Thinking Small

With Inspirations from Feynman

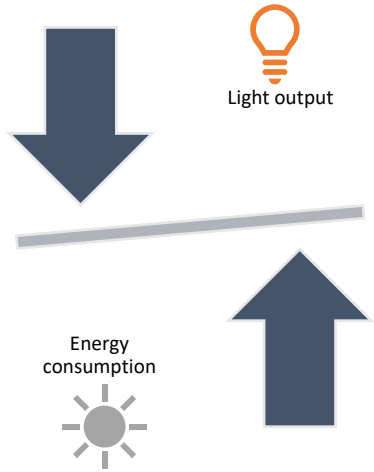
The Scale of the Universe

https://htwins.net/scale2/

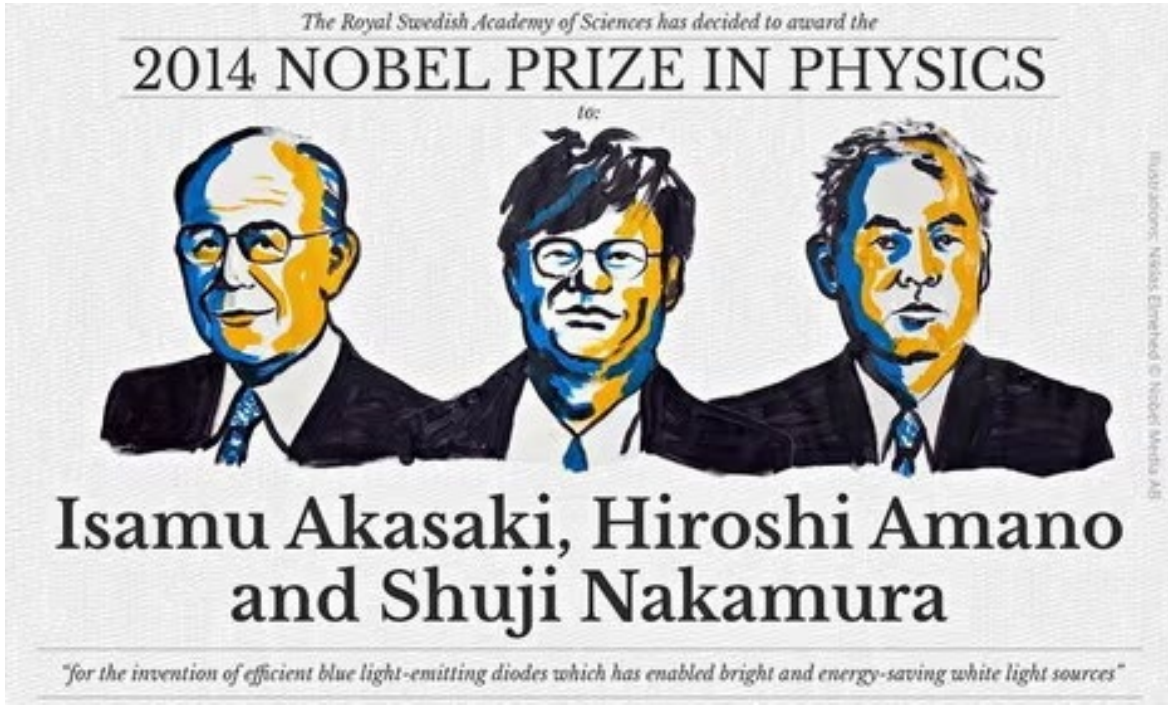
Discussion: https://www.gabrian.com/the-scale-of-universe/

Have you ever thought of making anything smaller?

Let’s take a case of scaling…



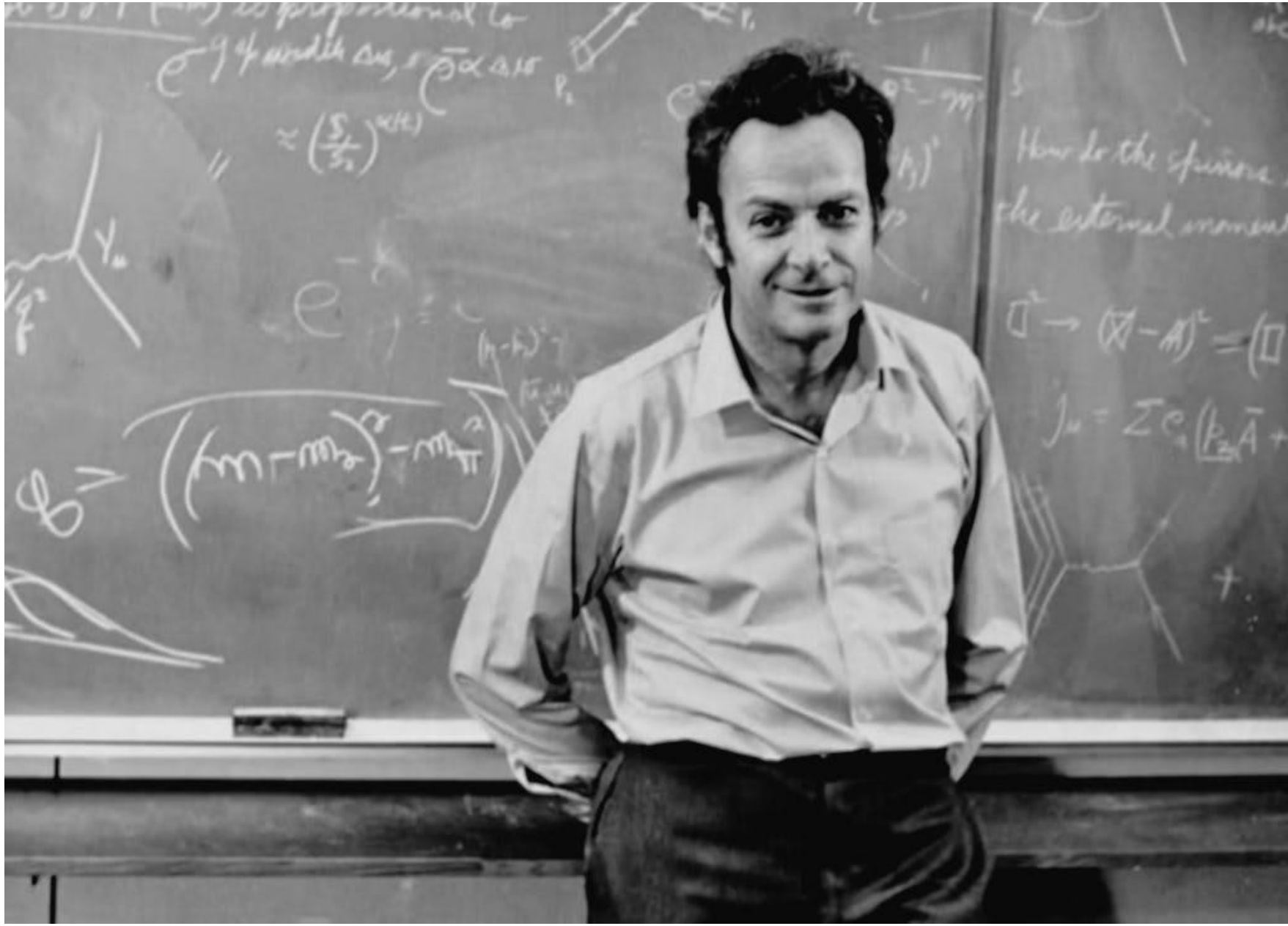
How light sources have scaled over time?



https://viribright.com/blogs/insights/comparing-led-vs-cfl-vs-incandescent-light-bulbs

Richard Feynman

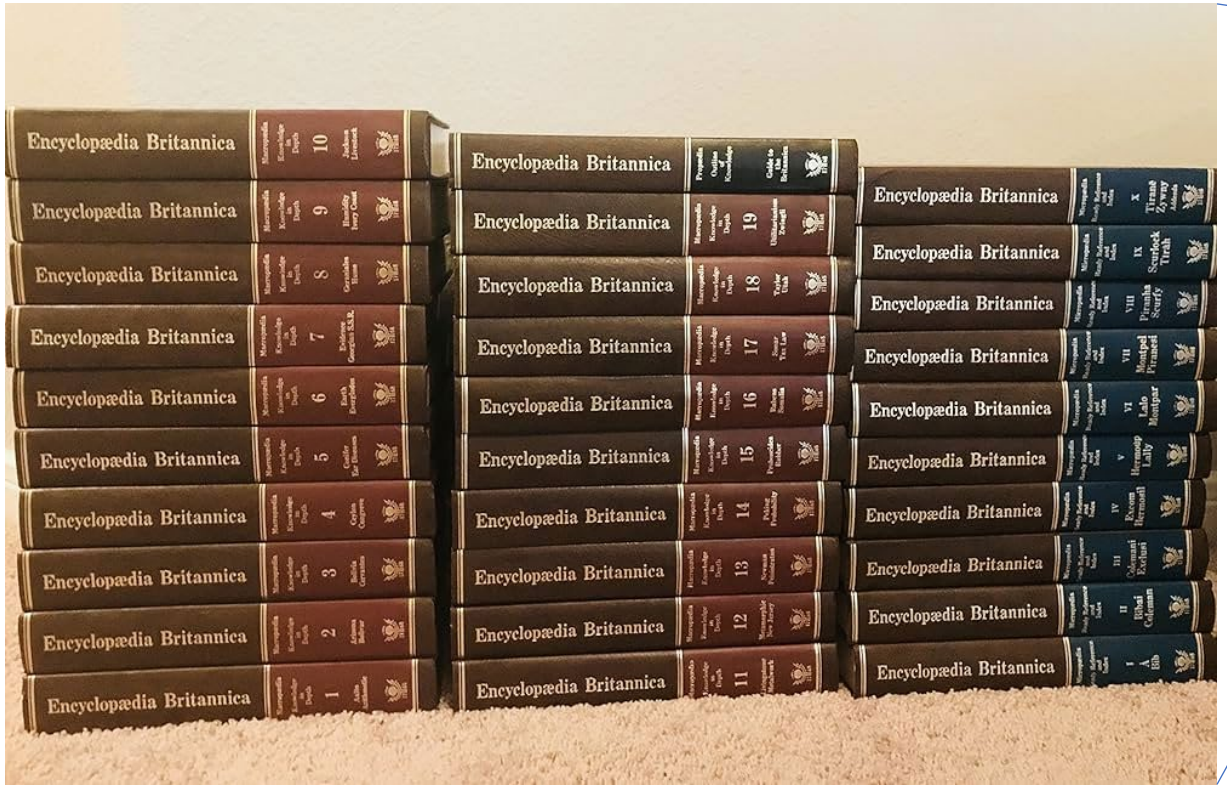
"There's Plenty of Room at the Bottom"
December 29th, 1959



https://web.pa.msu.edu/people/yang/RFeynman_plentySpace.pdf

https://piggsboson.medium.com/10-reasons-why-richard-feynman-was-more-than-just-a-physicist-1aed6a069d5d

The challenge posed: Writing 24 volumes of encyclopedia of Brittanica on the head of a pin



0.2 mm

25000 X ↓

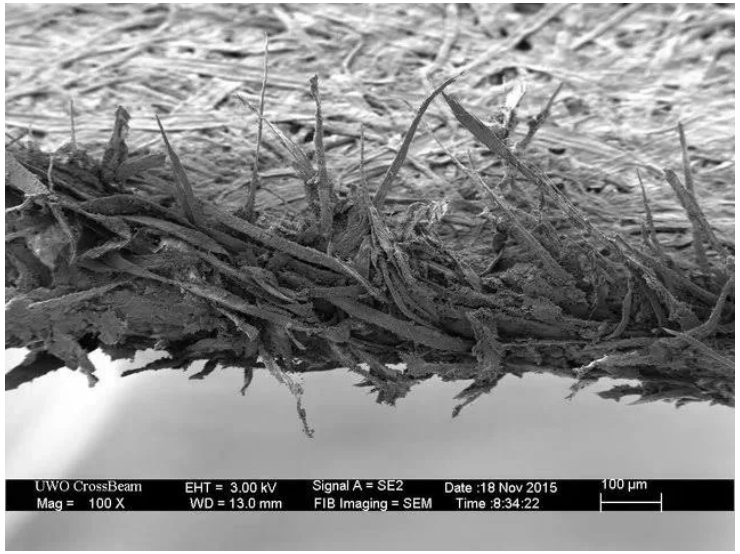
8 nm

1000 atoms

https://www.amazon.in/Encyclopaedia-Britannica/dp/0852293607

- Thus, there is enough room on the head of a pin
- Now, let's worry about the process of writing

What happens in writing anyway?



Cross-section of a paper

Ink on a paper

Ball-pen tip

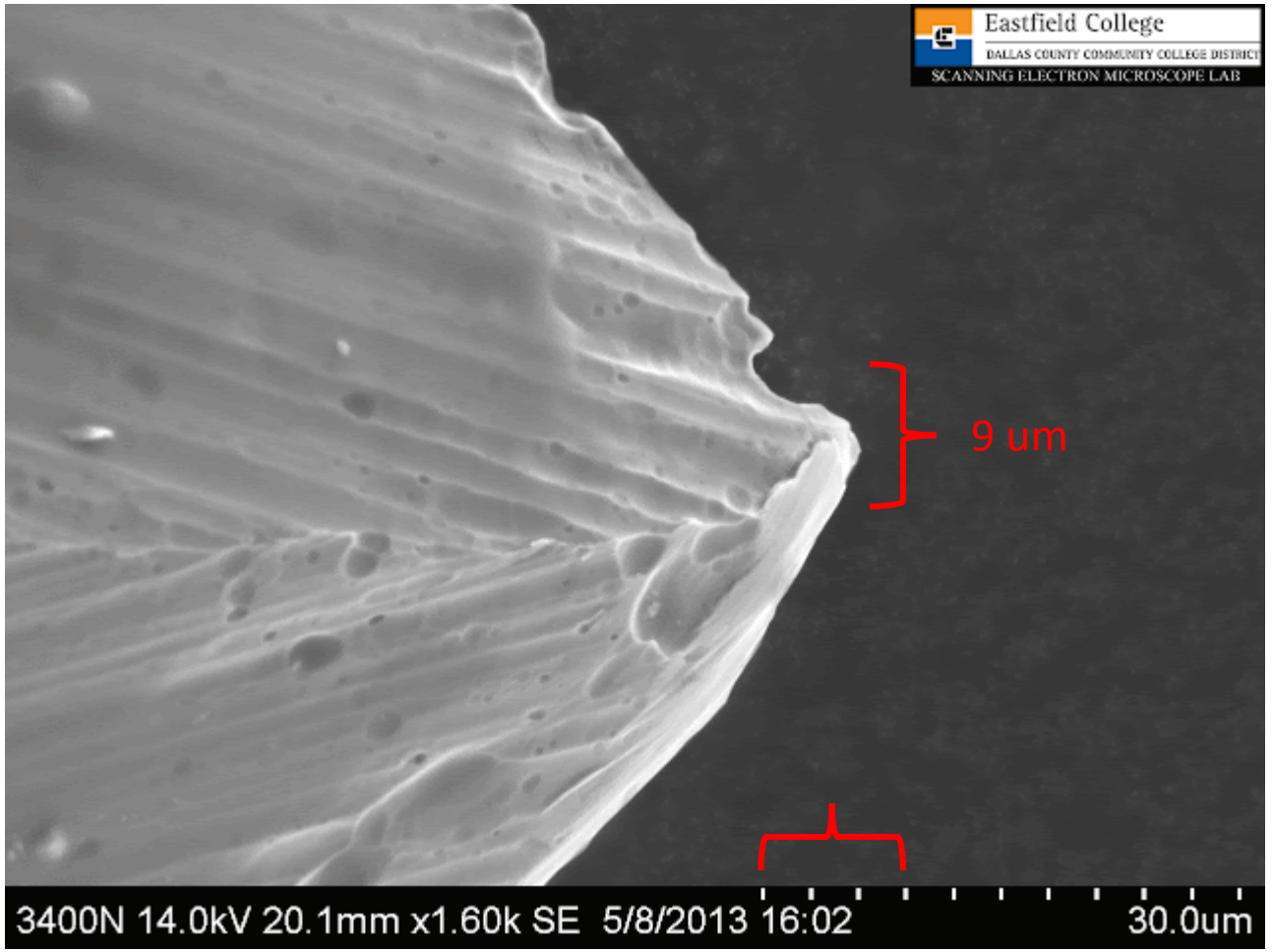
Fountain-pen tip

https://www.reddit.com/r/interestingasfuck/comments/ff9fjd/view_of_paper_under_the_microscope/?rdt=52836
https://www.flickr.com/photos/piyush02/7159827681/in/photostream/
https://www.facebook.com/superzoomvideos/videos/ball-pen-under-the-microscope-unseen-world-in-super-zoom/264181902562958/
https://www.fountainpennetwork.com/forum/topic/227368-microscope-camera-for-nib-work/

Can we add/remove atoms with a ‘sharp’ needle?

How sharp a needle tip is?

Around 9 µm – too blunt for our purpose



http://murry-gans.blogspot.com/2013/05/how-sharp-is-new-hypodermic-needle.html

What about photoengraving?

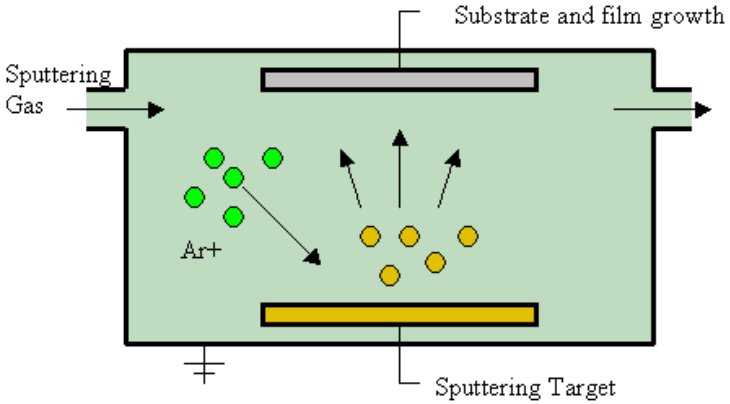
- Typical applications involve 200-300 dpi resolution
- For hi-res, let's say 1000 dpi, each dot would be 25 µm across
  - 1 inch/ 1000 = 25 mm/ 1000 = 25 µm
- But we can try using lens to obtain smaller laser spot size

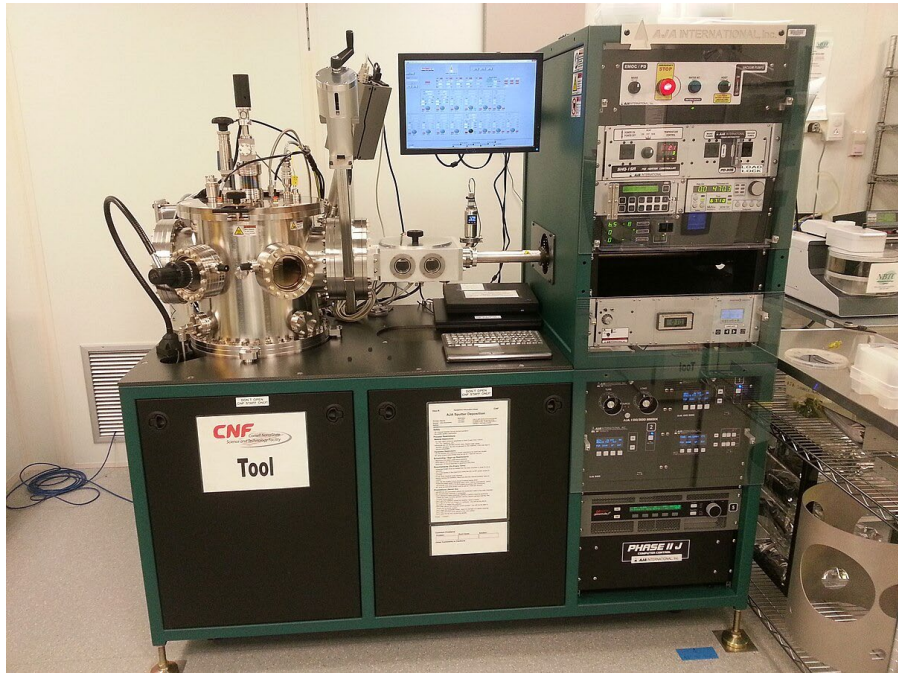
https://secure.mdg.com/ProductDetail.aspx?ItemID=19522&CategoryID=147&guide=0

Methods involving deposition of material

Raised letters

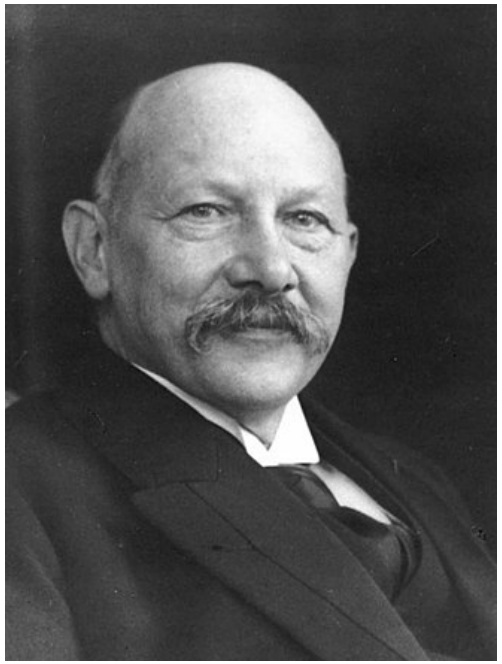
Sputtering



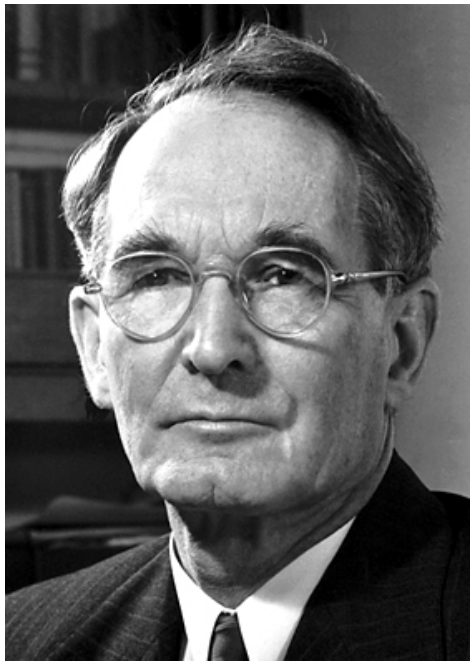


https://www.dreamstime.com/royalty-free-stock-images-brushed-metal-raised-alphabet-image11663599
https://en.wikipedia.org/wiki/Sputter_deposition
https://en.wikipedia.org/wiki/Sputtering

Feynman was pointing to a field, in which very little was done till then



Heike Kamerlingh Onnes was a Dutch physicist and Nobel laureate. He exploited the Hampson–Linde cycle to investigate how materials behave when cooled to nearly absolute zero and later to liquefy helium for the first time, in 1908. He also discovered superconductivity in 1911.



Percy Williams Bridgman (April 21, 1882 – August 20, 1961) was an American physicist who received the 1946 Nobel Prize in Physics for his work on the physics of high pressures.

Feynman could see the enormous technical applications that could be possible by having the ability to manipulate and control things on a small scale.

https://en.wikipedia.org/wiki/Heike_Kamerlingh_Onnes
https://en.wikipedia.org/wiki/Percy_Williams_Bridgman

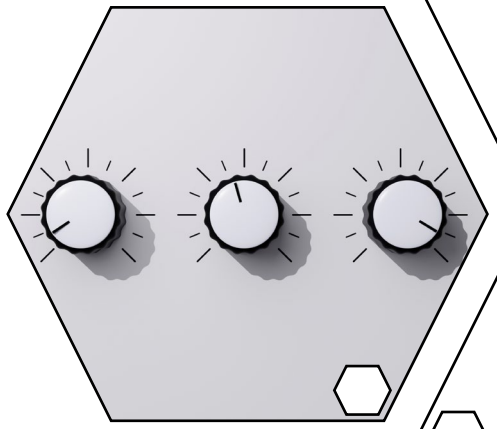
What nanotechnology is about?

Its about manipulating and controlling things on a **small** scale

The Basis for Making Small Things

Nanotechnology has become possible by accomplishing these at small scale

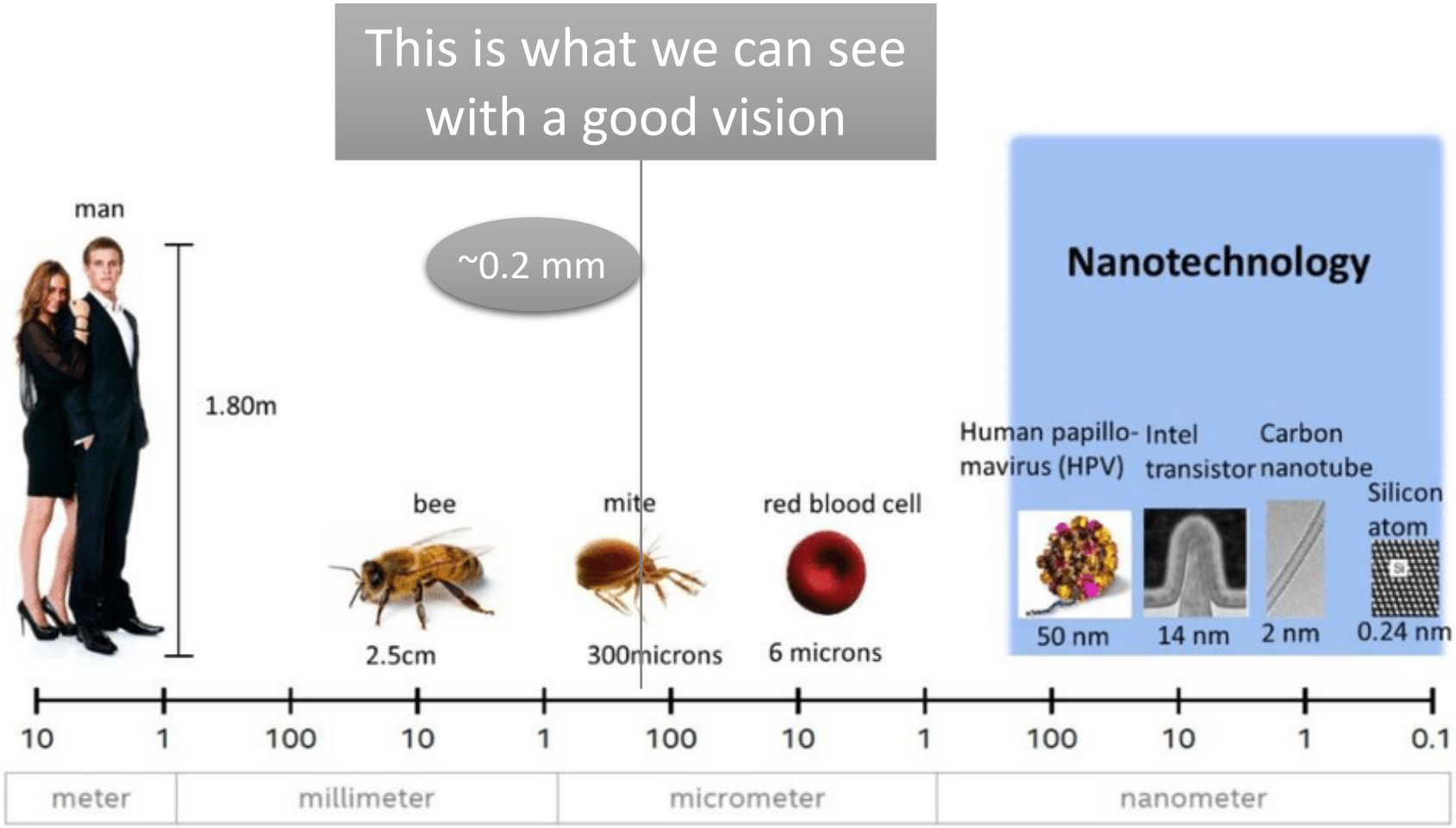
See



Manipulate

Control

How ‘small’ are we talking about?



https://www.researchgate.net/figure/Scale-of-dimensions-from-meter-down-to-nanometer-the-14nm-Intel-transistor-is-todays_fig1_301237832

Guess, what is it?

https://www.researchgate.net/figure/Microscope-photography-of-the-hair-magnification-100x-photographed-by-Olga-Negnevitsky_fig5_262478004

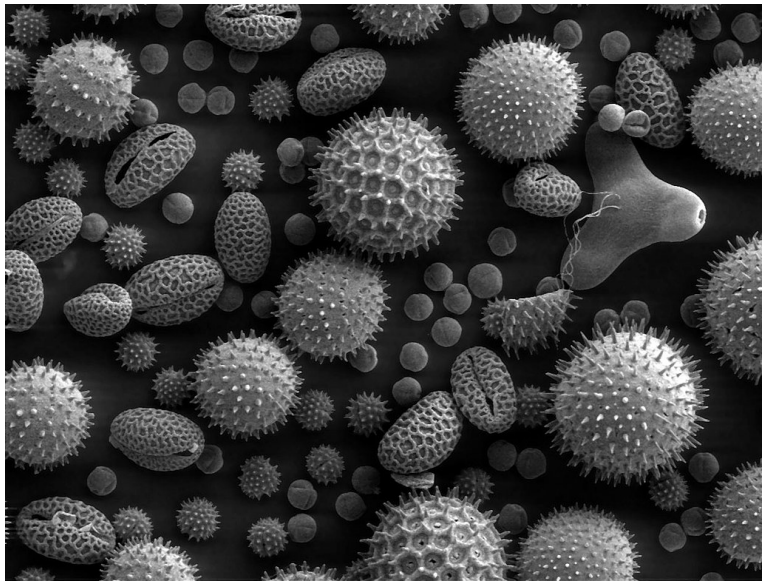
https://www.nisenet.org/catalog/scientific-image-sem-image-human-hair

Driving Factors

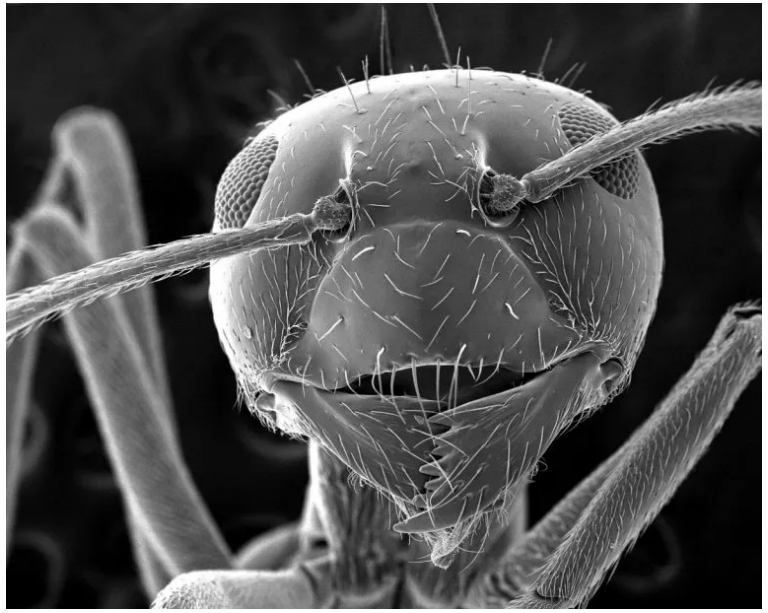
Technologies that enables seeing, manipulating and controlling

Scanning Electron Microscope

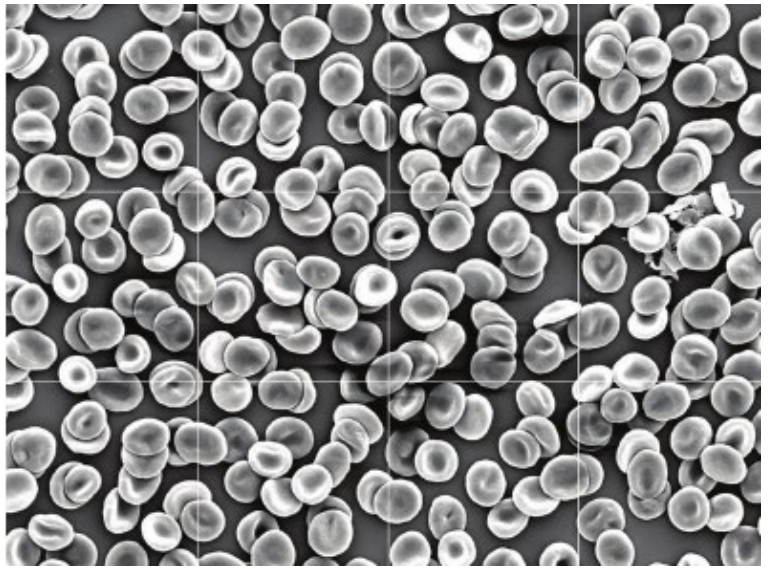
https://www.jeol.com/products/science/sem.php



Pollen grains



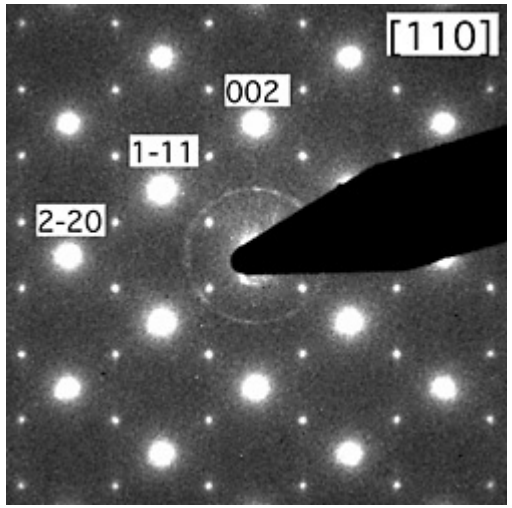
Face of an ant

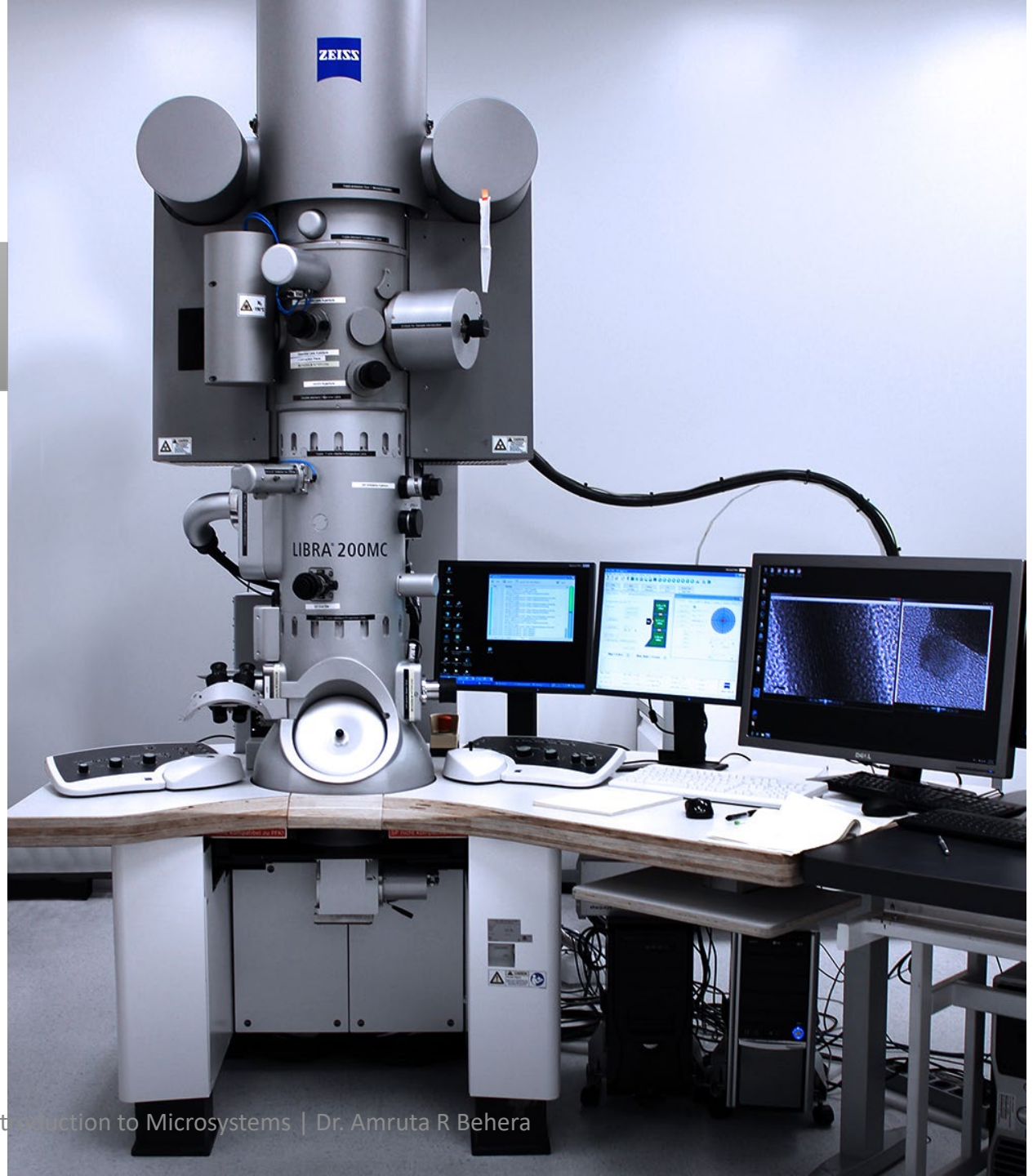


Red blood cells

https://en.wikipedia.org/wiki/Scanning_electron_microscope
https://www.secretsofuniverse.in/sem-and-images/
https://www.researchgate.net/figure/A-typical-SEM-image-of-red-blood-cells_fig1_258382204

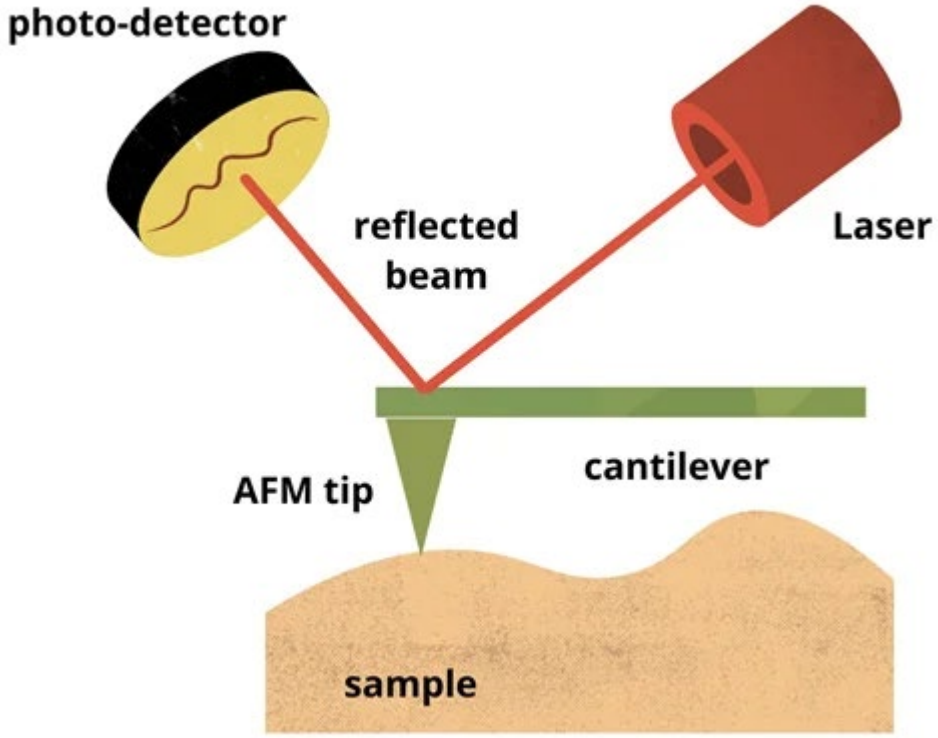
(Scanning) Tunneling Electron Microscope





https://uwaterloo.ca/metrology/tem-stem
https://www.nrel.gov/materials-science/transmission-microscopy.html

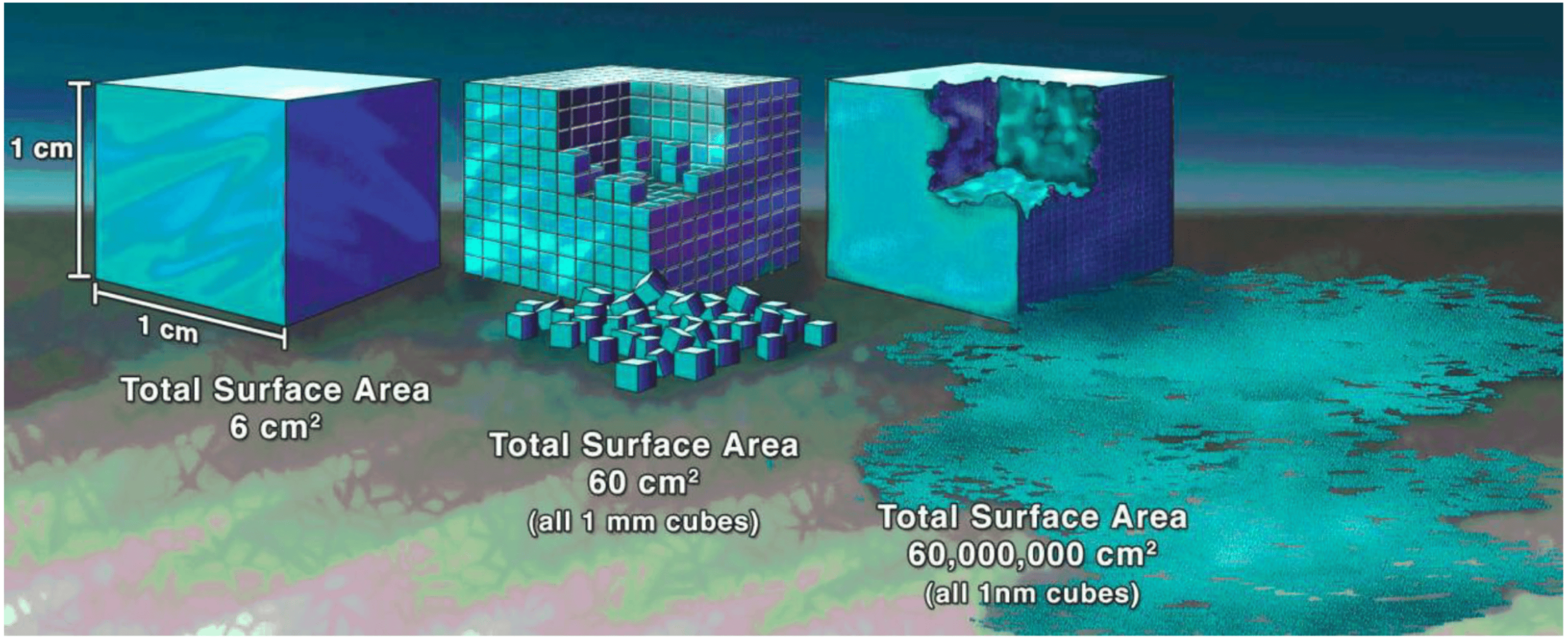
Atomic Force Microscope



https://www.azooptics.com/Article.aspx?ArticleID=2083
https://raman.oxinst.com/products/scanning-probe-microscopes/afm-alpha300a

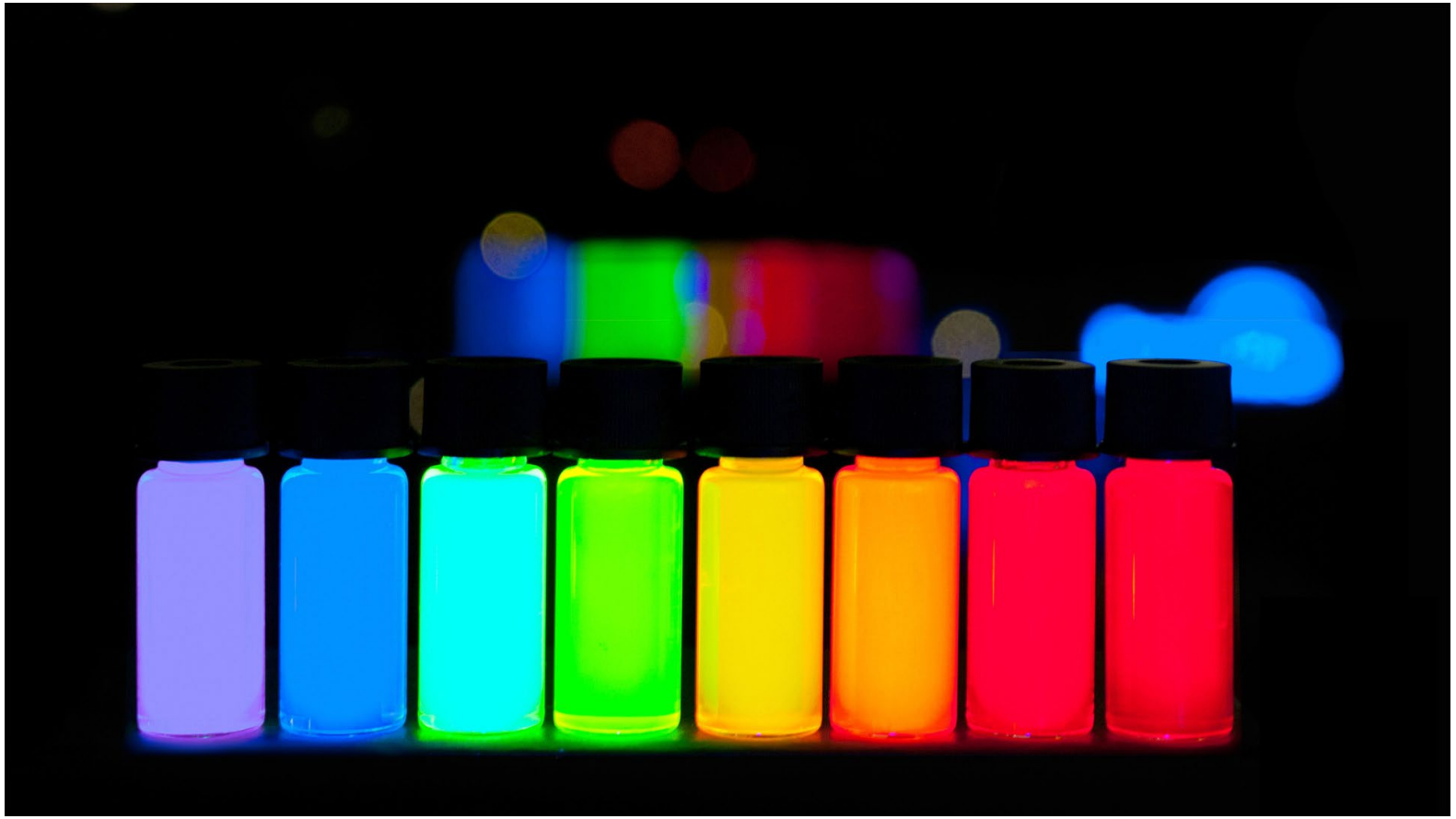
What Changes at Small Scale!

Surface Area at Small Scales



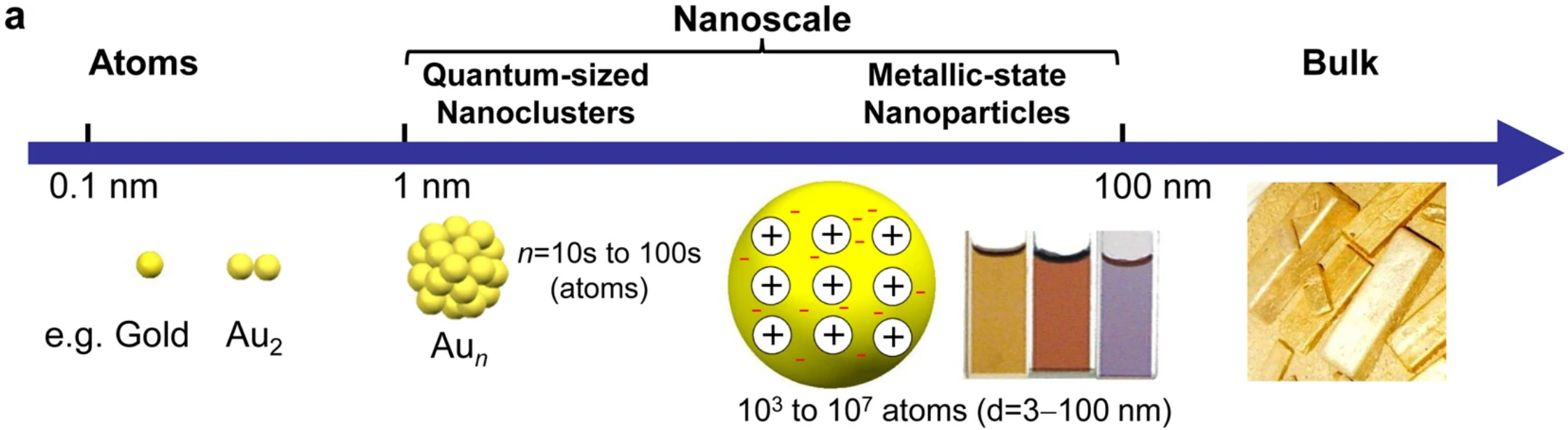
https://www.mdpi.com/2072-666X/13/9/1530

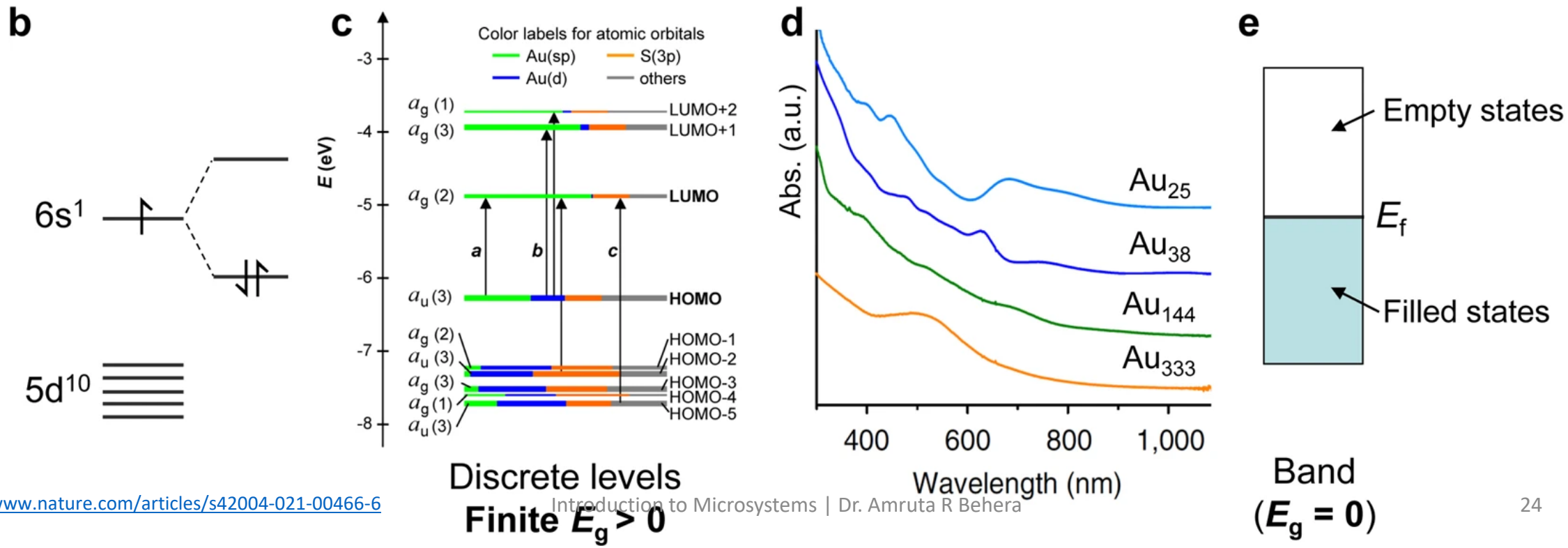
Same material behaves differently as the size of dispersed particle changes.



Increasing particle size

https://pcper.com/2014/07/quantum-dots-may-be-screening-on-your-mobile-by-2020/



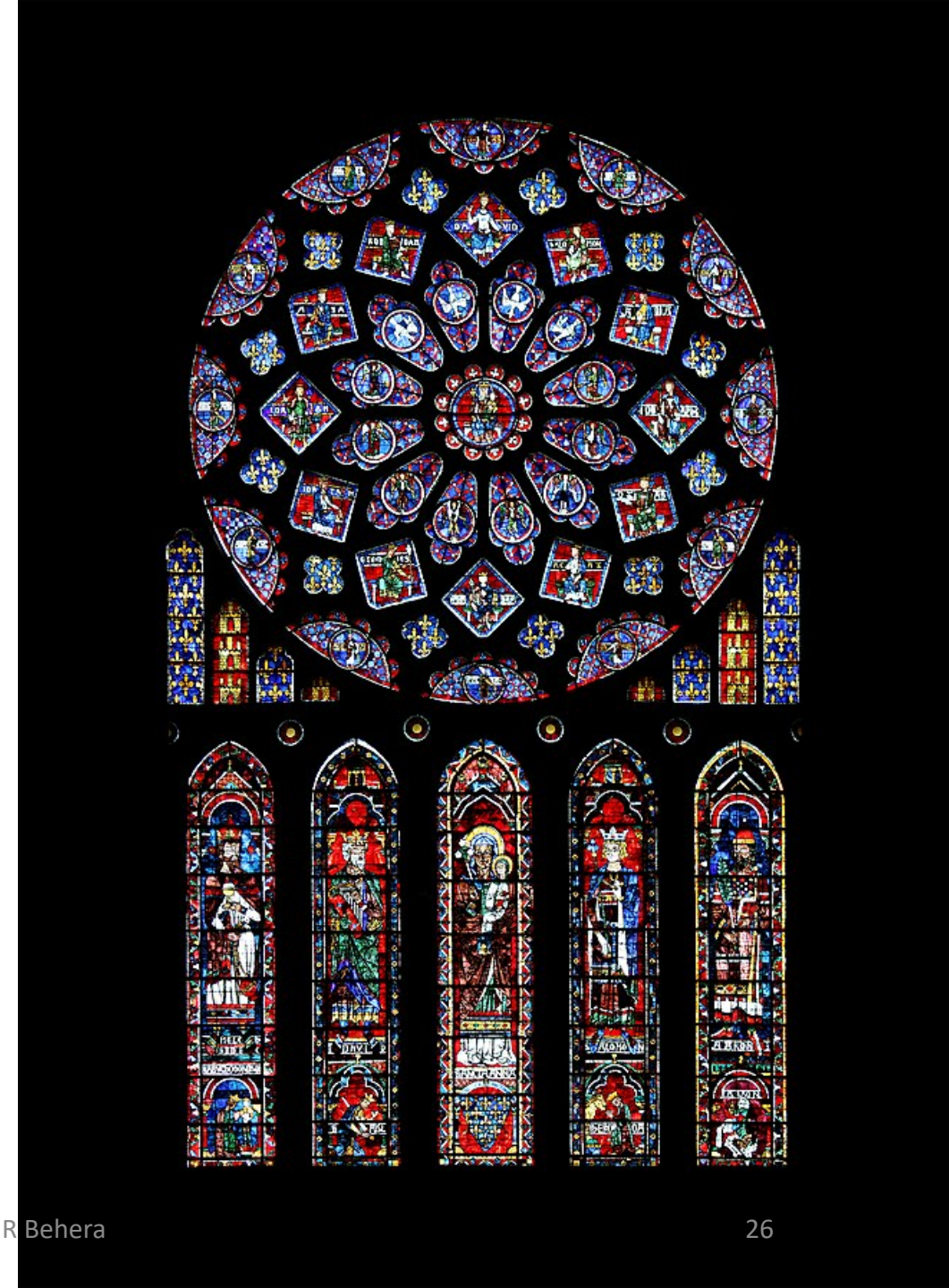


https://www.nature.com/articles/s42004-021-00466-6

Ancient use cases

Stained glass
5^{th}-15^{th} Century CE

Colours in stained glass windows in churches due to presence of nanoparticles of silver and gold. Size and shape of the particles impart colour.



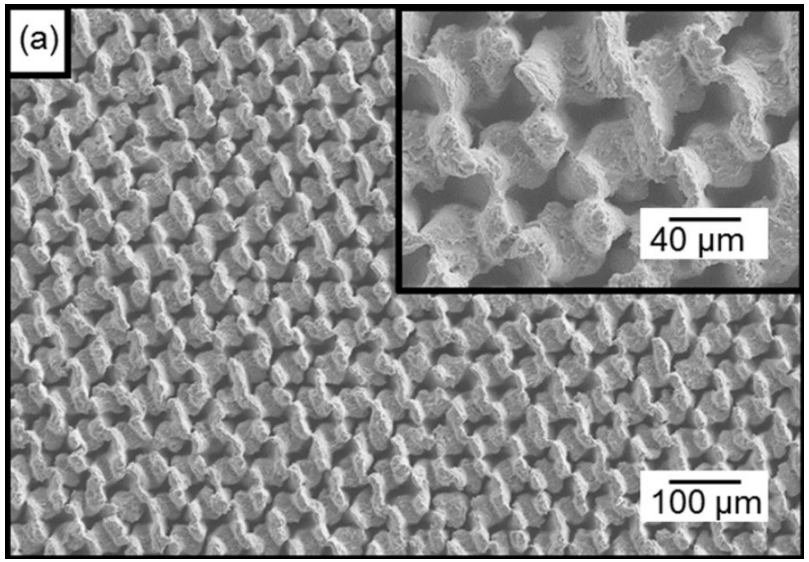
https://commons.wikimedia.org/w/index.php?curid=5945611

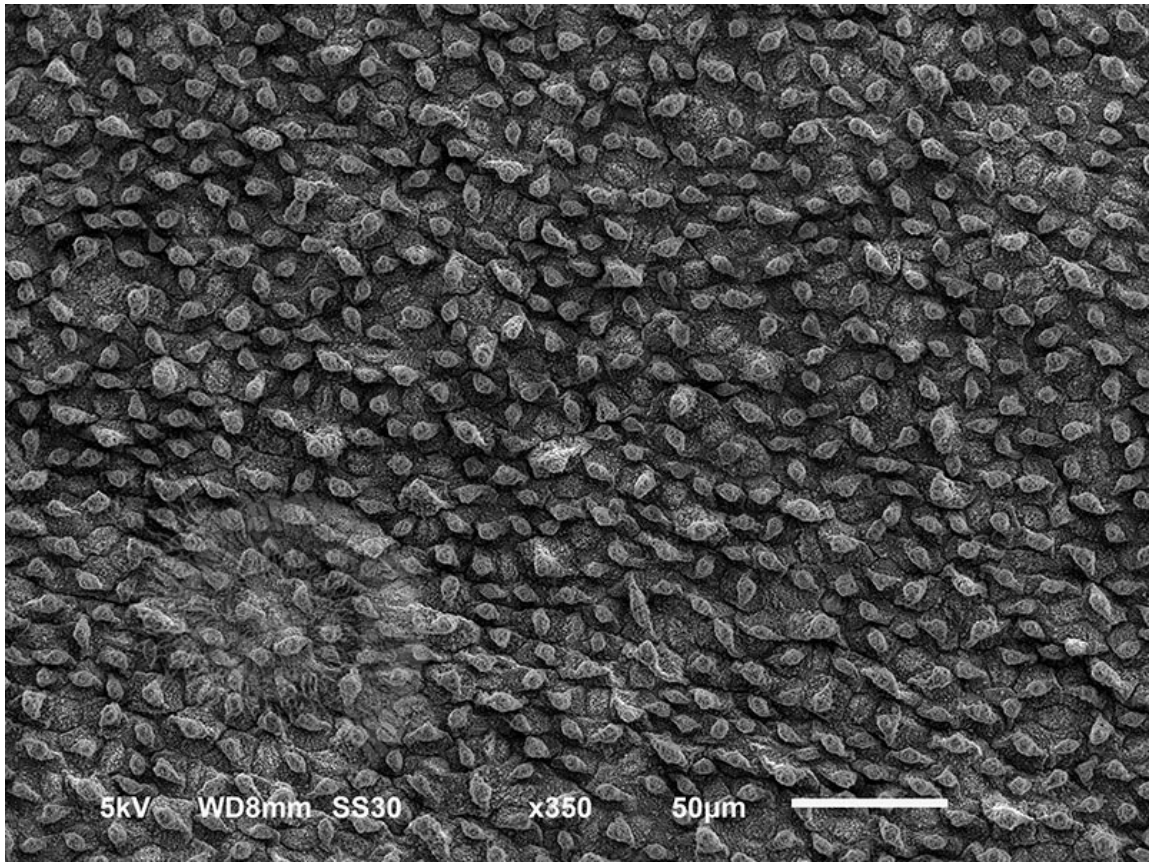
Different colors due to presence of 40 ppm of gold and 330 ppm of silver nanoparticles.

https://commons.wikimedia.org/wiki/File:Lycurgus_cup-_Dionysus.jpg
https://commons.wikimedia.org/wiki/File:Lycurgus_Cup-_Dionysus_in_red.jpg

Evidences from Nature

Water droplet on a lotus leaf





https://www.lichenlabs.net/product/lotus-leaf/
(a) https://www.nature.com/articles/s41598-019-49615-x

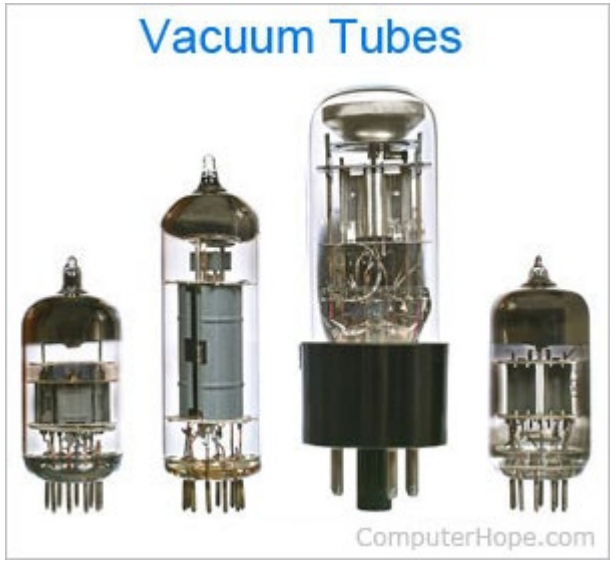
Stickiness of a gecko’s feet

https://www.livescience.com/47307-how-geckos-stick-and-unstick-feet.html
https://www.sciencephoto.com/media/479550/view/gecko-foot-hairs-sem
https://thekidshouldseethis.com/post/the-lizard-that-uses-nanotechnology-to-walk-upside-down

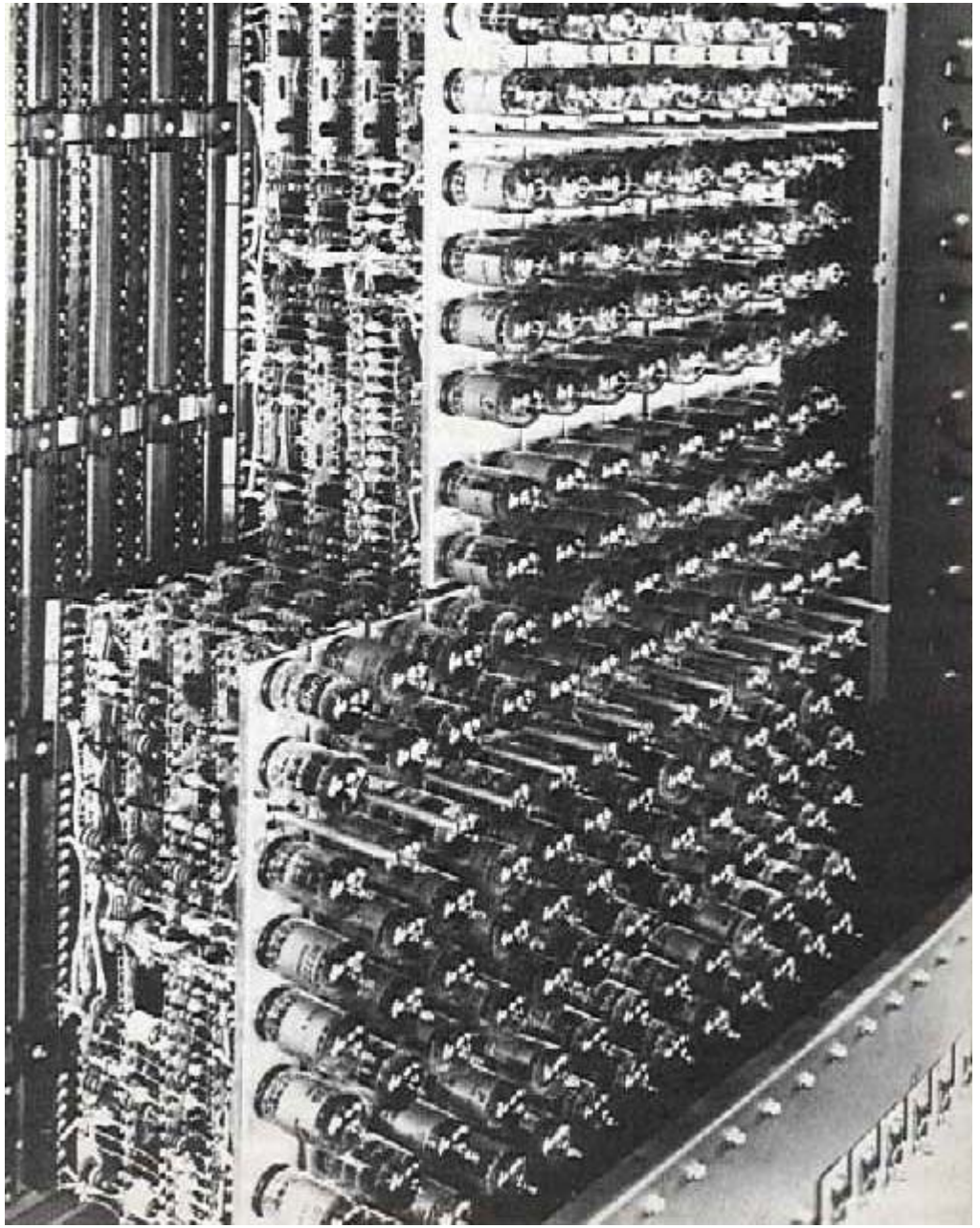
The Trend of Miniaturization in Computing

Moore’s law

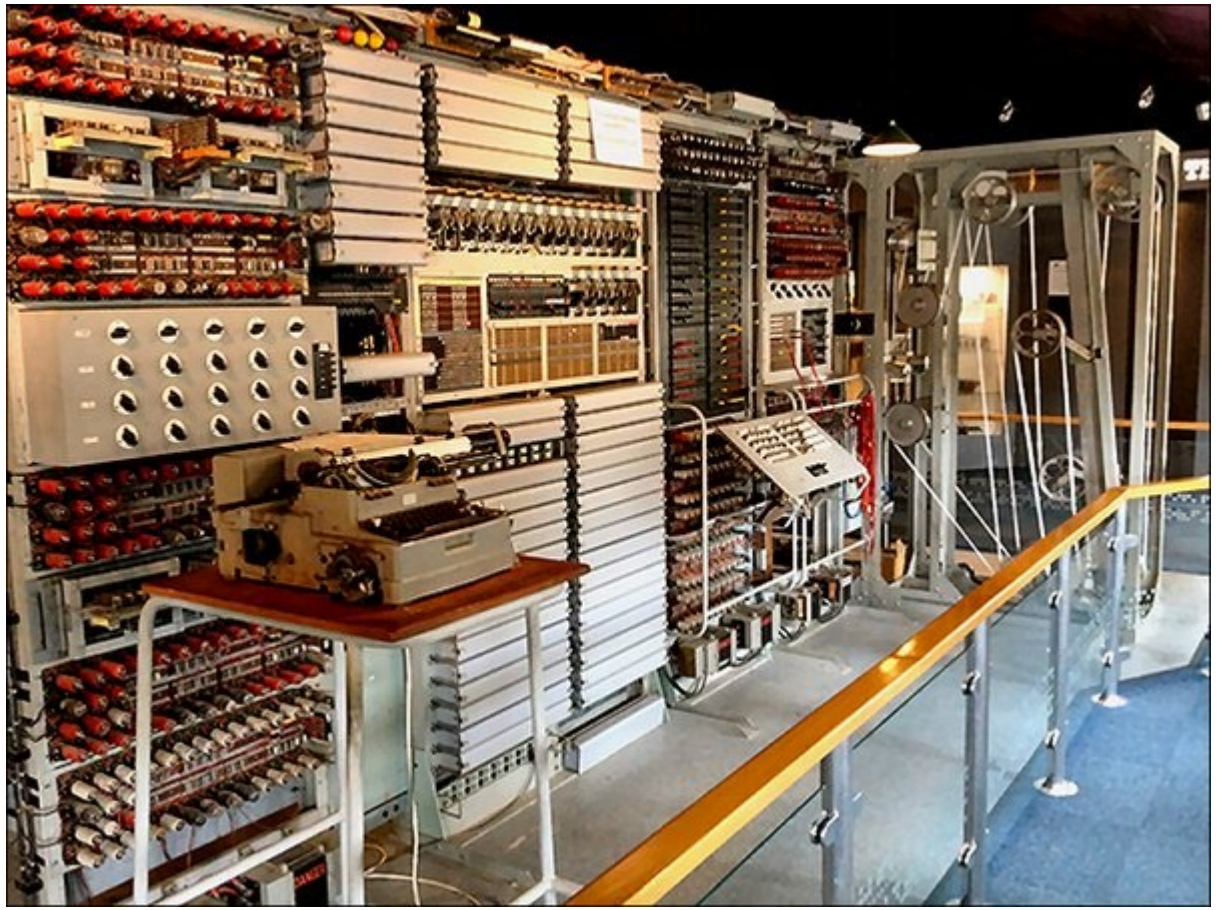
Vacuum tube-based memory

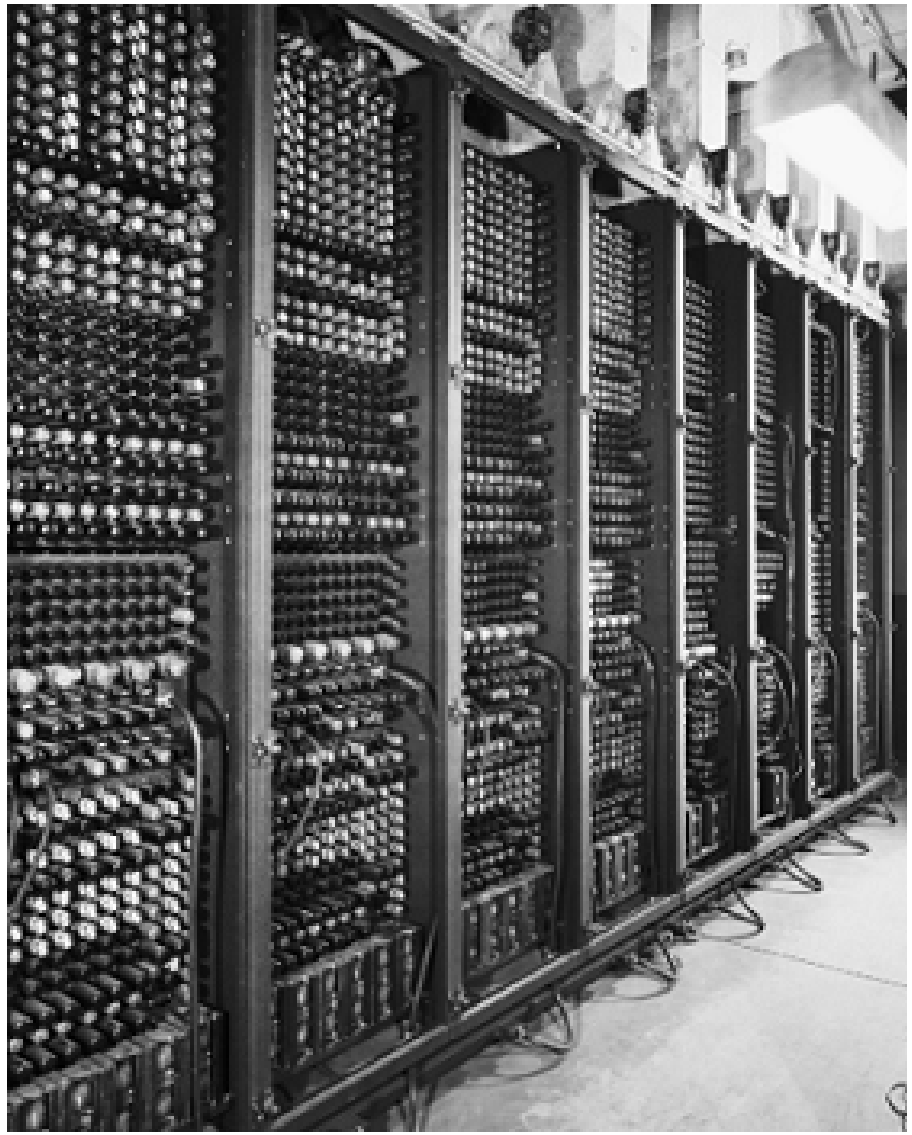


http://www.columbia.edu/cu/computinghistory/tubes.html



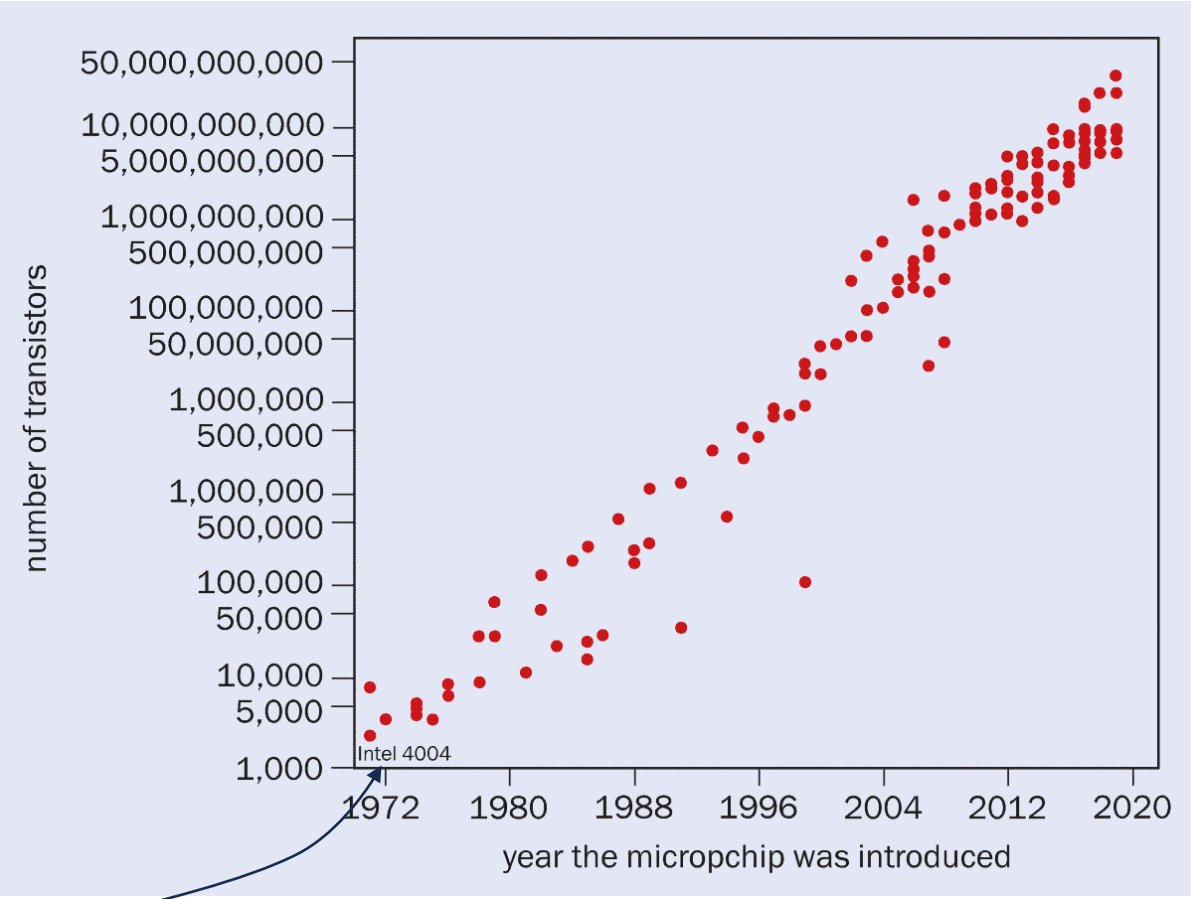
Vacuum tube-based computer





https://www.apogeeweb.net/article/1998.html
https://www.quora.com/How-were-vacuum-tubes-used-to-make-computers

1947|Invention of the Transistor



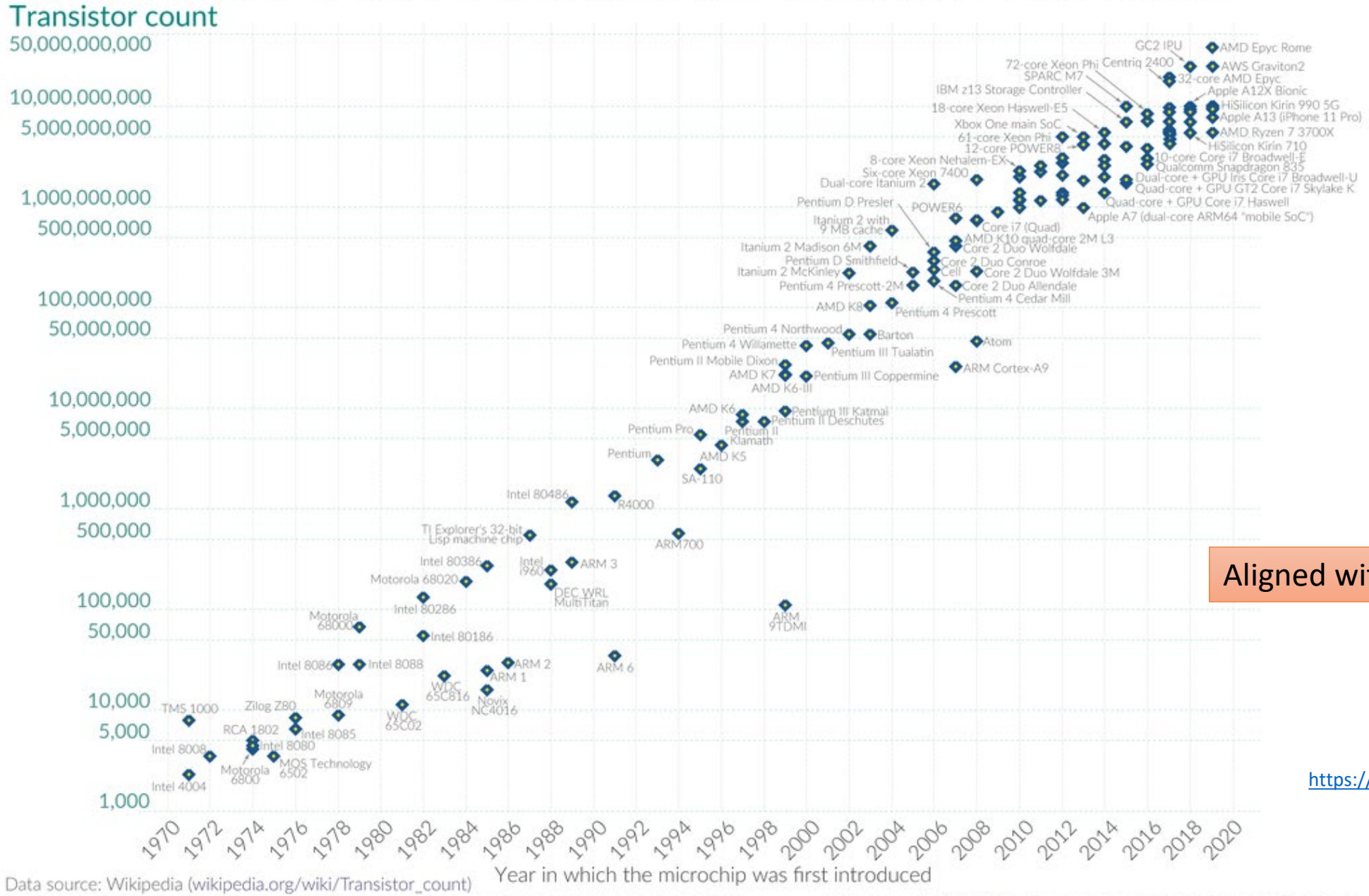
https://en.wikipedia.org/wiki/Intel_4004 | First commercially produced microprocessor

https://collection.sciencemuseumgroup.org.uk/objects/co8035899/replica-of-the-first-transistor-1947-2003-transistor
https://physicsworld.com/a/moores-law-further-progress-will-push-hard-on-the-boundaries-of-physics-and-economics/

Moore's Law: The number of transistors on microchips doubles every two years

Moore's law describes the empirical regularity that the number of transistors on integrated circuits doubles approximately every two years.
This advancement is important for other aspects of technological progress in computing – such as processing speed or the price of computers.

Our World in Data

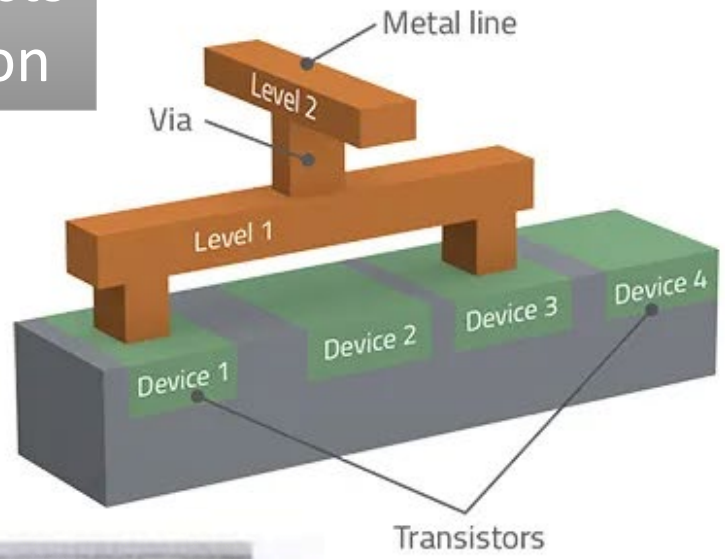


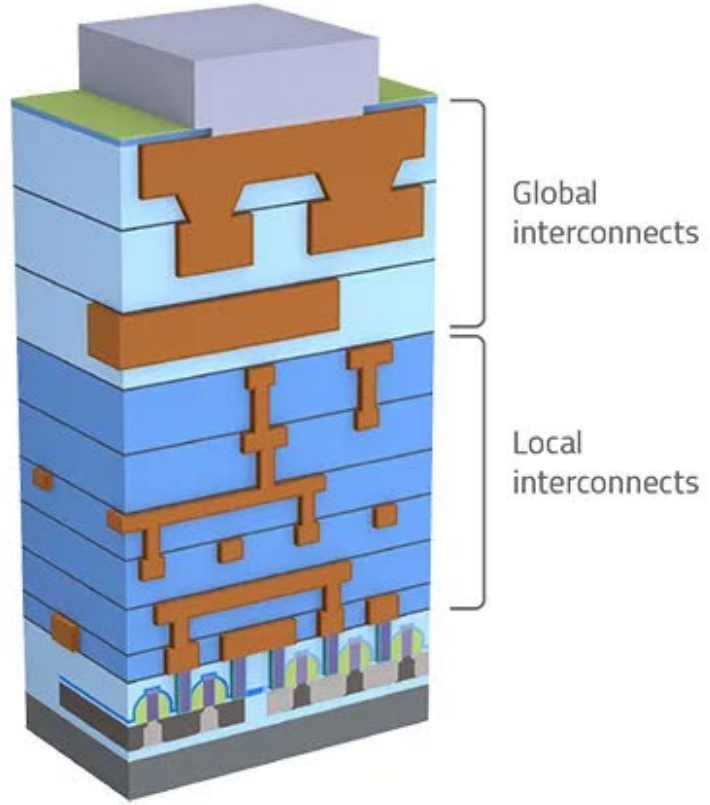
Aligned with Feynman's prediction

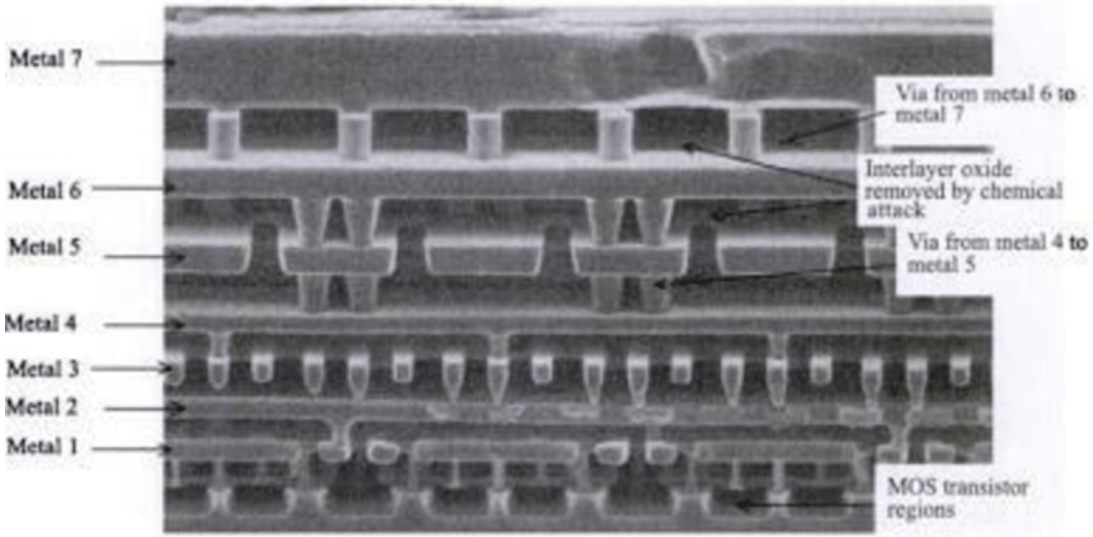
https://en.wikipedia.org/wiki/Moore%27s_law

Data source: Wikipedia (wikipedia.org/wiki/Transistor_count)
OurWorldinData.org – Research and data to make progress against the world's largest problems.

Atomically thin interconnects as per Feynman's prediction







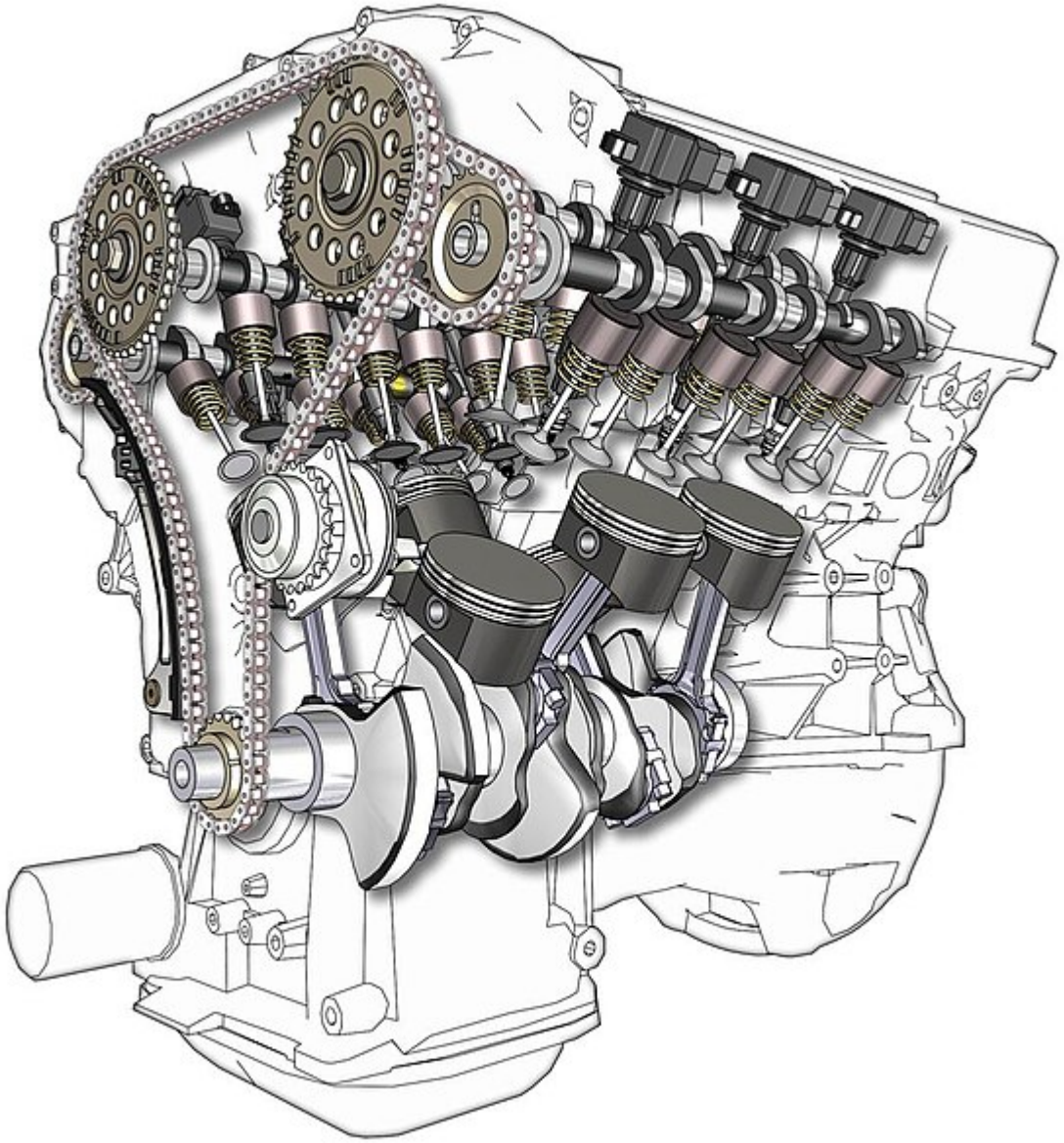
Cross-section of a 0.12 µm technology (*Courtesy:* Fujitsu)

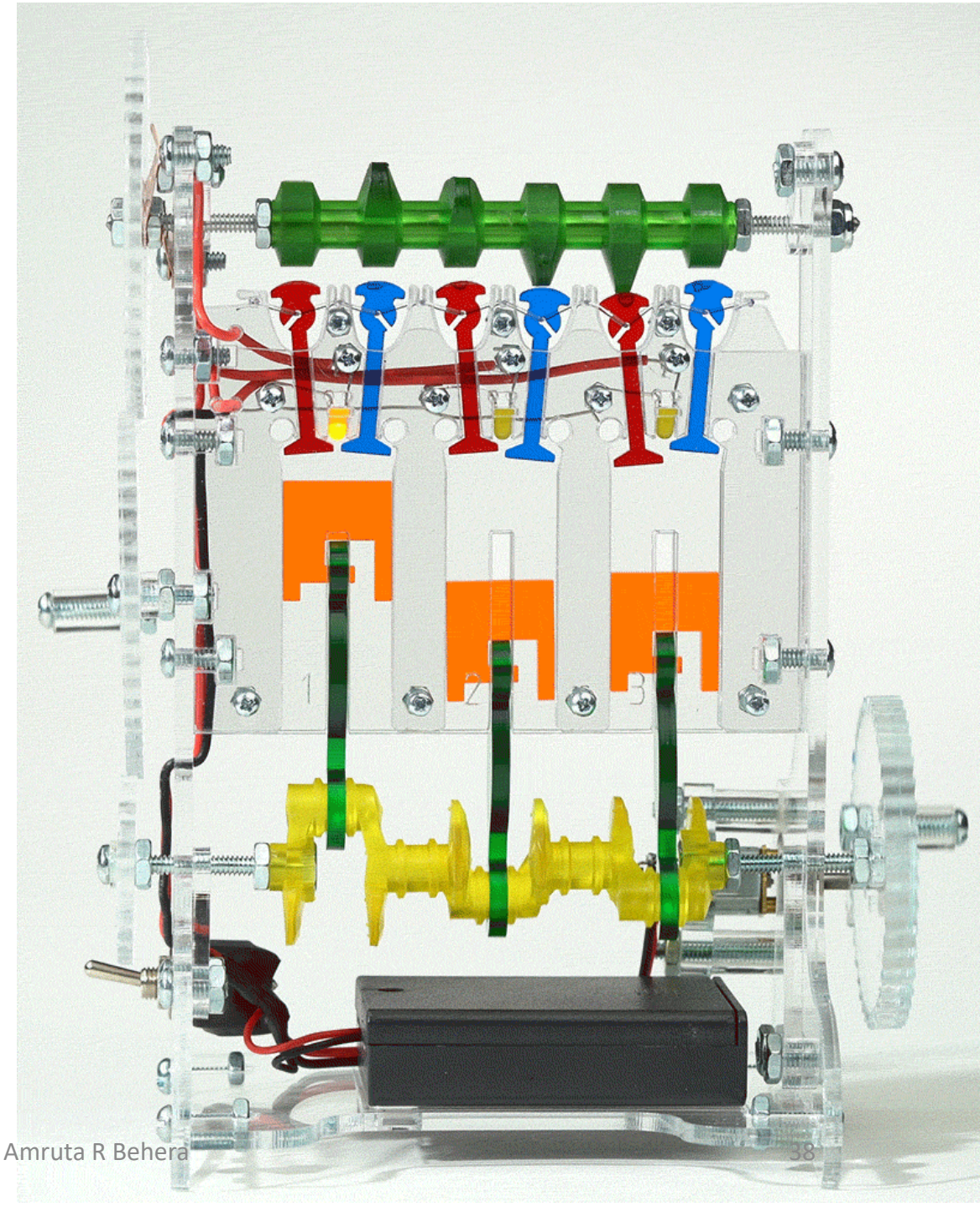
The fabrication technology was matured with the IC revolution

https://semiengineering.com/all-about-interconnects /
https://www.researchgate.net/figure/16-Cross-section-of-interconnect-metal-layers-75_fig8_348364314

Let’s do another thought experiment…

- How about making an **IC Engine** smaller?
- What will be its use for?
  - Transportation!
    - Of what and where?
    - May be drugs to specific organs
  - Drilling and cutting!
    - Of what?
    - Blockages in arteries
    - Tumor





https://en.m.wikipedia.org/wiki/File:IC_engine.JPG
https://mechanicalgifs.com/internal-combustion-engine-2

How do you go about thinking on scope for miniaturizing machines?

Thank You