Molecular Motors and Nanoscale Devices

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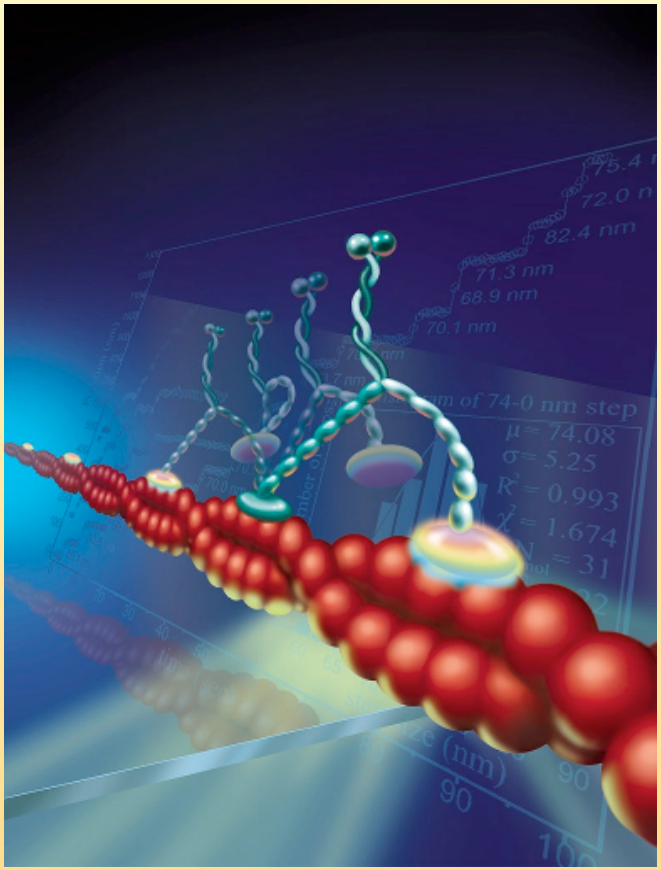


A. Yildiz,..., P. Selvin,
Science **300**, 2061 (2003).

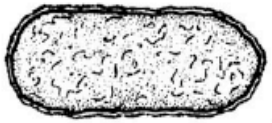
CIS 170, March 6, 2008

The size of stuff:

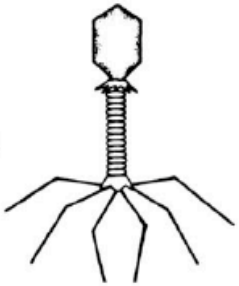
flea
1 mm

protozoan
0.1 mm

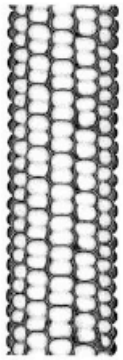
white blood cell
0.01 mm



E. coli
1 μm



T2 phage
0.1 μm

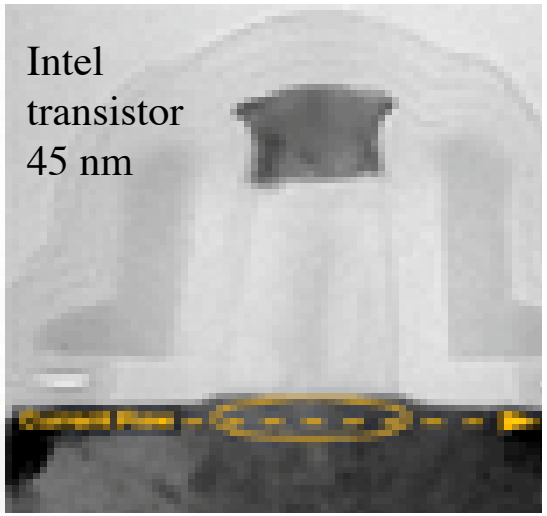


microtubule
25 nm

DNA
2 nm

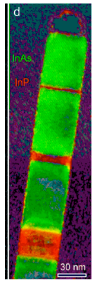
atoms in DNA
0.2 nm

Human hair
$\approx$ 10 μm

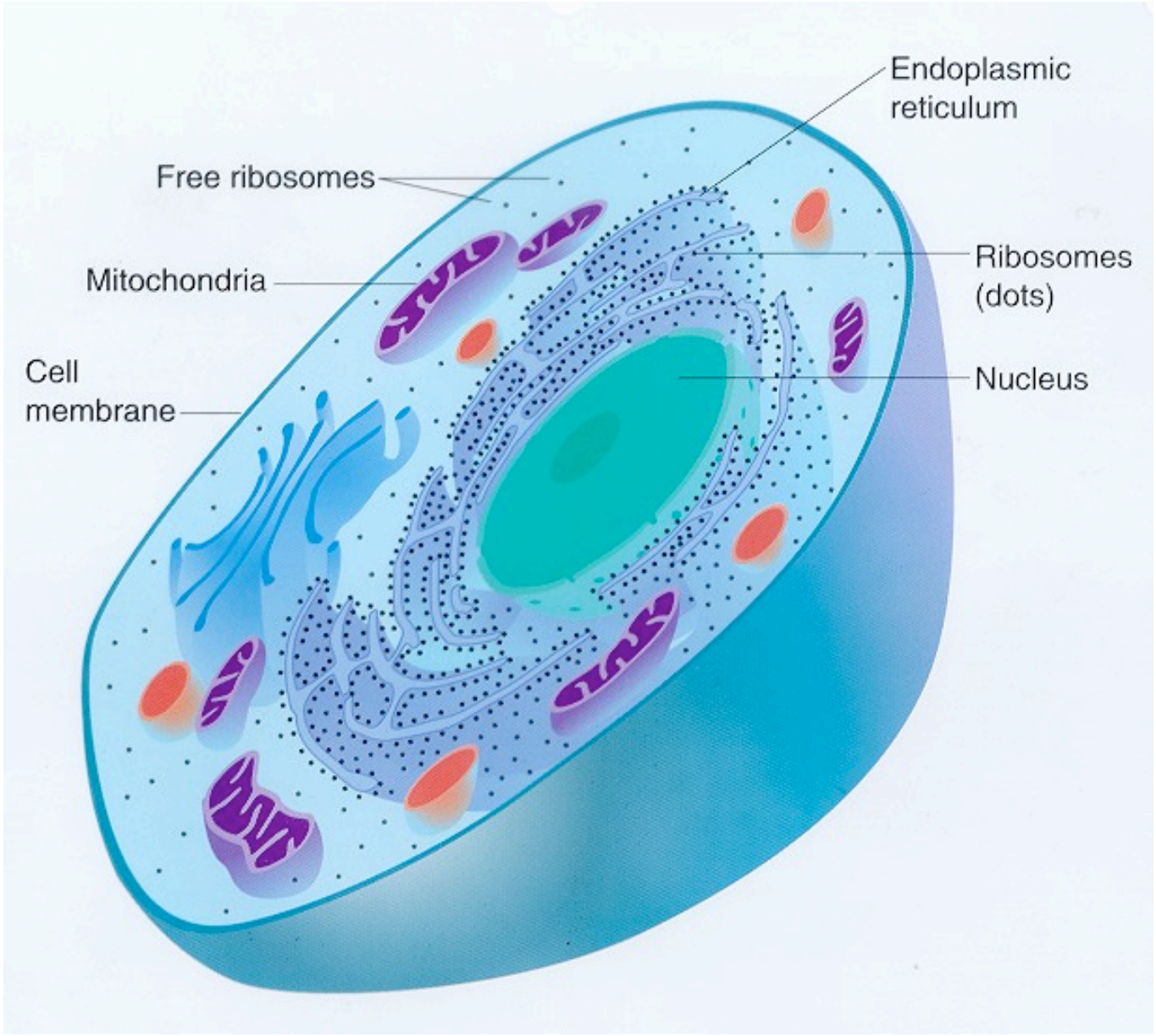


Intel transistor
45 nm

Man-made nanowire
30 nm

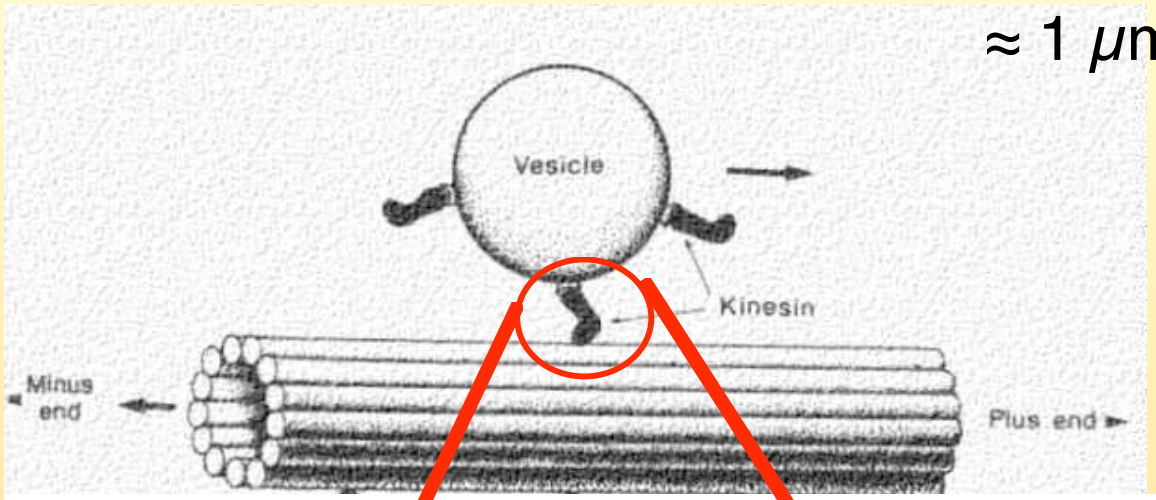


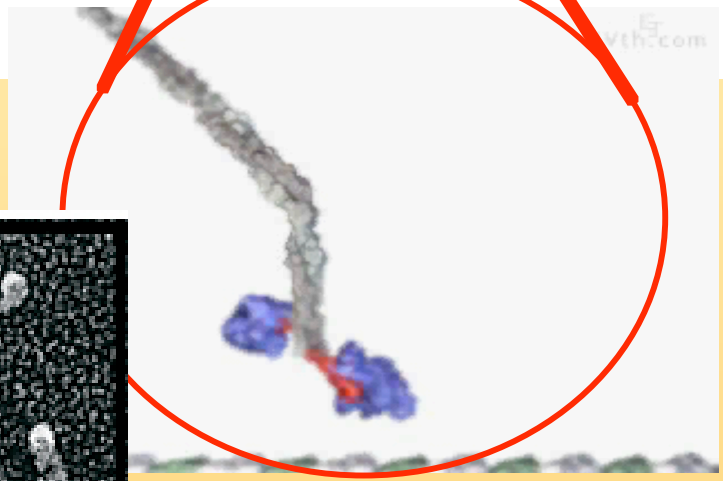
Eukaryotic cell

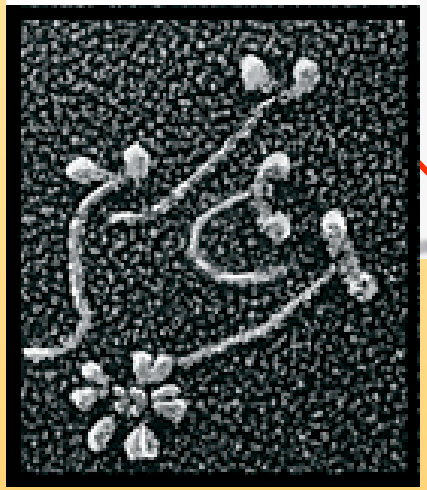


A molecular motor: kinesin

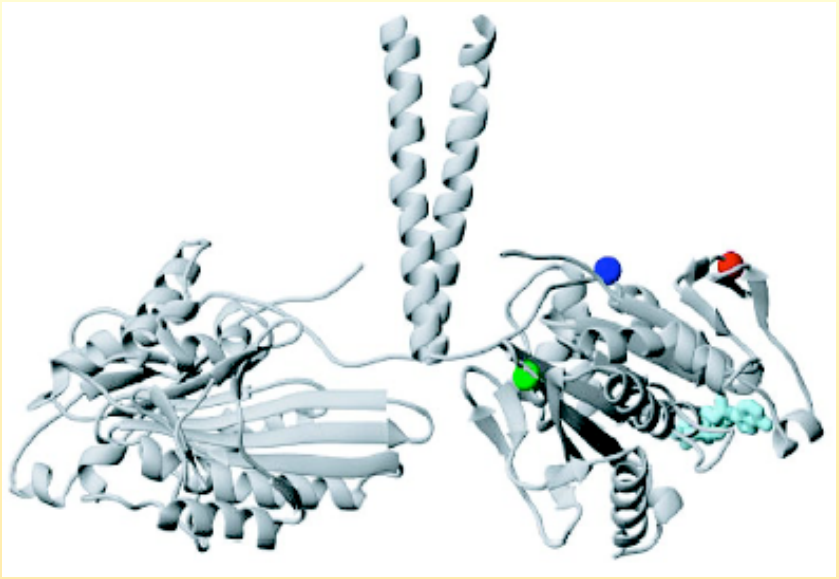
≈ 1 μm/s

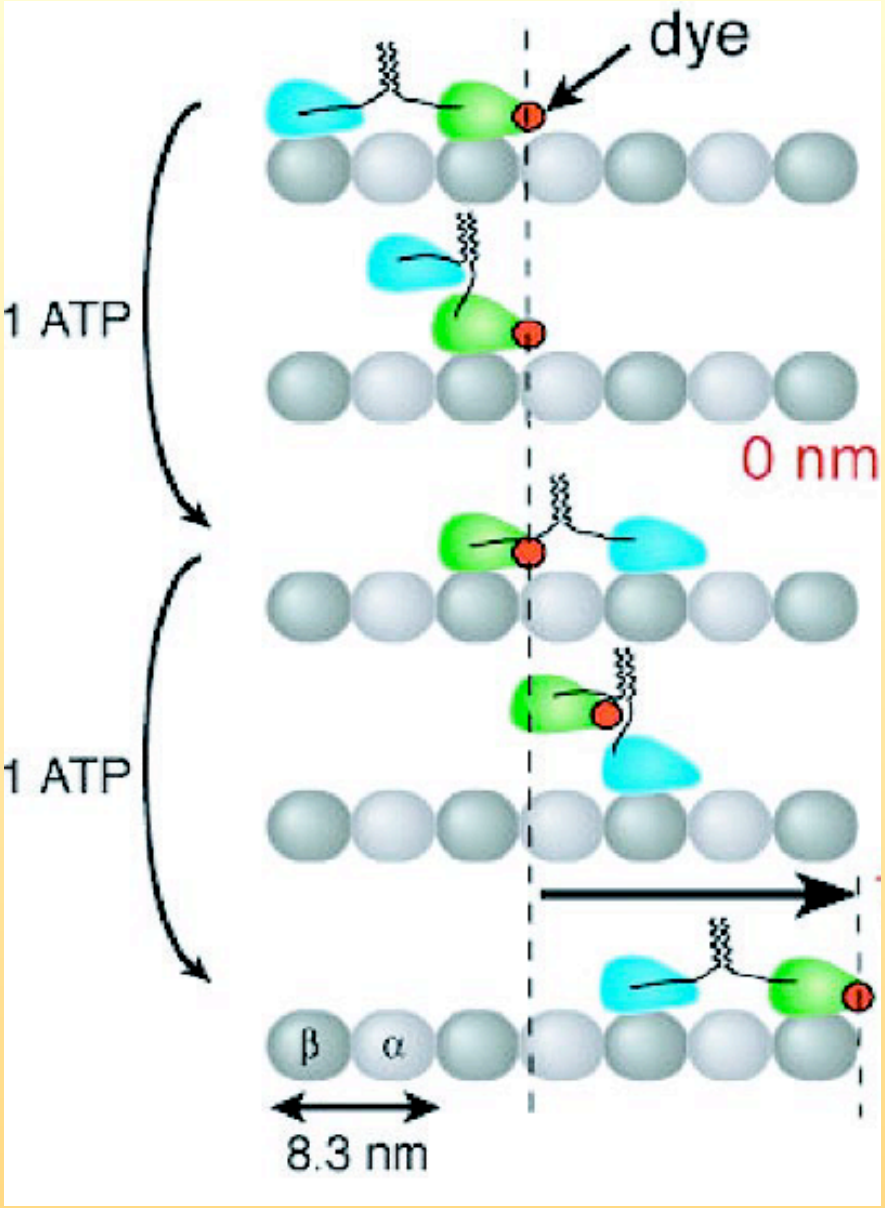






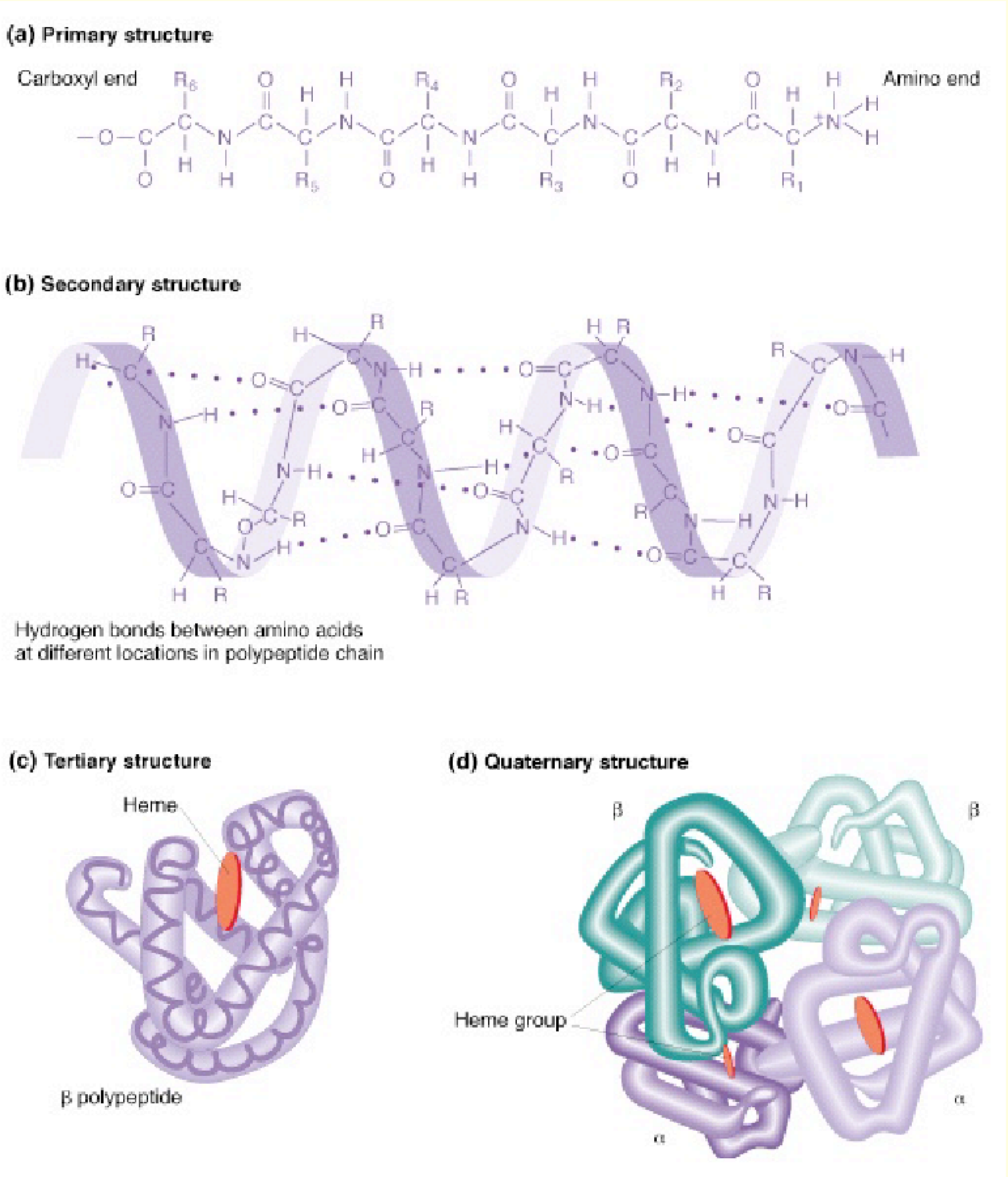
Nobutaka Hirokawa et al





Yildiz, Selvin et al.,
Science **303**, 676 (2004)

Protein Structure Overview



Primary Structure

= *AA sequence*

Secondary Structure

= *Local regularities* in chain conformation

- Alpha helix
- Beta sheet
- Regular turns

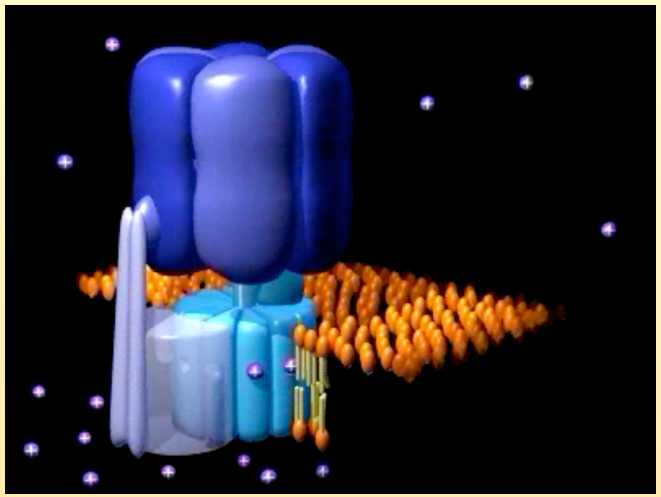
Tertiary structure

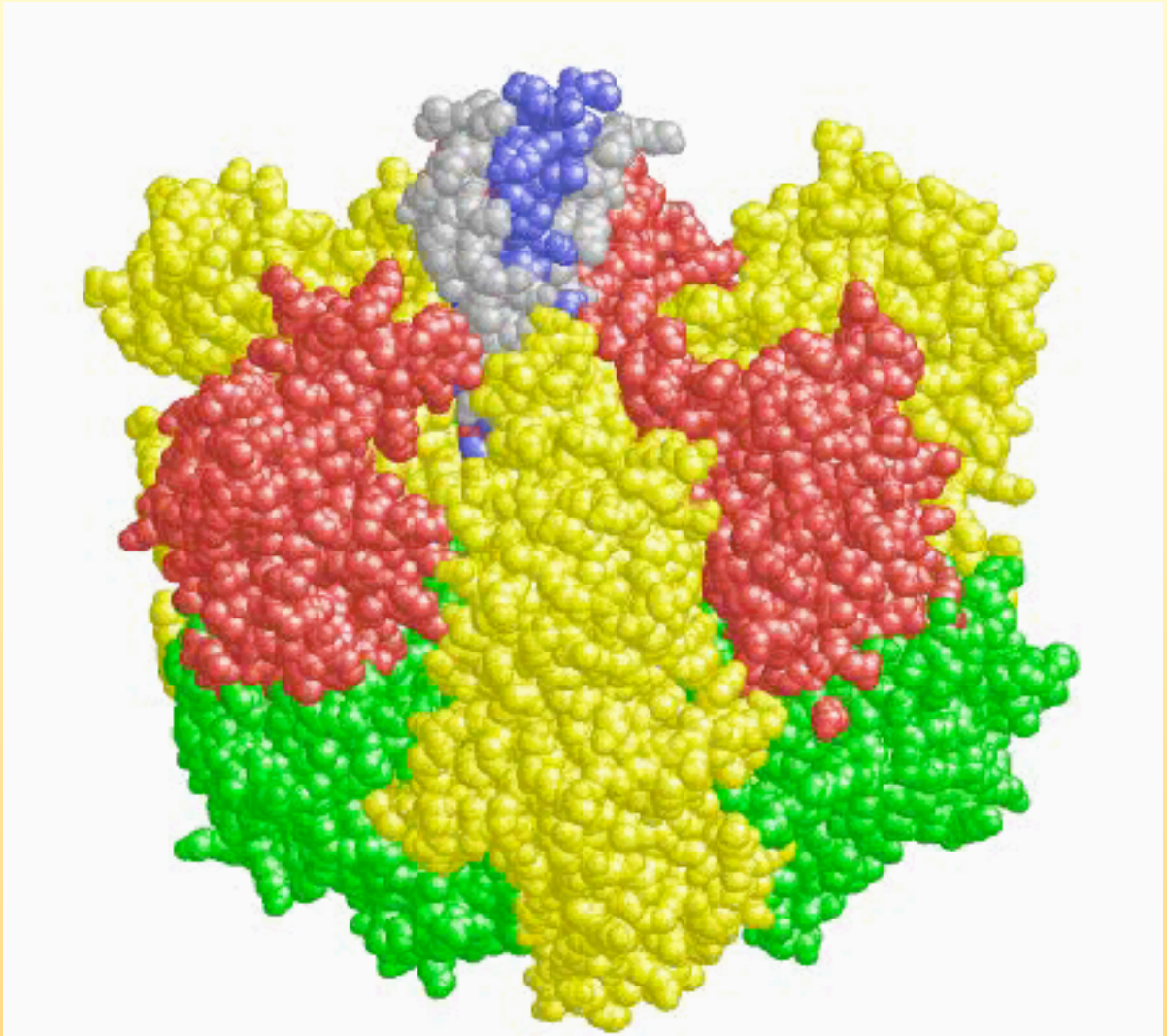
= *Self assembly* of secondary structure into compact globule

Quaternary structure

= *Self assembly* of subunits into particles

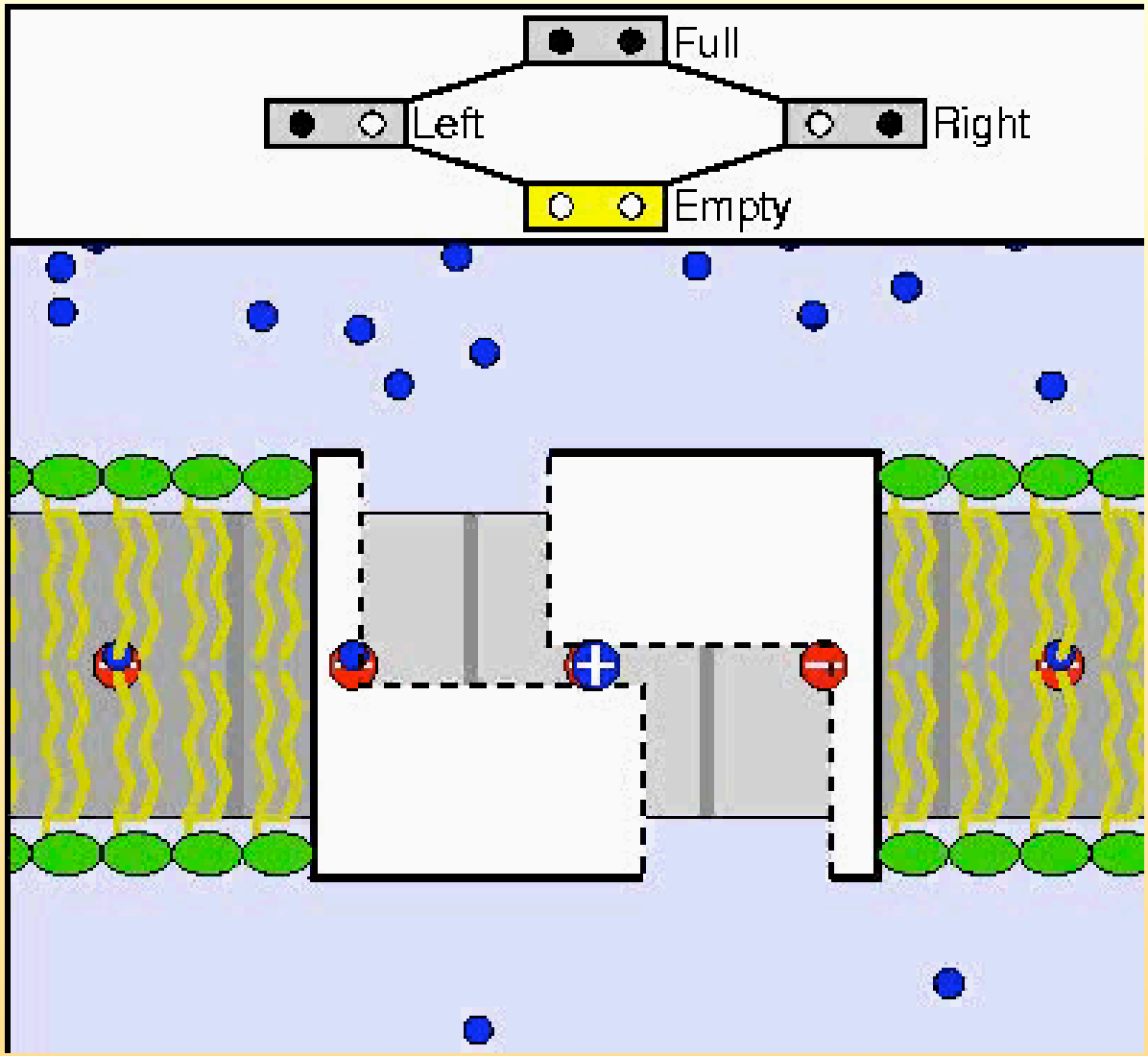
ATP Synthase





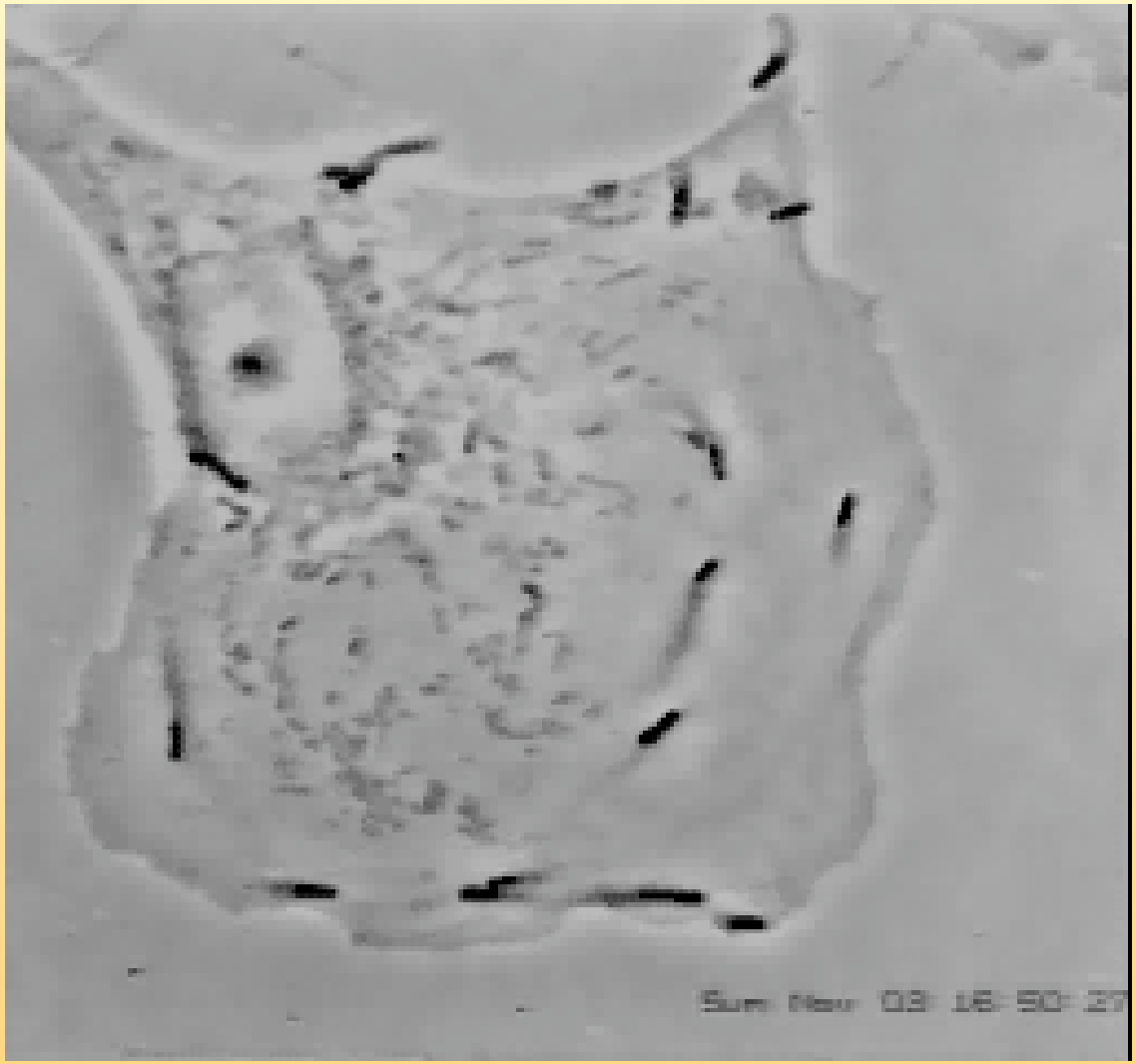
A 3D view of alpha3-beta3-gamma
By Hongyun Wang & George Oster, U.C.Berkeley

Kinosita et al. (1999)



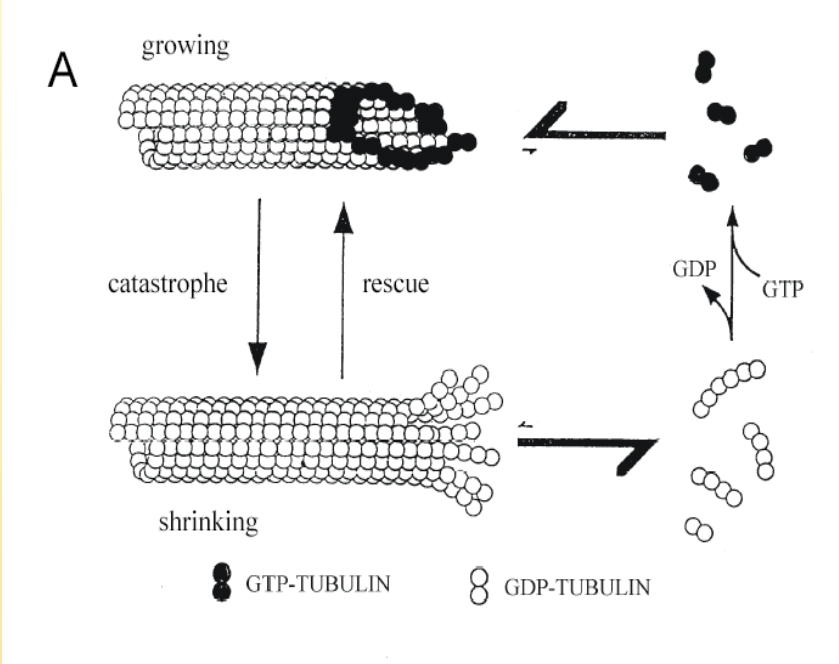
Hongyun Wang and George Oster
Nature **396**, 279 (1998)
Nature **399**, 510 (1999)
nature.berkeley.edu/hongwang

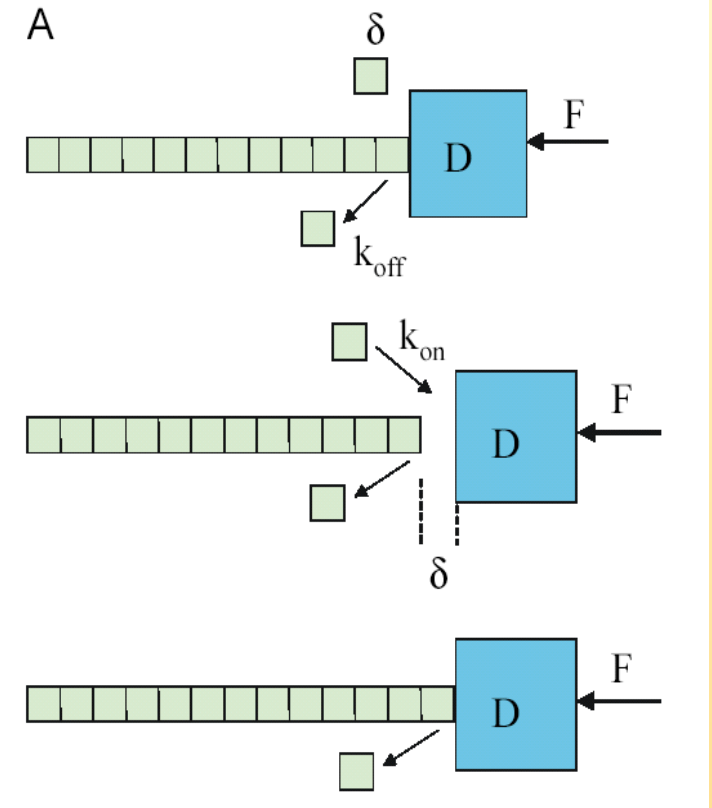
Listeria are bacterias that hijack the cell's skeleton to propel themselves

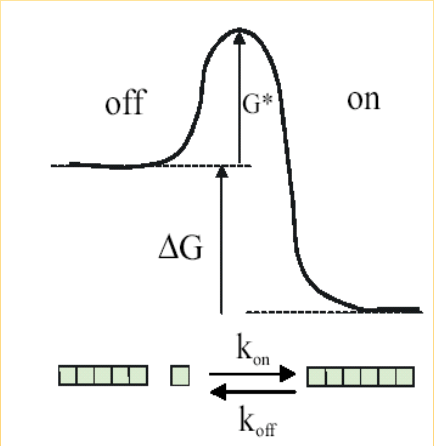


http://cmgm.stanford.edu/theriot/movies.htm#Hits

Force generation by polymerizing microtubules

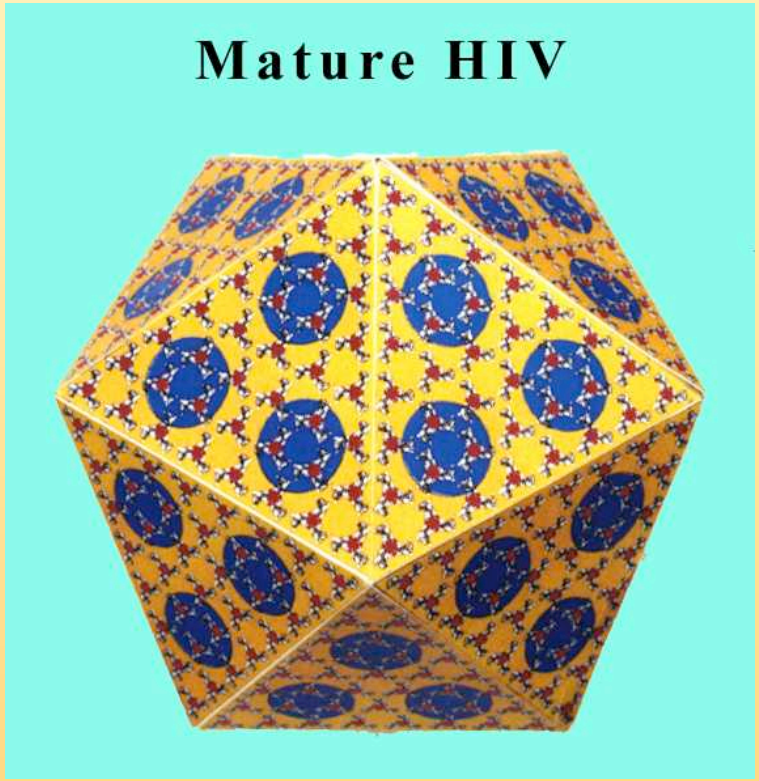




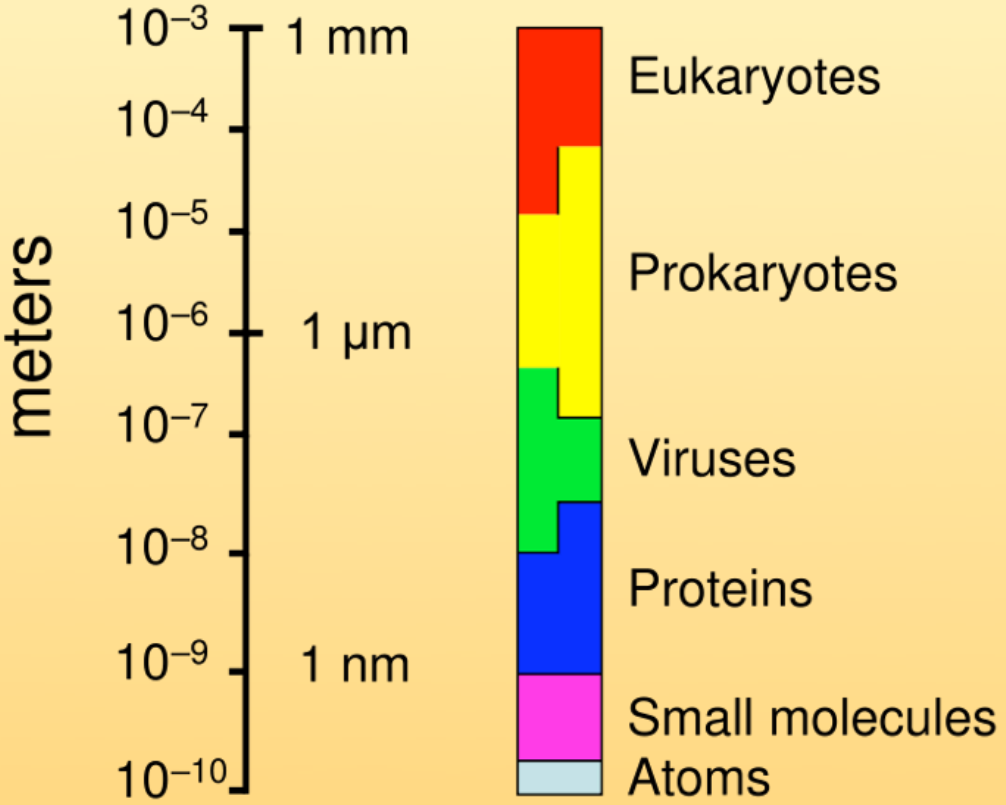


Peskin, Odell, Oster Biophys. J. 65, 316 (1993)
Oster and Mogilner, Eur. Biophys. J, 28, 235 (1997)
M. Dogterom et al, Appl. Phys A **75**, 331 (2002)

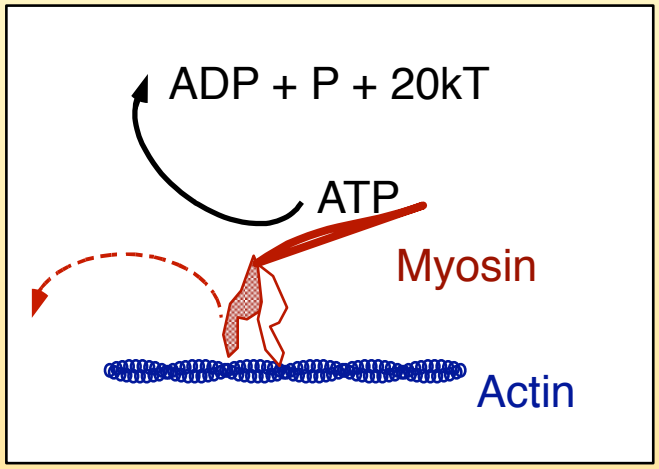
Viruses are containers for genetic material. They need a host cell to generate new viruses using the genetic code



80 - 100 nm diameter

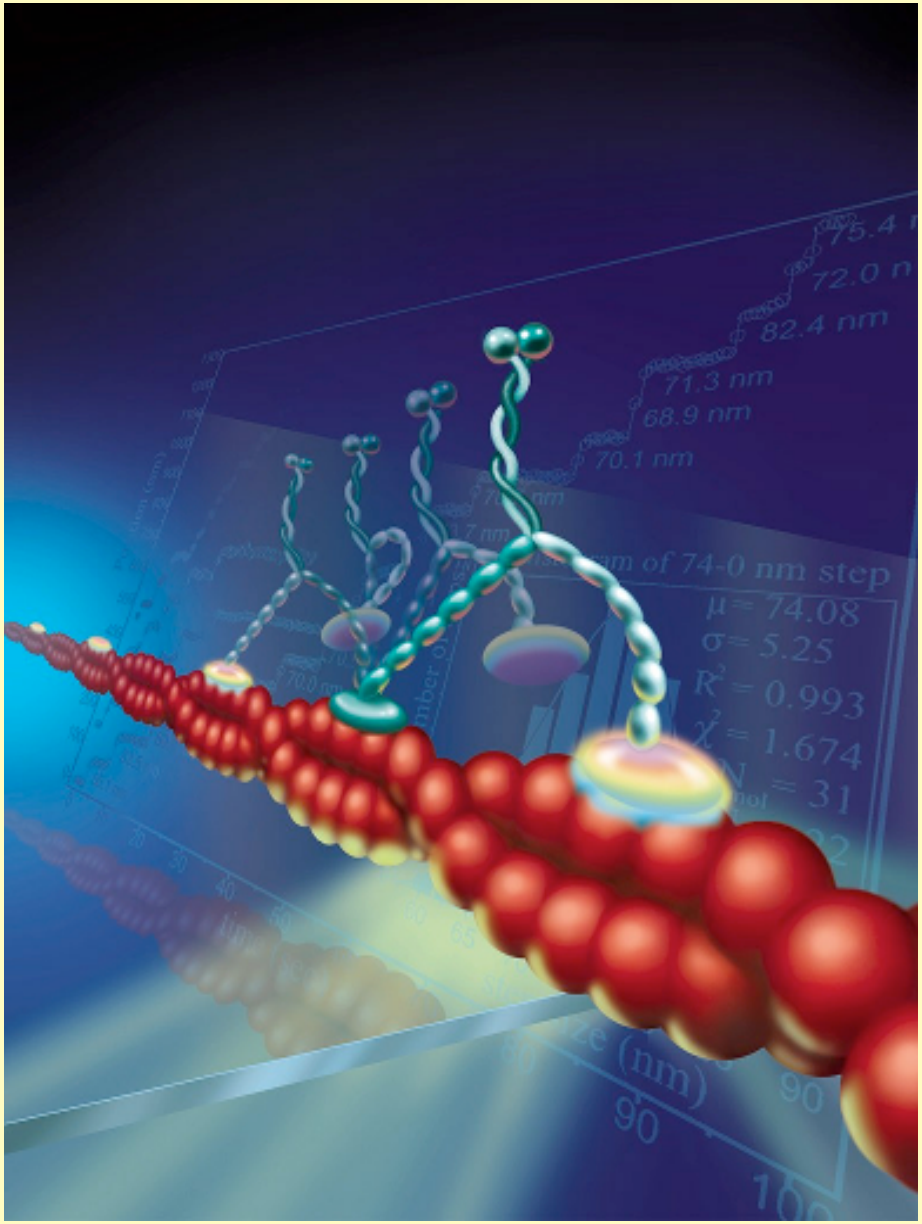


Inherent to nanodevices: Thermal fluctuations are huge!

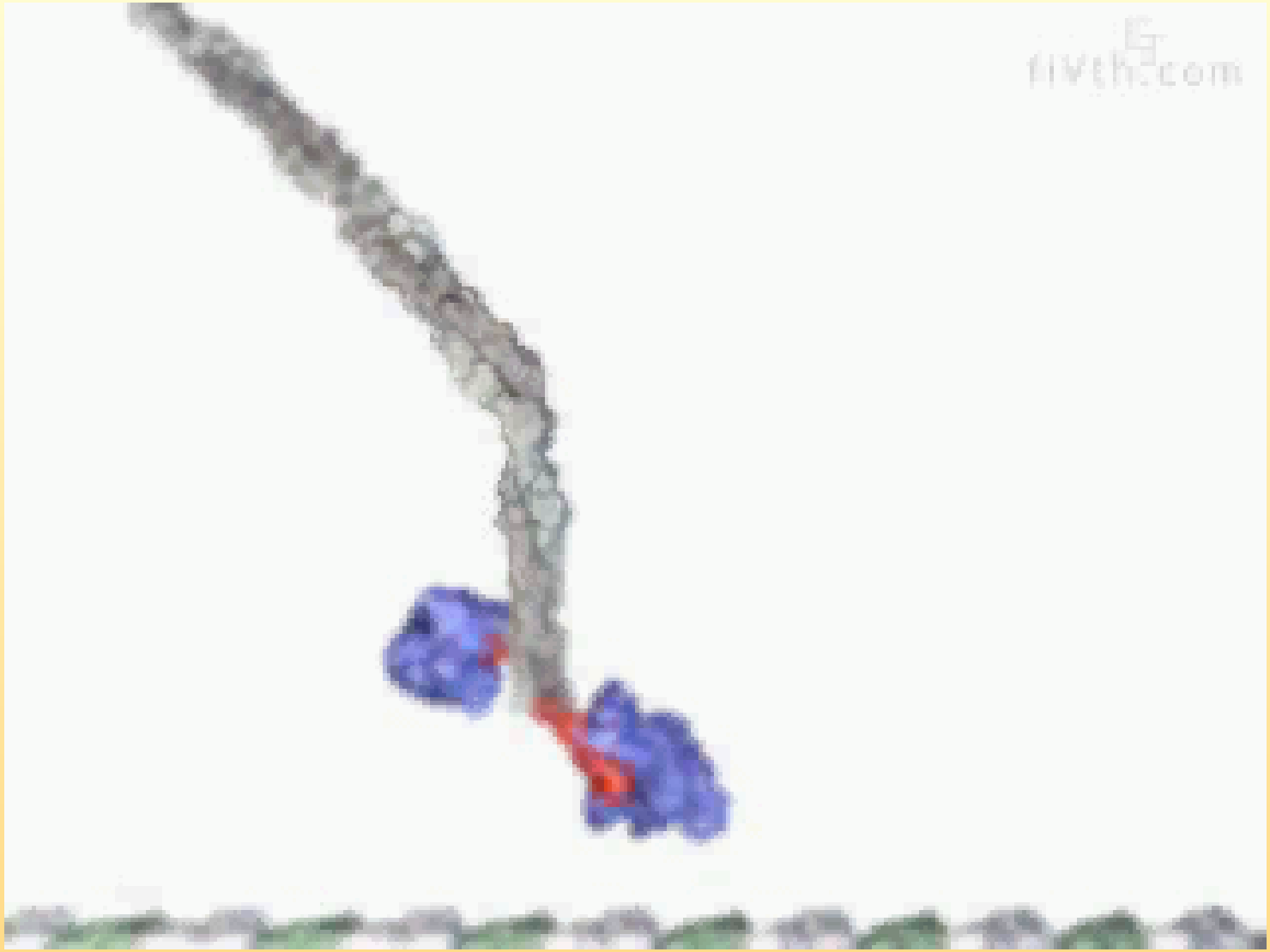


▪ Average speed	≈ 0.1 - 1 μm/s
▪ Thermal fluctuations	≈ cm/s
▪ Free energy budget	1 ATP ≈ 10 - 20 kT
▪ Step size	Δx ≈ 10 nm
▪ Stall force	0.1 - 1 pN
▪ Work output	1 kT ≈ 4 pN nm

Myosin V walks hand-over-hand



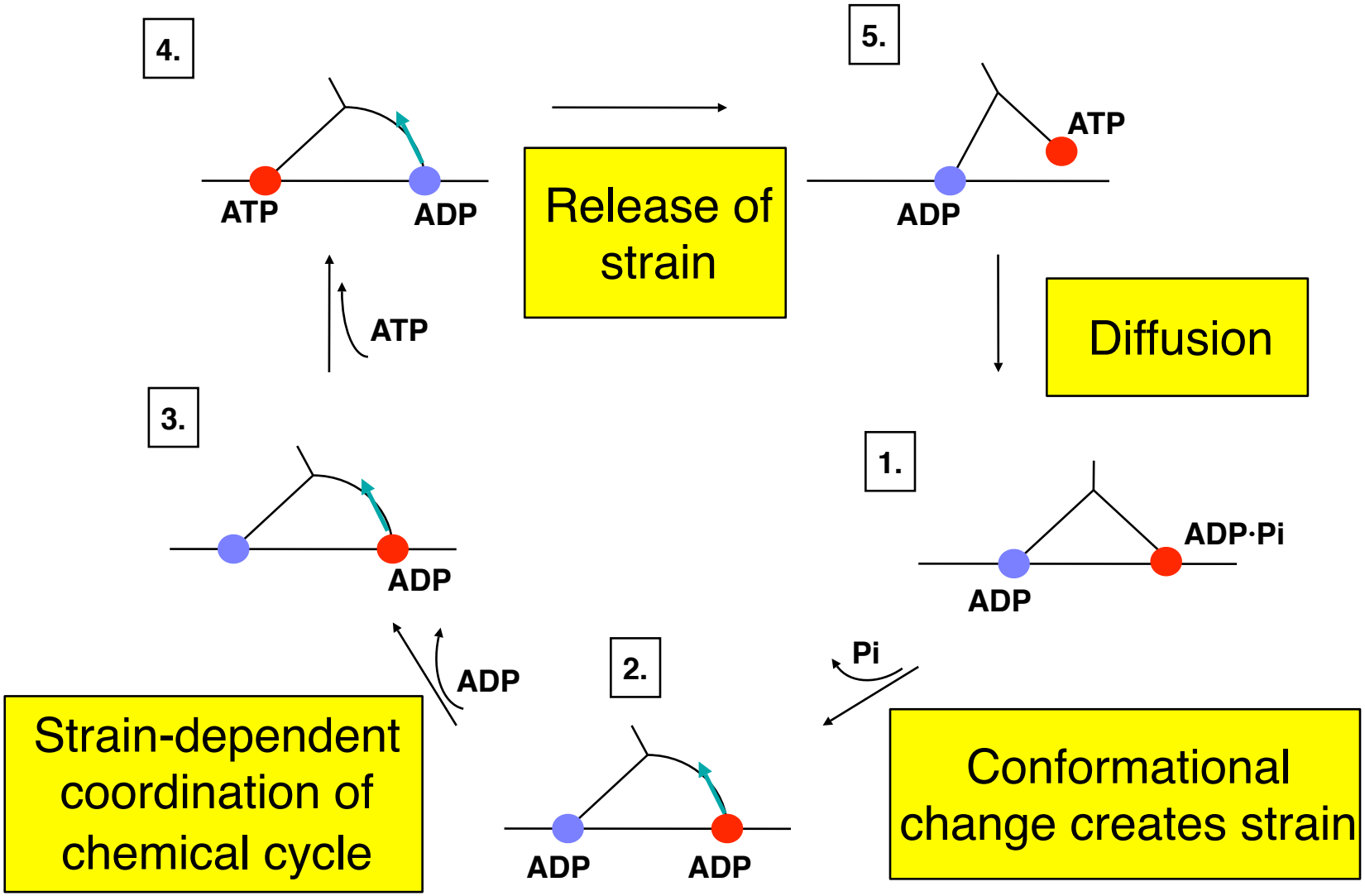
A. Yildiz,..., P. Selvin,
Science **300**, 2061 (2003).



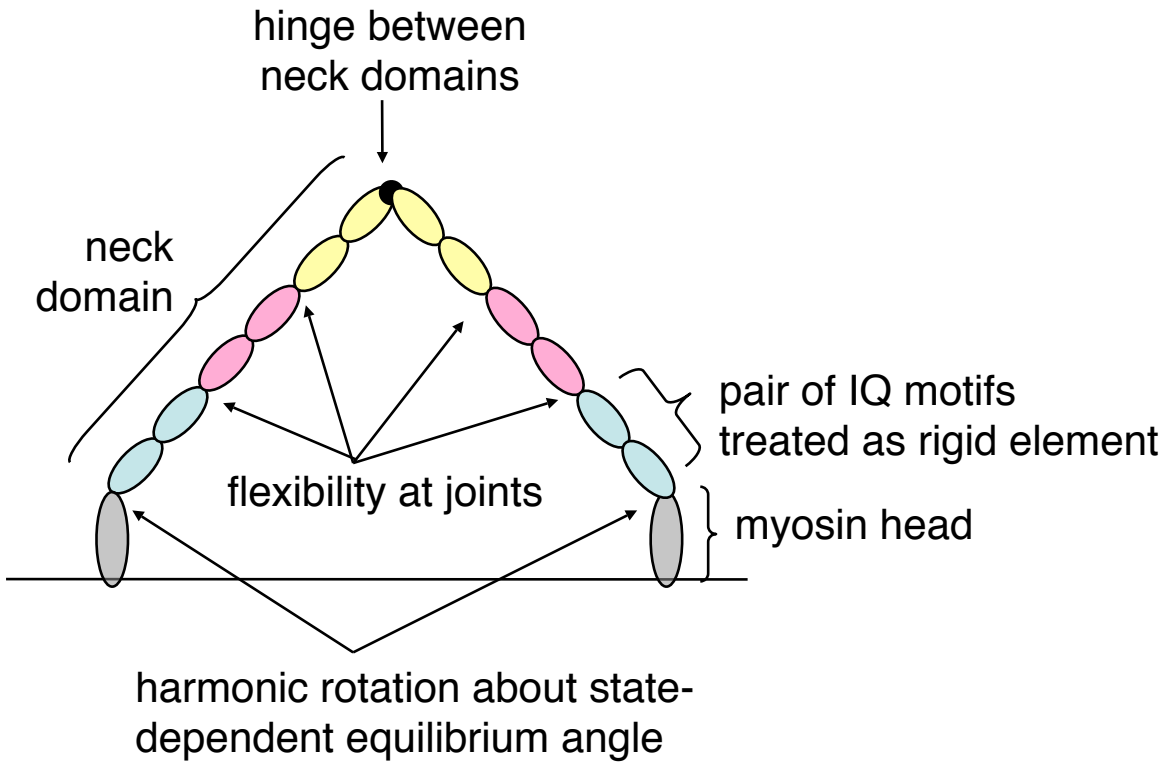
R.D. Vale and R.A. Milligan
Science **288**, 88 (2000)

Myosin V mechanochemical cycle

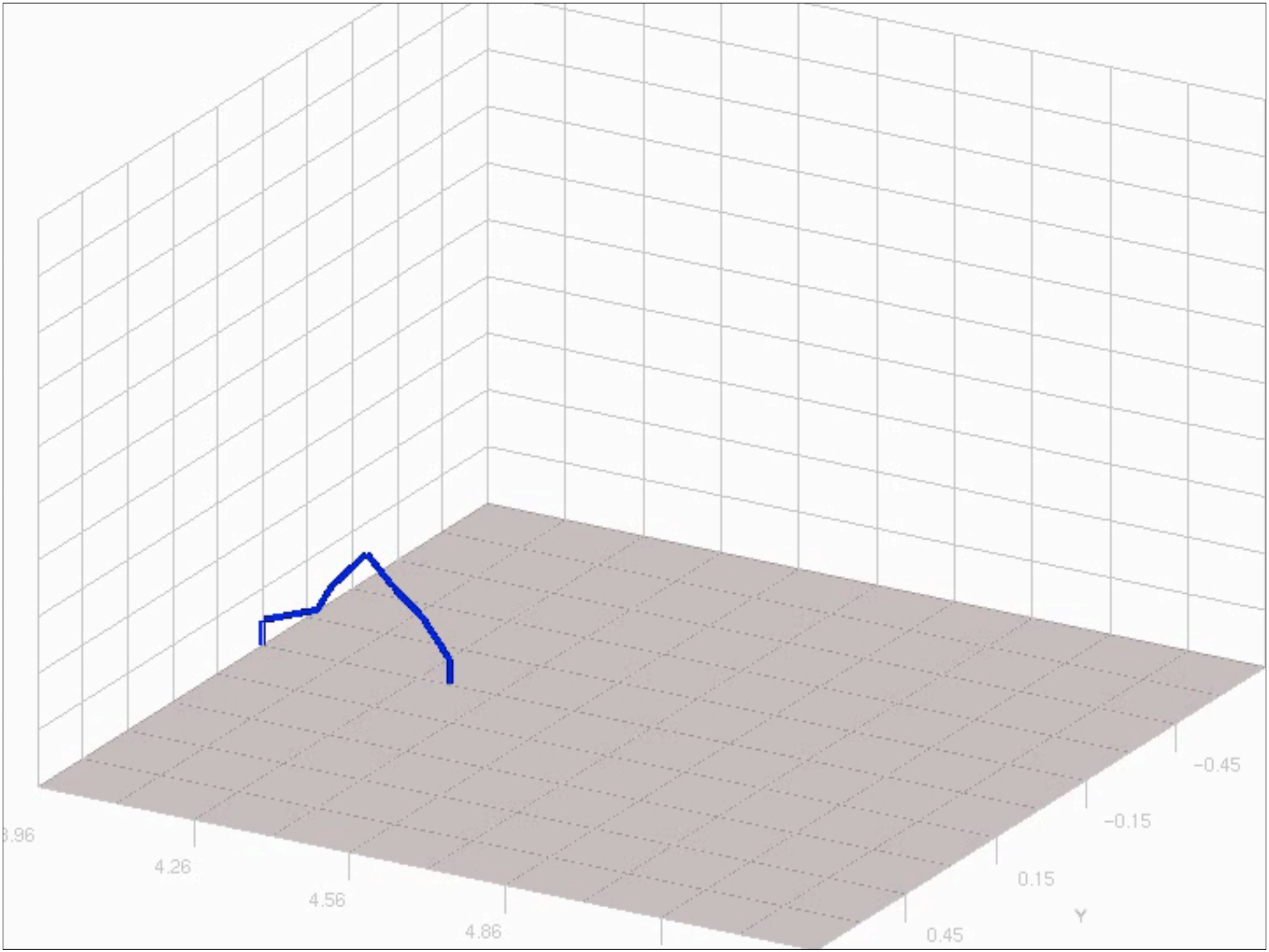
K.I. Skau et al. BPJ 91, 2475 (2006)
M. Rief et al. PNAS 97, 9482 (2000)



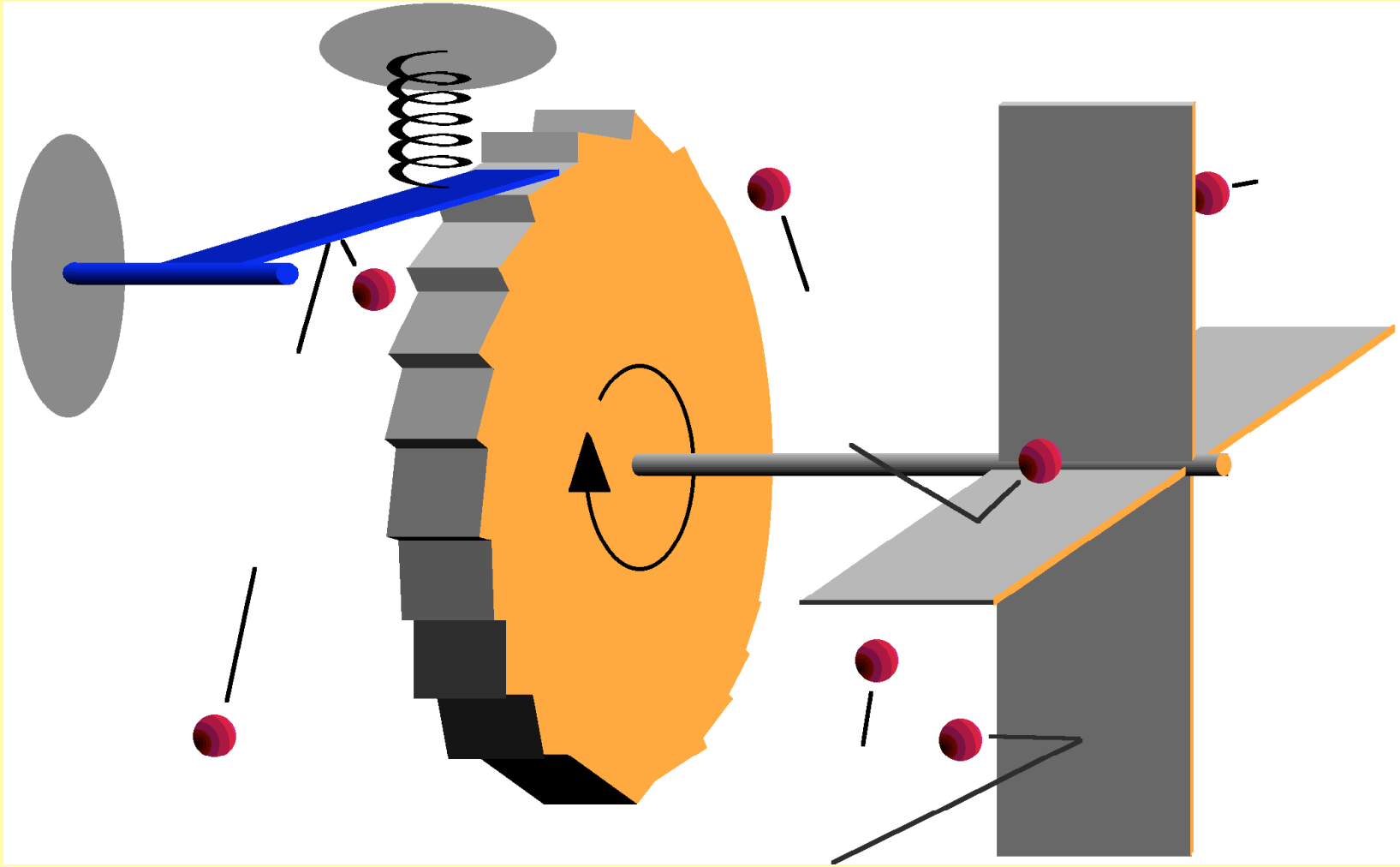
Myosin V: 3D model



Erin Craig


3.96
4.26
4.56
4.86
0.45
0.15
−0.15
−0.45
Y

Feynman's Ratchet



Adapted from: Feynman Lectures on Physics, Vol. 1, Ch. 46

Lessons from thermal fluctuations

Forget about "**robot arms**" (Kurzweil, p. 233):

At body temperature, the motion or position of a nanoscale arm cannot be controlled.

Its very notion becomes meaningless.

Lessons from thermal fluctuations

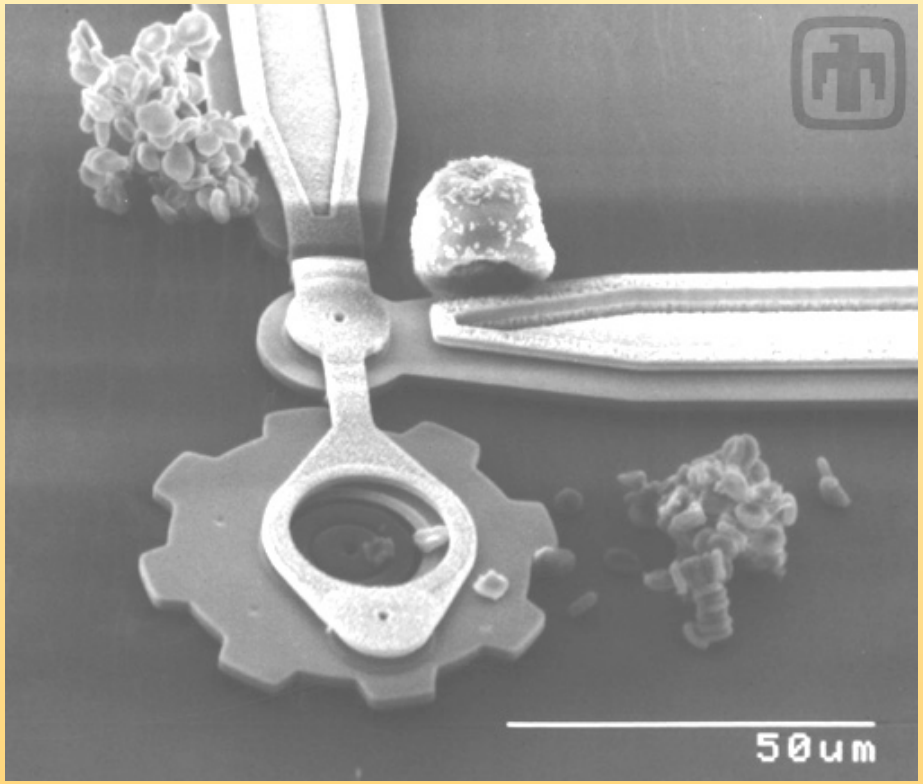
Forget also about "**molecular-scale mechanical components such as gears, rotors, and levers**" (Kurzweil, p. 234):

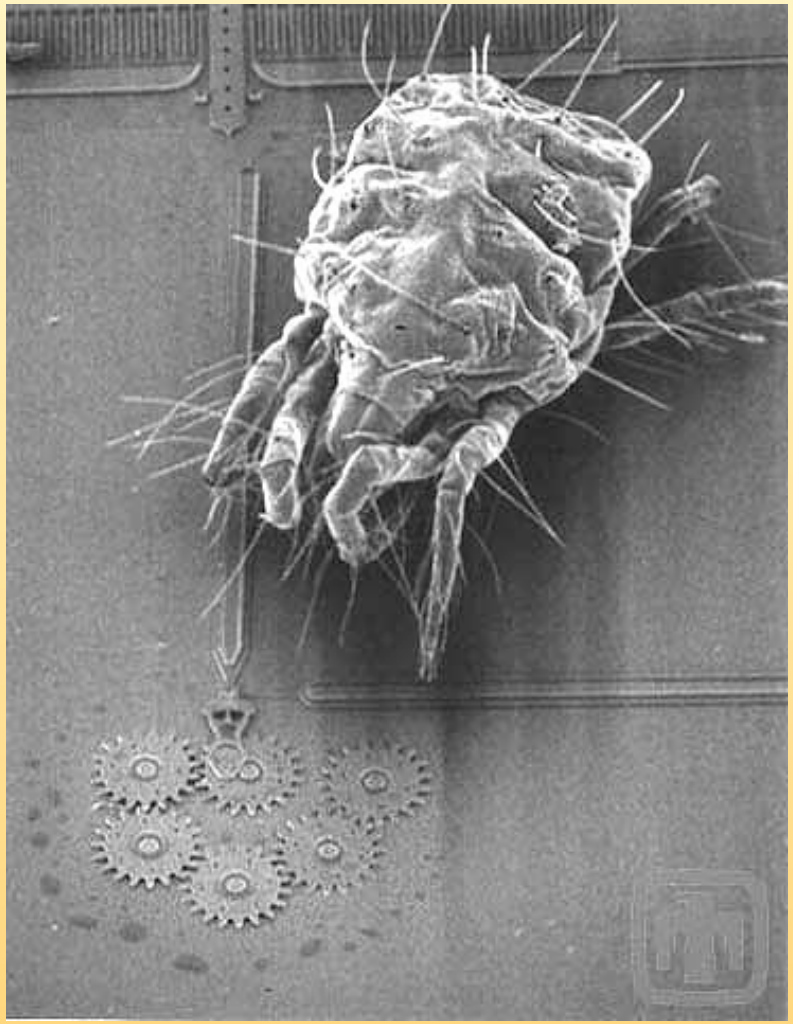
Near room or body temperature, none of these can function the way their names suggest.

Some synthetic systems that do exist

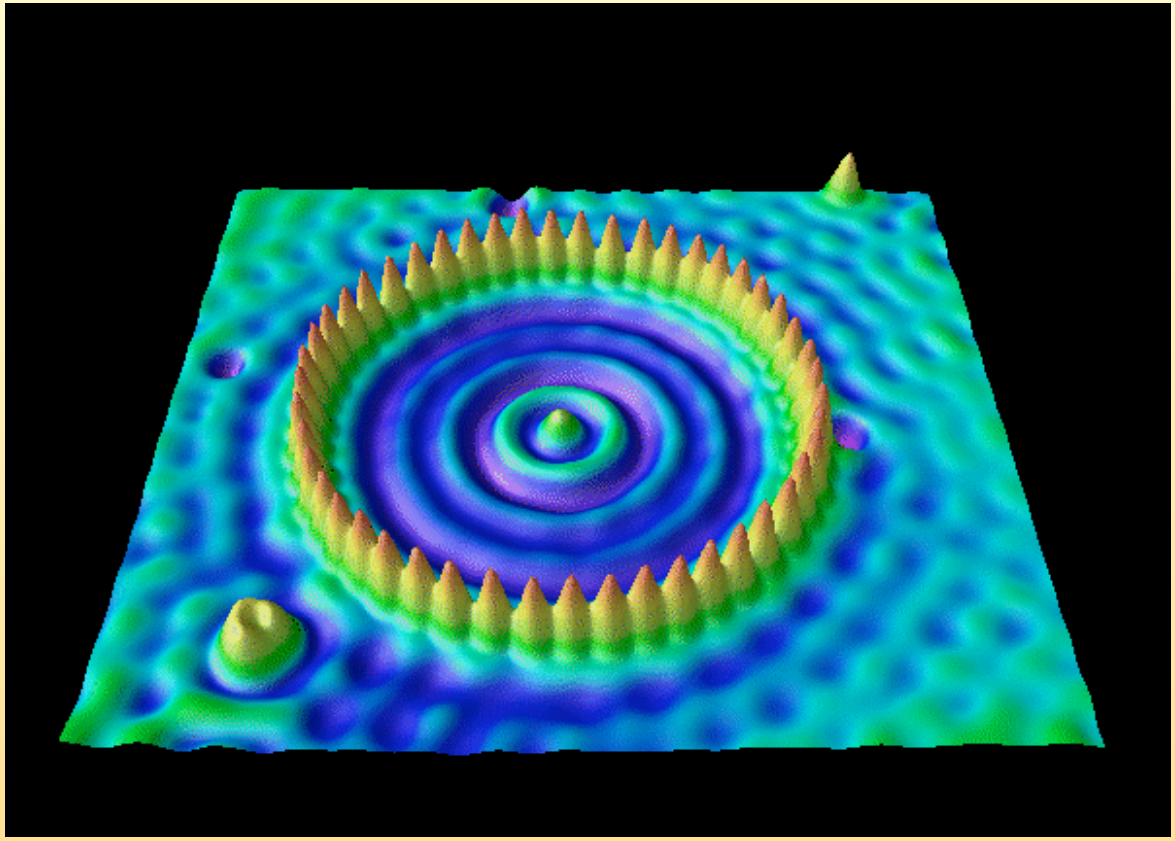
Gears

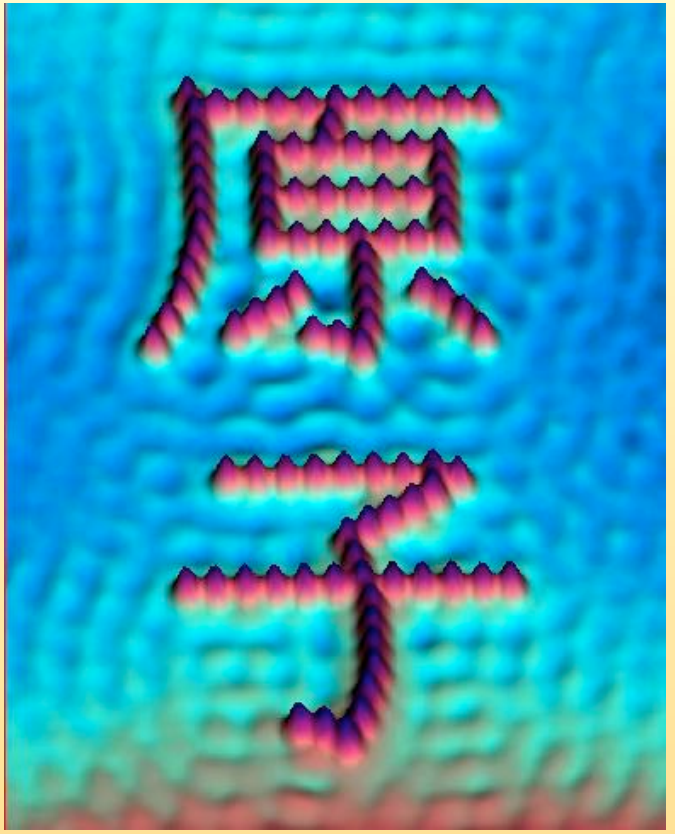
(but **not**
molecular scale)





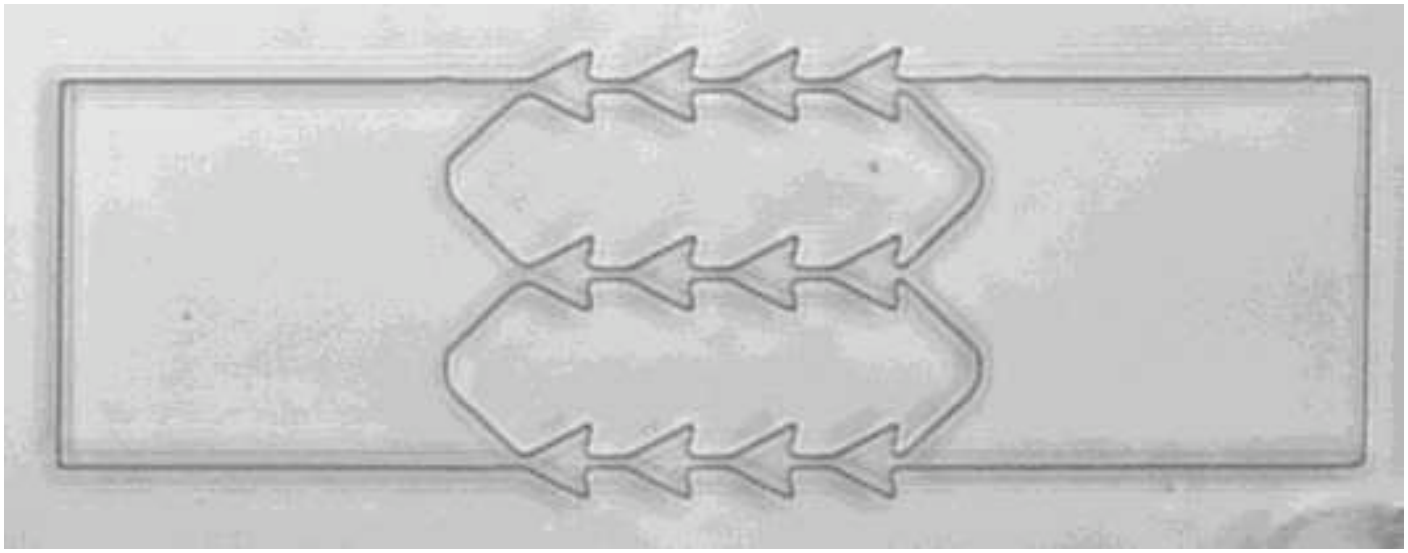
Positioning of atoms

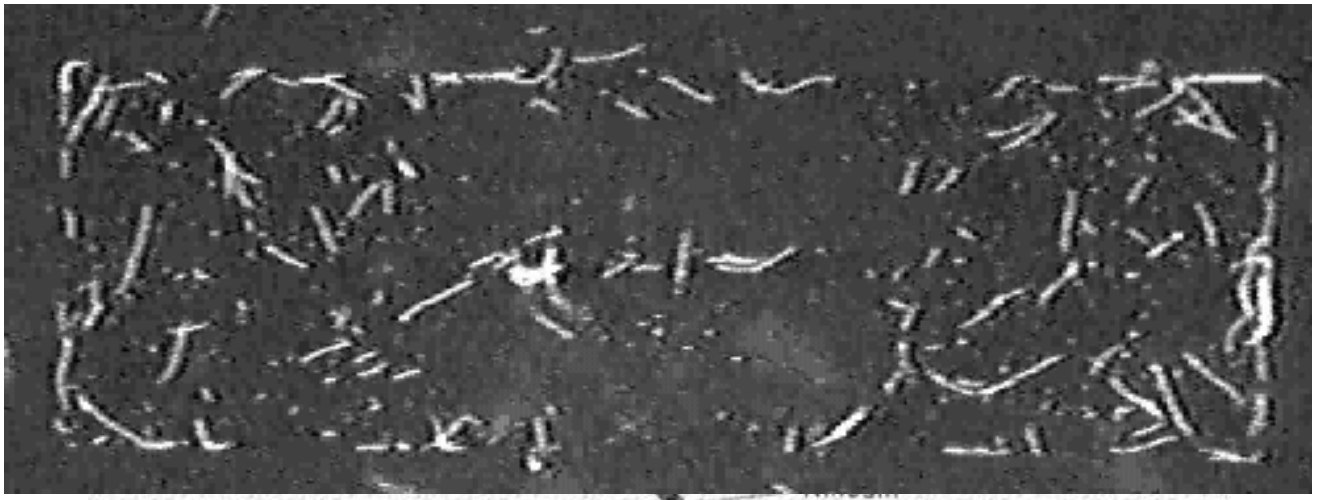


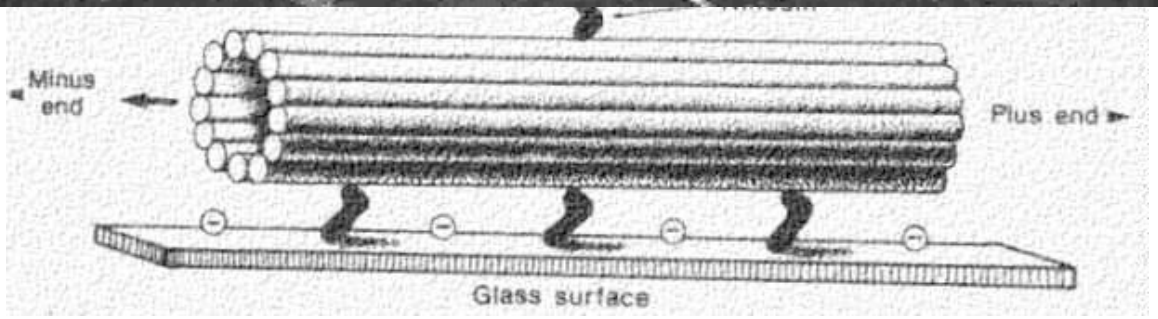


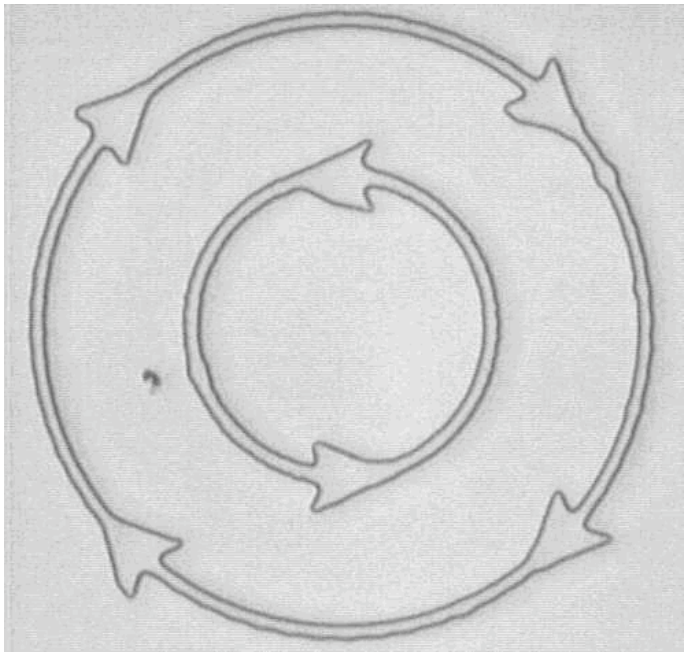
http://www.almaden.ibm.com/vis/stm/images/stm.gif

This really is “molecular scale”. Performed at -296 C (4K from absolute zero) under ultra-high vacuum conditions.

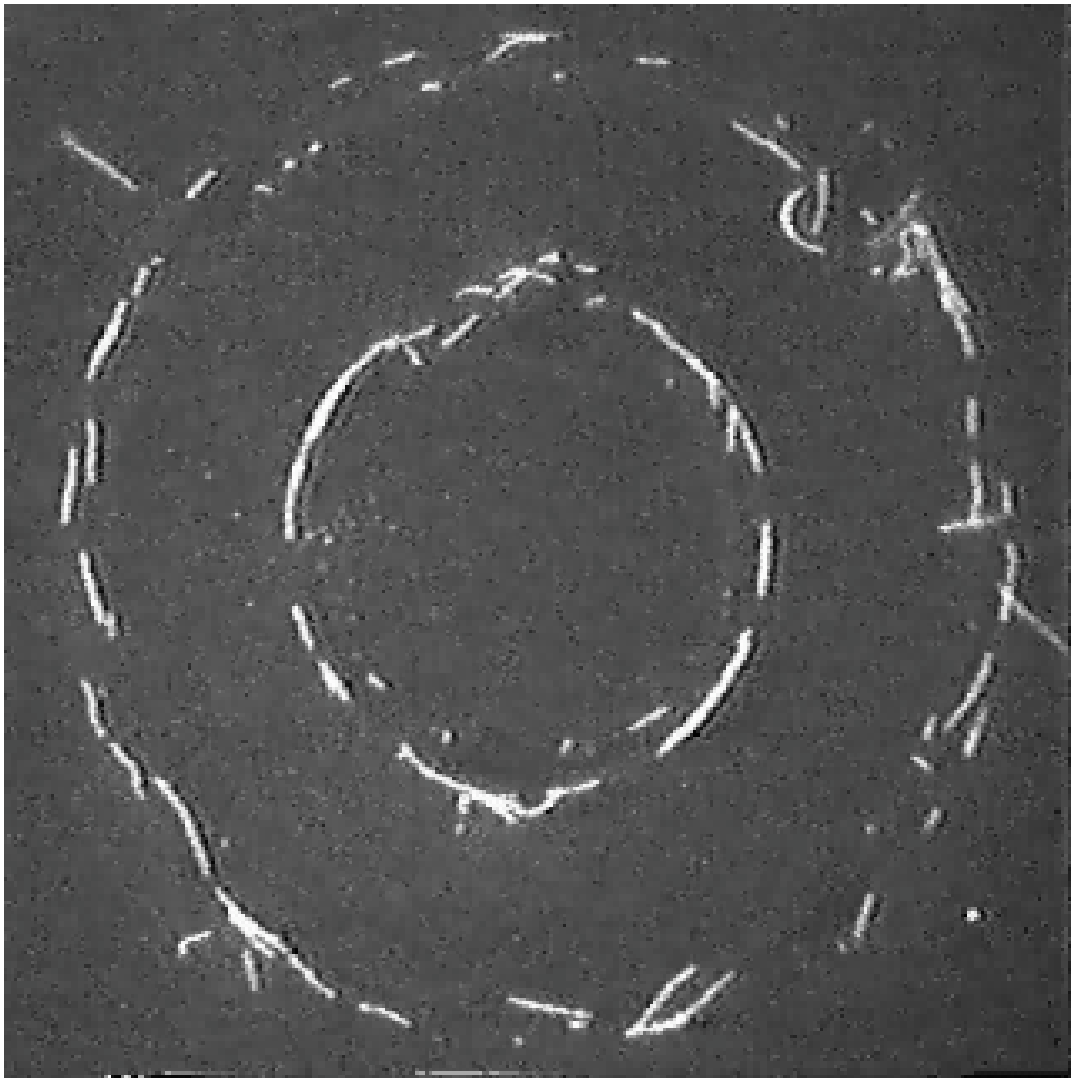





Minus end
Plus end
Glass surface



20 μm



Hiratsuka, Tada, Oiwa, Kanayama, Uyeda
Biophys. J. 81, 1555 (2001)
http://unit.aist.go.jp/genediscry/motility/biophysj/moviedl.html

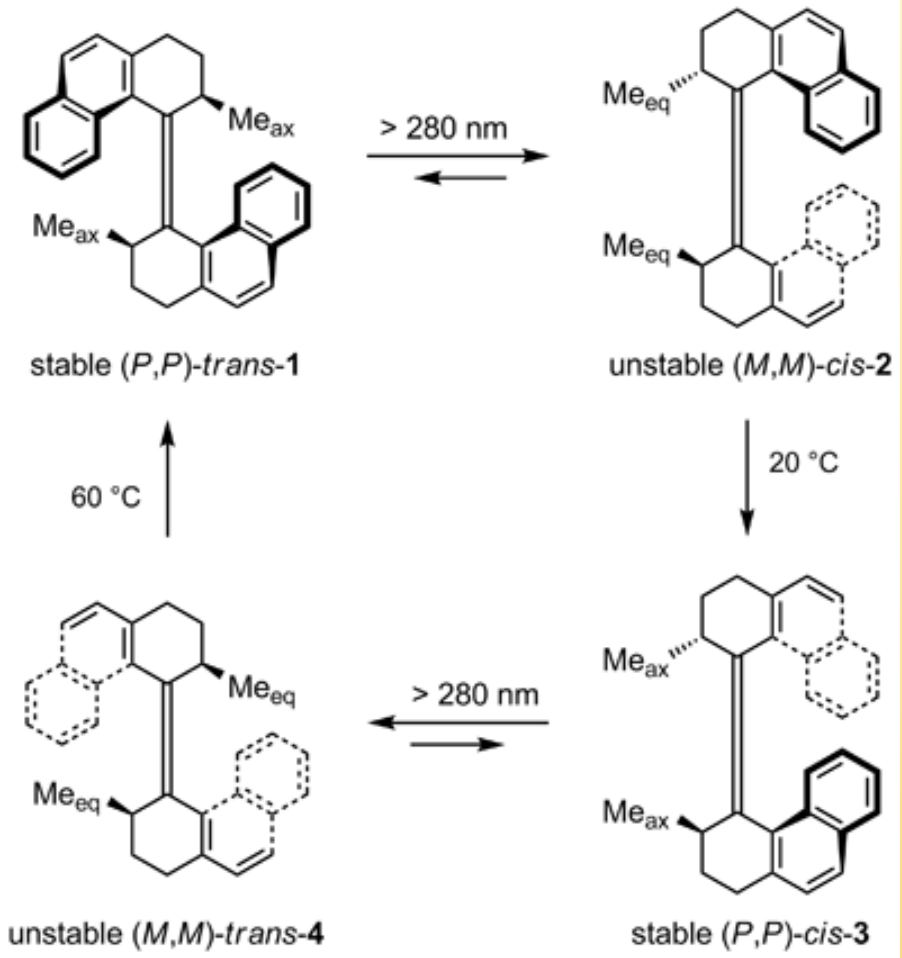
Kurzweil, p. 234

"In the decade since publication of Drexler's *Nanosystems,* each aspect of Drexler's conceptual designs has been validated...through simluations...and...actual construction of related molecular machines....

Another molecular sized motor fueled by solar energy was created out of 58 atoms by Ben Feringa ... in the Netherlands."

What really has been done

- Solution chemistry
- NMR needed to detect any changes
- Several hours per “revolution”
- Light wave length 280 nm (UV).
- Thermal cycling needed (impossible in human body)



Kurzweil, p. 241

"By the 2020s molecular assembly will provide tools to effectively combat poverty, clean up our environment, overcome disease, extend human longevity..."'

Molecular assembly = chemistry: will likely achieve some progress in some areas.

Molecular assembly = nanobots: Basis for 2020 claim? No serious nano*scientist* would agree with any of this.

Telegraph.co.uk

Today's headline:
Former royal butler could face inquiry over allegations he lied to Diana inquest.

Micro-robot that can clear arteries

A microscopic robot small enough to travel through blood vessels has been built by scientists.

Less than a millimetre in size, the robot walks like a crab on six legs and has been designed to clear blocked arteries.

It was produced by researchers at Chonnam National University in Korea, who found the robot was able to travel 55 yards in a week.

Once inside a blocked artery, it is able to release drugs to dissolve blood clots, which are often the cause of heart attacks.

By attaching grafted heart muscle to the legs, the scientists found the legs would bend as the muscle cells contracted. The cells get their energy from sugar in the patient's blood.