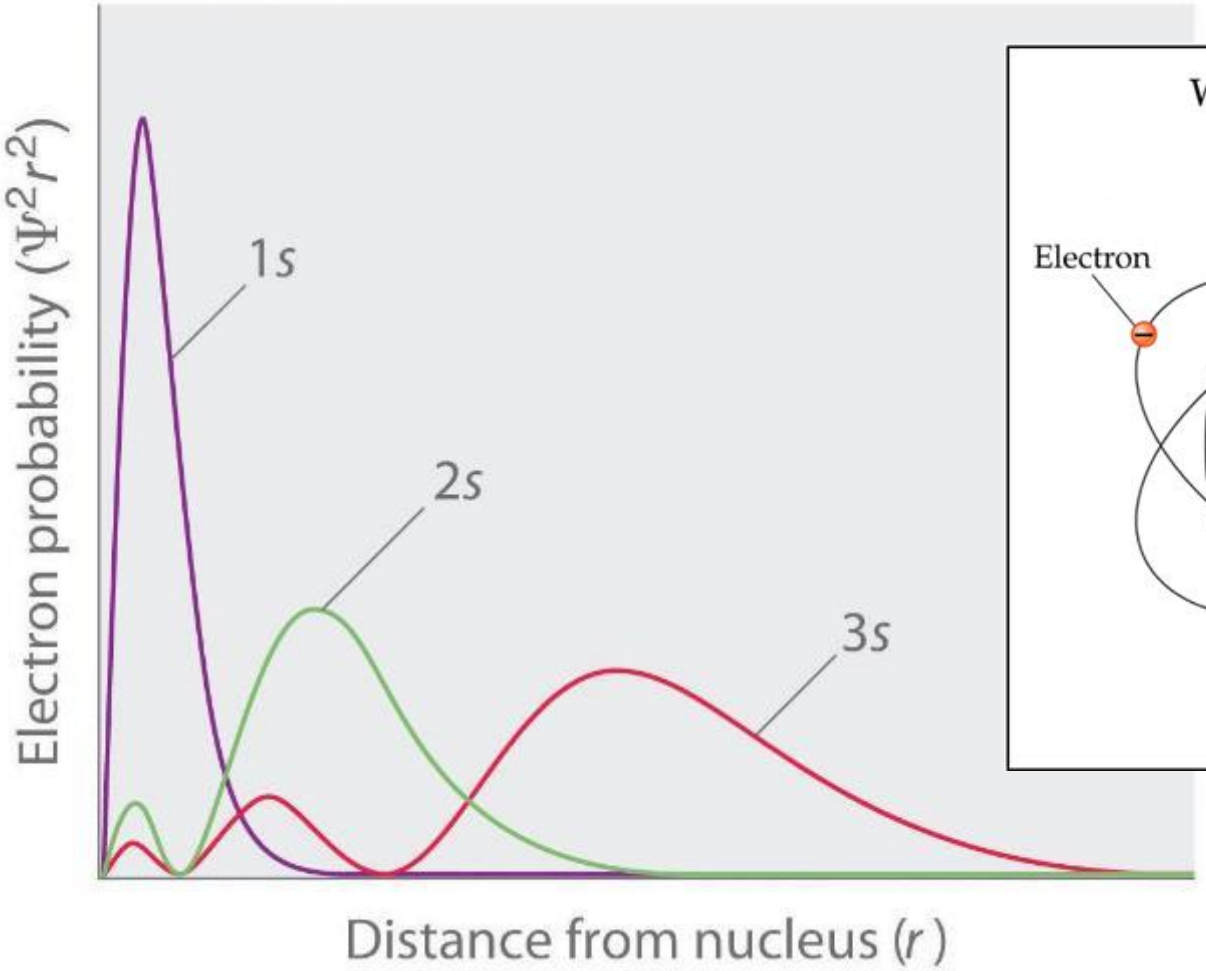
Our discontinuous universe

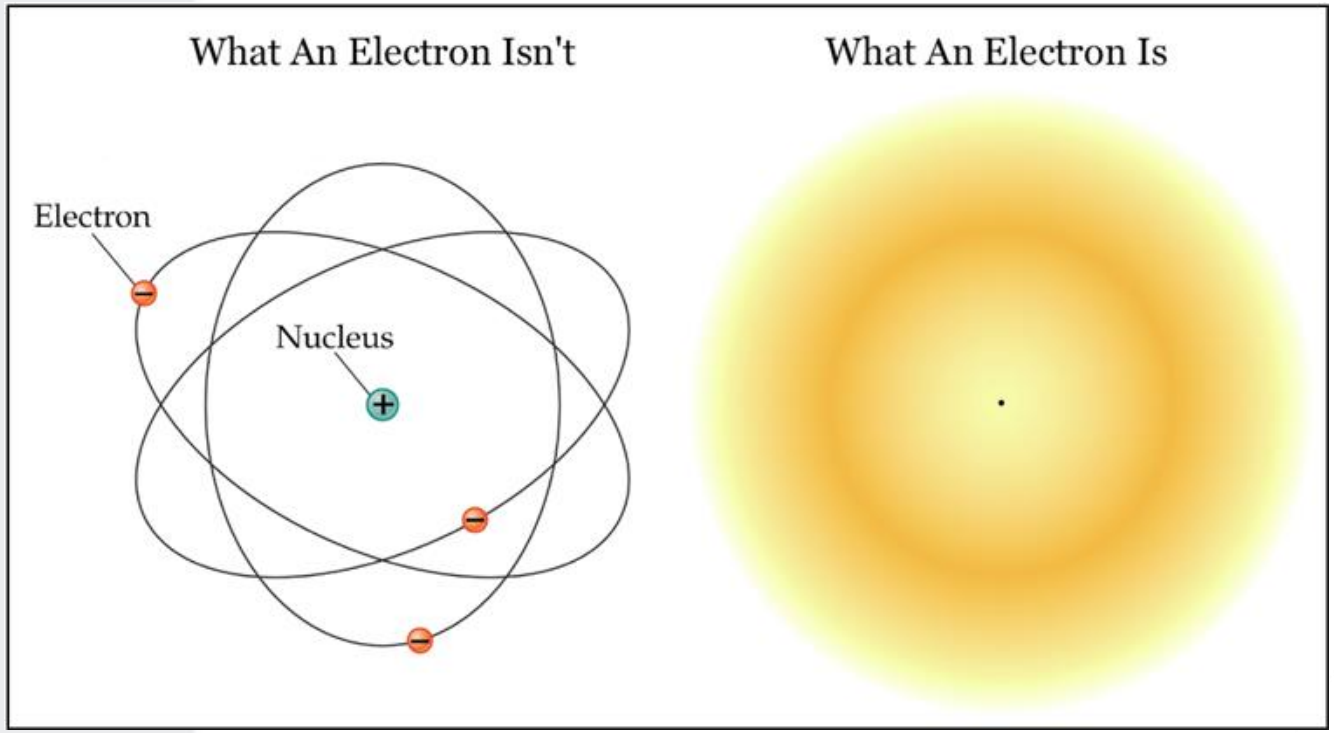




https://sites.google.com/site/mrjhelectromagneticspectrum/home/visible-light
https://www.green-the-world.net/photoelectric_effect.html

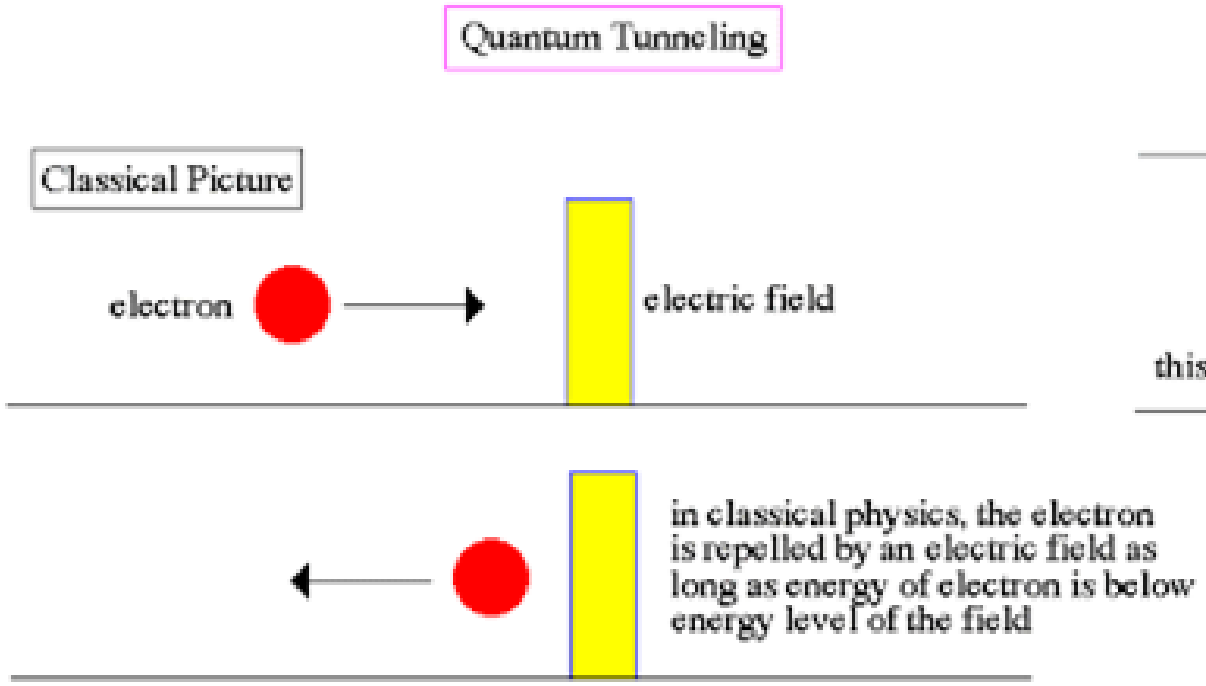
Probabilistic nature of matter

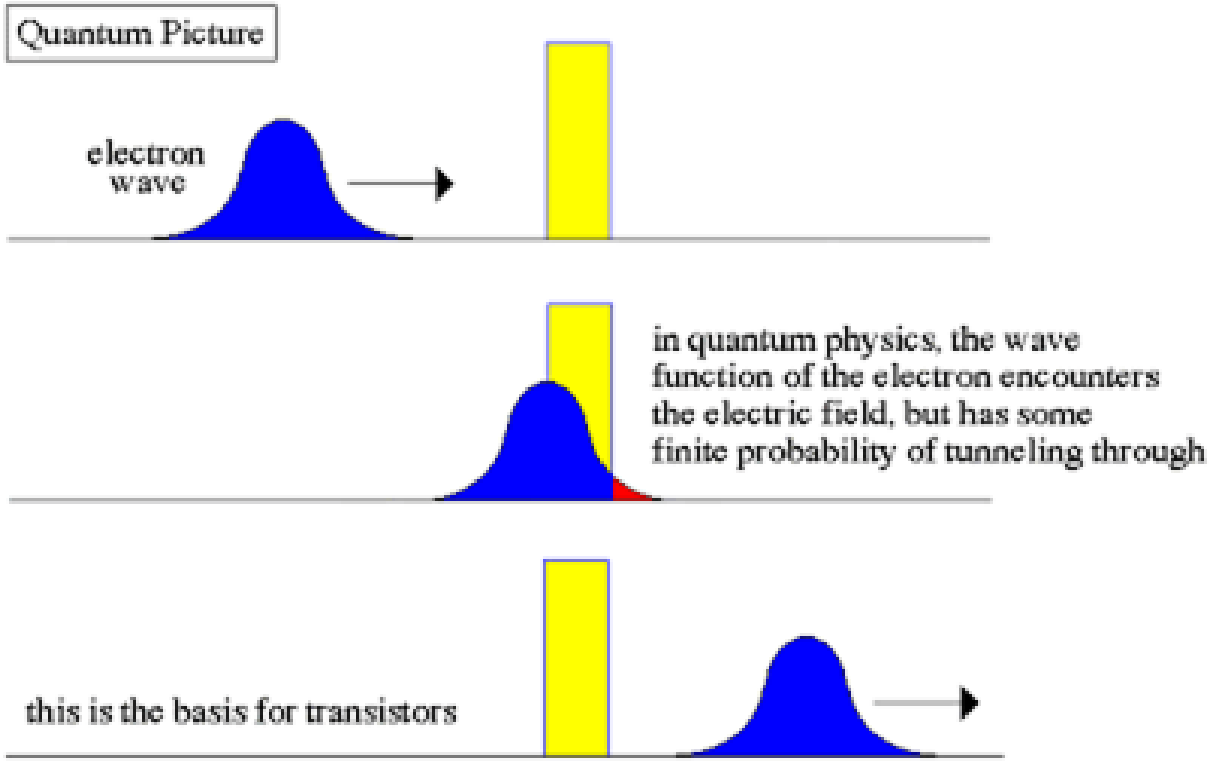




https://faculty.wcas.northwestern.edu/~infocom/The%20Website/plates/Plate%201.html
https://www.khanacademy.org/science/physics/quantum-physics/quantum-numbers-and-orbitals/a/the-quantum-mechanical-model-of-the-atom

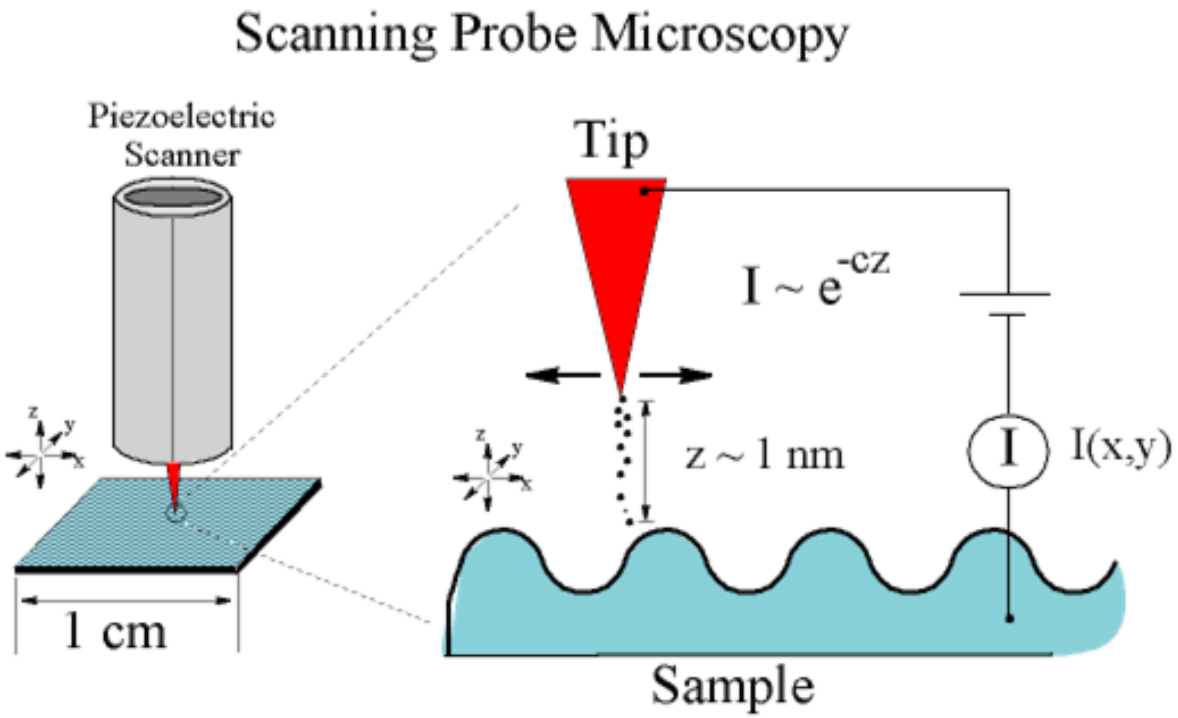
Quantum tunneling

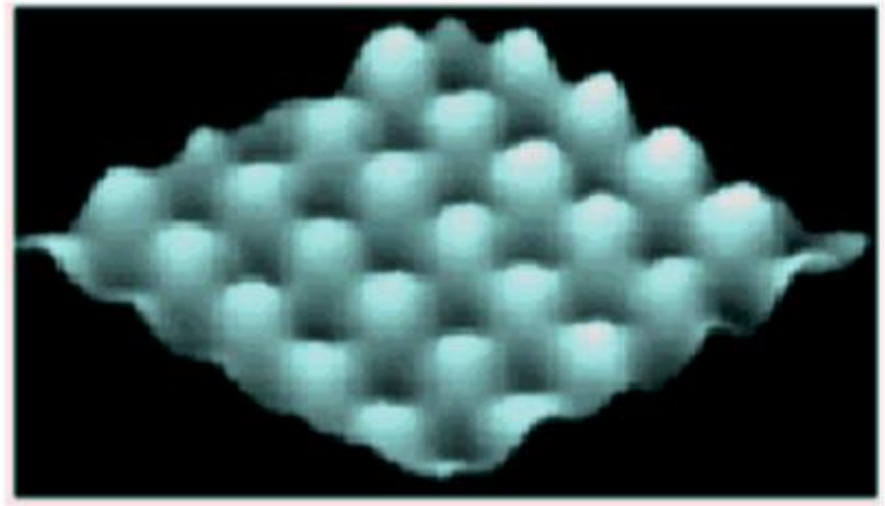




http://abyss.uoregon.edu/~js/glossary/quantum_tunneling.html

Scanning Tunneling Microscopes

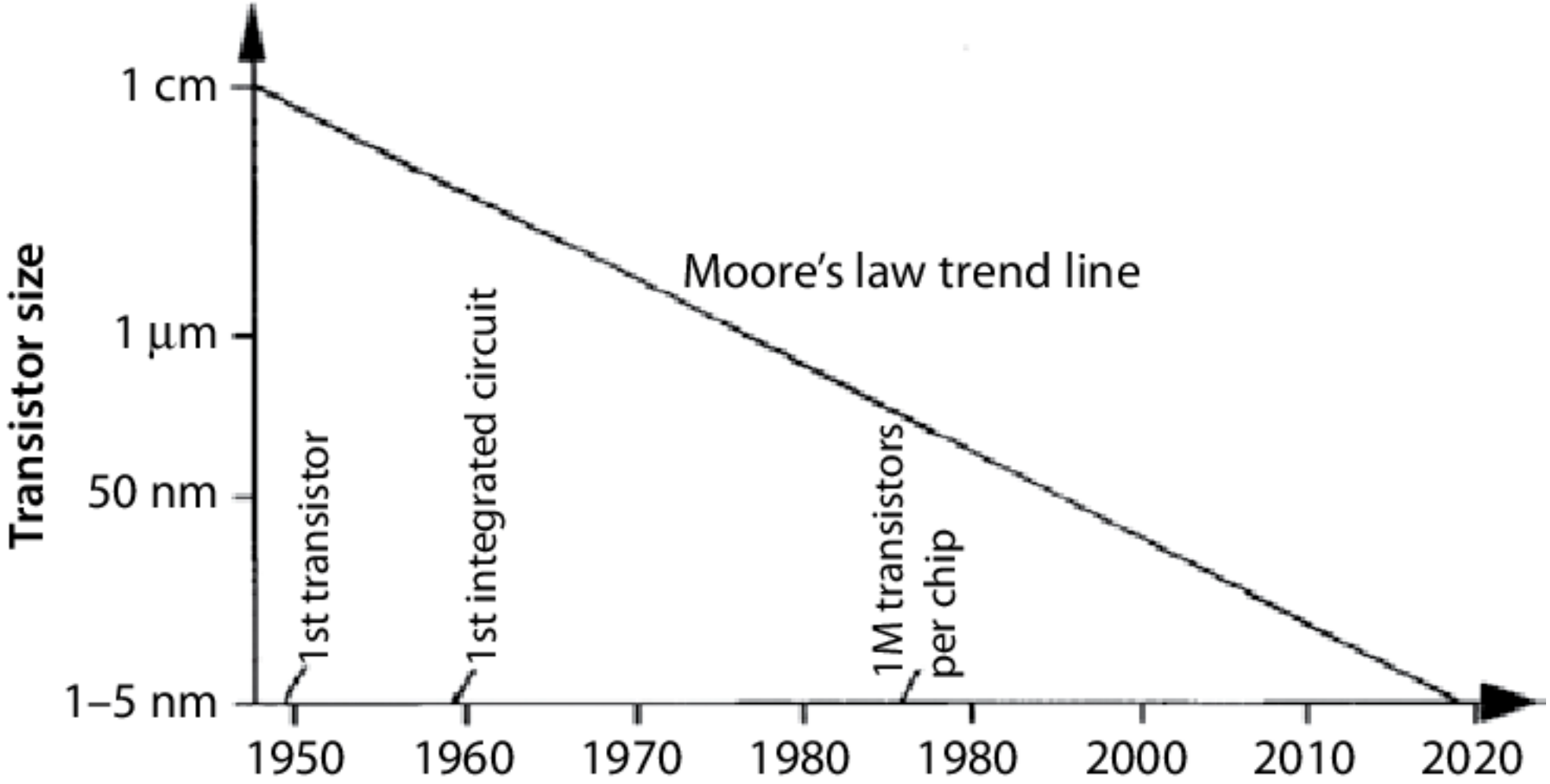




Graphite - 1 nm x 1 nm scan

https://www.d.umn.edu/~jmaps/stm1.html

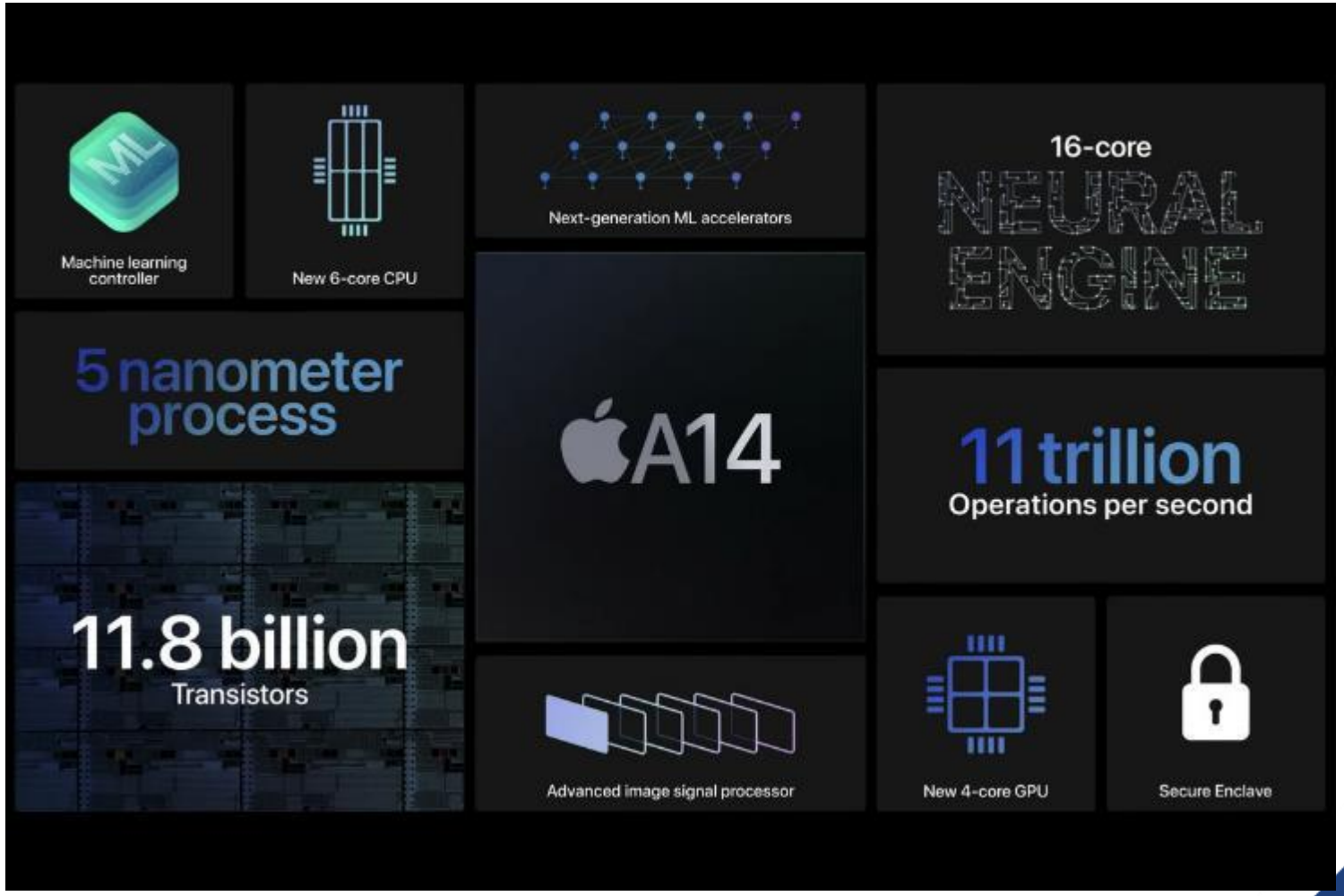
Moore's Law



https://www.researchgate.net/publication/318510665_Nanomaterials_in_Energy_Generation

The end of Moore's Law

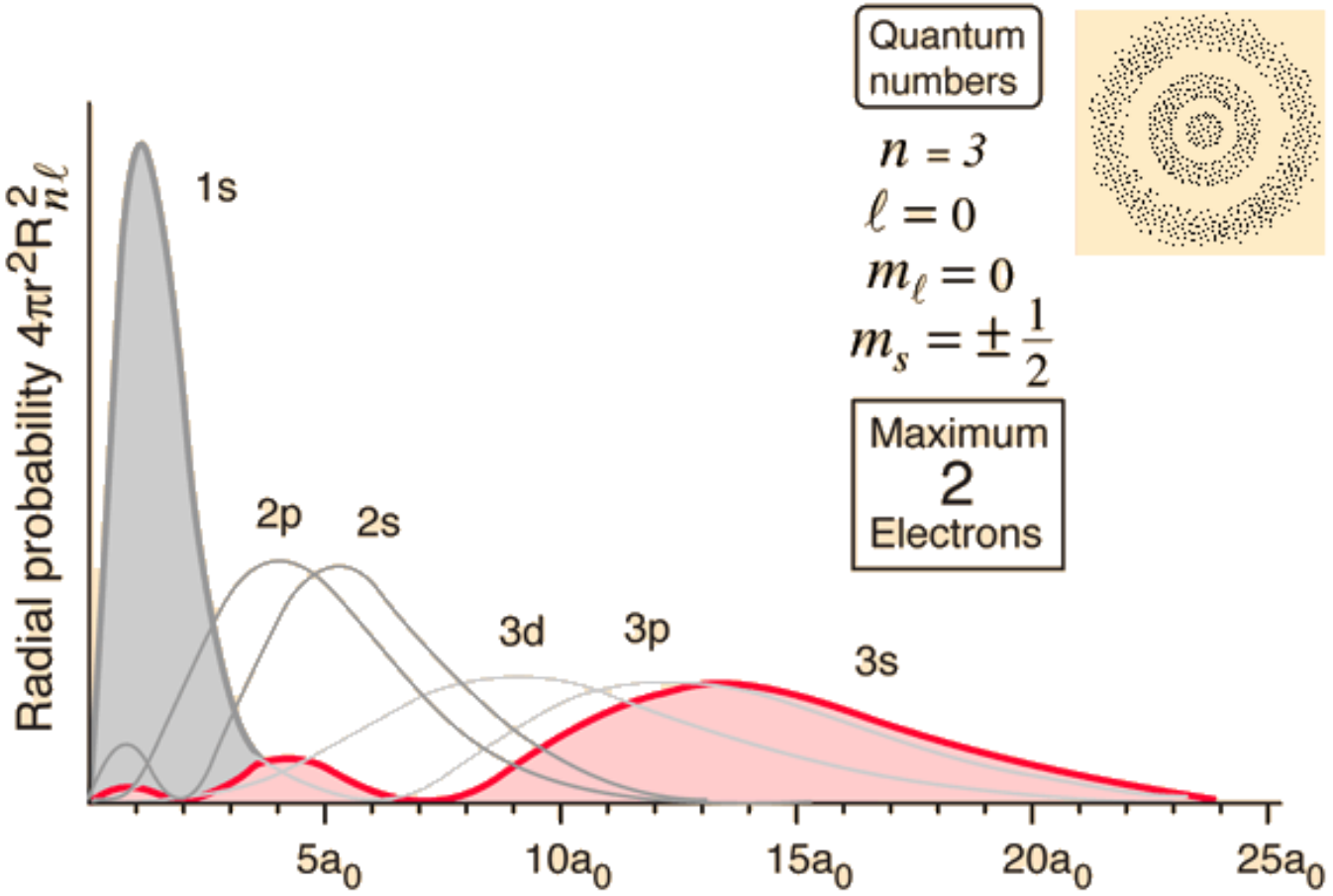
Apple's iPhone 12 contains 5 nm transistors.



https://www.bbc.com/news/technology-54510363

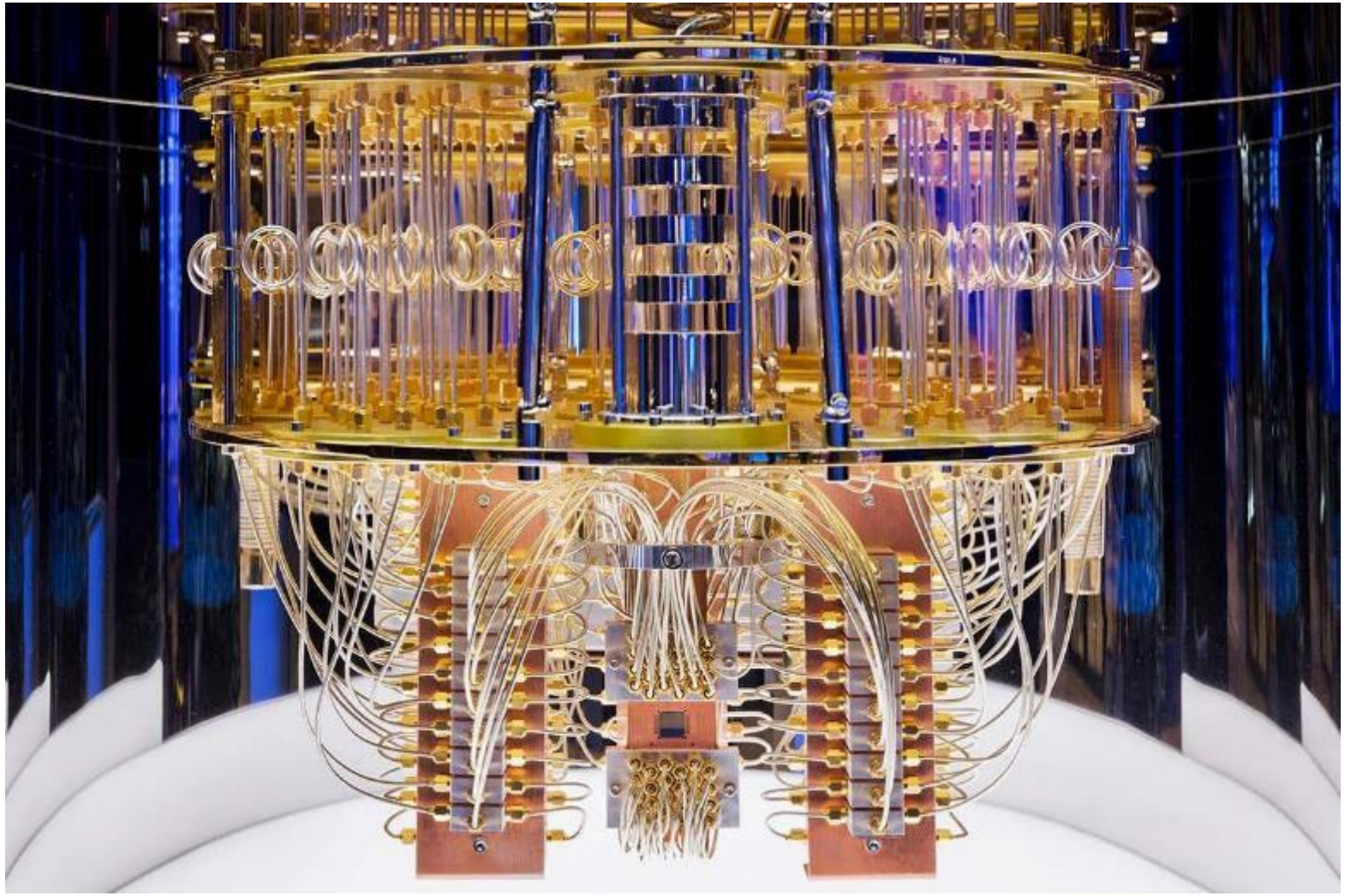
The end of Moore's Law?

What is 25 Å in nanometers?



http://hyperphysics.phy-astr.gsu.edu/hbase/hydwf.html

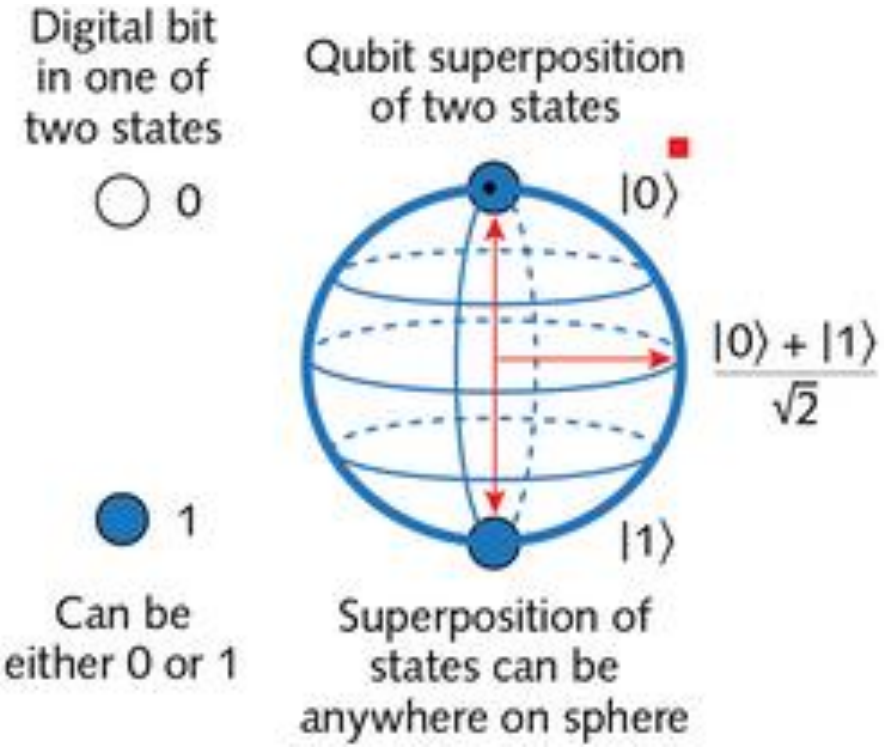
Quantum Computing



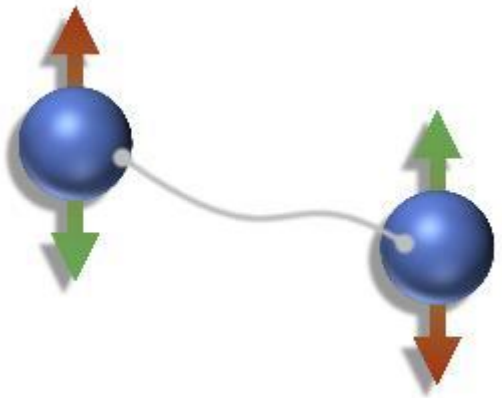
https://www.newscientist.com/article/2252933-quantum-computers-may-be-destroyed-by-high-energy-particles-from-space/

Quantum effects

Superposition

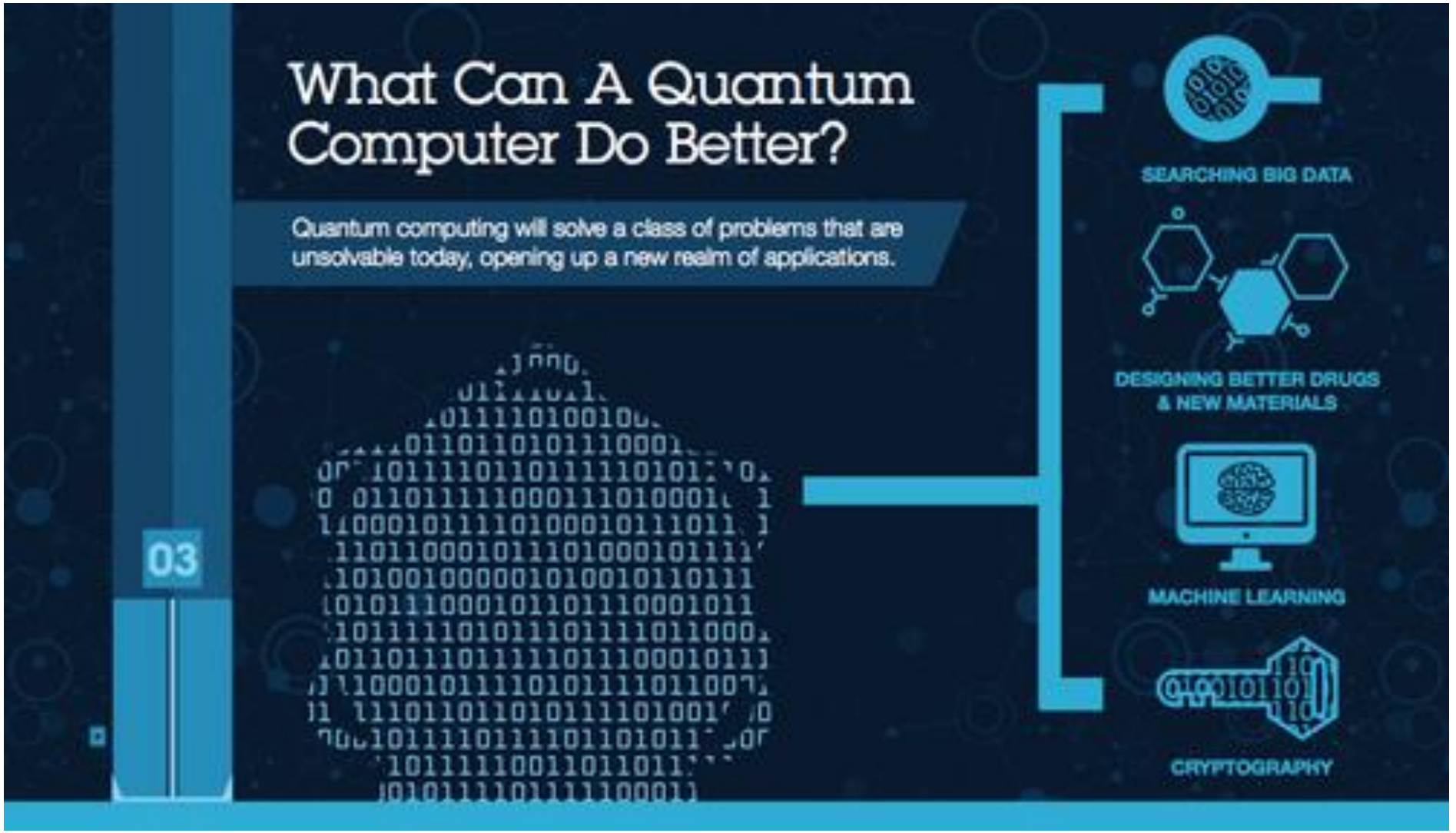


Entanglement



https://sciencenewsnet.in/tag/quantum-entanglement/
https://www.laserfocusworld.com/lasers-sources/article/14176179/quantum-science-the-quest-for-quantum-information-technology-expands

Quantum computing



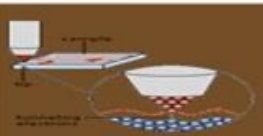
https://www.21stcentech.com/quantum-computers-dos/

The science of making small

Preview

Fabrication

Application Areas for Nanotechnology

Medicine and Health	Information Technology	Energy Production / Storage	Materials Science	Food, Water and the Environment	Instruments
 Drug delivery	 GMR Hard Disk	 Hydrogen Fuel Cells	 Lightweight & strong matls.	 Remediation methods	 Tunneling microscopy
 Treatments for Cancer	 Molecular Switches	 Solar Cells	 City-Sized Skyscrapers	 "Smart" Membranes	 Nano Manipulators

Is impacting virtually all technological sectors as an "enabling" or "key" technology