What is the smallest thing a person can see?

Marya Lieberman, University of Notre Dame
Department of Chemistry and Biochemistry

What is the smallest thing a person can see?

Nanotechnology is all about the very smallest structures that nature and people can make. This talk will explore one area of nanotechnology, DNA origami, that uses DNA to build two- and three-dimensional objects.

What are different ways to see things? What is the smallest thing you can see? Is building something out of DNA like building something out of blocks or clay? Where do they get the DNA? Why do they want to build things that small?

Who did the work?

Who did the work?

Lesli Mark (not shown)

Genetic Science Learning Center, University of Utah, http://learn.genetics.utah.edu.

scale

- http://learn.genetics.utah.edu/content/begin/cells/scale/

Cell Size and Scale

http://learn.genetics.utah.edu/content/begin/cells/scale/

coffee bean

12 x 8 mm

grain of rice

Times regular, 12 point

Meter (m) Centimeter (cm) Millimeter (mm) Micrometer (μm) Nanometer (nm) Angstrom (Å) Picometer (pm)

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Cell Size and Scale

http://learn.genetics.utah.edu/content/begin/cells/scale/

UC10 - Unco...tation 2010 Faculty App...ts Summary ChemLibrary FastLane NIST Chemistry WebBook UW-Madison MRSEC Undergradua... Questions

Meter (m) Centimeter (cm) Millimeter (mm) Micrometer (μm) Nanometer (nm) Angstrom (Å) Picometer (pm)

PaulaOlenkaAnastazia.jpg

Cell Size and Scale

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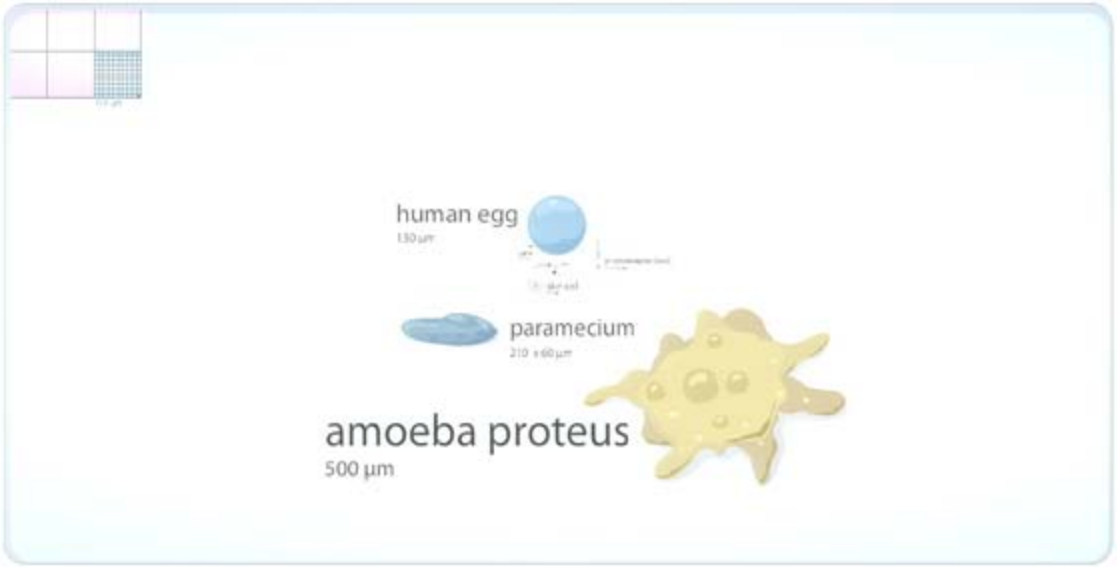
Cell Size and Scale

http://learn.genetics.utah.edu/content/begin/cells/scale/



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Cell Size and Scale

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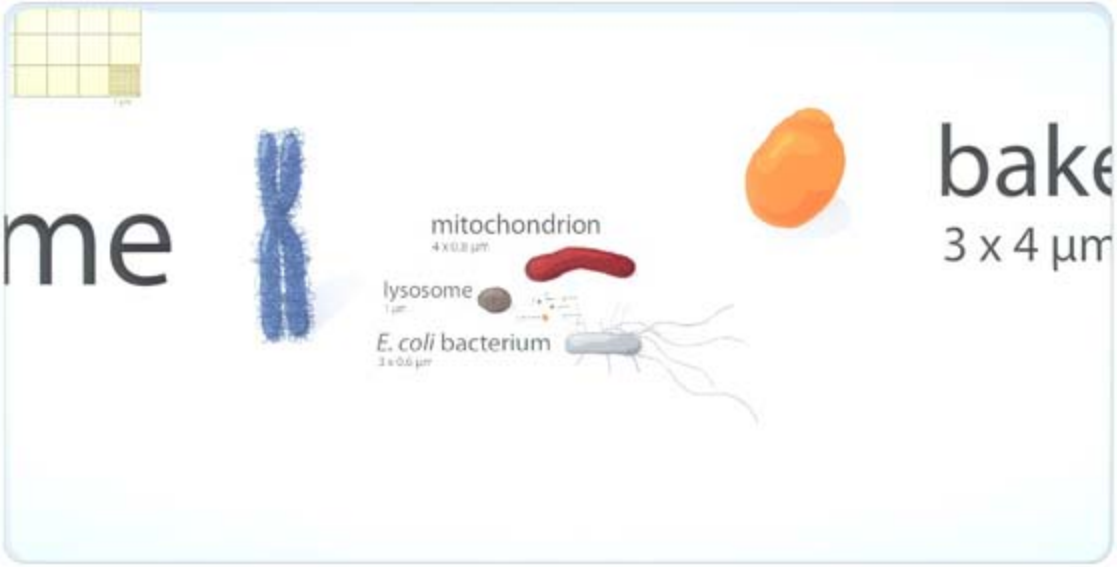

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Cell Size and Scale

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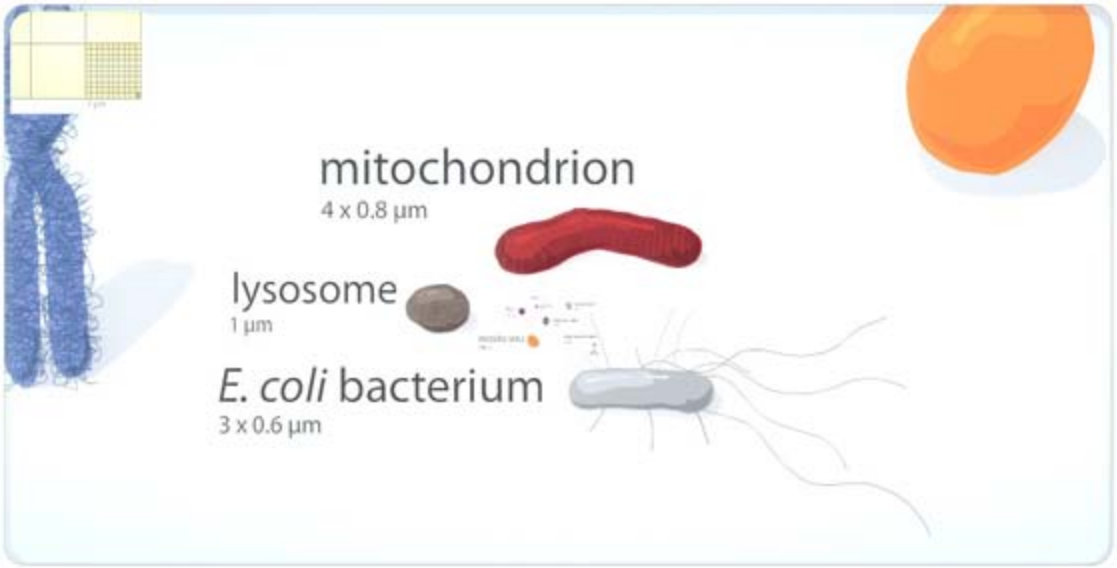

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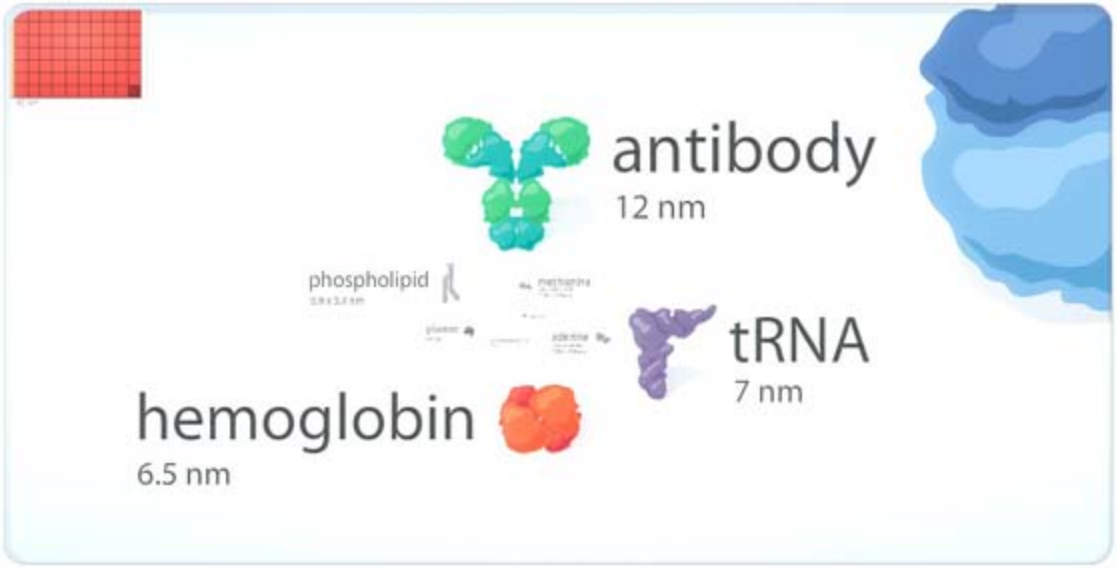

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Cell Size and Scale

http://learn.genetics.utah.edu/content/begin/cells/scale/

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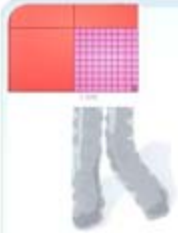


methionine
(an amino acid)
1100 x 700 pm

carbon atom

glucose

00 pm

water molecule
275 pm

adenine
(a nucleotide)
1300 x 760 pm

© 2008 Genetic Science Learning Center, University of Utah

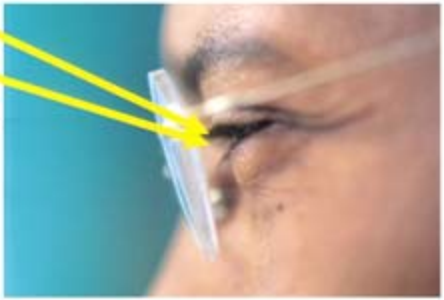
Meter (m) Centimeter (cm) Millimeter (mm) Micrometer (μm) Nanometer (nm) Angstrom (Å) Picometer (pm)

PaulaOlenkaAnastazi
a.jpg

How we see

source

target

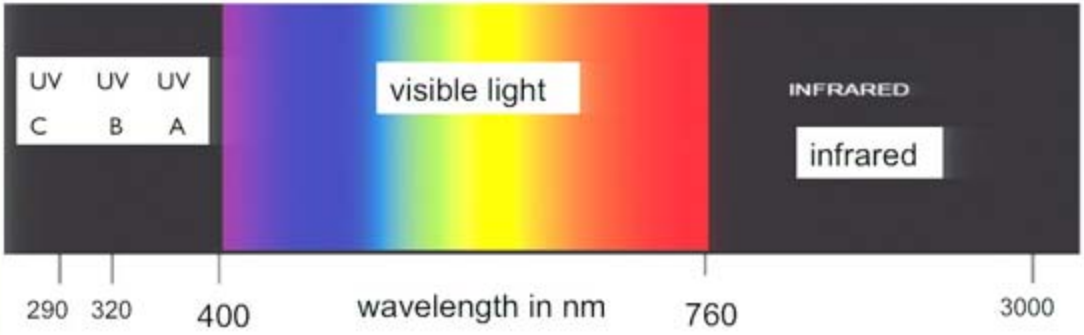


detector

…and often you'll need a lens

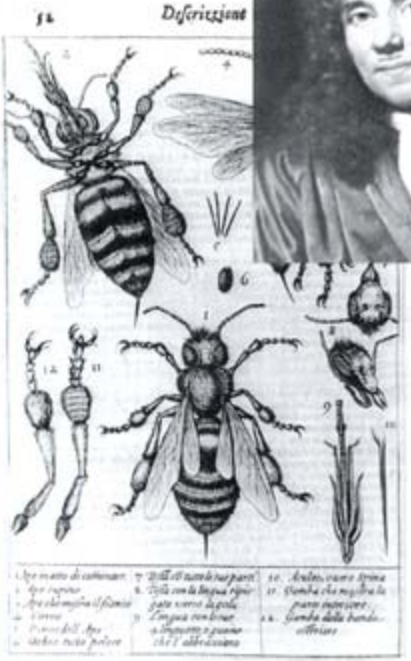
The visible spectrum

- The light that reaches the eye must have a color between red (760nm) and blue (400nm) – or a mixture of these colors



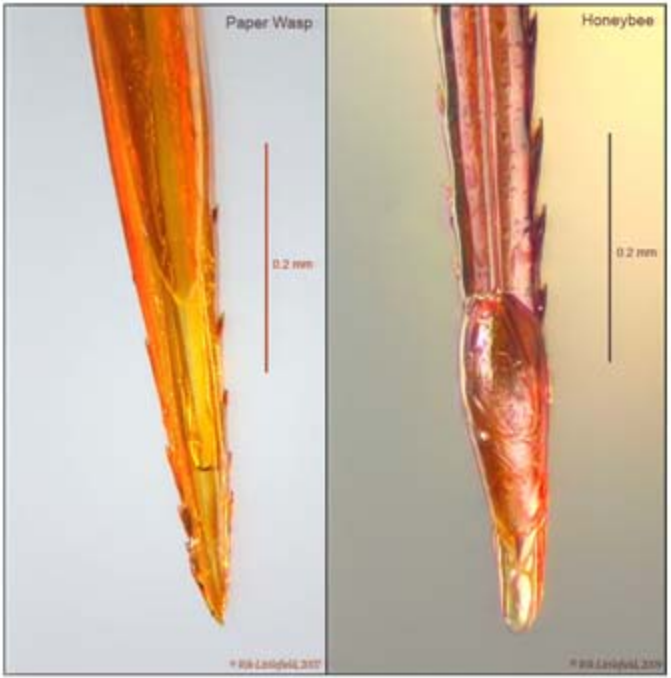
Early microscope

Leeuwenhoek

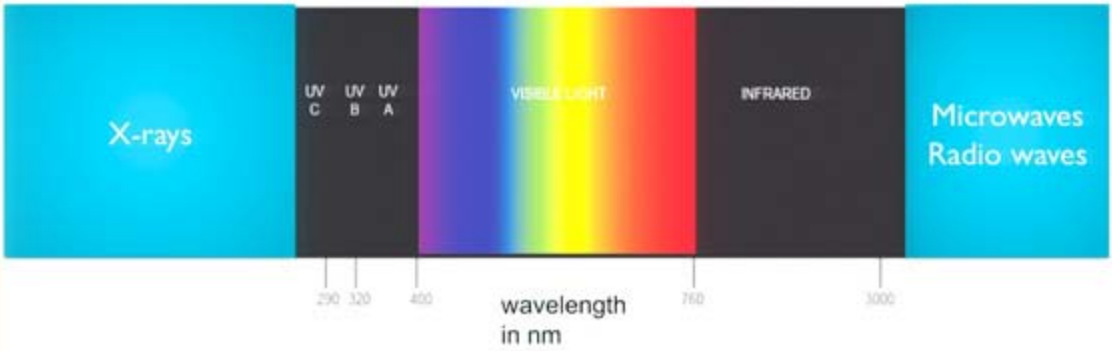


in Joseph G. Gall (1996). A Pictorial History - Views of the Cell, published by The American Society for Cell Biology

Seeing with light

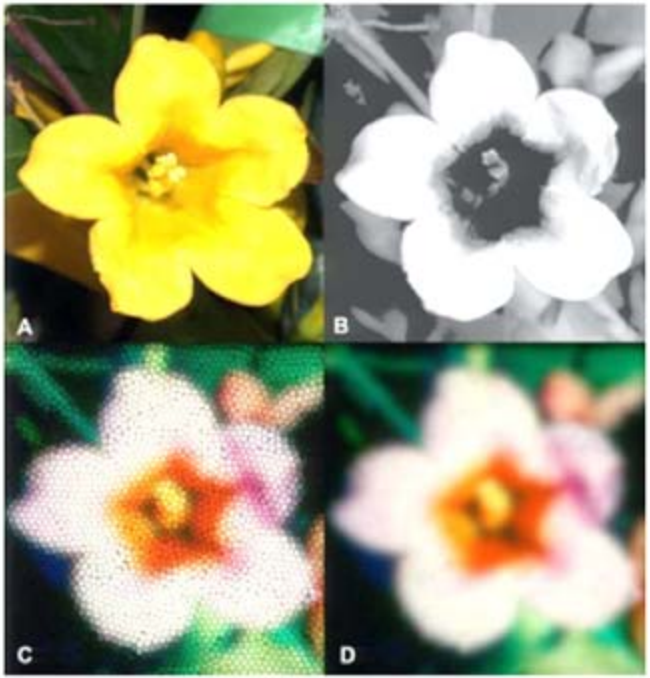


The invisible spectrum



What a bee sees

We see:



UV camera sees:

Bee's lenses see

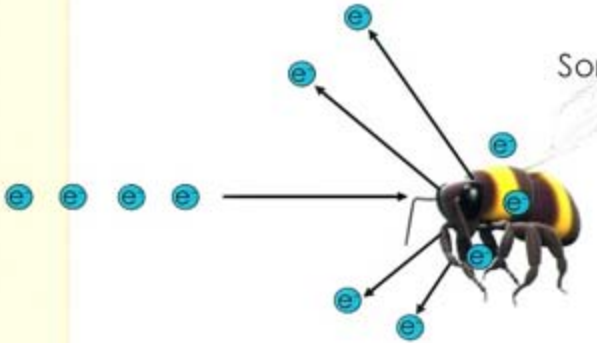
Image smoothed to remove facets

http://www.monash.edu.au/news/monashmemo/assets/images/20070523/what-a-bee-sees.jpg

Electron vision

Our eyes and traditional microscopes detect light that has bounced off an object

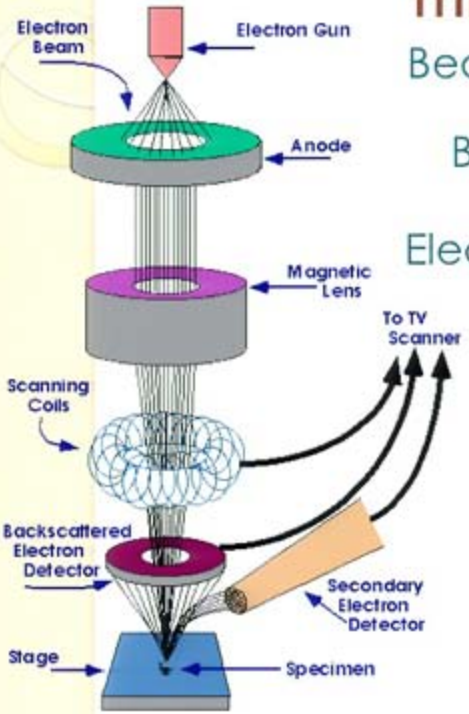
Let's bounce something else off the object…how about electrons?



Some are "reflected"

Some are absorbed

How a scanning electron microscope works



Beam created from heated filament

Beam travels through a vacuum

Electro-magnetic fields act as lenses

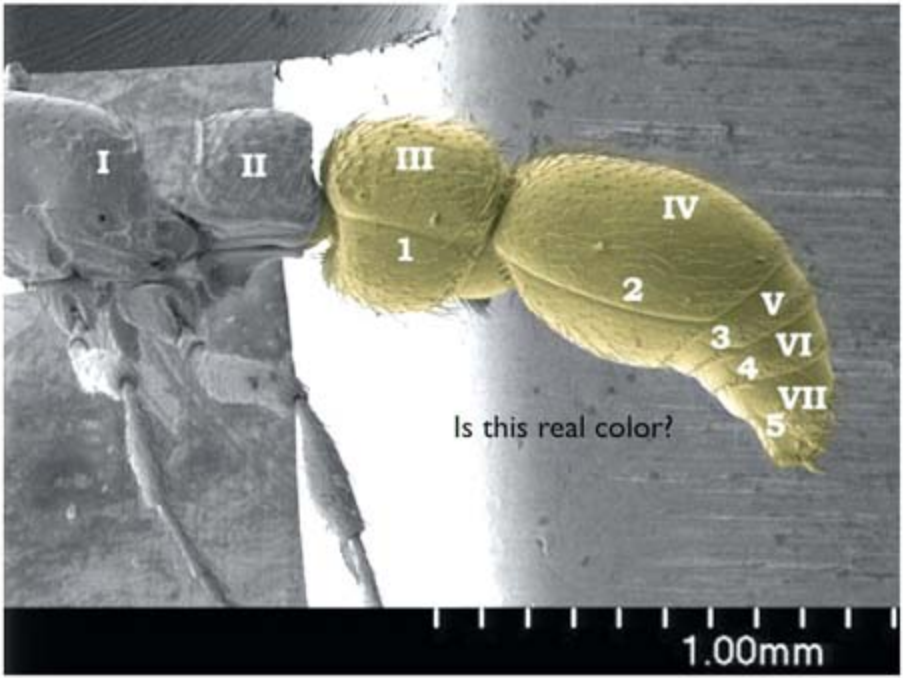
Electron beam hits the sample in a precise location

Scattered and "secondary" electrons are detected

Beam scans back and forth to make up an image of the whole object

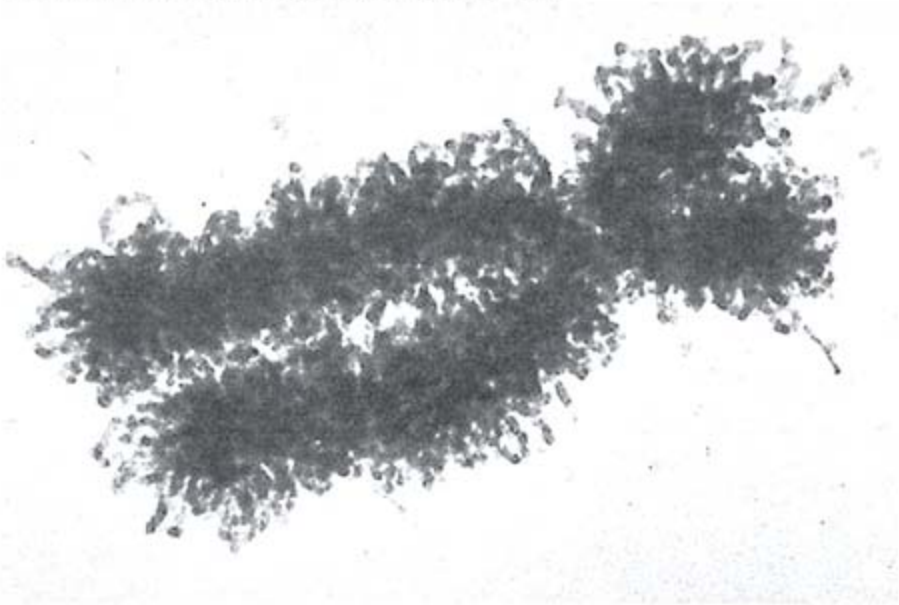
http://bioweb.usu.edu/emlab/TEM-SEM%20Teaching/How%20SEM%20works.html

Seeing with electrons



Seeing with electrons

- Human chromosome 12



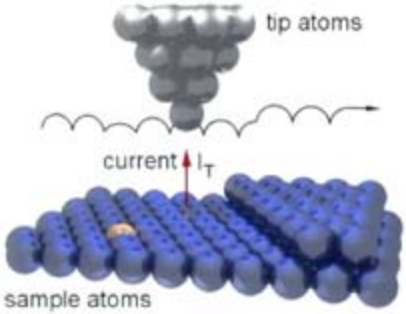
University of Waikato http://cnx.org/content/m15083/latest/

Scanning tunneling microscopy

- Electrons tunnel!

- With a higher probability than cars

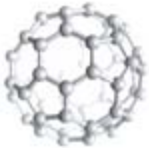
- STM measures the current created by tunneling electrons

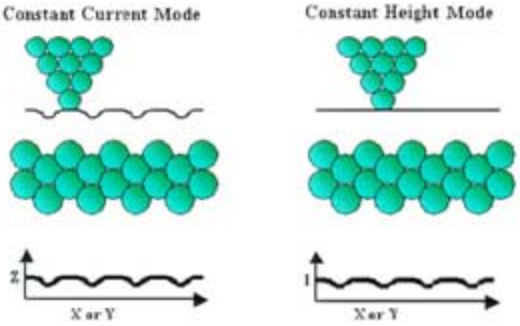


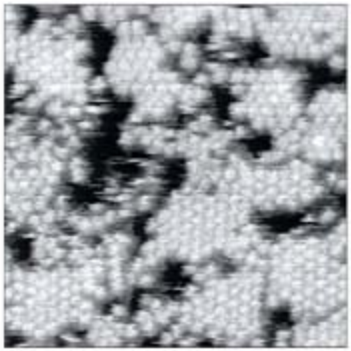
Images courtesy of http://www.ieap.uni-kiel.de and www.renault.com

STM imaging

C60 "Bucky Balls"





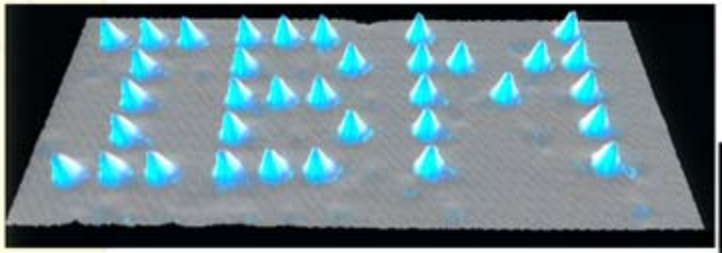


Each C60 diameter is ~ 10Å
1 Å = 1x 10^{-10} m

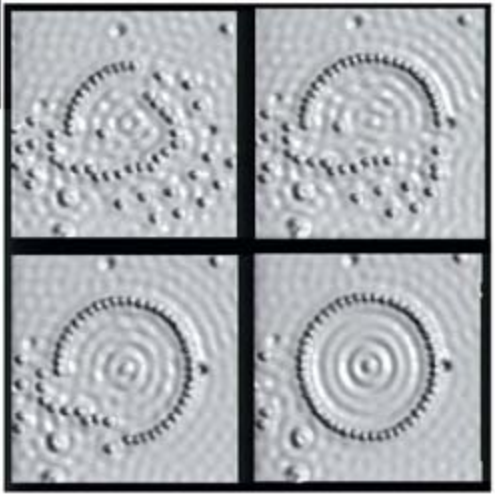
http://nano.tm.agilent.com

STM image by Rebecca Quardokus

The smallest thing a person can see…single atoms



Xenon on Nickel



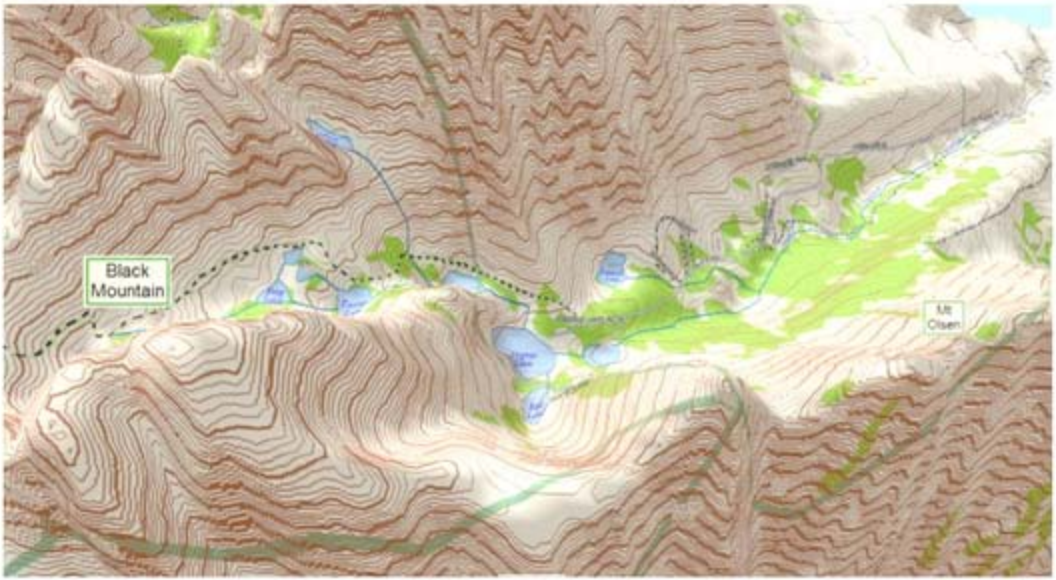
Iron on Copper

Images courtesy of
http://www.almaden.ibm.com

There are other ways to see…

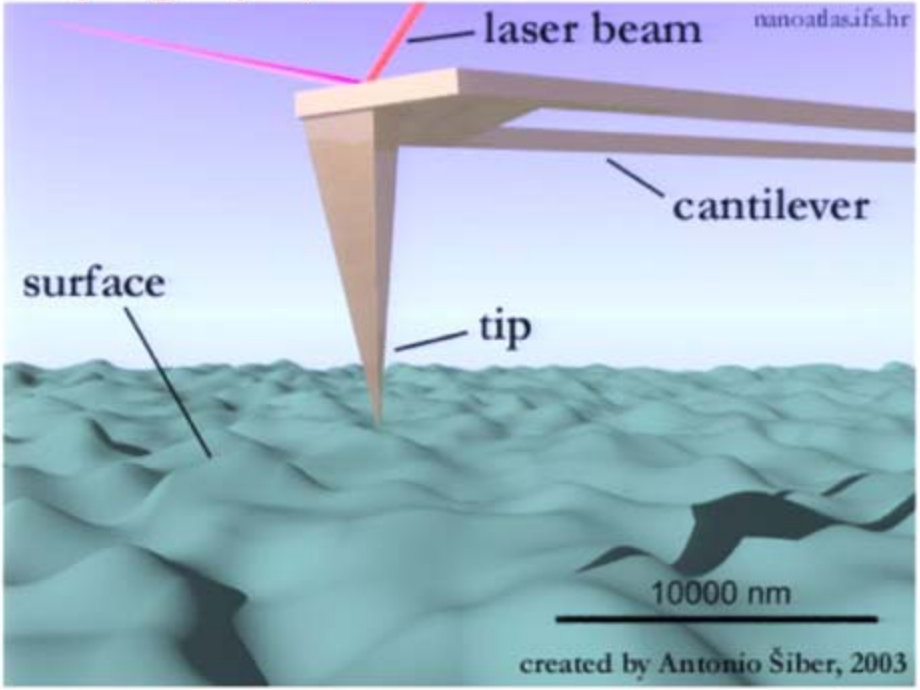
http://www.accesslinx.com/Braille.jpg

Topography is important!



http://www.virginialakesresort.com/images/vlrtopo6.jpg

Atomic force microscopy "sees" topography

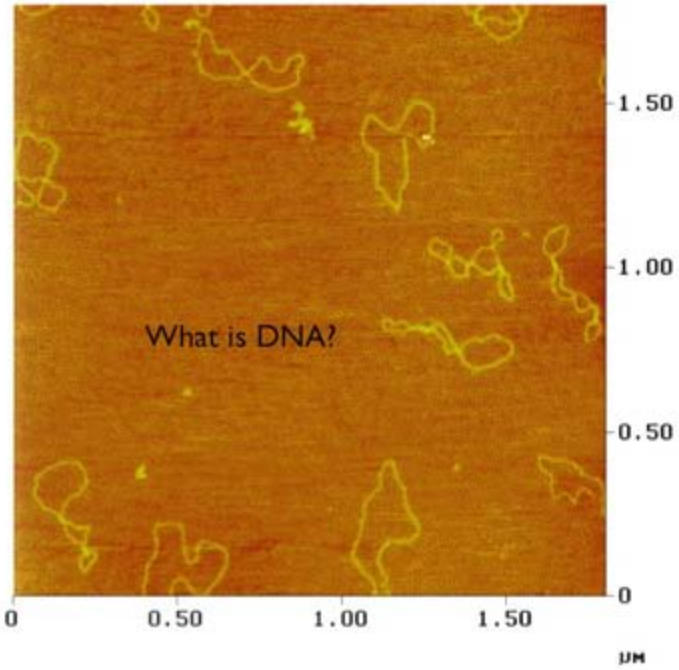


AFM cantilever and tip

www.veeco.com

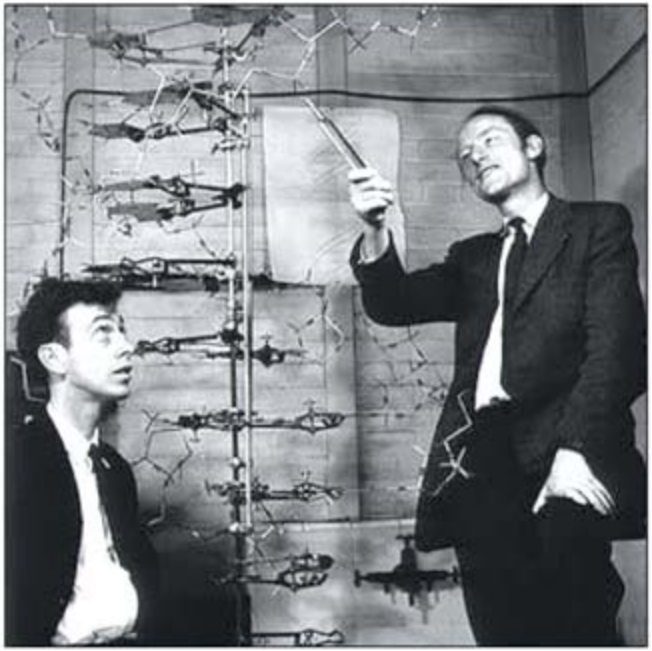
AFM image of a bacterial "chromosome" (plasmid DNA)

- Image taken by Mr. Rick Horvath, 2008
- Reilly High School biology teacher



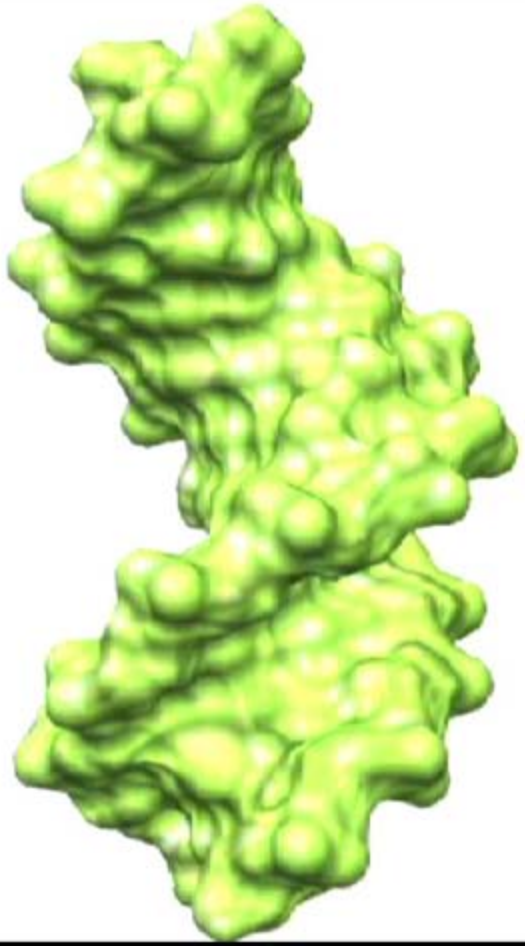
DNA = deoxyribonucleic acid

- DNA structure movie

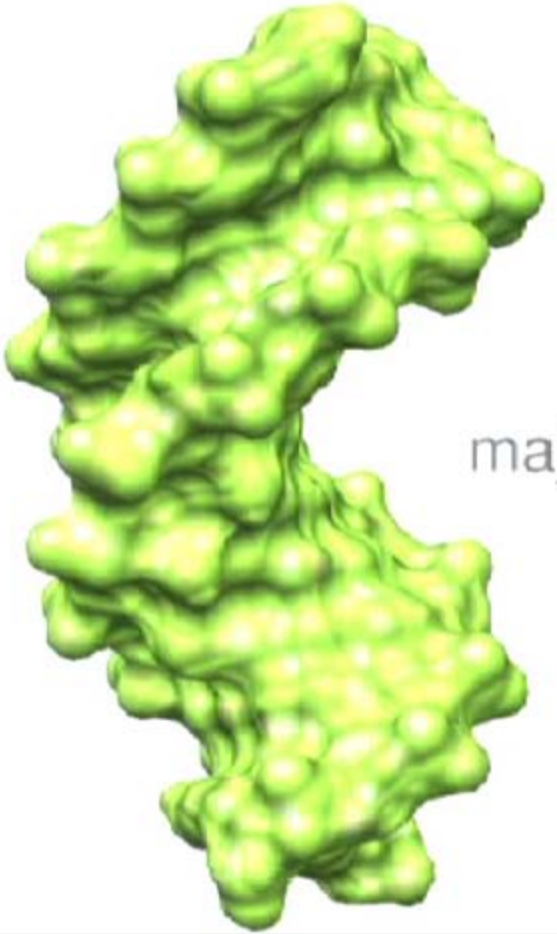


1953: Watson and Crick with early model of DNA structure

DNA



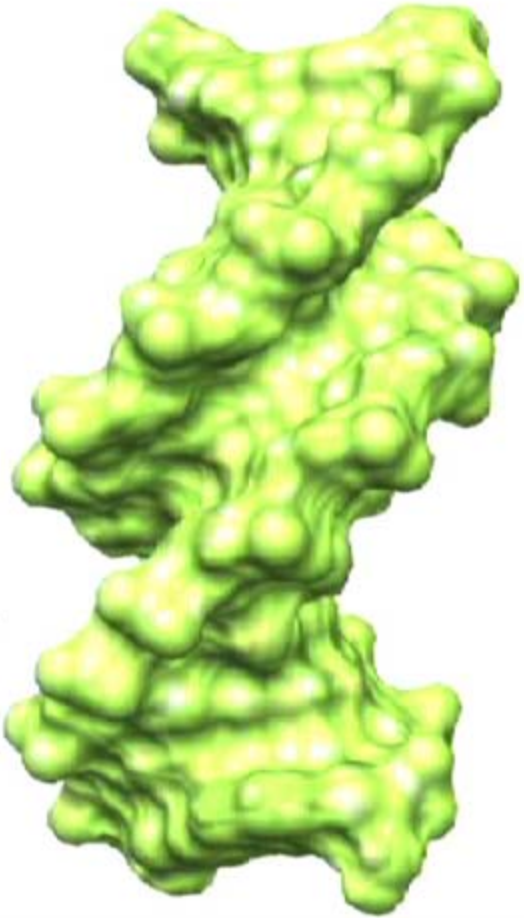
DNA



major groove

DNA

minor groove



DNA

simplified
representation

backbone as ribbon

DNA

sequence
color-coded

C G
G C
C G
A T
A T
T A
T A
G C
C G
G C

DNA

sequence
color-coded

C G
G C
C G
A T
A A
A A
T A
T A
T A
G A
C C
G G

DNA

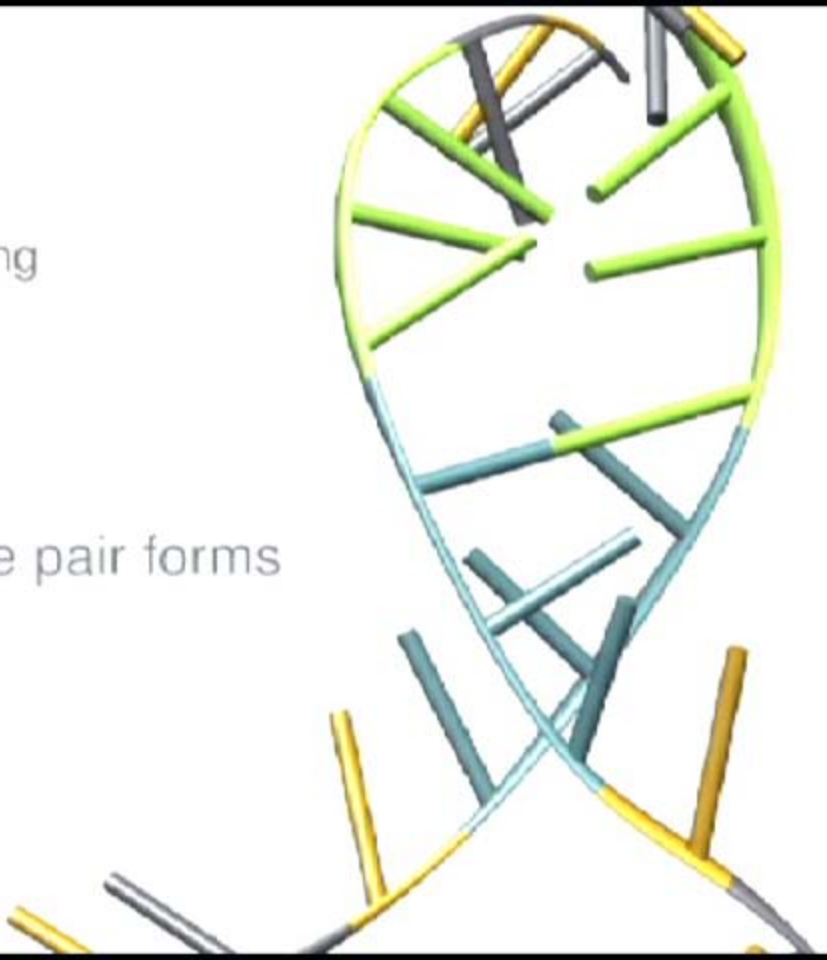
sequence
color-coded

C
G
C
A
A
A
T
T
T
G
C
G

DNA

base pairing

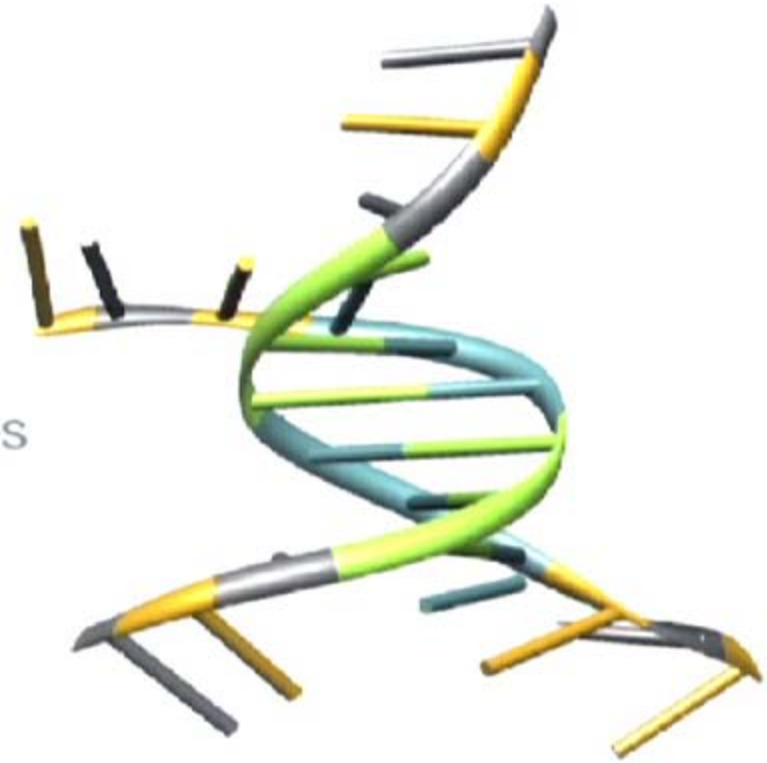
first base pair forms



DNA

base pairing

pairing continues



DNA

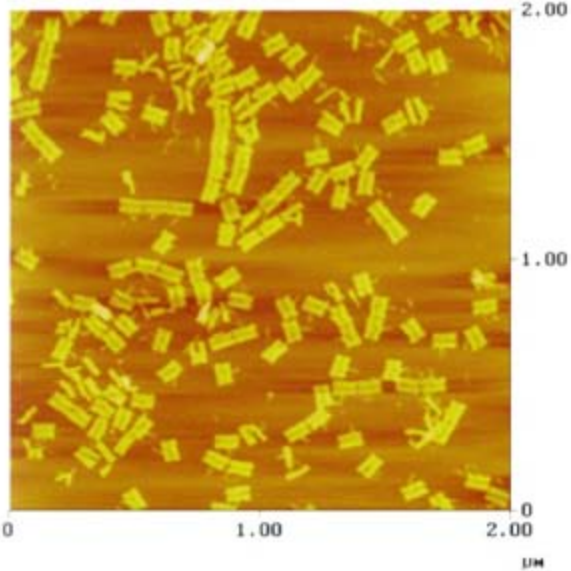
base pairing

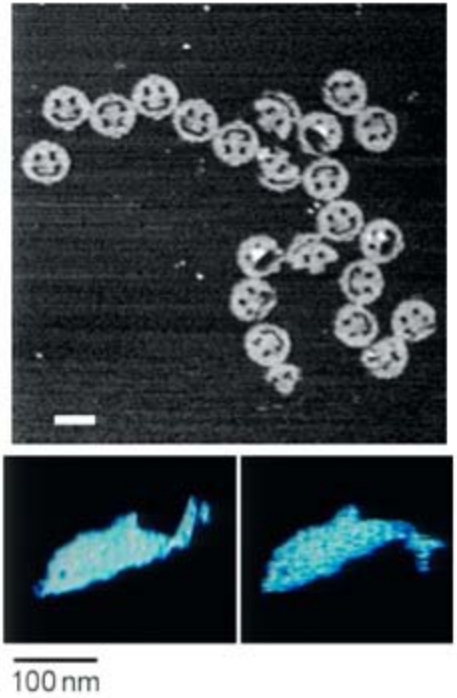
all bases paired

DNA

base pairing

DNA origami



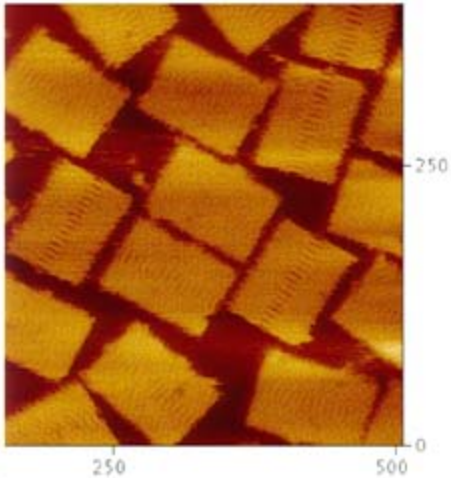


P. Rothemund "Templated DNA Nanostructures," Nature 440 297-302 (2006)

E. S. Andersen et al, "DNA origami design of dolphin-shaped structures with flexible tails. " *ACS Nano*, *2*(6), 1213-8 (2008)

How DNA origami are made

A long strand of DNA is woven back and forth…it is held in place by "staples" made from DNA.

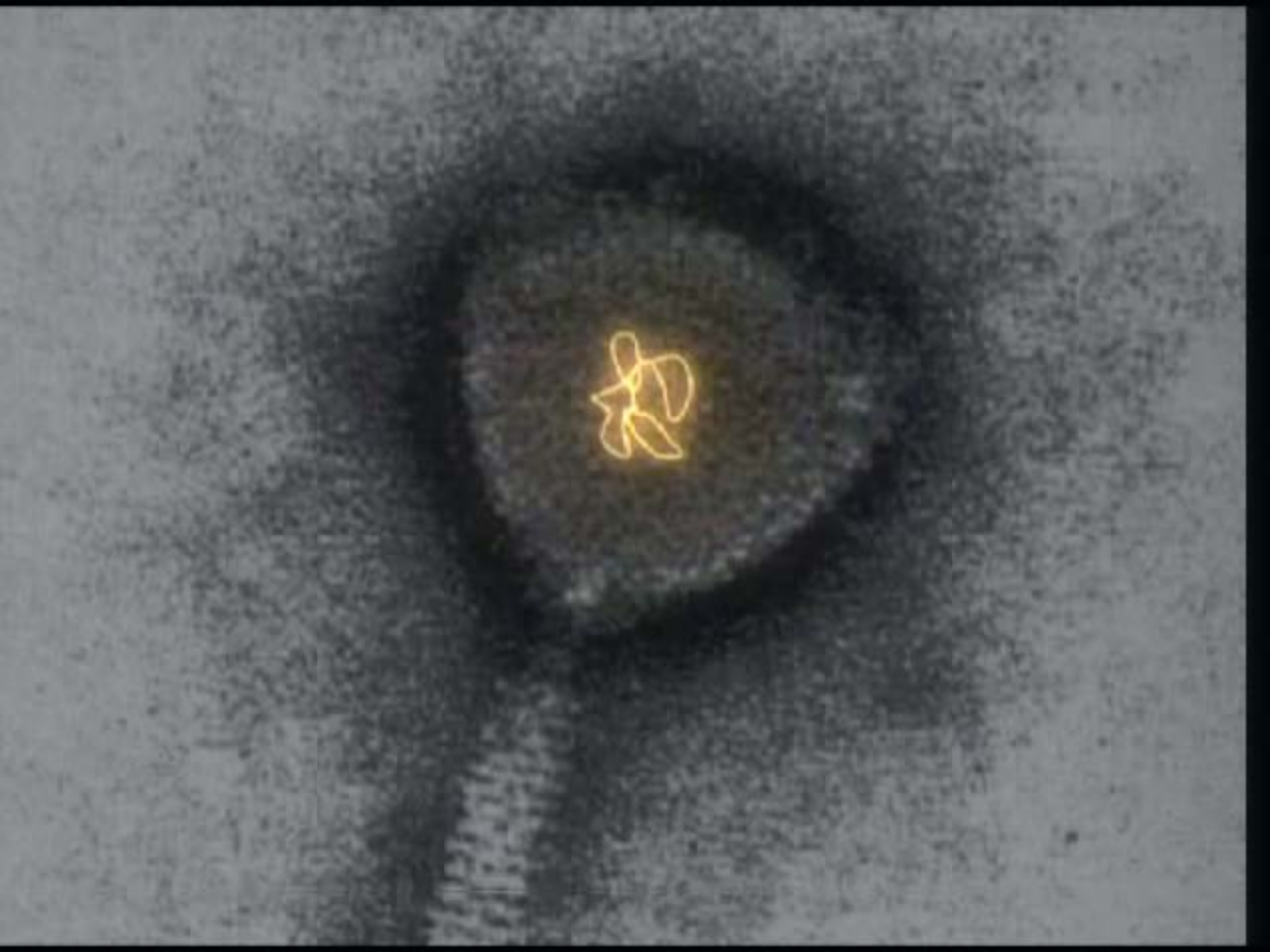


http://kidoinfo.com/ri/wp-content/uploads/2009/

How DNA origami are made

- Origami movie


genetic material
DNA

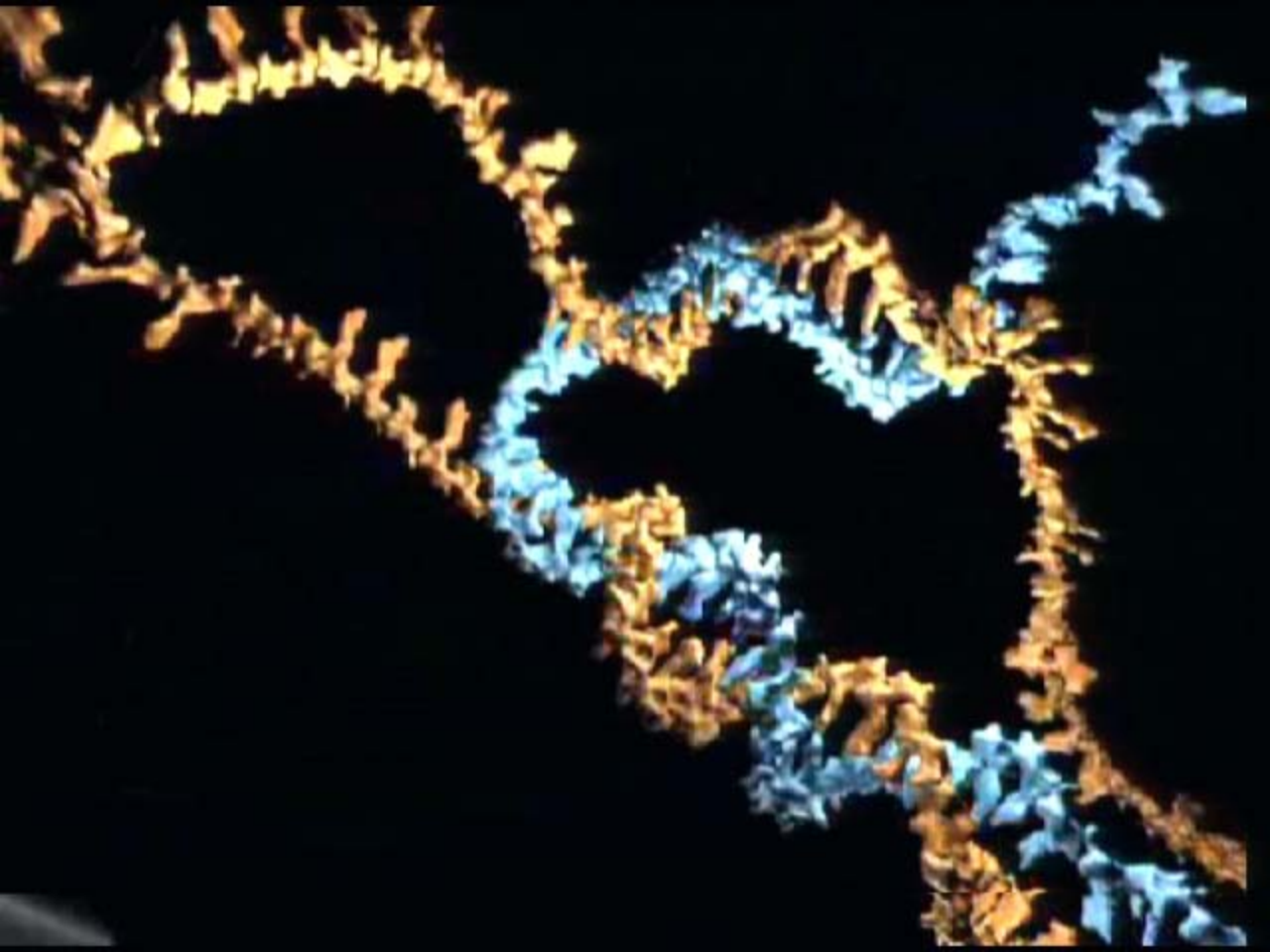


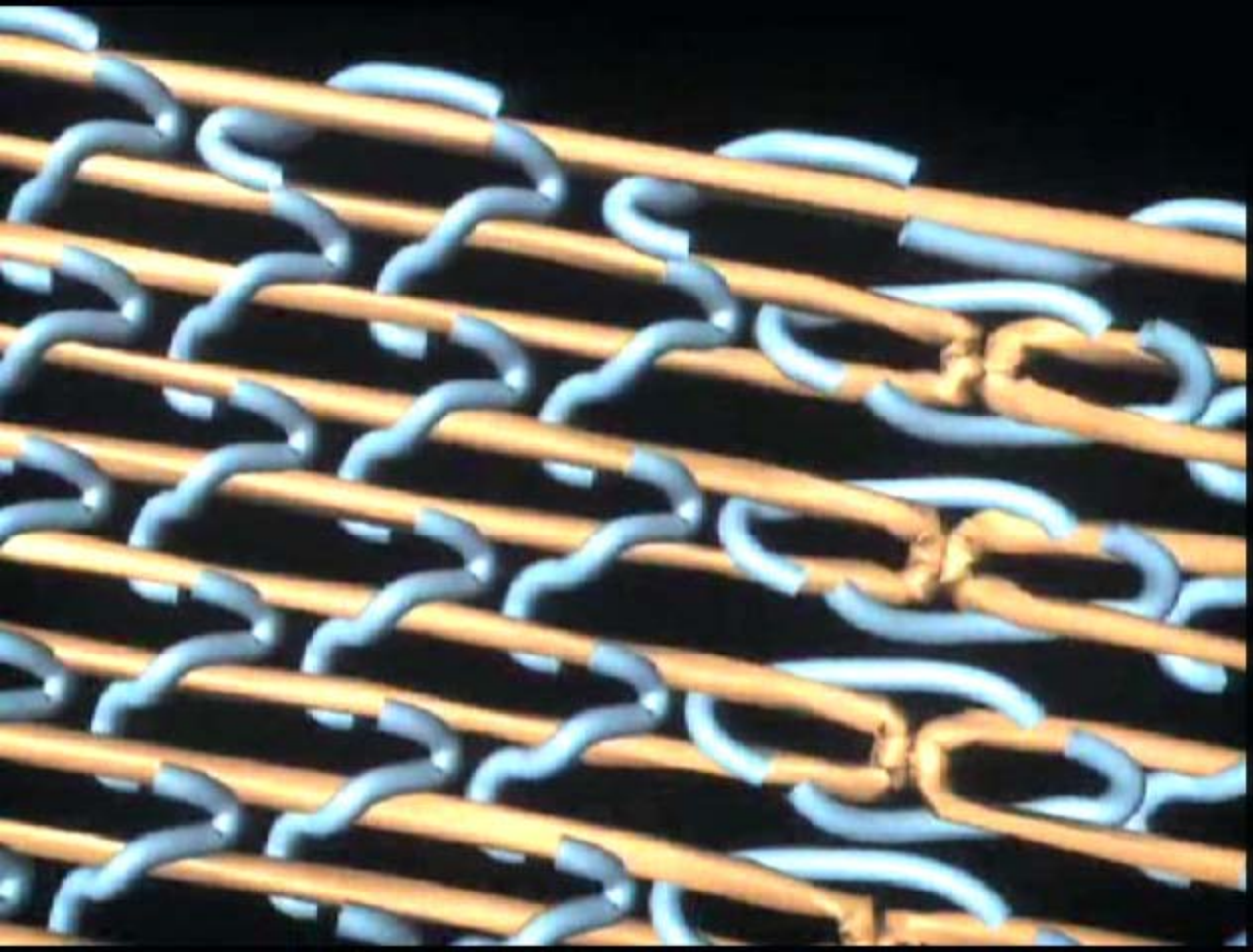

Atomic force microscope image
DNA

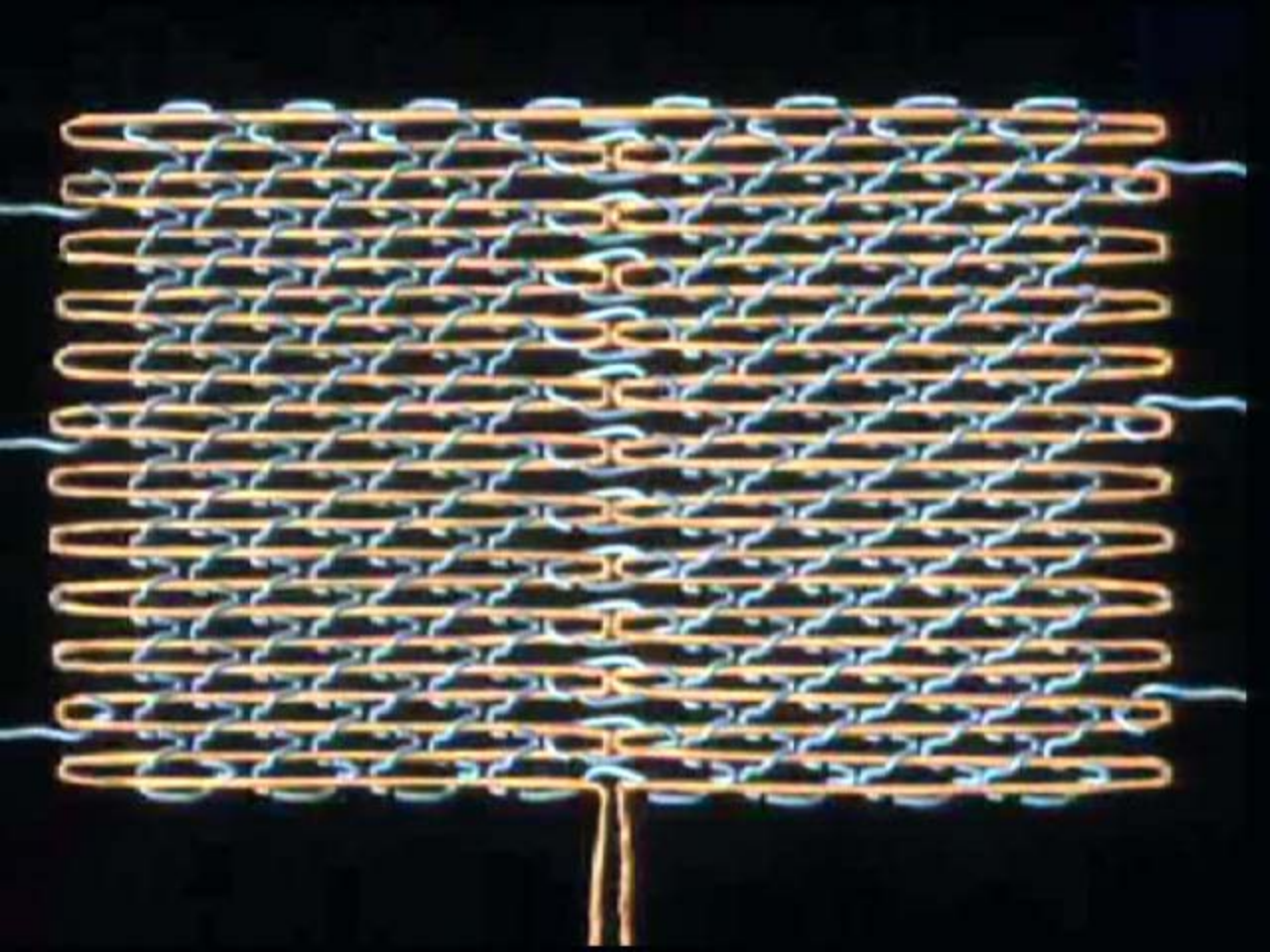

Template strand
floating in solution

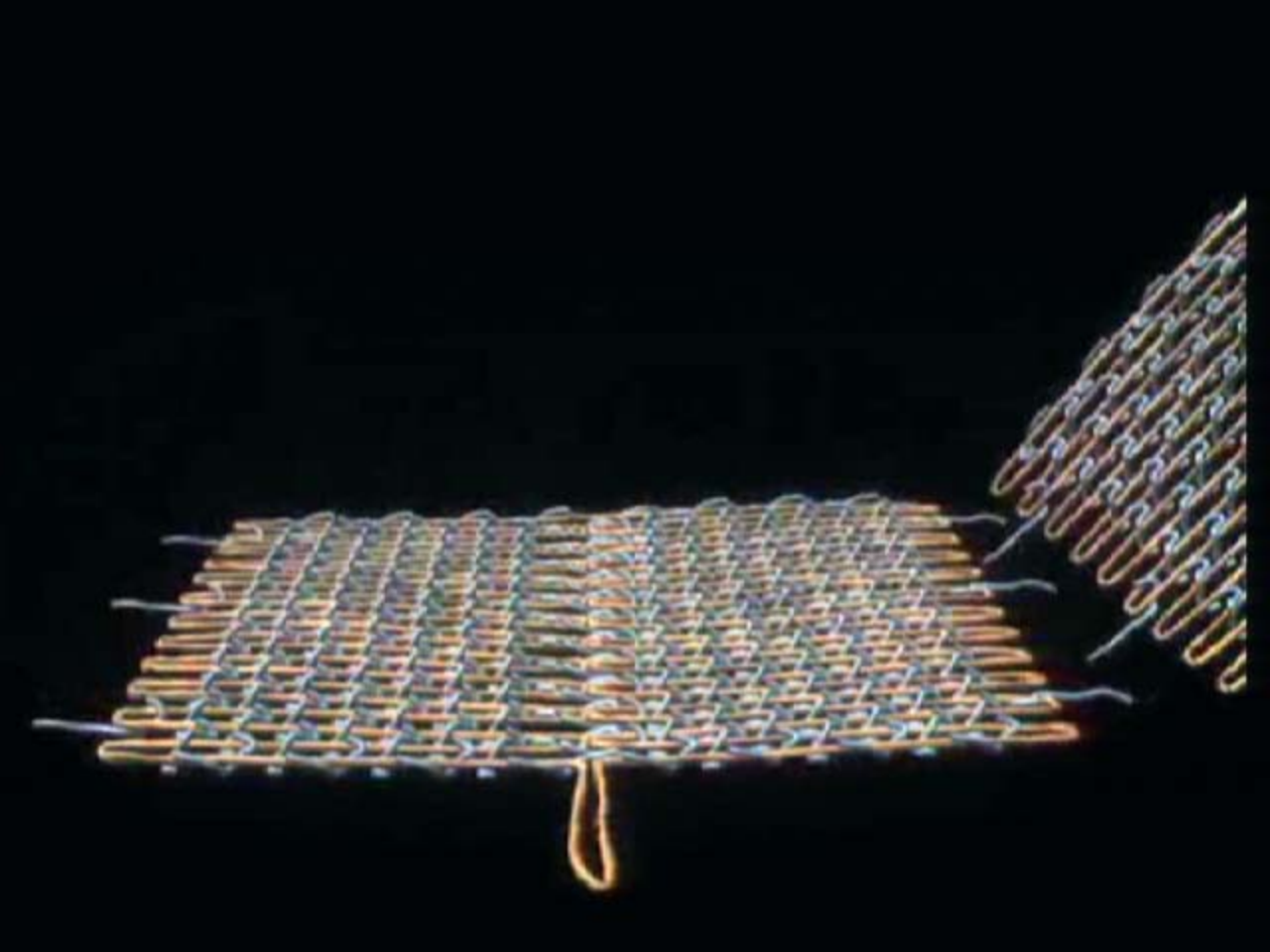

staple strands

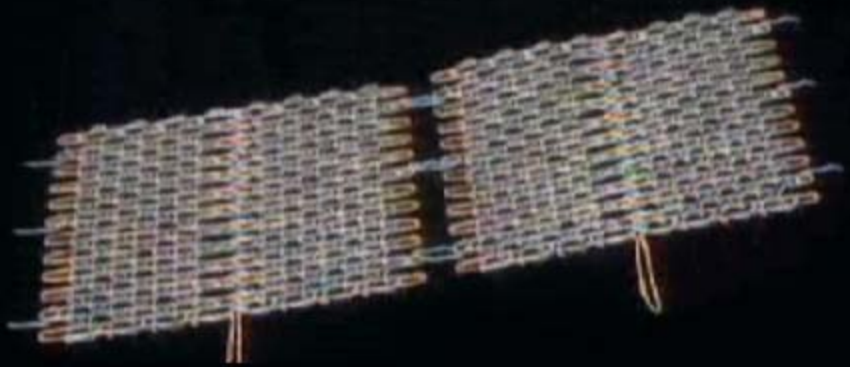

base pairing



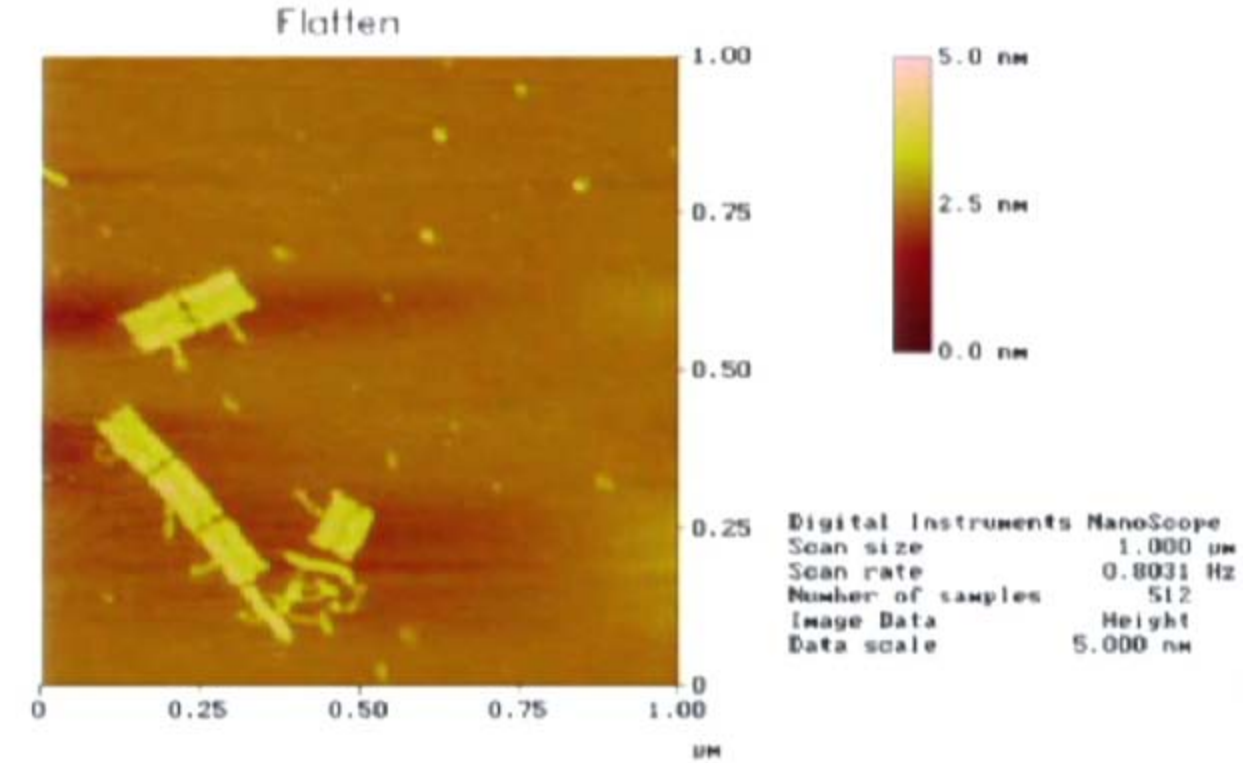






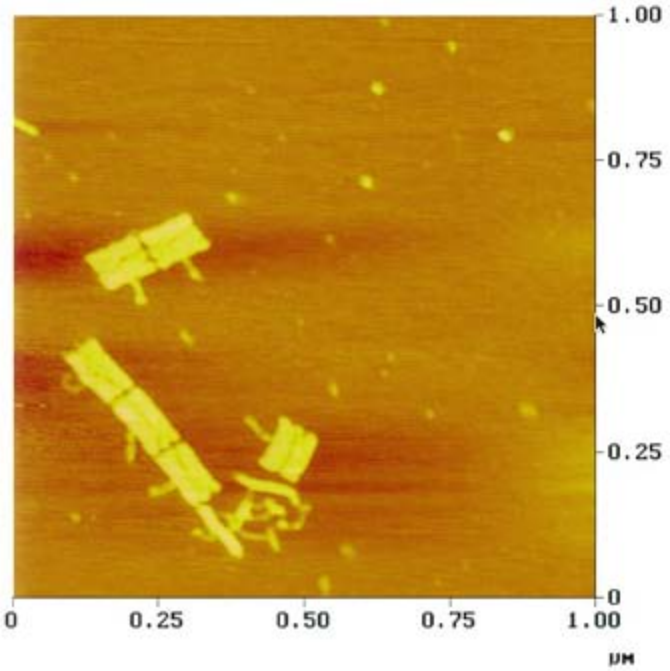


Clear Execute Undo



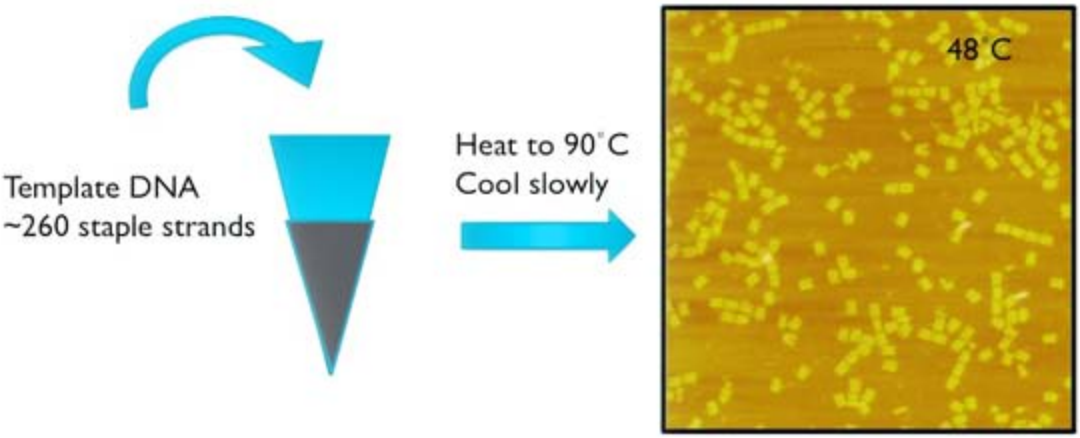
nk11_2hr.004

DNA choo-choo train

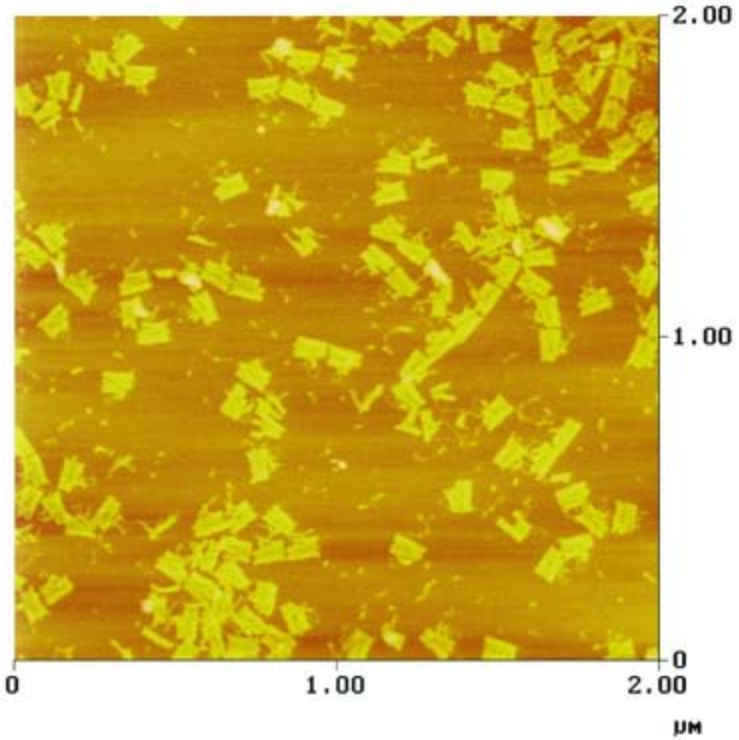


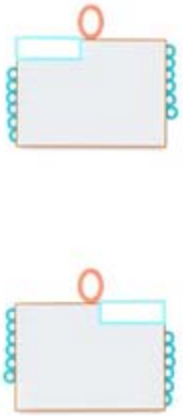
A High School Research Project

- Lesli Mark (St. Joseph High School) wanted to see how the origami assemble.



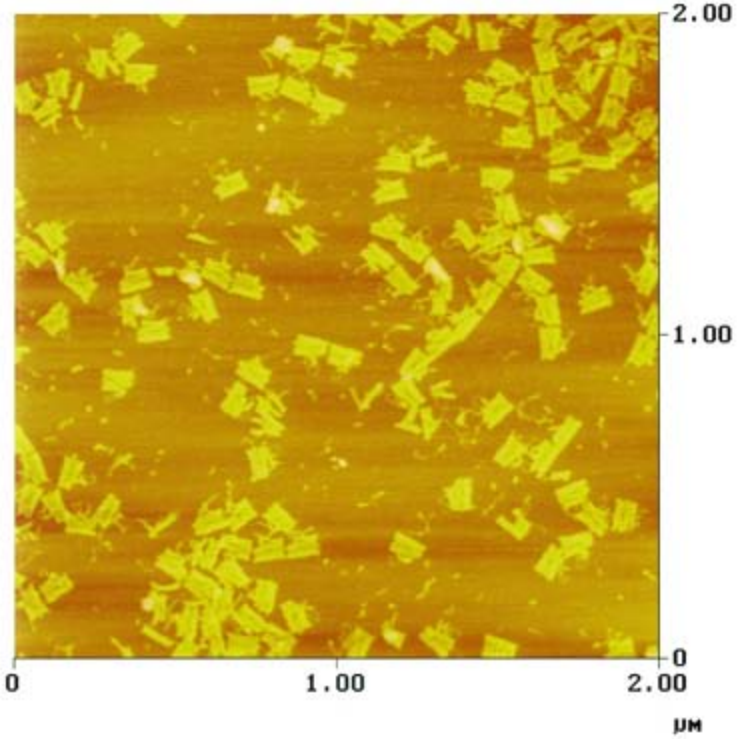
Which side is up?



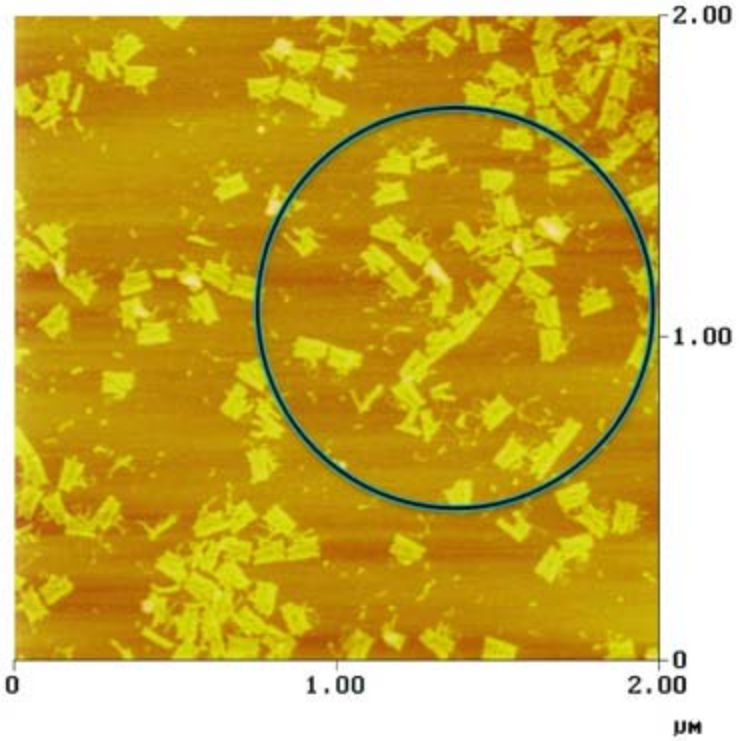


"notched" origami
Are these the same?

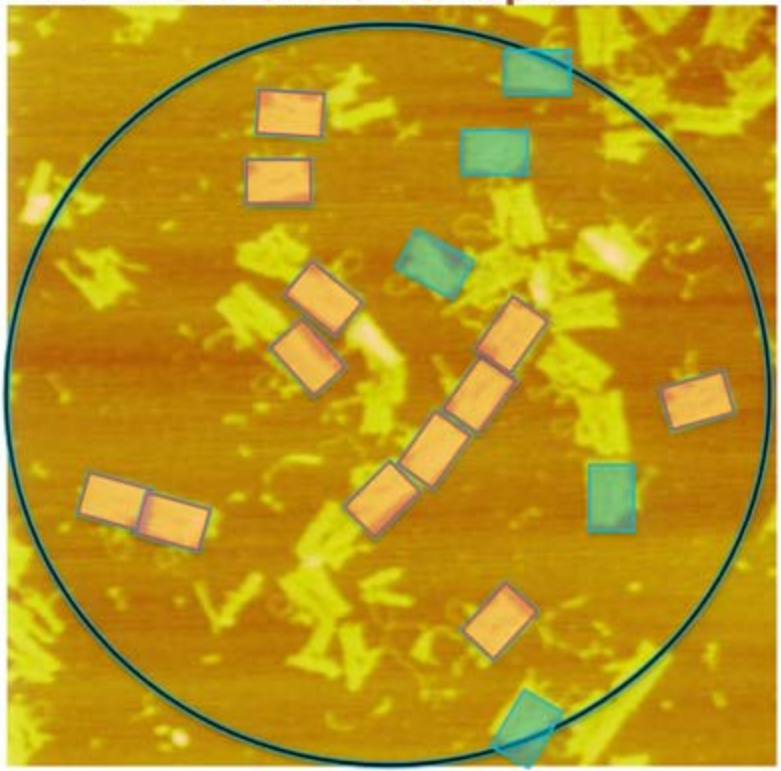
Which side is up?



Which side is up?



Which side is up?



Why we want to make this structure: Molecular electronics

- Here's how electrons flow through a wire (electrical current)

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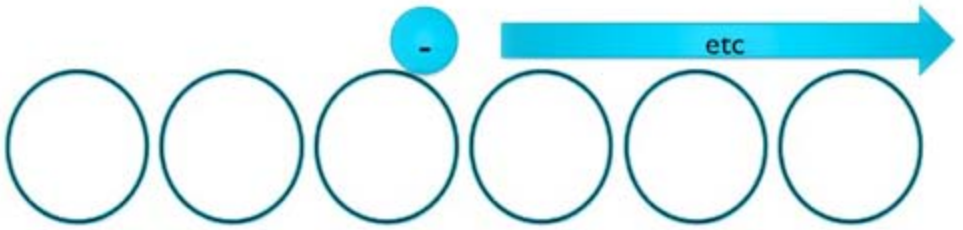
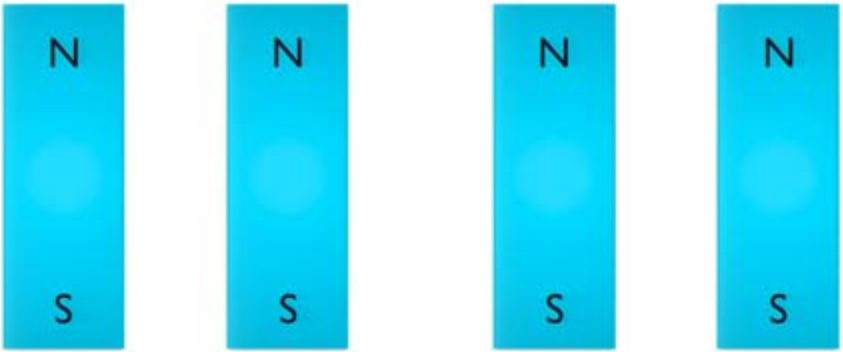


Problem: heating

Why we want to make this structure: Molecular electronics

- Sending information does not require sending electrons. Here's how:



Magnets

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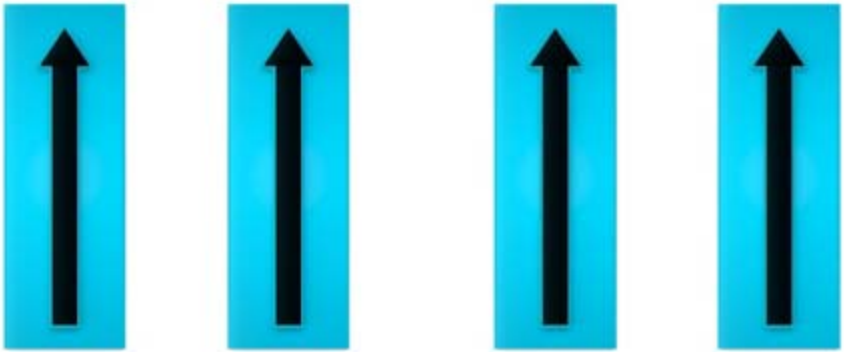

Magnets

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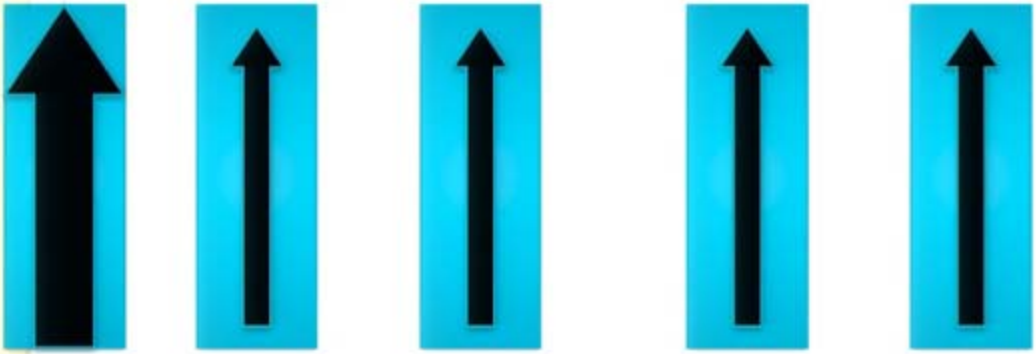

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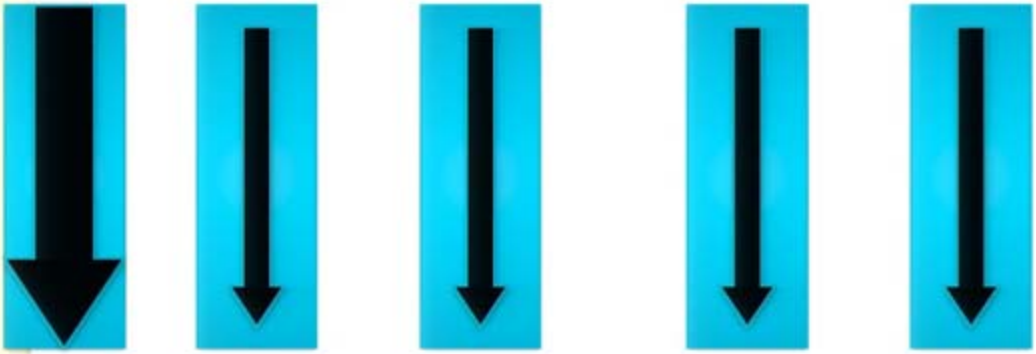
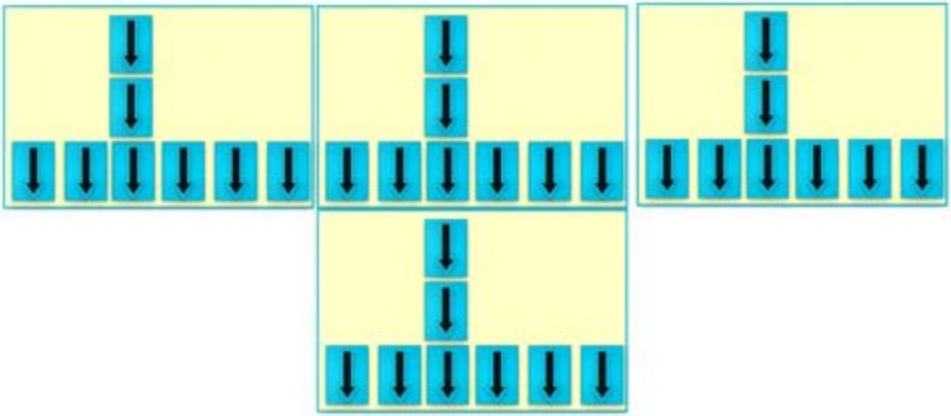


Magnets don't heat up

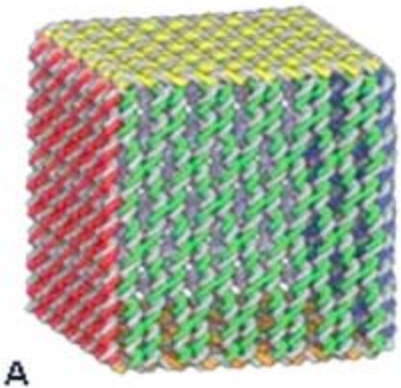
Why we want to make this structure: Molecular electronics

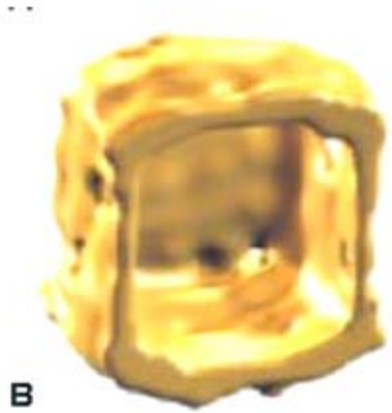
- We want to use DNA origami to hold very small nanomagnets in place to make circuits.



We still have not figured out how to do this properly. But we keep working on it…one day we will know how to do it!

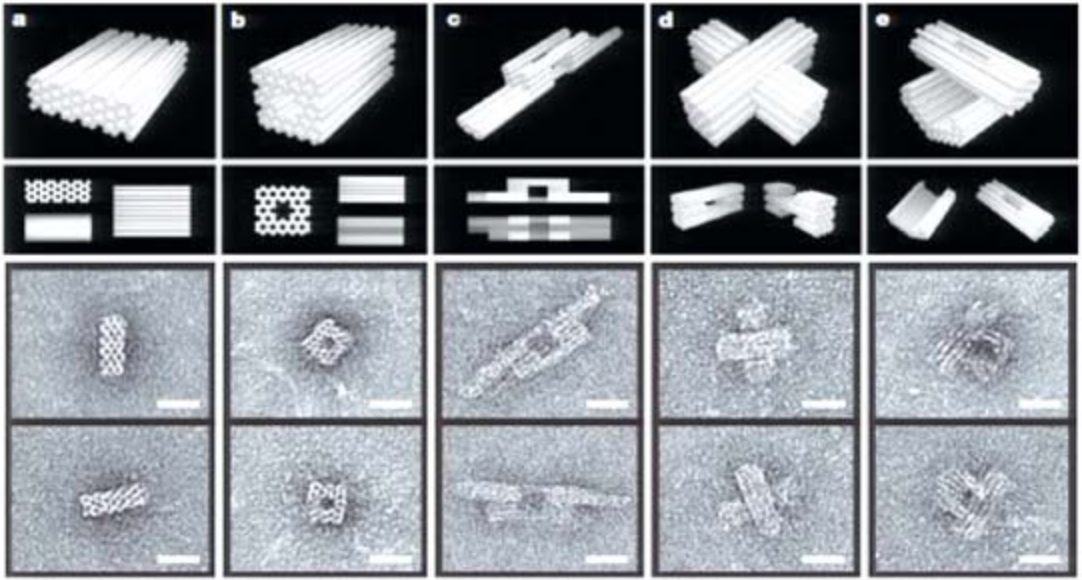
What is the next vision for DNA origami?





E. S. Andersen et al., "Self-assembly of a nanoscale DNA box with a controllable lid," Nature 459, 73-76 (2009)

DNA origami into 3D



S. M. Douglas, A. H. Marblestone, S. Teerapittayanon, A. Vasquez, G. M. Church, and W. H. Shih, "Rapid Prototyping of DNA origami with caDNAno," Nucl. Acids Res.; *37*, 5001-5006, (2009)

Questions?

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Jan Vermeer
~1670