PH 481/581 Introduction to Nano-Materials Science and Engineering

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Tu,Th 18:40 – 20:30

web.pdx.edu/~pmoeck/nanoMSE.htm

Outline

What is nanotech? Is it new? Is it dangerous?

Incremental, evolutionary, and radical nanotech

Approach of the Oregon Nanoscience and Microtechnologies Institute

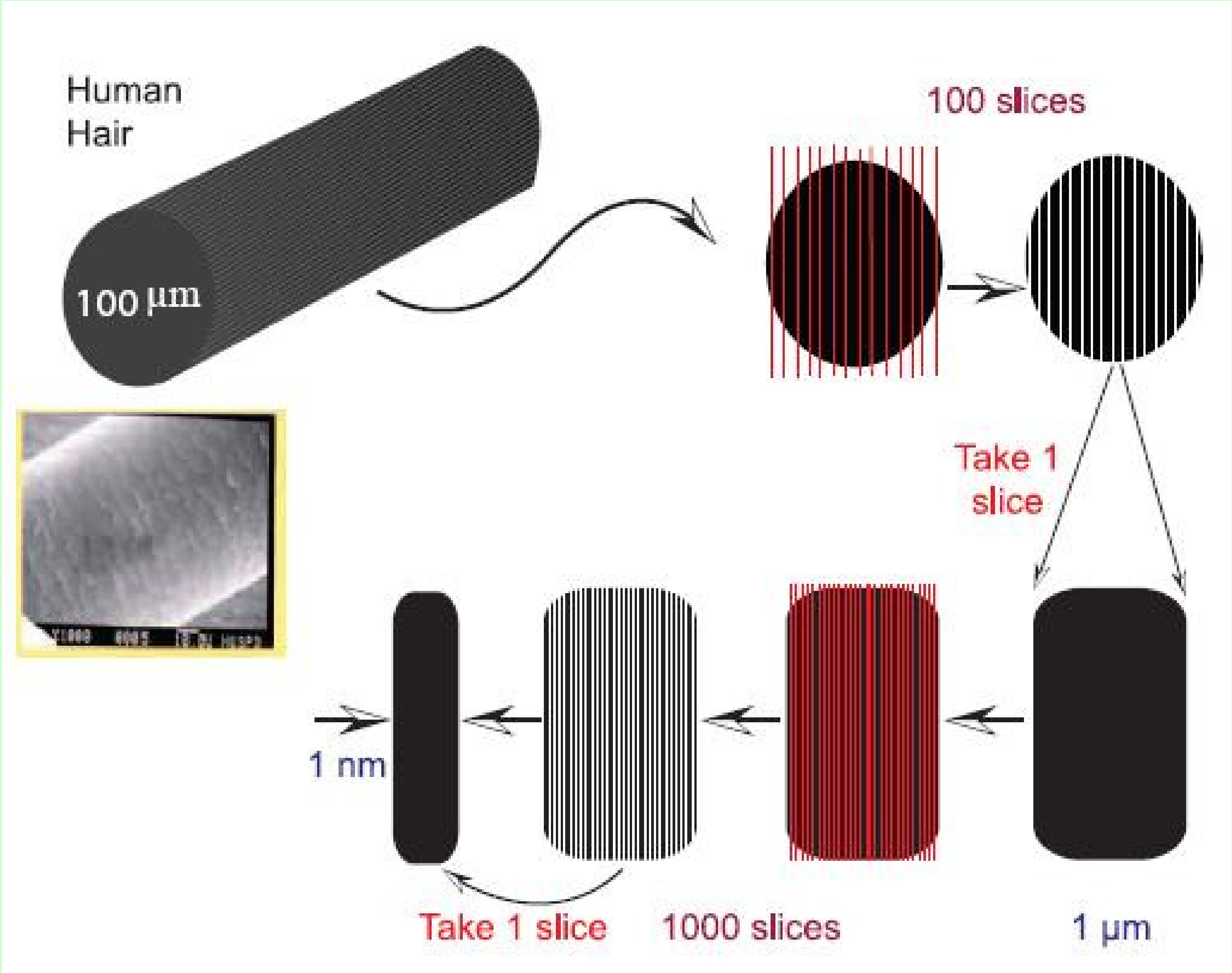
Nano-materials science and –engineering tetrahedron

Summary and Conclusions

Just how small is nano?

Name	Abbrev.	Sci. Unit	Representative objects with this size scale
metre	m	1	Height of an about 7-year-old child.
deci-	dm	10^{-1}	Size of our palm.
centi-	cm	10^{-2}	Length of a bee.
milli-	mm	10^{-3}	Thickness of ordinary paperclip.
micro-	μm	10^{-6}	Size of typical dust particles.
nano-	nm	10^{-9}	The diametre of a C_{60} molecule is about 1 nm.
pico-	pm	10^{-12}	Radius of a Hydrogen Atom (in ground state) is about 50 pm.
femto-	fm	10^{-15}	Size of a typical nucleus of an atom is 10 fm.
atto-	am	10^{-18}	Estimated maximal size of an electron.

Scaling Down to Nanometer



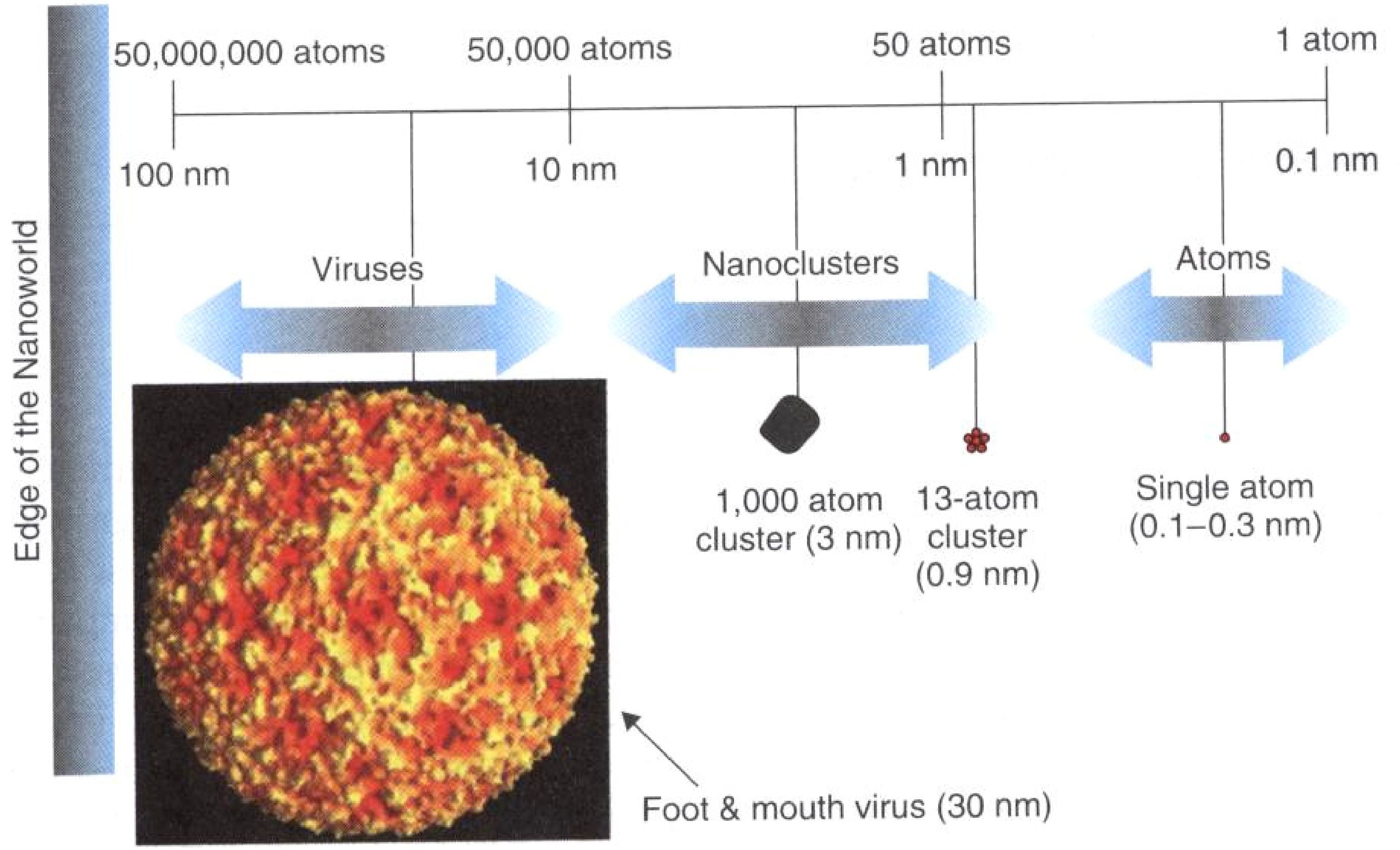


Fig. 0.1 The nanoworld. The size range of interest in nanotechnology and some representative objects.

Scale of Things

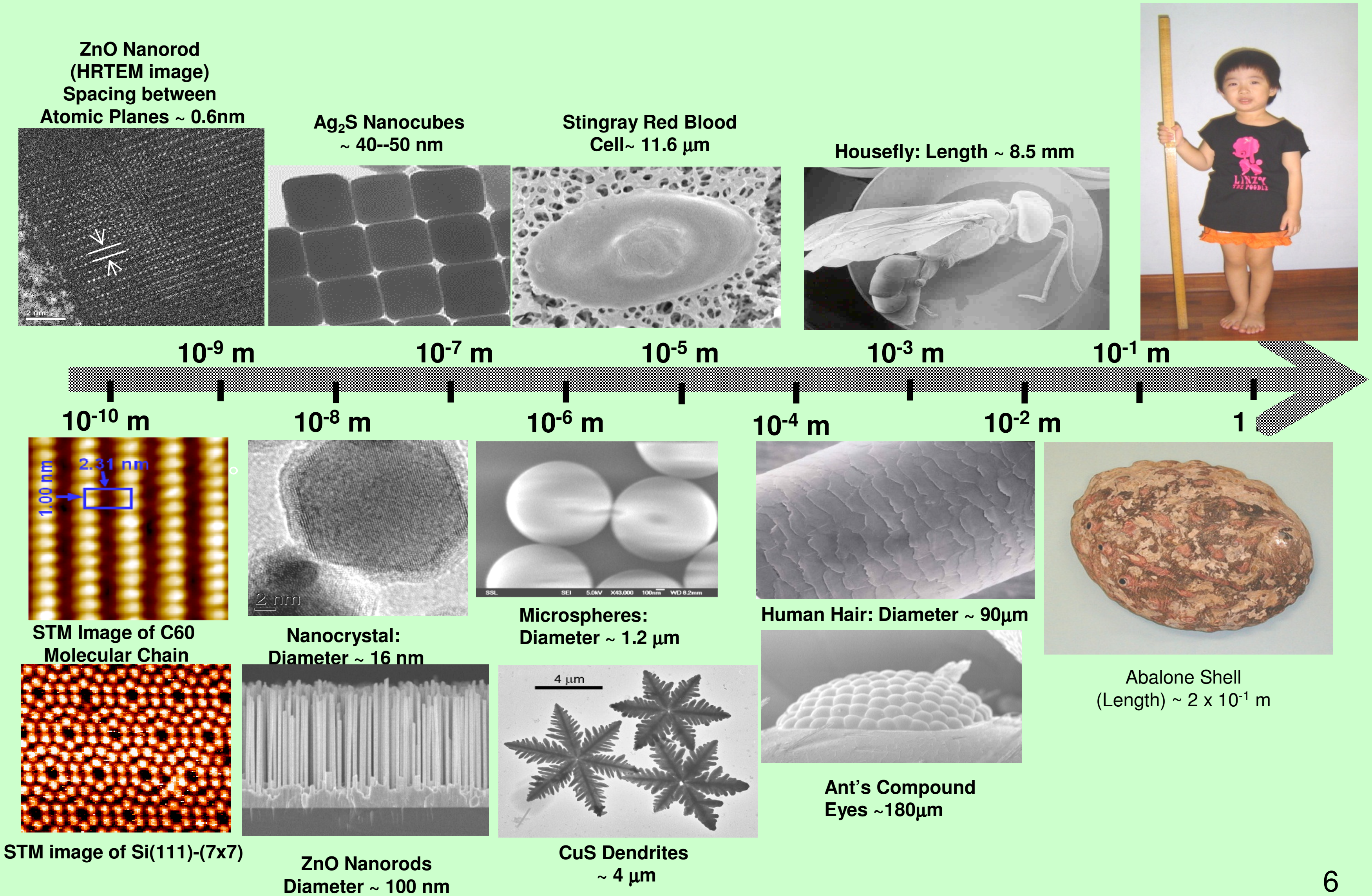


TABLE 1.4. Examples of Material Systems on the Size Scale

Size	Scientific Notation (m)	Example (In This Neighborhood)	Observation Tools/ Techniques
1.7 m	1.7×10^{0}	Human height	Human eye
1 cm	1×10^{-2}	Wedding ring	Human eye
1 mm	1×10^{-3}	Thickness of a CD	Human eye Optical microscope
100 µm	1×10^{-4}	Plant cell	Human eye Optical microscope Electron microscope
10 µm	1×10^{-5}	Animal cell	Human eye Optical microscope Electron microscope
1 µm	1×10^{-6}	Bacterial cell	Optical microscope Electron microscope
100 nm	1×10^{-7}	Virus	Electron microscope
10 nm	1×10^{-8}	Virus, Protein molecule	Electron microscope
1 nm	1×10^{-9}	Protein molecule, aspirin molecule	Electron microscope
100 pm	1×10^{-10}	Water molecule	Electron microscope
		Atoms	Indirect observation by tools (e.g., cyclotrons)
0.001 pm	1×10^{-15}	Proton	Indirect observation by tools (e.g., cyclotrons)
<1 pm	$<1 \times 10^{-12}$	Other subatomic particles	Indirect observation by tools means (e.g., particle accelerators and particle colliders)

Sizes of biological systems are at the nanoscale

Atom	0.1 nm up to about 0.5 nm
Water	0.2 nm
DNA (width)	2 nm
Protein	5 nm
Cell membrane	5 nm thick
Virus	75 – 100 nm
Materials internalized by cells < 100 nm	
Bacteria	1,000 – 10,000 nm
White Blood Cell	10,000 nm

Living objects consists of self assembled "nano-machines", i.e. cells, that actually work for some time (outside of the realm of isolated system where the second law of thermodynamics requires that everything gets more disordered over time), nothing man made is comparable so far

TABLE 11.4. Summary of the Molecules of Life

Category of Molecules	Components	Examples and Functions
Carbohydrates	Monosaccharide (simple sugar) monomers	**Monosaccharide** Glucose: Source of energy. **Disaccharide** Sucrose: Most common form of sugar **Polysaccharides** Cellulose: Strengthens cell walls in plants Glycogen: Stores energy in form of glucose in animals Starch: Stores energy in form of glucose in plants
Lipids	Glycerol: Composed of three fatty acids Phospholipids: Phosphate group with two fatty acids Steroids: Four fused carbon rings with chemical groups attached to them.	Triacylglycerols (fats and oils): Storage of energy Phospholipid bilayers: Key components of cell membranes Cholesterol (steroid): Components of cell membranes Hormones (steroids): Signals that travel through the body.
Nucleic Acids	Chains of monomers called nucleotides with each nucleotide compoased of a five-carbon sugar, phosphate group, and nitrogen-containing base.	DNA: Stores all hereditary information. RNA: Carries instructions to make protein from DNA to protein-making machinery
Proteins	Composed of one or more polypeptide chains; each chain consists of covalently linked amino acids	Collagen: Structural component of bones. Defensive proteins: protect against disease Enzymes: Catalyze chemical reactions. Keratin: Structural component of hair and nails. Motor proteins: Facilitate cell movement

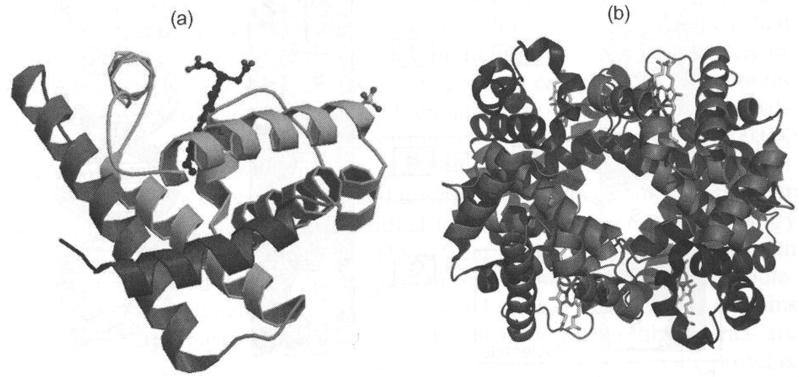


Figure 11.8. Representation of the 3D structure of protein molecules called myoglobin (a) and hemoglobin (b) at 1.6-Å resolution showing helices called alpha helices. Courtesy of the Protein data bank http://www.rcsb.org/pdb.

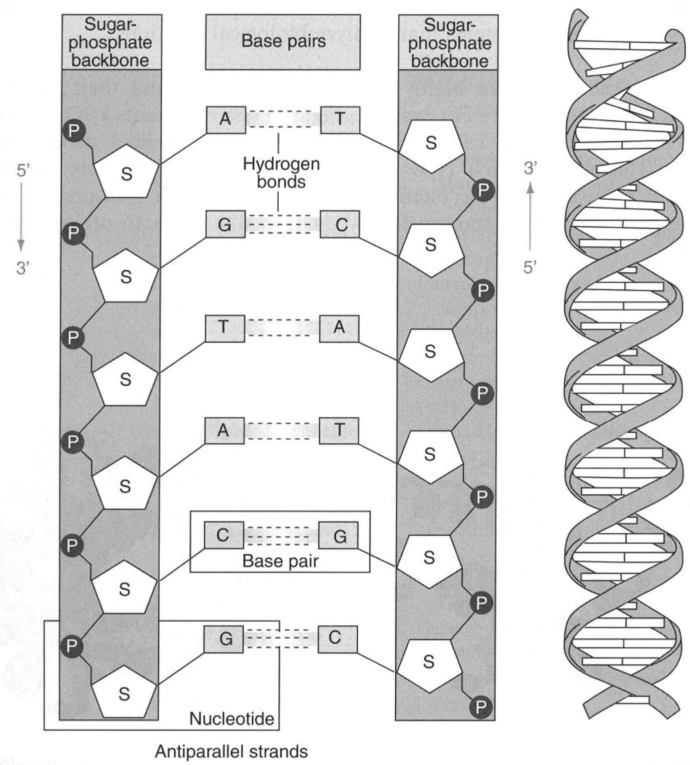


Figure 11.9. Illustration of the double helix structure of the DNA molecule that carries genetic instructions in all living things. Courtesy of the National Institute of Health.

Atomic Model of CPV Reveals the Mechanism Used by This Single-Shelled Virus to Economically Carry Out Functions Conserved in Multishelled Reoviruses

Xuekui Yu,[1,2] Peng Ge,[1,2] Jiansen Jiang,[1,2] Ivo Atanasov,[1,2] and Z. Hong Zhou[1,2,*]
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DOI 10.1016/j.str.2011.03.003

Structure *19*, 652–661, May 11, 2011

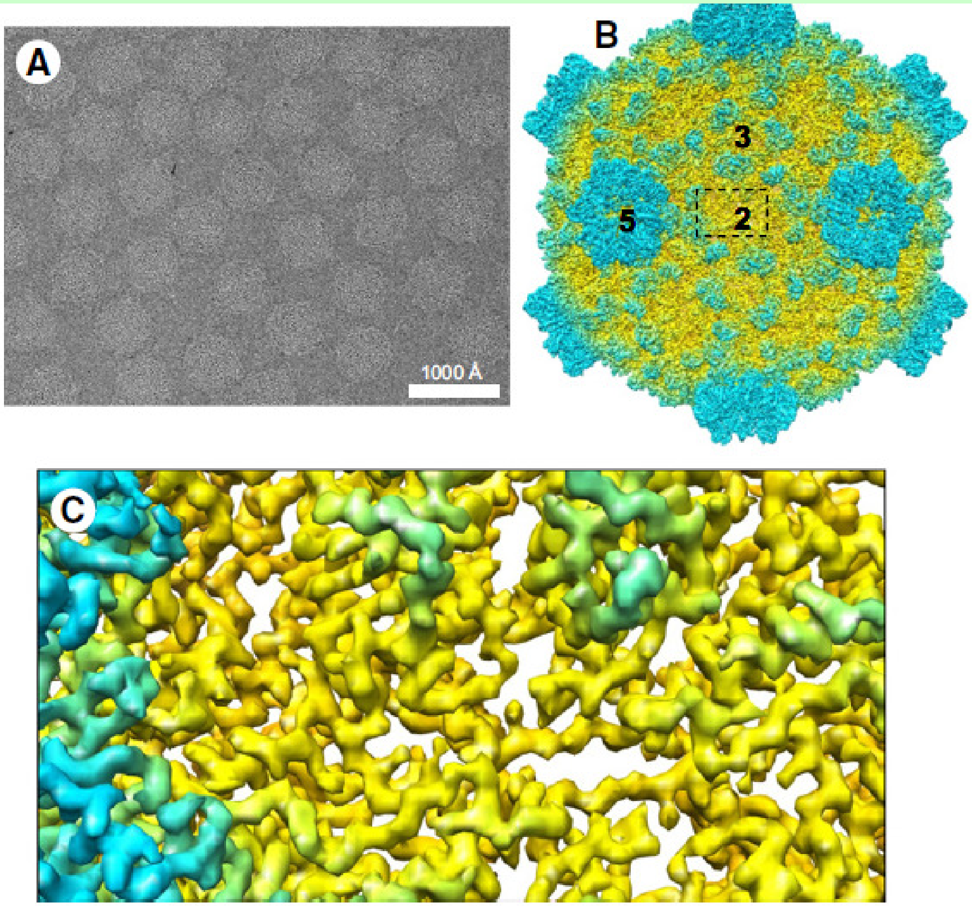


Figure 1. CryoEM and 3D Reconstruction of CPV at 3.1 Å Resolution
(A) A representative cryoEM image of CPV particles (white) embedded in vitreous ice, recorded on Kodak SO 163 film in an FEI Titan Krios cryo electron microscope operated at 300 kV at liquid-nitrogen temperature.
(B) Radially colored, shaded surface representation of the CPV reconstruction at 3.1 Å resolution, as viewed along a 2-fold axis. Three symmetry axes—one 2-fold, one 3-fold, and one 5-fold—are indicated by "2," "3," and "5," respectively.
(C) A zoom-in view of the boxed region of (B).
See also Figures S1–S4.

Table 1. CryoEM Imaging and Data Processing Statistics

Films recorded	996
Films used	645
Particles boxed	73,596
Particles included in the final reconstruction based on phase residue	28,993
Defocus range (μm)	1.15–3.45
B factor ($Å^2$)	240
Resolution (Å)[a]	3.1

[a] Based on Rosenthal and Henderson (2003) 0.143 FSC criterion.

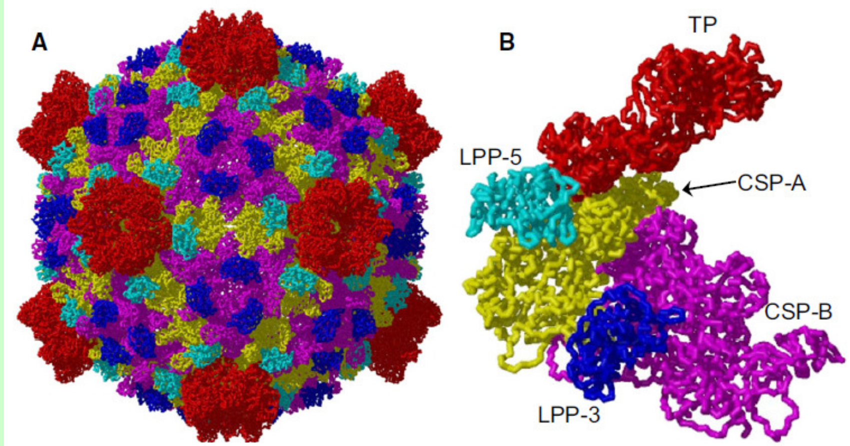


Figure 2. Atomic Model of CPV
(A and B) Atomic model of CPV capsid (A) and its asymmetric unit (B), color coded by protein subunits. TP is in red. CSP has two conformers: CSP-A (yellow), and CSP-B (magenta). LPP also has two conformers: LPP-5 (cyan), and LPP-3 (blue).

TABLE 11.5. Typical Sizes of Various Biological Particles–Structures at the Nanoscale Level

Particle	Molecular Mass (Da) Dalton = g/mol	Size: d (nm)	Type	Comment
DNA	6,569	2.5	Nucleic acids	The molecular mass is for a DNA molecule of 20 nucleotides and the size refers to the diameter of the double helix.
Glycine	75	0.42	Amino acids	Simplest of the 20 standard amino acids.
Tryptophan	204	0.67	Amino acids	One of the 20 standard amino acids. Essential in human neutrition.
Cytosine monophosphate	309	0.81	Nucleotides	Smallest DNA nucleotide
Guanine monophosphate	361	0.86	Nucleotides	A DNA nucleotide on the larger end of size spectrum
Insulin	58,00	2.2	Proteins	A polypeptide hormone that regulates carbohydrate metabolism
Hemoglobin	68,000	7.0	Proteins	Carries oxygen in human blood
Lipoprotein	1,300,000	20	Lipids and proteins	Carry fats around the body
Fibrin	400,000	50	Proteins	Involved in clotting of blood

TABLE 11.6. Typical Sizes of Various Biological Particles–Structures on a Microscopic Scale

Particle	Size: d (μm)	Type	Comments
Chloroplasts	2–10	Organelle	Structures in the cells
Human blood platelet	1.5–3	Cells	Circulating in the blood and involved in formation of blood clots
Leukocytes	8–15	Cells	White blood cells
Human chromosome	9	DNA molecules	Constitutes an organized form of DNA in a cell

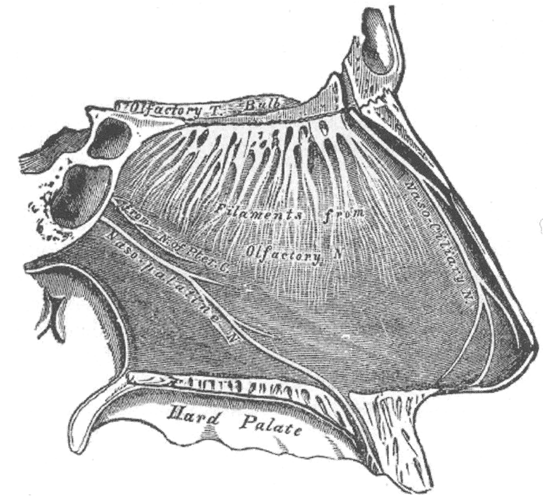


Figure 11.12. The olfactory nerve.

Note: The olfactory nerve, also called cranial nerve I, illustrated in Figure 11.12, is the first of 12 cranial nerves. It is instrumental in the sense of smell. The specialized cells of the olfactory nerve called olfactory receptor neurons are located in the olfactory mucosa of the upper parts of the nasal cavity. Sense of smell is created by the interaction of odorant molecules with the receptor neurons.

Note the size range, it is exactly where quantum mechanics applies, …

smell for example is thought of to arise from molecules binding to rather unspecific receptors in the nose but vibrating there at very characteristic frequencies, it is these vibrations that give us the sense of a small

Size Matters

- 10 centimeters

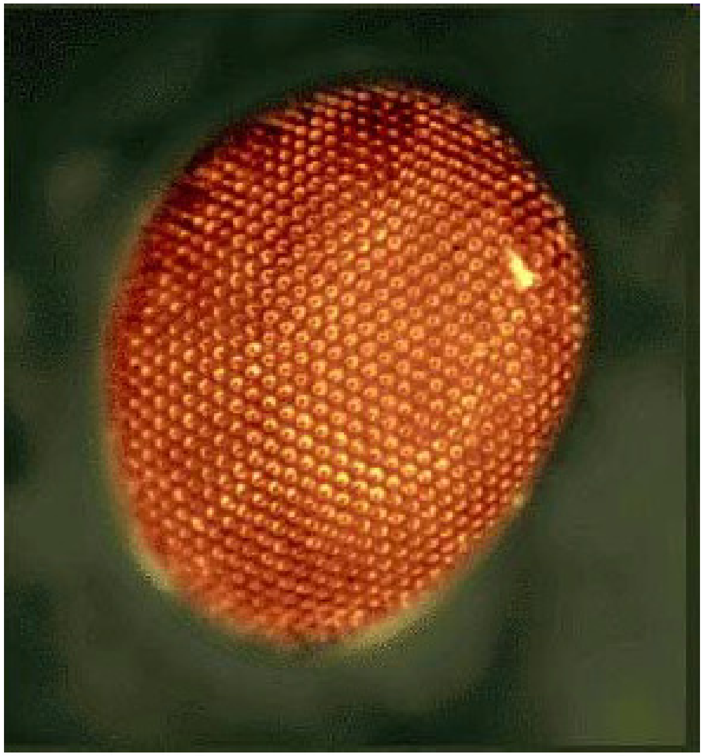
source: CERN http://microcosm.web.cern.ch/microcosm

Size Matters

- 1 centimeter

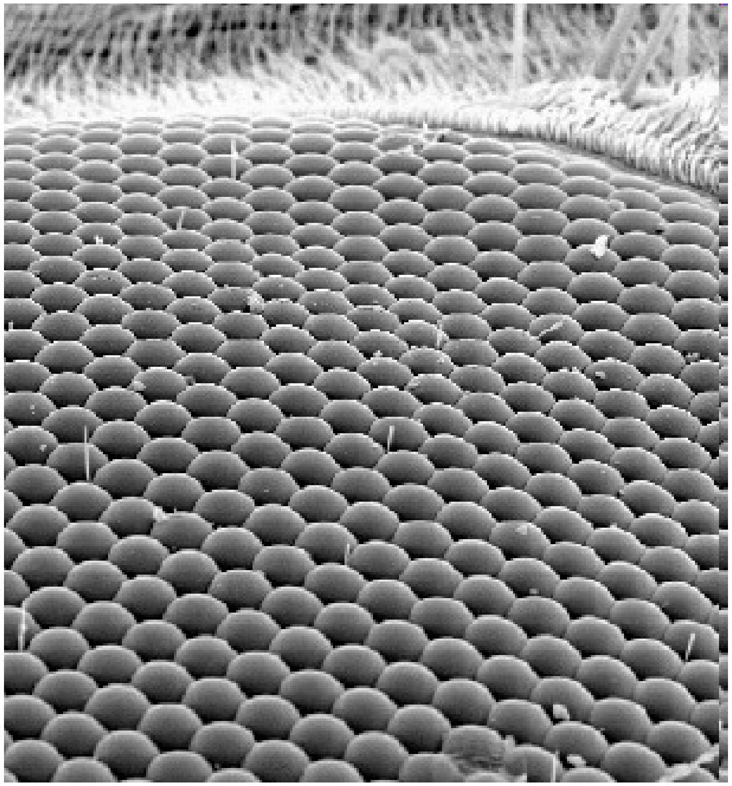
source: CERN http://microcosm.web.cern.ch/microcosm

Size Matters



- 100 micrometers
- The fly's eye is made of hundreds of tiny facets, resembling a honeycomb.

Size Matters

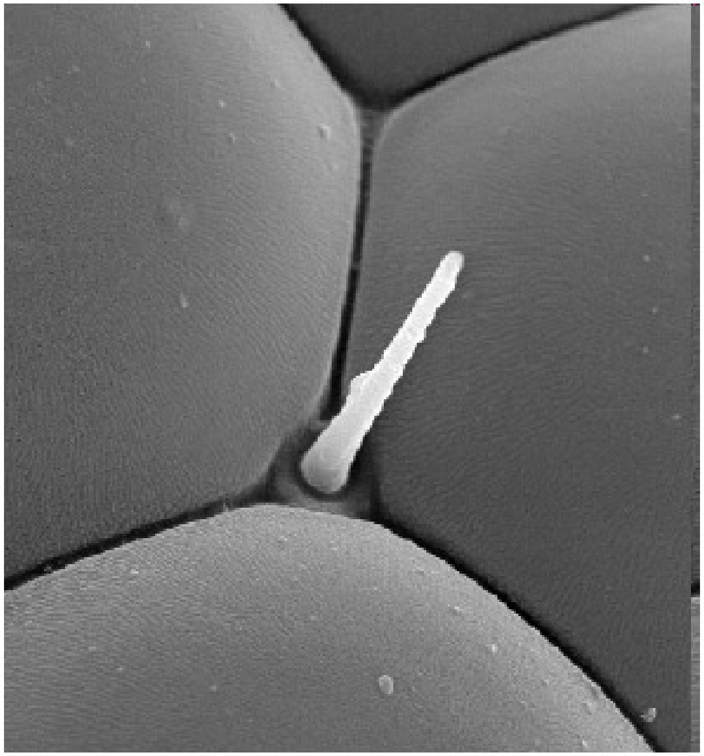


- 10 micrometers
- The fly's eye is made of hundreds of smaller eyes. Each facet is a small lens with light sensitive cells underneath.

source: CERN

http://microcosm.web.cern.ch/microcosm

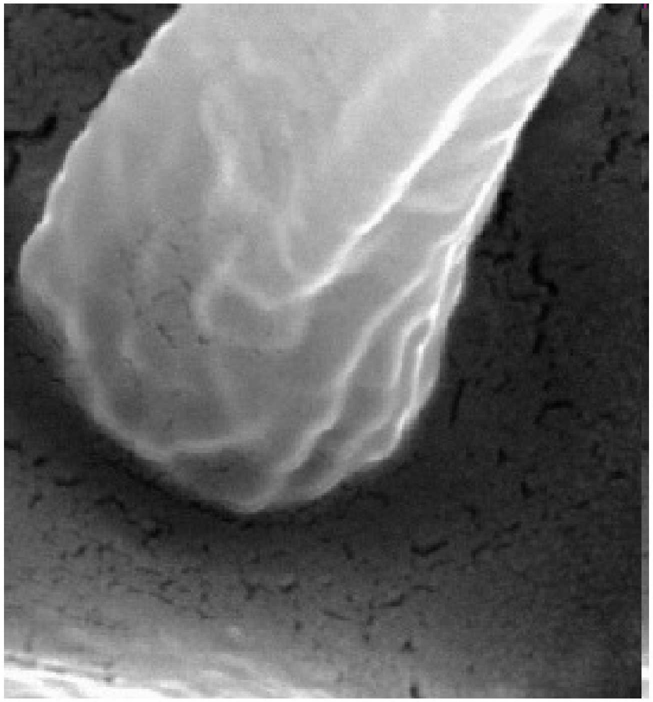
Size Matters



- 1 micrometer
  - In between the facets are bristles which give sensory input from the surface of the eye.

- source: CERN http://microcosm.web.cern.ch/microcosm

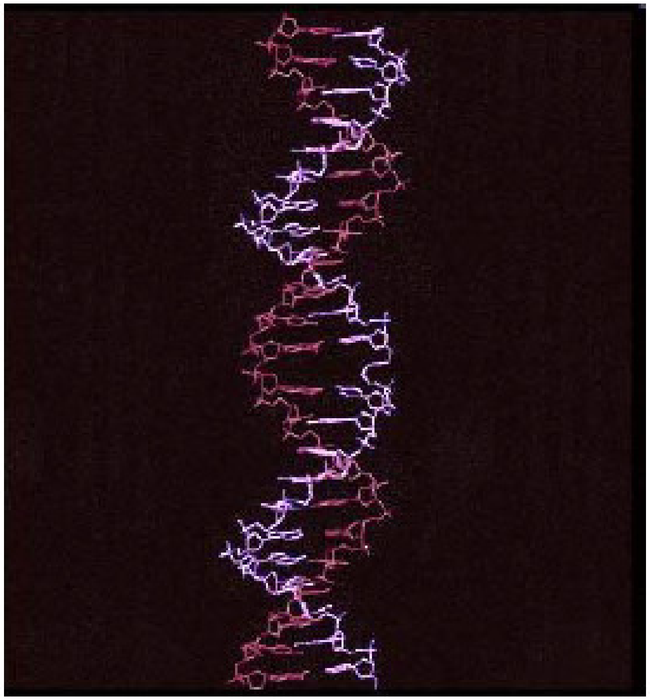
Size Matters



- 100 nanometers

source: CERN
http://microcosm.web.cern.ch/microcosm

Size Matters

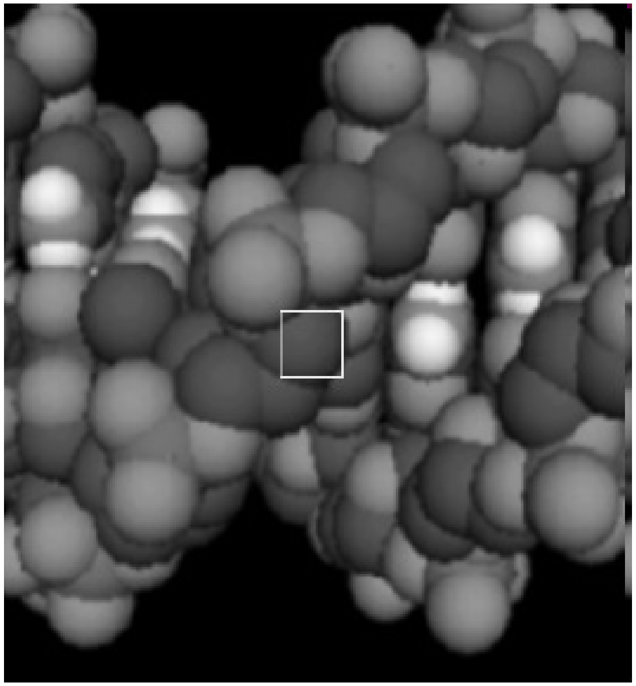


"Diameter" of chain: 2 nm

- 10 nanometers
  - At the center of the cell is the tightly coiled molecule DNA.
  - **It contains the genetic material needed to duplicate the fly.**

source: CERN http://microcosm.web.cern.ch/microcosm

Size Matters



- 1 nanometer

source: CERN
http://microcosm.web.cern.ch/microcosm

Size Scales
Caeser's last breath

- 1 mole at STP occupies 22.4*l*, one breath is ca. 0.05 Mole N_2
- Mass of earth's atmosphere 5×10^{18} kg (80% N_2), 1 mole of N_2 weighs 28 g.
- Moles N_2 in atmosphere is ca. 2×10^{20}
- Fraction exhaled by Caesar: $0.05/ 2 \times 10^{20}$ 2.5×10^{-22}: 150 "Caesar Molecules"/mole
- In each breath we breath in: 0.05 x 150 or about 7 molecules

National Nanotechnology Initiative [1] spelled out the magnitude of the challenge to post secondary education in 2002, i.e. that

“*about 2 million nanotechnology workers will be needed worldwide in 10-15 years*“

by 2007 **“*nanoscience and engineering education*”** needs to be **“*enabled in at least 25 % of research universities”*.**

Except for projected size of “nanotech workforce” [2], many of the predictions of 2002 were borne out by actual developments [3], forecasted 2 million “nanotech-workers” and $1 trillion market of 2015 should triple to ***6 million workers and $3 trillion market in 2020.***

1. M. C. Roco, “The Vision and Action Plan of the National Nanotechnology Initiative”*, Proc. Comp. Nanosc. Techn.*, vol. 2, pp. 1-5, 2002.
2. P. Stephan, G. C. Black, T. Chang, “The Small Size of the Small Scale Market: The Early-Stage Labor Market for Highly Skilled Nanotechnology Workers”, *Res. Policy*, vol. 36, pp. 887-892, 2007.
3. *Nanotechnology Research Directions for Societal Needs in 2020, Retrospective and Outlook*, National Science Foundation, Springer, 2010, see also http://www.wtec.org/nano2/.

"It depends on whom you ask. Some folks apparently reserve the word to mean whatever it is they do as opposed to whatever it is anyone else does."

S. M. Block, Stanford University

Crabbed and obscure definitions are of no use beyond a narrow circle of students, of whom probably every one has a pet one of his own.

Frederick Pollock, 1845-1937

http://www.yourdictionary.com/crabbed

crab·bed (krab'id)
adjective
peevish; morose; cross
hard to understand because intricate or complicated
hard to read or make out because cramped or irregular: crabbed handwriting

Juliet:
"What's in a name? That which we call a rose
By any other name would smell as sweet."

"The grand aim of all science is to cover the greatest number of empirical facts by logical deduction from the smallest number of hypotheses or axioms."

Albert Einstein, 1879 – 1955, physicists

"One good definition is worth three axioms."

Godfrey Harold Hardy, 1877-1847, mathematician

from wikipedia, March 2011

Nanoscience

From Wikipedia, the free encyclopedia

Redirect page

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Nanotechnology

Nanoengineering

Nanoengineering is the practice of engineering on the nanoscale. It derives its name from the nanometre, a unit of measurement equalling one billionth of a meter. Nanoengineering is largely a synonym for nanotechnology, but emphasizes the engineering rather than the pure science aspects of the field.

Nanotechnology (sometimes shortened to "**nanotech**") is the study of manipulating matter on an atomic and molecular scale. Generally, nanotechnology deals with structures sized between 1 to 100 nanometre in at least one dimension, and involves developing materials or devices within that size. Quantum mechanical effects are very important at this scale, which is in the quantum realm.

Nanotechnology is very diverse, ranging from extensions of conventional device physics to completely new approaches based upon molecular self-assembly, from developing new materials with dimensions on the nanoscale to investigating whether we can directly control matter on the atomic scale.

Technology is the usage and knowledge of tools, techniques, crafts, systems or methods of organization in order to solve a problem or serve some purpose. The word *technology* comes from Greek *τεχνολογία (technología)*; *τέχνη (téchnē)*, meaning "art, skill, craft", and *-λογία (-logía)*, meaning "study of-".The term can either be applied generally or to specific areas: examples include *construction technology*, *medical technology*, and *information technology*.

US National Nanotechnology Initiative (NNI):
A possible definition

• ***Technology and research development*** at the atomic, molecular or macromolecular levels, in the length scale of approximately 1 to 100 nanometer range, ***to provide*** a fundamental understanding of phenomena and materials at the nanoscale and ***to create*** and use structures, devices and systems that have novel properties and functions because of their small and/or intermediate size.

…

• Within these larger scale assemblies, the control and construction of their structures and components remains at the nanometer scale.

M.C. Roco

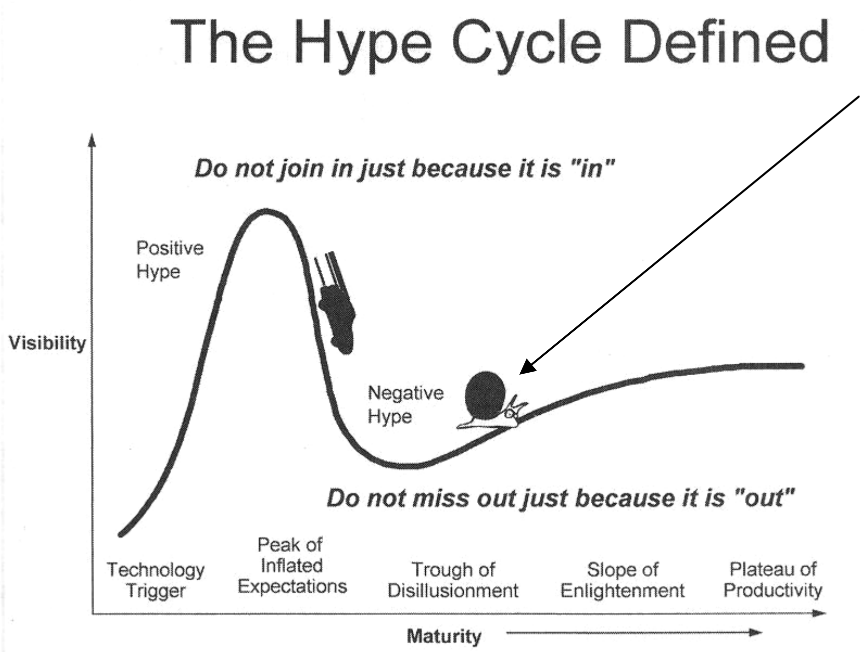
Clear enough, so there is ***purpose*** *to "usage and knowledge of tools, techniques, crafts, systems or methods of organization", so* ***nanotechnology it there to do both, the science and the engineering at the nanometer length scale***

Pieter Stroeve, University of California, Davis

Nanotechnology is an exciting interdisciplinary field which has tremendous potential to develop … novel materials, devices, sensors and processes. The development of this dynamic field depends on close collaboration between chemists, physicists, biologists, material scientists, and engineers to bring together their expertise to solve unique problems.

historically first definition of nanotechnology:

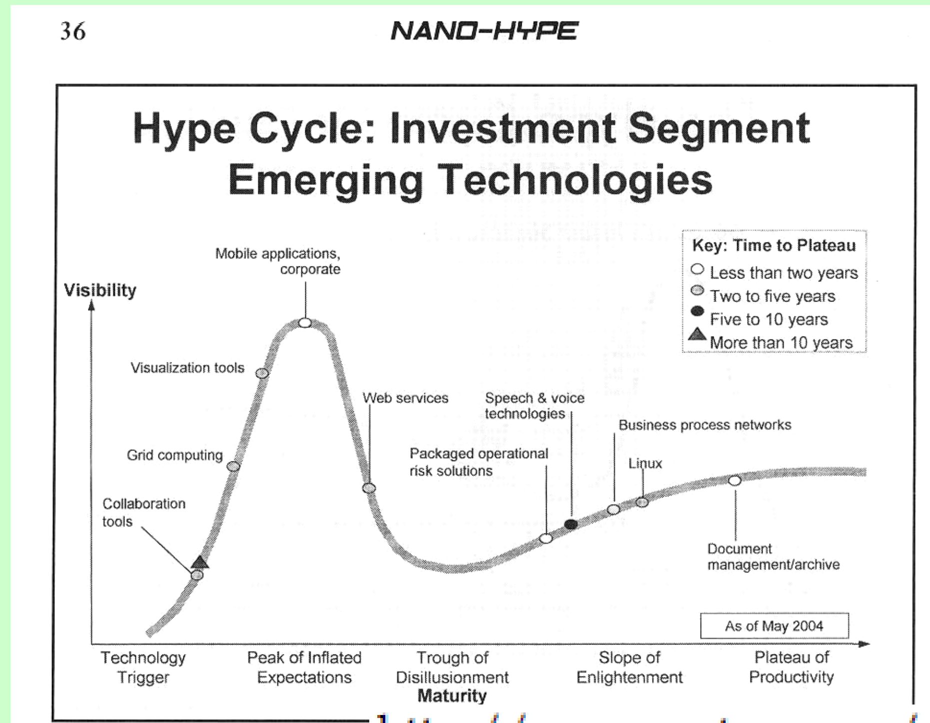
"mainly consists of the processing of, separation, consolidation, and deformation of materials by one atom or by one molecule" N. Taniguchi, "On the Basic Concept of Nano-Technology", *Proc. Int. Conf. Prod. Eng.* Part 2, pp. 18, 1974.



K. Kulinowski, "Nanotechnology: From "Wow" to "Yuck"?", *Bulletin of Sci. Technol. & Society*, vol. 24, pp. 13-20, 2004.

" Presumably, once the hype recedes, a more serious discussion about the true nature of nanoscience and nanotechnology can proceed, though this may be an incorrect assumption." D. M. Berube

David M. Berube, *Nano-Hype: the Truth Behind the Nanotechnology Buzz*, Prometheus, 2007.



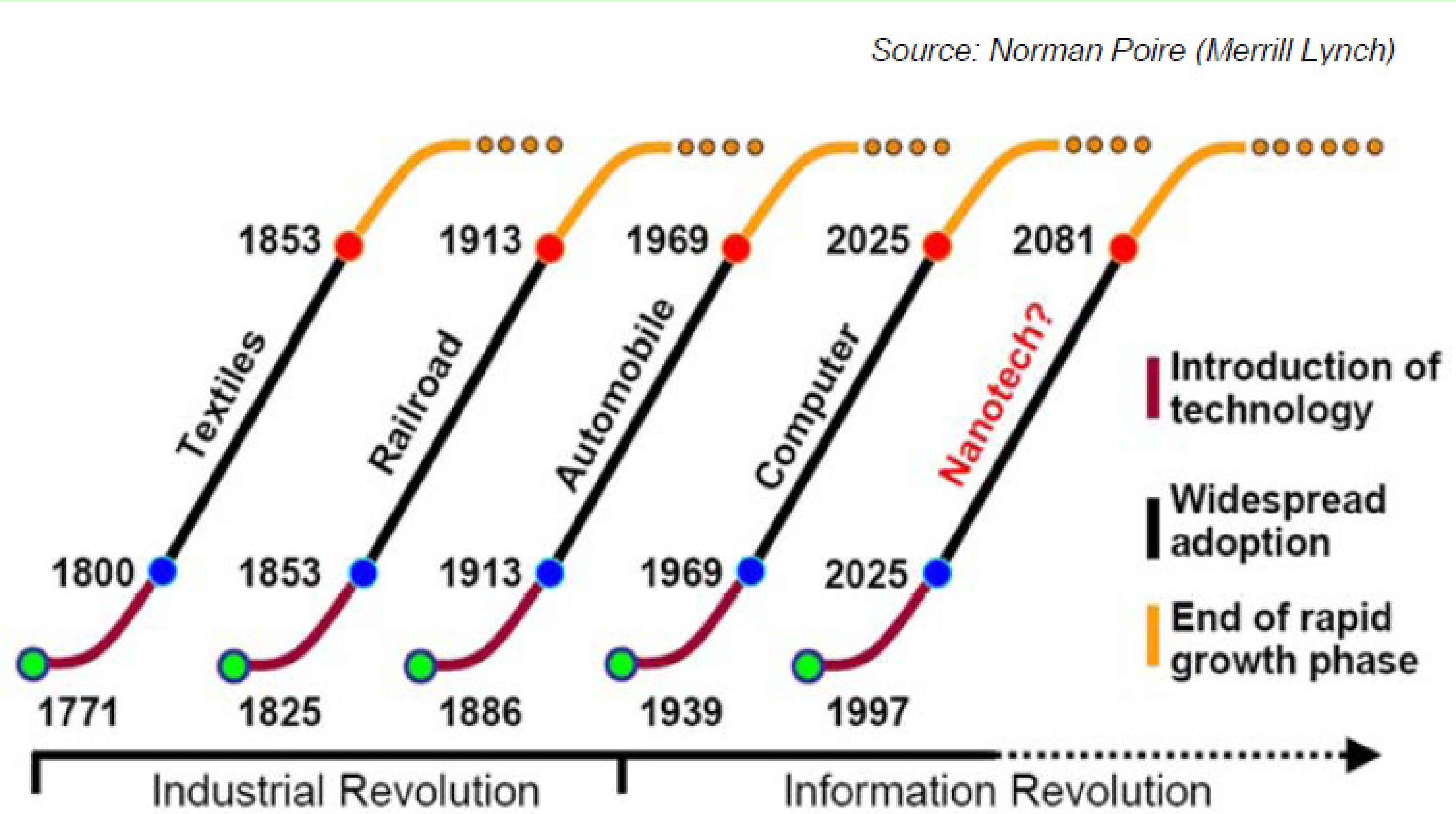
http://www.gartner.com/

Predictions **2002 ,** M.C. Roco, NSF

US $1 trillion of nano-enabled products , "*about 2 million nanotechnology worked will be needed in 10 to 15 years*"

In 2010: *"both the number of worldwide nanotech-workers and the size of the "nanotech-enabled products market" will double approximately every three years.*

“Nanotechnology has become a favorite, and successful term among America’s most fraudulent stock promoters, see M. Reisch, Chem. Eng. News **82** (2004) 82” quoted from V. Balzani, small **1**(3), p. 278-283 (2005)



Allegedly, significant innovations come along only twice per century

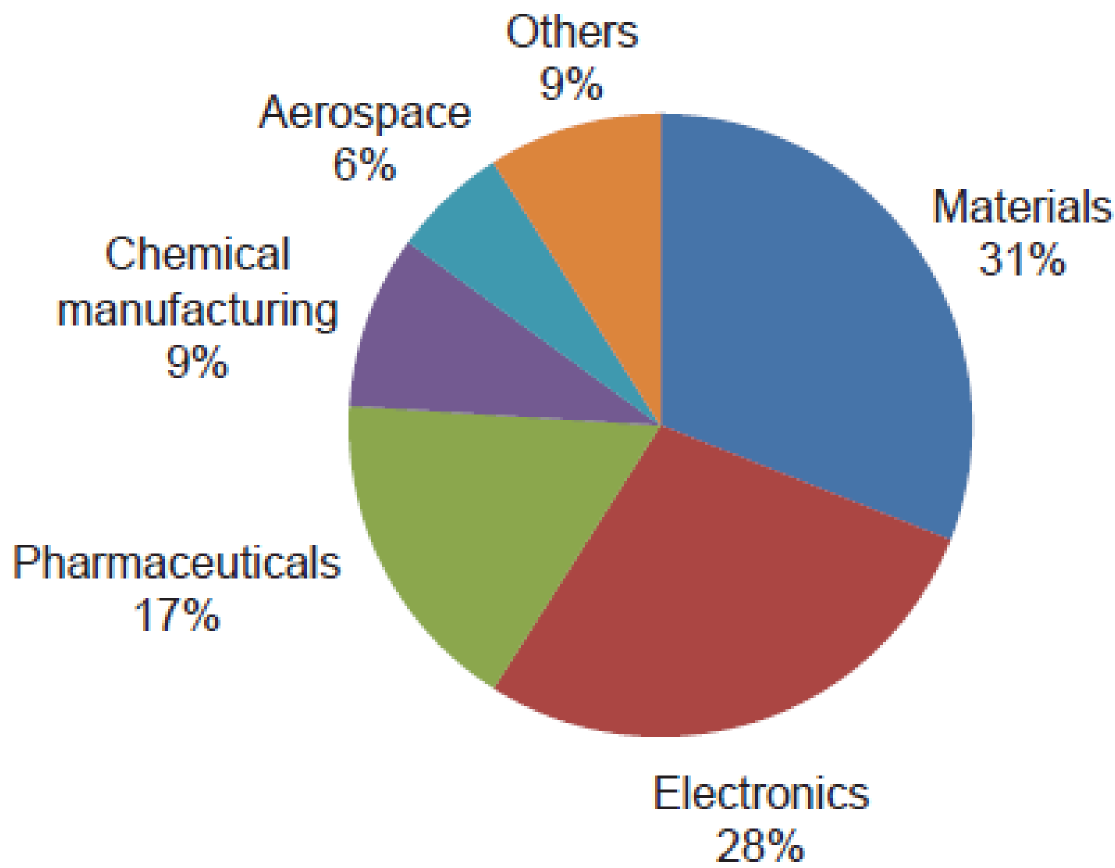


Figure 9.1. Estimates of the US$1.1 trillion nanotechnology market by 2010–2015 (Source: National Science Foundation, USA).

Predictions, M. Roco, NSF

2002 US $1 trillion of nano-enabled products , "*about 2 million nanotechnology worked will be needed in 10 to 15 years*"

2010: *"both the number of worldwide nanotech-workers and the size of the "nanotech-enabled products market" will double approximately every three years".*

"The nature of nanotechnology seems to be as obscure as its origin." V. T. Yadugiri, R. Malhotra, 'Plenty of room' – fifty years after the Feynman lecture, Current Science 99(7), 900-907, 2010

So when we have clarified what its nature might be, we should also explore its origin(s).

small 2005, 1, No. 1

The Beginning of a *Small* Revolution

*Chad A. Mirkin**

What is the nanoscience and technology opportunity?

To discuss a field in a meaningful way, a definition and description of that field is needed. One can argue the details of an appropriate definition, but the following three-part definition captures the opportunity and distinguishes the field from other initiatives. Nanoscience and technology is a field that focuses on: 1) the development of synthetic methods and surface analytical tools for building structures and materials, typically on the sub-100 nanometer scale, 2) the identification of the chemical and physical consequences of miniaturization, and 3) the use of such properties in the development of novel and functional materials and devices.

How does the field of nanoscience and nanotechnology fit into the existing scientific and engineering disciplines?

If one thinks of the established disciplines in terms of a Venn diagram, where each scientific and engineering discipline is described by a circle within the diagram, nanotechnology is not an independent, isolated circle but rather one that overlaps all of the existing circles and will continue to grow as the field is developed (Figure 2). This is what distinguishes the field from scientific fads that have focused on a particular class of materials (e.g., high-temperature superconductors). It is a field fueled by novel tool development

What are the consequences of miniaturization?

Every substance regardless of composition, when miniaturized to the sub-100 nm length scale, will have new properties. This is where much of the scientific opportunity lies. Noble metal and semiconductor nanoparticles are beautiful examples of this principle. The optical, electrical, mechanical, magnetic, and chemical properties can be systematically manipulated by adjusting the size, composition, and shape of this class of materials on the sub-100 nanometer length

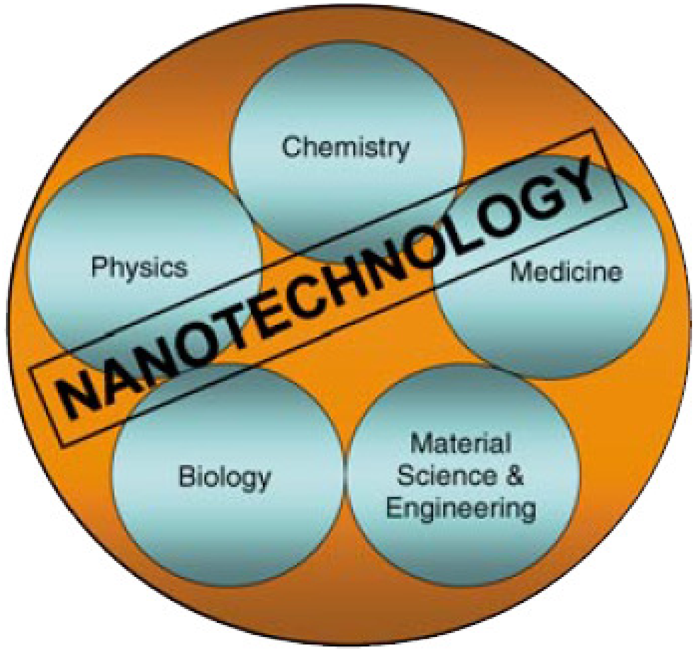


Figure 2. Nanotechnology encompasses all fields: Traditional subdisciplines each play their hand in modern nano and micro science and technology; *Small* looks to all of these areas to provide its readers with a truly interdisciplinary journal.

Nanoscience, Nanotechnology, and Chemistry**

*George M. Whitesides**

Keywords:
- chemistry
- devices
- nanoscience
- nanotechnology

DOI: 10.1002/smll.200400130

small 2005, 1, No. 2, 172–179

What is Nanoscience?

"Nanoscience" is the emerging science of objects that are intermediate in size between the largest molecules and the smallest structures that can be fabricated by current photolithography; that is, the science of objects with smallest dimensions ranging from a few nanometers to less than 100 nanometers.[1–3] In chemistry, this range of sizes has historically been associated with colloids, micelles, polymer molecules, phase-separated regions in block copolymers, and similar structures—typically, very large molecules, or aggregates of many molecules. More recently, structures

chemistry.[9,10] Synthesizing or fabricating ordered arrays and patterns of colloids poses a different and equally fascinating set of problems.[11]

Third, because many nanoscale structures have been inaccessible and/or off the beaten scientific track, studying these structures leads to new phenomena.[12–14] Very small particles, or large, ordered, aggregates of molecules or atoms, are simply not structures that science has been able to explore carefully. Fourth, nanostructures are in a range of sizes in which quantum phenomena—especially quantum

Honorary Member of the Editorial Advisory Board

George M. Whitesides received his AB from Harvard (1960) and carried out his PhD research with J. D. Roberts at the California Institute of Technology. From 1963–1982, he was a member of faculty at the Massachusetts Institute of Technology, and since then he has been at Harvard University. His present research covers, amongst others, physical organic chemistry, materials science, biophysics, microfluidics, self-assembly, micro- and nanotechnology, and cell–surface biochemistry. He is the recipient of numerous awards, including the Kyoto Prize (2003) and the National Medal of Science (1998), and is a member of the American Academy of Arts and Sciences and the National Academy of Sciences. His public roles include positions on the National Research Council, the National Science Foundation, and the National Institutes of Health.

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P. J. A. Borm and D. Berube

"One thing is sure: to fully comprehend and realize its potential, a renaissance of science and education is needed, accompanied by open minds in politics, investment funds, and grant-awarding bodies. This includes giving full attention to sustainable development, which may be enabled by new methods and protocols for testing nanomaterials for their potential adverse effects. We would benefit by heeding the following: 'nano' is a society of creative 'yes-sayers' associated, and as such it may well be that this discussion will prelude the end of environmental protectionism."

"… nanotechnology is presently more concept than fact, although it is certainly a media and funding reality".

Edward L. Wolf, Nanophysics and Nanotechnology, An Introduction to Modern Concepts in Nanoscience, Wiley-VCH, 2nd revise and expanded edition, 2006

"Nanotechnology is* science *at the size of individual atoms and molecules." Chi Anyansi-Archibong, and Silvanus J. Udoka, **Potential Ethical Concerns in Nanotechnology**, Chapter 16, pp. 261-271, Nanotechnology and Microelectronics: Global Diffusion, Economics and Policy, N. Ekekwe (ed.), IGI Global, 2010

How can a technology possibly be a science? ***NNI definition is clear about the purpose, i.e. technology being the usage and knowledge of tools, techniques, crafts, systems or methods of organization in order to solve a problem or serve some purpose.***

What the involved scientist and text book authors say

"Nanoscience" is the emerging science of objects that are intermediate in size between the largest molecules and the smallest structures that can be fabricated by current photolithography; that is the science of objects with smallest dimensions ranging from a few nanometers to less than 100 nanometers.

George M. Whitesides small vol. **1**, no. 2, (2005) 172-179

"Nanoscience is about the phenomena that occur in systems with nanometer dimensions."

Stuart M. Lindsay, Introduction to Nanoscience, Oxford University Press, 2010

"… the science *of materials whose properties scale with size."*

J. W. Steed, J. L. Atwood, Supramolecular Chemistry, Wiley 2009

"… there is no such thing as nanotechnology. Nanotechnology is now the buzzword and an umbrella term to designate nothing less than the state-of-the-art in science and technology in what is the normal progression and evolution of the relationship of humankind with its habitat and environment."

D. Jost, "Nanotechnology for Policymakers, An Introduction from the Physical Science Perspective", *nccr trade regulations*, Swiss national center of competence in research, working paper no. 2009/21, May 2009; http://phase1.nccr-trade.org/images/stories/publications/IP9/ed.Nanotechnology Introduction v9 march2009.pdf

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Wow, nothing less than the state-of-the-art in science and technology will be difficult to teach in a 4 credit hours course over 10 weeks !! So there need to be priorities, omissions, …

perhaps best thing students can pick up might be capabilities for life long learning in this field?

background and intelligence to work out for themselves what nanoscience and –technology may mean over their lifetime?

Problems: Much of what the public thinks will be shaped by the media, that will also be what some of the incoming student expect, ***so we have to fight both scaremongers and unrealistic visionaries***

I

since we have to provide ***nanoeducation***, and nanotech is according to NNI more or less technology and research development at the length scale of 1 to 100 nm, ***to provide*** a fundamental understanding of phenomena and materials at the nanoscale and ***to create*** and use structures, devices and systems that have novel properties and functions because of their small and/or intermediate size.

i.e. **both nanoscience and nanoengineering**, we have to strike a balance, in my opinion, science first, engineering second

science shall allow the students to recognize the faults of the visionaries!!!

Fantastic Voyage

1966 movie

– Journey into the living body of a human

→ Midget submarines or robots (nanobots) that swim in the human blood stream to repair people.

The Gray-Goo Problem, By LAWRENCE OSBORNE, New York Times: December 14, 2003

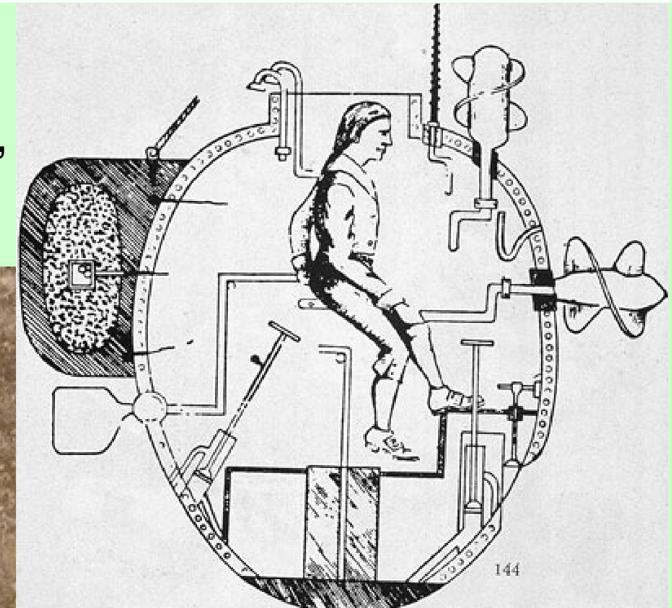
For years, many members of the scientific community have been excited by the prospect of nanotechnology, the design of machines and robots on a molecular scale. But scientific ethicists and environmental activists are increasingly alarmed by its potential abuses. In January, the ETC group, a Canadian watchdog organization for socially responsible technology, released ''The Big Down,'' a report on nanotechnology. No less a figure than Prince Charles, having read the report, publicly announced that he was distressed by something called the gray-goo problem, in which a swarm of millions of rapidly self-replicating microscopic robots, in a ravenous quest for fuel, would consume the entire biosphere until nothing remained but an immense, sludge like robotic mass.

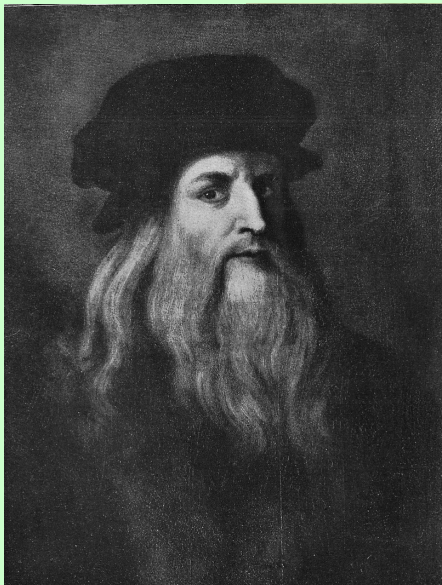
How would it happen? As Eric Drexler, a former researcher at M.I.T., predicted in his 1986 book, ''Engines of Creation,'' in the future we will be able to enlist nanobots to build things for us -- circuit boards, cars, chairs, TV sets, whatever. The strategy would be to create nanofactories or ''auto-assemblers'' the size of cells, which would be programmed to collect raw material from the natural world (atoms, molecules) and convert it (slowly, piece by piece) into the building blocks of the desired product. In order to build the product on a human scale, these auto-assemblers would have to be able to reproduce themselves -- also using raw material from the natural world -- in massive numbers.

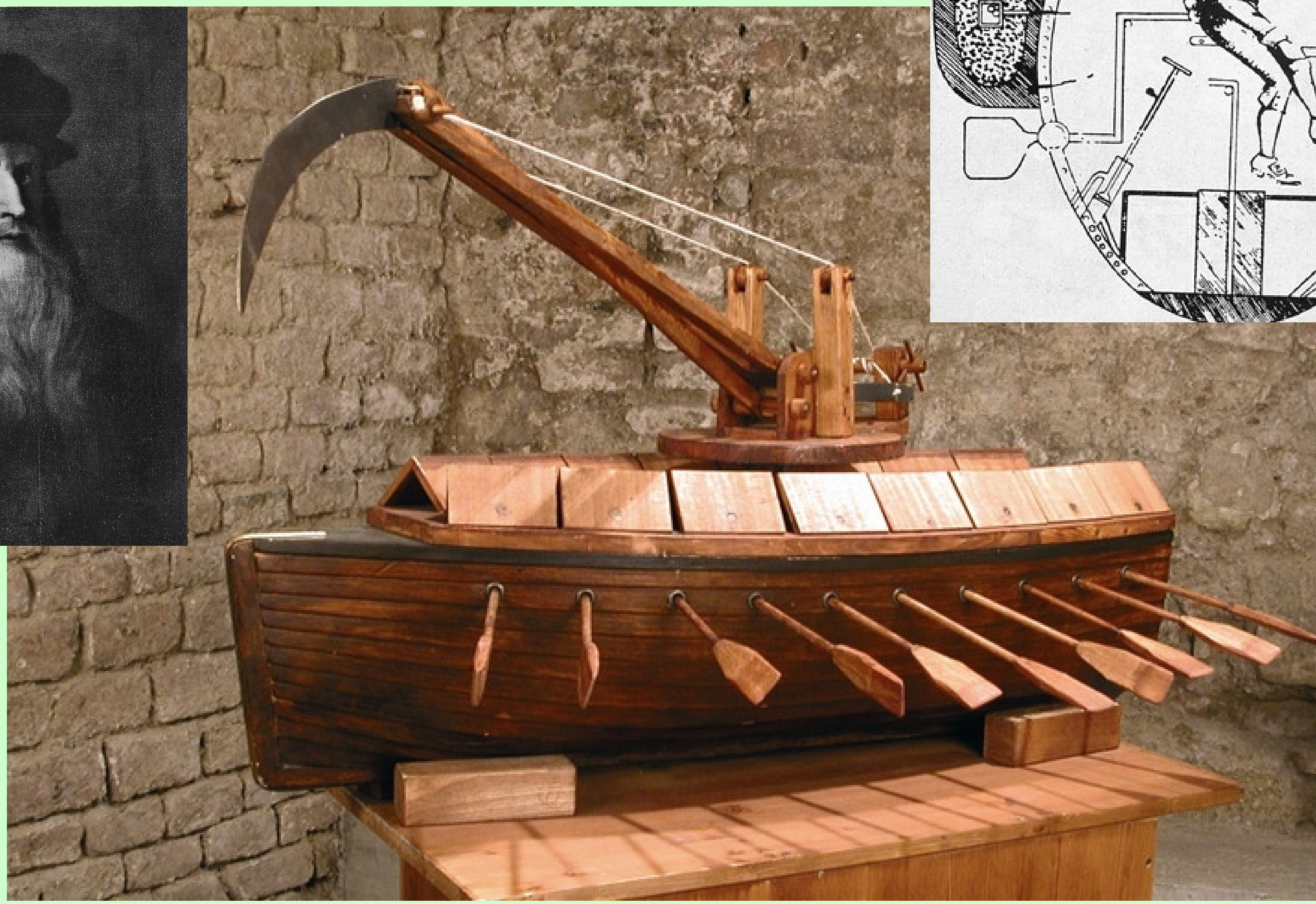
Gray goo is what would happen if one of the auto-assemblers went haywire and the self-replication never stopped. According to Drexler's calculations, in just 10 hours an unchecked self-replicating auto-assembler would spawn 68 billion offspring; in less than two days the auto-assemblers would outweigh the earth.

The executive director of the ETC group, Pat Mooney, says that the threat of gray goo lies far in the distant future. But his group's report stresses an equally worrisome but more immediate danger: the green-goo problem. Green goo is roughly the same as gray goo, only it involves the re-engineering of living things to do our bidding. Such cyborg organisms would eat and reproduce as nature intended, but they would be technologically enhanced -- with unforeseeable consequences.

American inventor David Bushnell,1775, “The Turtle”

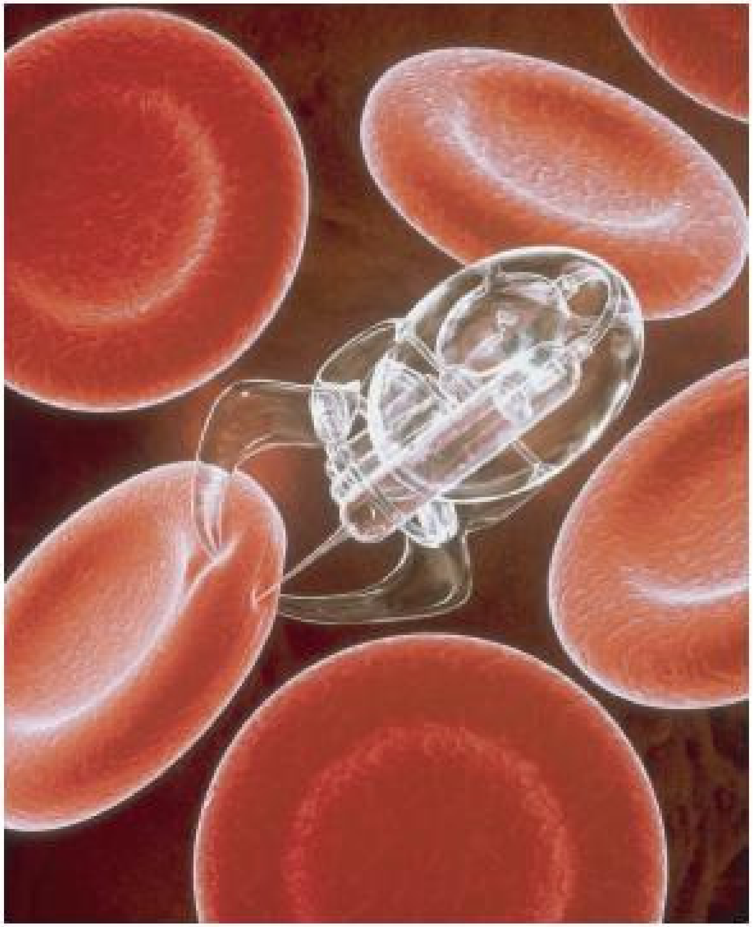






Leonardo da Vinci, 1452-1519, Italian artist and scientist, the original Renaissance man

Nanobot ??? – Artist's Impression

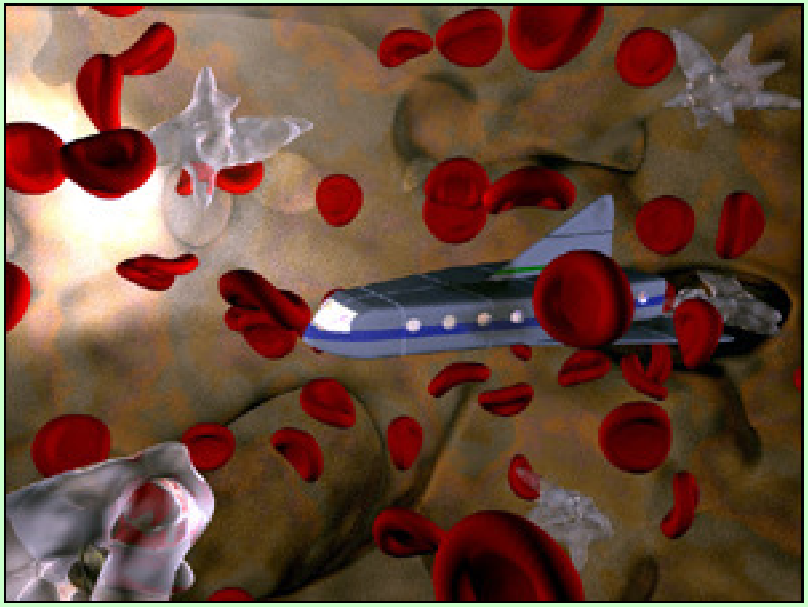


C. W. Shong, S. C. Haur, A. T. S. Wee, *Science at the Nanoscale, An Introductory Textbook*, Pan Stanford, 2010.

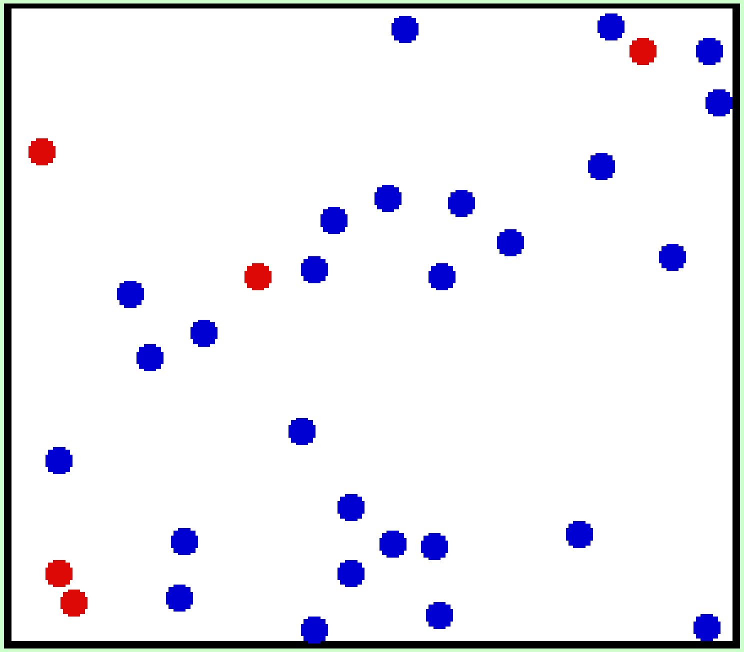
Artist's impression of a (very large) nanobot pinching a red blood cell (diameter 6 – 8 μm), note that micro-machines do scarcely exist,

Fully fledged nano-machines and bots are currently science fiction, most importantly they may never look like some miniature version of the machines we are used to,

G. Stix, *Sci. Amer.* 285(3) 26, 2001: **Nanotechnology is "*long on vision and short on specifics*"**, well what if some of the specifics were just increments of plain old materials science and engineering as applied to the nanometer length scale?

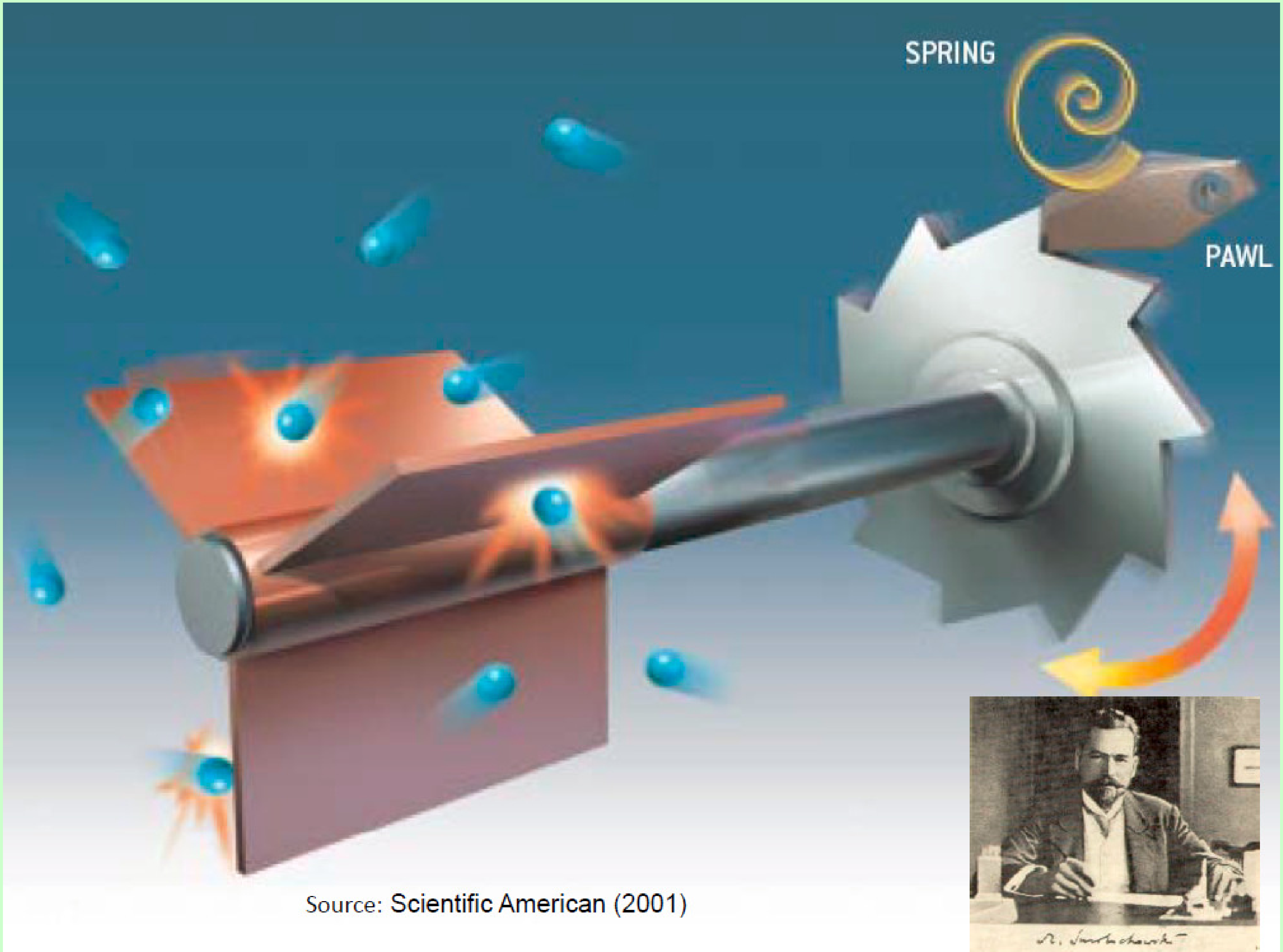


1773 - 1858



1879 - 1955

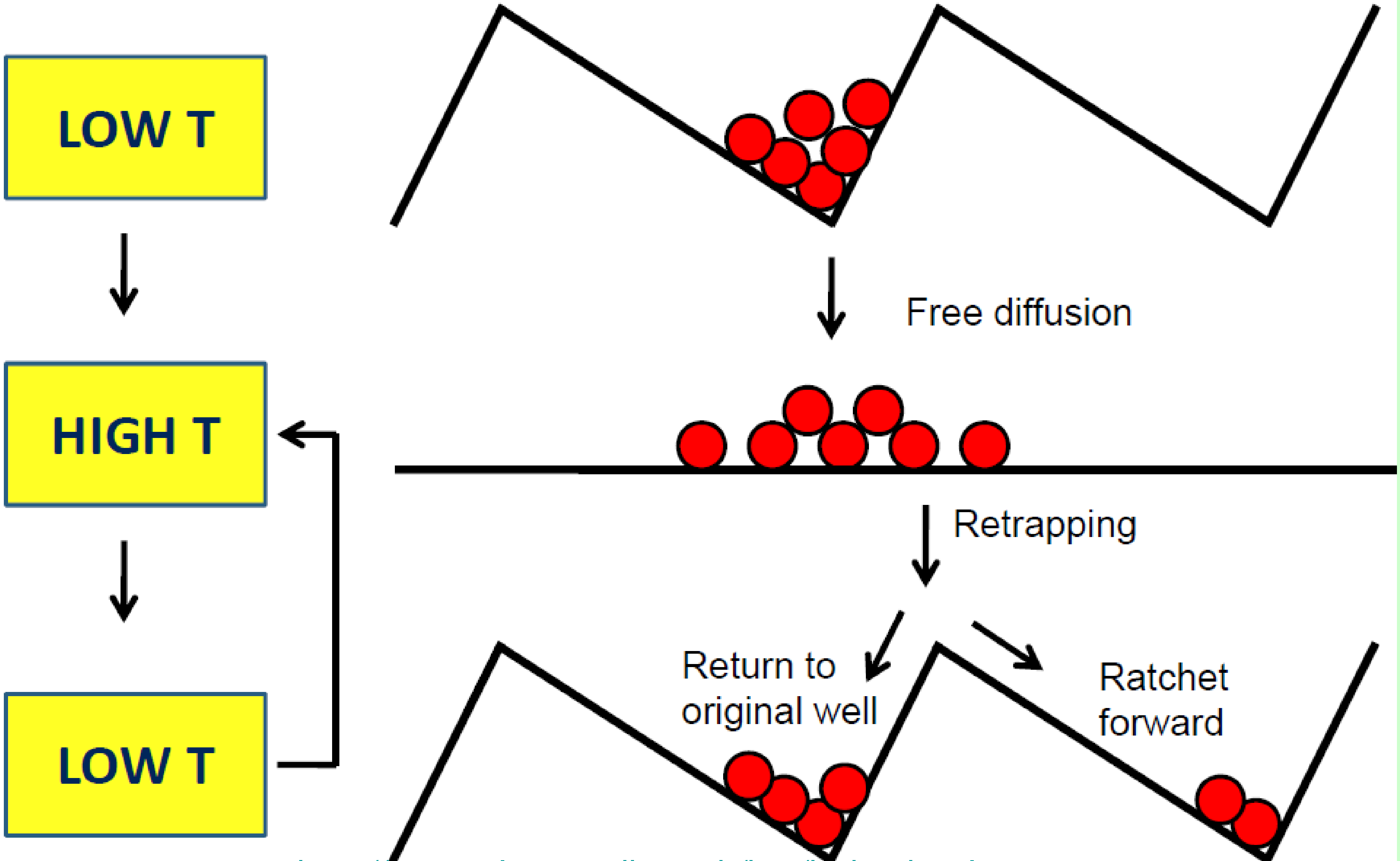
http://en.wikipedia.org/wiki/Brownian_motion#Einstein.27s_Theory



Source: Scientific American (2001)

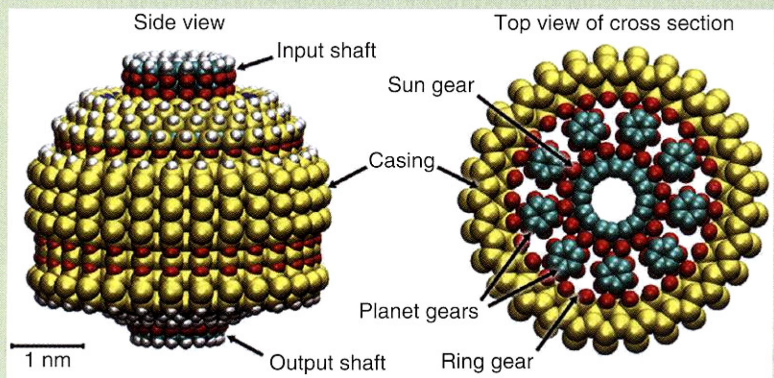
Marian Ritter von Smolan Smoluchowski (1872-1917)

Temperature / Flashing Ratchet



http://www.elmer.unibas.ch/bm/index.html

FIG. 16.11 *A molecular planetary gear is shown. The structure is held together with strong covalent bonds and is able to rotate at a frequency of 1 GHz while delivering power density of 10^{15} $W \cdot m^{-3}$. A molecular machine such as this resembles a conventional machine; but do these molecular analogues really perform like conventional machines? And, what factors exist at the nanoscale that serve to disrupt this notion? According to molecular dynamic models, at temperatures much less that k_BT, molecular models have shown that "bearing interfaces" of strong covalent solid molecular machines show no static friction. Dynamic friction, however, is likely through phonon interactions. Another aspect is thermal fluctuations. Thermal fluctuations could provide a real barrier to accelerated use of nanomaterials. Thermal fluctuations, as one might imagine, contribute to increasing uncertainty in position and reduce energy barriers. One solution to reduce thermal fluctuations is to operate at extremely low temperatures.*

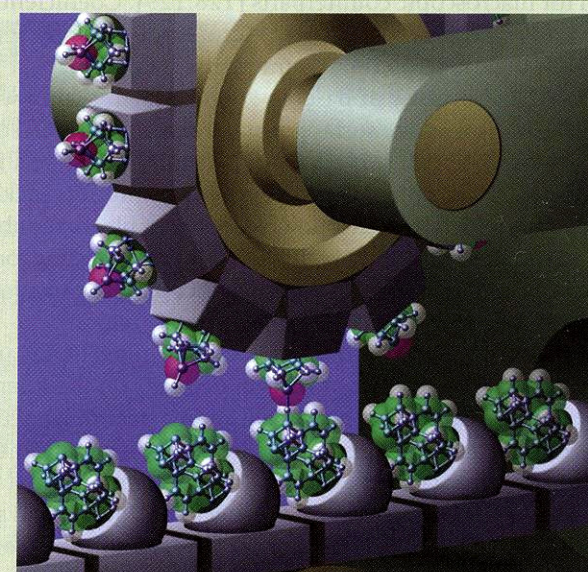


Source: K. E. Drexler, Productive nanosystems: The physics of molecular fabrication, *Physics Education*, 40, 339-
With permission.

Some more visions by some artists, lesser than Michelangeo,

do note parts of the machinery are of "stuff" so homogenous that one does not see an internal structure at the length scale of atoms and molecules

FIG. 16.12 *In this artist's rendition, the concept of atomic precision is depicted by a mechanical system that forces components to react, for example, guiding molecular reactions. In the image, a molecular machine attaches a hydrogen atom to a cluster. The machine components are shown undersized and without detail.*



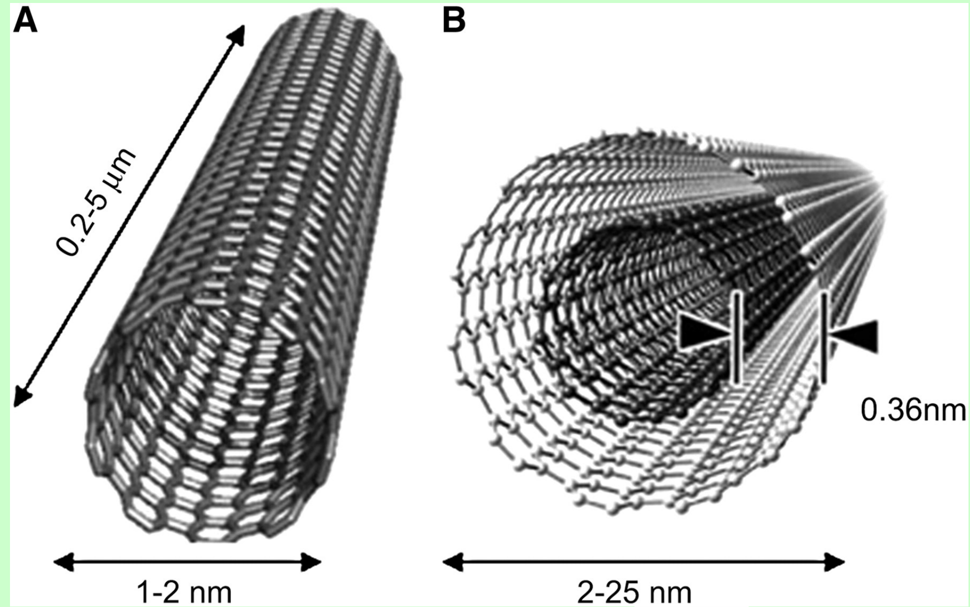
Source: Image courtesy of Eric Drexler. With permission.

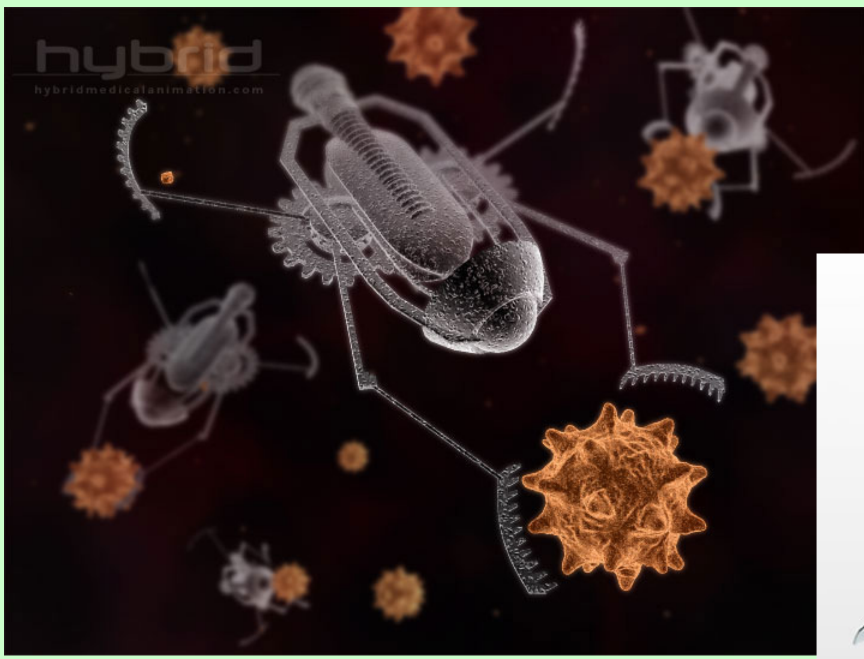
http://www.youtube.com/watch?v=zqyZ9bFl_qg

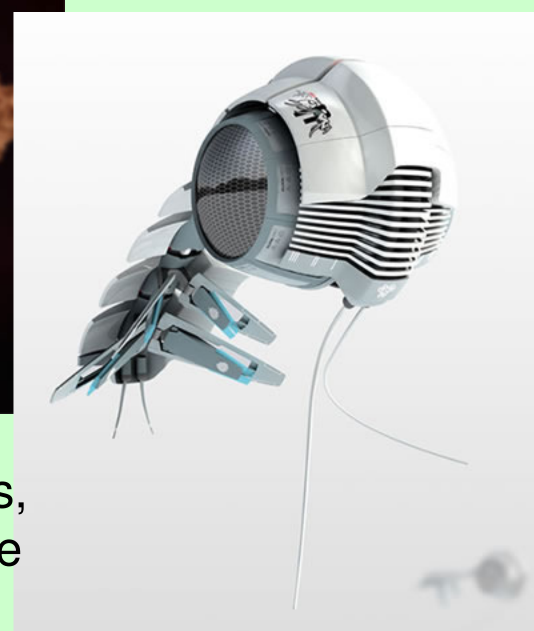
Finally, there are serious doubts in the community that the *radical* (Drexlerian) approach [5] to "nanotech" might be feasible. According to a 2007 poll, only about 5 % of the participating "nano-scientists" have concerns about "self-replicating robots" [34]. In any case, *radical* "nanotech" is likely to be at least decades away [5]. To this author, it seems to be sensible to postpone debates until such times. The good news for educators in the meantime is that the proportion of participants in three different studies which judged nanotechnology as more beneficial than risky did rise with their level of familiarity with the field [34].

[34] T. Satterfield, M. Kandlikar, C. E. H. Beaudrie, J. Conti, B. Herr Harthorn, "Anticipating the perceived risk of nanotechnologies", *Nature Nanotechnology*, vol. 4, pp. 352-358, 2009.

“Friction, resistance to movement” is generally very high at the nanoscale, (almost everything is pretty sticky), but can be small for certain high symmetry arrangements, e.g. the inner tubes in a multi-walled carbon nanotube







Sure nanobots will need moving parts, rotations about some axes, resistance to rotation is usually very high

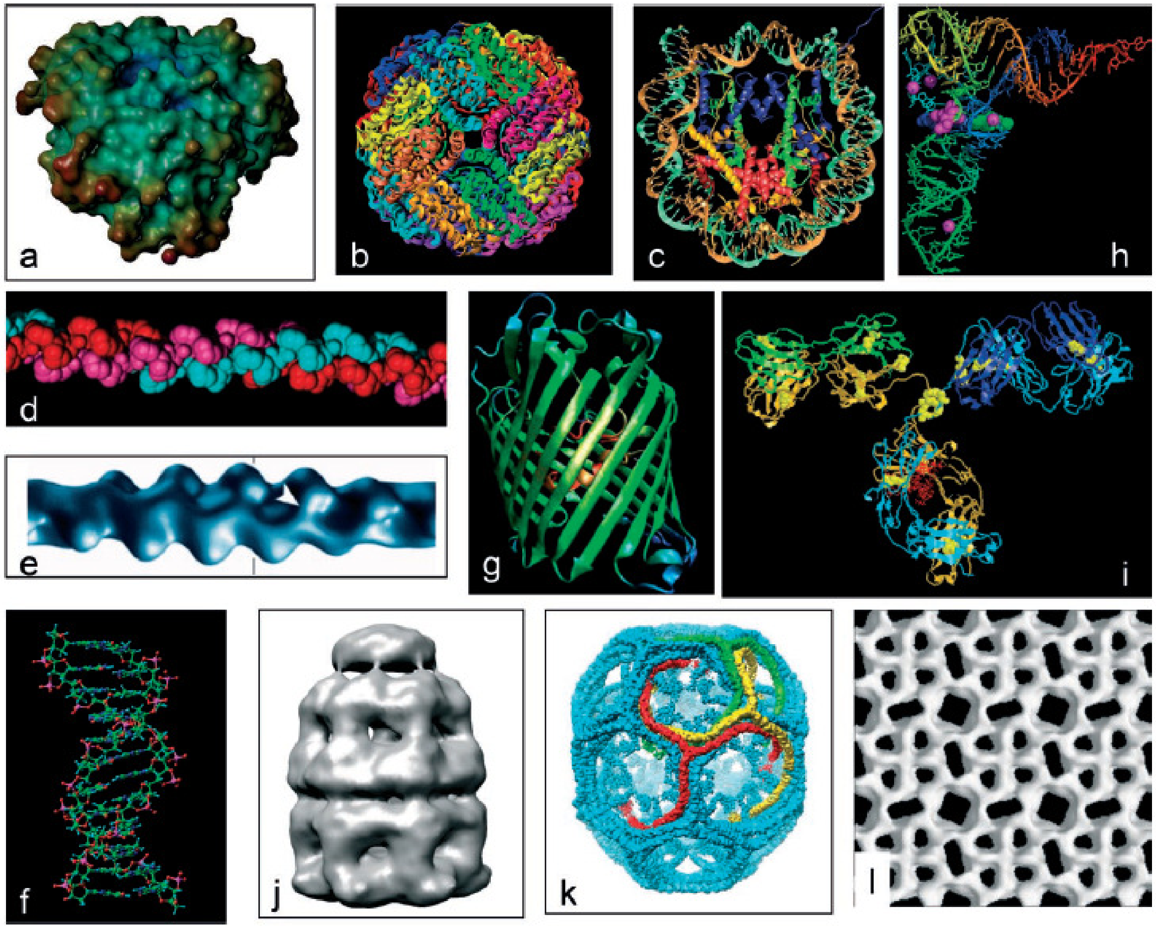


Figure 1. Examples of biological nanoobjects (see Table 1 for details and other examples): a–c) nanoparticles (a, globular (myoglobin); b, hollow/core–shell (ferritin); c, wrapped (nucleosome)); d–f) helical nanofilaments (d, triple coiled-coil (collagen); e, nanoparticle chain (F-actin); f, double-strand (DNA); g) nanotube (membrane protein (porin)); h,i) nanopods (h, L-shaped (tRNA)), i, Y-shaped (IgG)); j) nanobarrel (chaperonin groEL/ES complex); k) nanocage (clathrin); l) bacterial S-layer. Figures adapted from: c) ref. [28]; d) http://www.med.unibs.it/~marchesi/pps97/course/section11/assembli.html; e) ref. [79]; f) http://www.nmr.cabm.rutgers.edu/photogallery/proteins/htm/page26; g) http://www.palaeos.com/Eukarya/Images/BetaBarrels.jpg; h) http://www.biochem.umd.edu/biochem/kahn/teach_res; i) http://www.sci.sdsu.edu/TFrey/Chem365/Proteins/AntibodyStructCh365.htm; j) http://www.rbvi.ucsf.edu/Outreach/Workshops/UCSF-Fall-2005/07-VolumeData/tutorial/chaperonin.html; k) ref. [73]; l) ref. [60].

Table 1: Biological nanoobjects.

Type	Examples	Size [nm]
nanoparticles		
globular	(many proteins)	> 2.5
hollow	apoferritins	12
	lumazine synthase	15
	cowpea chlorotic mottle virus	28
core–shell	lipoproteins (LDL)	20
	ferritins	8 (core) + 4 (shell)
wrapped	nucleosomes	11
nanofilaments (helical)		
double-strand	DNA	2 (width)
coiled coil	collagen	1.4×300
multiheaded	myosin	2×135
nanoparticle chains	F-actin	$[7 \times 36]_n$
	deoxyhemoglobin S	20 (width)
nanotubes	tobacco mosaic virus	18×300
	microtubules	25 (width)
	porins	1×5
	α-hemolysin	$1.5/4.5 \times 10$
nanopods	clathrin triskelion	2×45 (per leg)
	IgG (Y-shaped)	$4 \times 5 \times 8$
	tRNA (L-shaped)	5.5×7
nanobarrels	chaperonins	14×15 (4.5 pore)
	proteasomes	15×11 (5×2 pore)
nanocages	clathrin	60
nanorotors	F_0F_1- ATPase	10×8 (F_1), 13×5 (F_o)
nanosheets	lipid bilayer	5 (thickness)
	S-layers	5–20 (thickness)

7. Conclusions

In this Review we have considered the living cell as a self-regulated, self-maintained complex chemical system that operates principally through nanoscale miniaturization via a systems interface (cognition) and internal self-processing networks (autopoiesis). We postulated that the evolution of an integrated and functional cell membrane, as well as the emergence of metabolic processing networks based on globular macromolecules, were dependent on up-scaling of molecular interactions to length scales beyond 3 and 2.5 nm, respectively. These boundary conditions were imposed by

Stephen Mann, Life as a Nanoscale Phenomenon, *Angew. Chem. Int. Ed.* **47** (2008) 5306-5320

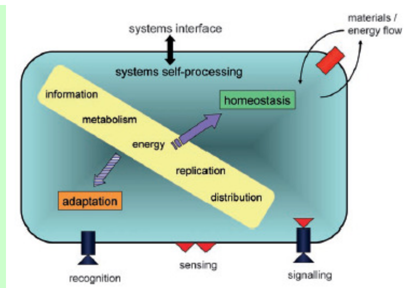


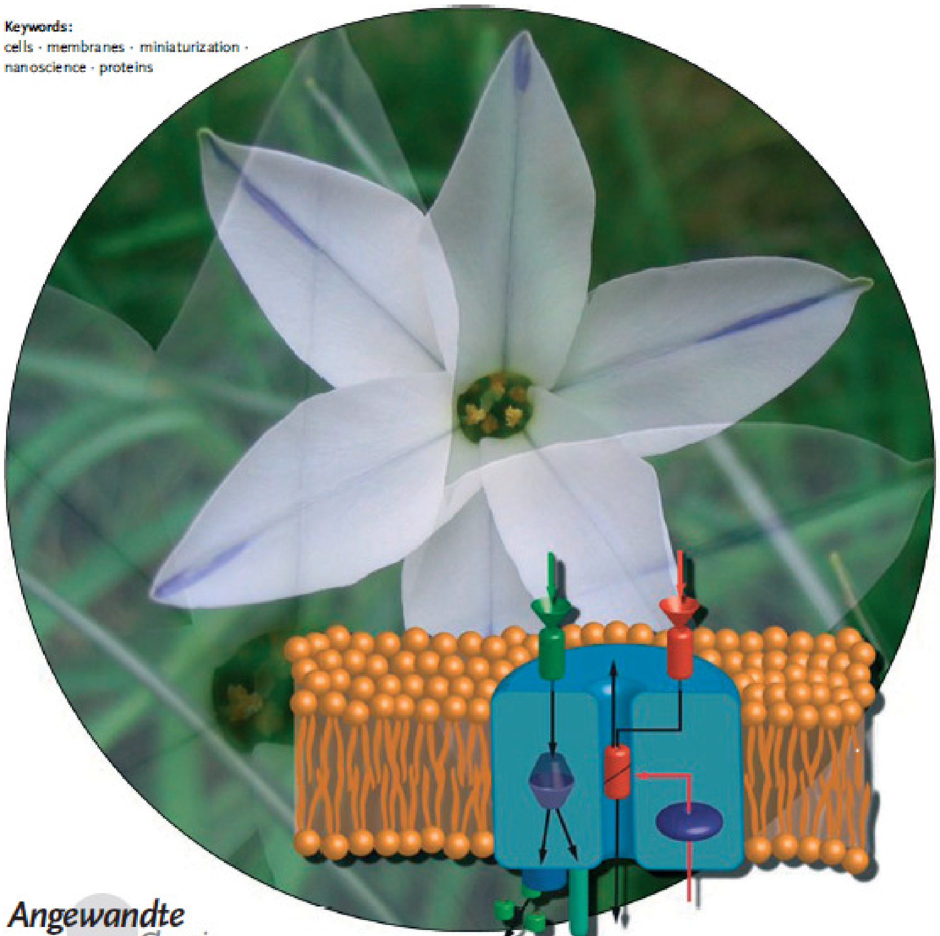
Figure 2. Systems of cellular life.

Artificial Life
DOI: 10.1002/anie.200705538

Life as a Nanoscale Phenomenon**

Stephen Mann*

Keywords:
cells · membranes · miniaturization · nanoscience · proteins



Angewandte Chemie

Table 2: Examples of nanoscale miniaturization of biosystems operations.

Operation	Examples
a) Systems interface	
materials/energy flow	
passive transport	porins, gap junctions
active transfer	pumps (amino acids/Na^+, lactose/H^+)
synport exchange	ATPases (Na^+/K^+, Ca^{2+}/H^+)
capture	siderophores, endocytosis, clathrin pits
	photoreceptors (bacteriorhodopsin)
sensing	
chemotaxis	chemoreceptors (methylation)
hormone signalling	receptor/G-proteins
	receptor/phospholipase C
	EGF receptors (tyrosine kinases)
signalling cascades	adenylate cyclase/G_sGTP
neurotransmission	acetylchoine/catecholamine receptors
	GABA receptors/Cl^-
cell/matrix	integrins/RGD
antigens	B-lymphocyte immunoglobins,
MHC peptides	T-cell/CD4/CD8 receptors
b) Internal processing	
general metabolism	
structure	F-actin, tubulin (microtubules), collagen
	spectrin, intermediate filaments
enzymatic catalysis	globular proteins
signalling	calmodulin/Ca^{2+}
recognition	immunoglobins
motors	microtubules/kinesin, actin/myosin
protein synthesis	ribosomes
protein folding/transport	chaperonins. endoplasmic reticulum membrane
energy	mitochondrial membrane
storage	ferritins, metallothioneins
detoxification	lysosome/P450, peroxisome/catalase
destruction	ubiquitin/proteasome
	caspases (apoptosis)
information	
storage	nucleosomes
unwinding	helicase, gyrase
replication	DNA polymerase, RNA primase
error correction	DNA polymerases
clipping	restriction endonucleases
repair	ligase
translation	tRNA/mRNA
splicing	spliceosome proteins

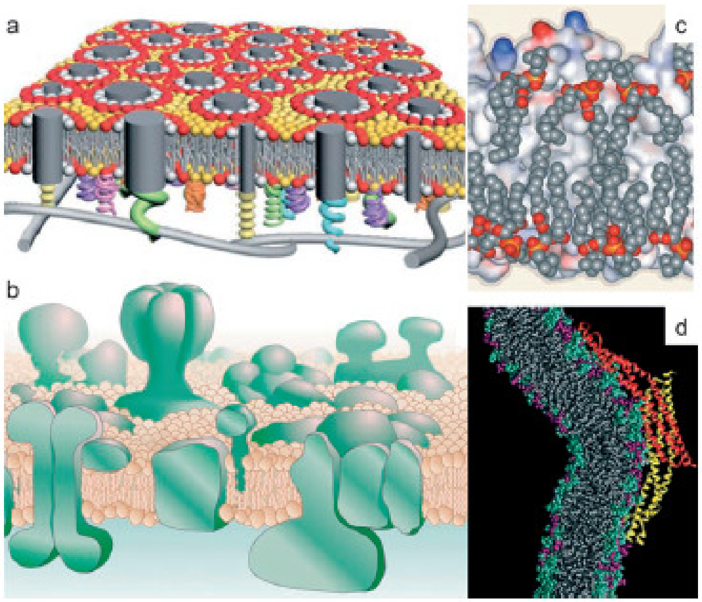


Figure 3 a) Schematic showing hierarchical arrangement in a lipid/protein nanocomposite membrane. The high concentration of membrane proteins induces local clustering on a length scale of 1–10 nm. Lipid molecules located in the first (white), second (red) boundary layers, as well as between the clustered shells (yellow) are shown. From ref. [40]. b) Modified model for the lipid/protein nanocomposite membrane. Variations in the thickness of the lipid bilayer are associated with patchiness arising from segregated regions of membrane proteins, some of which have extensive extracellular domains (e.g. F_0F_1-ATPase, as depicted in the center left of the drawing). From ref. [42]. c) Electron crystallographic structure showing a side view of one face of an aquaporin AQP0 tetramer stabilized by ordered packing of lipid molecules of the bilayer membrane. (AQP0 tetramer is shown as a surface plot (light background) with regions of negative charge (red), positive charge (blue), and hydrophobic domains (gray); lipid molecules are shown as a space-filled image (foreground) with polar headgroups (O, red; P, orange) and hydrophobic tails (gray)). Adapted from ref. [54, 55]. d) Molecular dynamics simulation showing induced curvature in a lipid bilayer by binding of a protein N-BAR domain ($t = 27$ ns). The bilayer bends to match the curvature of the surface of the N-BAR domain facing the membrane; charged phosphatidylserine (purple) and polar phosphatidylcholine (green) head groups are shown. From ref. [58].

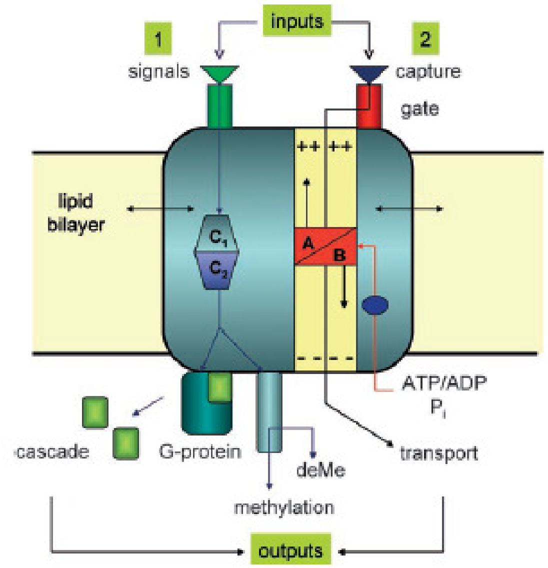
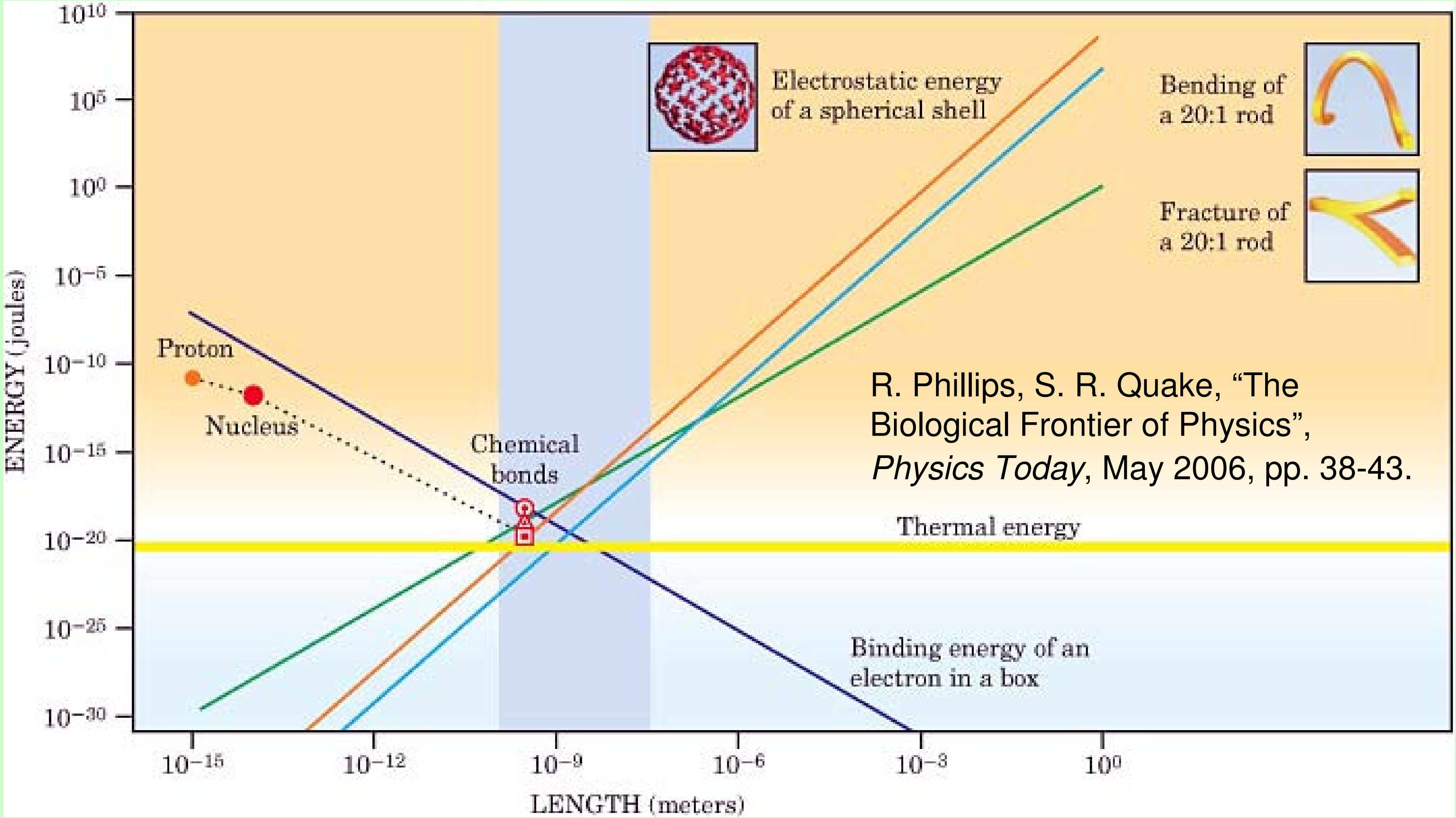


Figure 4 General scheme depicting the operation of integral membrane proteins in cellular cognition. These proteins are involved in diverse processes such as passive and active ion/molecule transport, proton gradients for ATP production, generation of action potentials via voltage-dependent charge migration, light harvesting and transduction, receptor-mediated signal transduction cascades, chemotaxis, and transduction of molecular motion. 1) Receptor-mediated information flow (signal transduction cascades). Extracellular binding of hormones and chemosensors produces conformational rearrangements (C_1, C_2) in the receptor that result in activation of intracellular processes. For example, chemosensors affect signal transmission to the flagella by influencing the rate of glutamate methylation/demethylation (deMe) on the cytoplasmic side of the receptor, whilst hormones activate the intracellular binding of peripheral G-proteins and the subsequent release of αGTP-bound subunits. The latter initiate cascades by activating other membrane-bounded proteins (adenylate cyclase) to produce second messengers (cAMP) that stimulate protein kinases for phosphorylation-mediated modulation of target proteins involved, for example, in glycogen degradation. 2) Transport-mediated information flow. Selected ions and molecules are bound close to the extracellular side depending on charge, size, and polarity, and transmission is activated by gated responses determined by proton gradients, electrochemical potentials, auxiliary ligand binding, or photoinduced conformational changes. Chemical activation via ATP binding and hydrolysis is common in many antiport systems in which the binding affinities associated with the two conformations required to transport the species (A and B) are switched either on or off by phosphorylation (P). Pathways (1) and (2) can also be modulated by interactions of the transmembrane proteins with the surrounding lipid bilayer (Section 3).



R. Phillips, S. R. Quake, “The Biological Frontier of Physics”, *Physics Today*, May 2006, pp. 38-43.

The confluence of energy scales is illustrated in this graph, which shows how thermal, chemical, mechanical, and electrostatic energies associated with an object scale with size. As the characteristic object size approaches that at which molecular machines operate (shaded), all the energies converge. The horizontal line shows the thermal energy scale kT which, of course, does not depend on an object's size. We estimate binding energy (purple) by considering an electron in a box; for comparison, the graph shows measured binding energies for hydrogen bonds (square), phosphate groups in ATP (triangle), and covalent bonds (circle), along with characteristic energies for nuclear and subatomic particles. In estimating the bending energy (blue), we took an elastic rod with an aspect ratio of 20:1 bent into a semicircular arc, and to compute the fracture energy (green) we estimated the energy in chemical bonds in a longitudinal cross section of the rod. The electrostatic energy (orange) was obtained for a spherical protein with singly charged amino acids of specified size distributed on the surface.

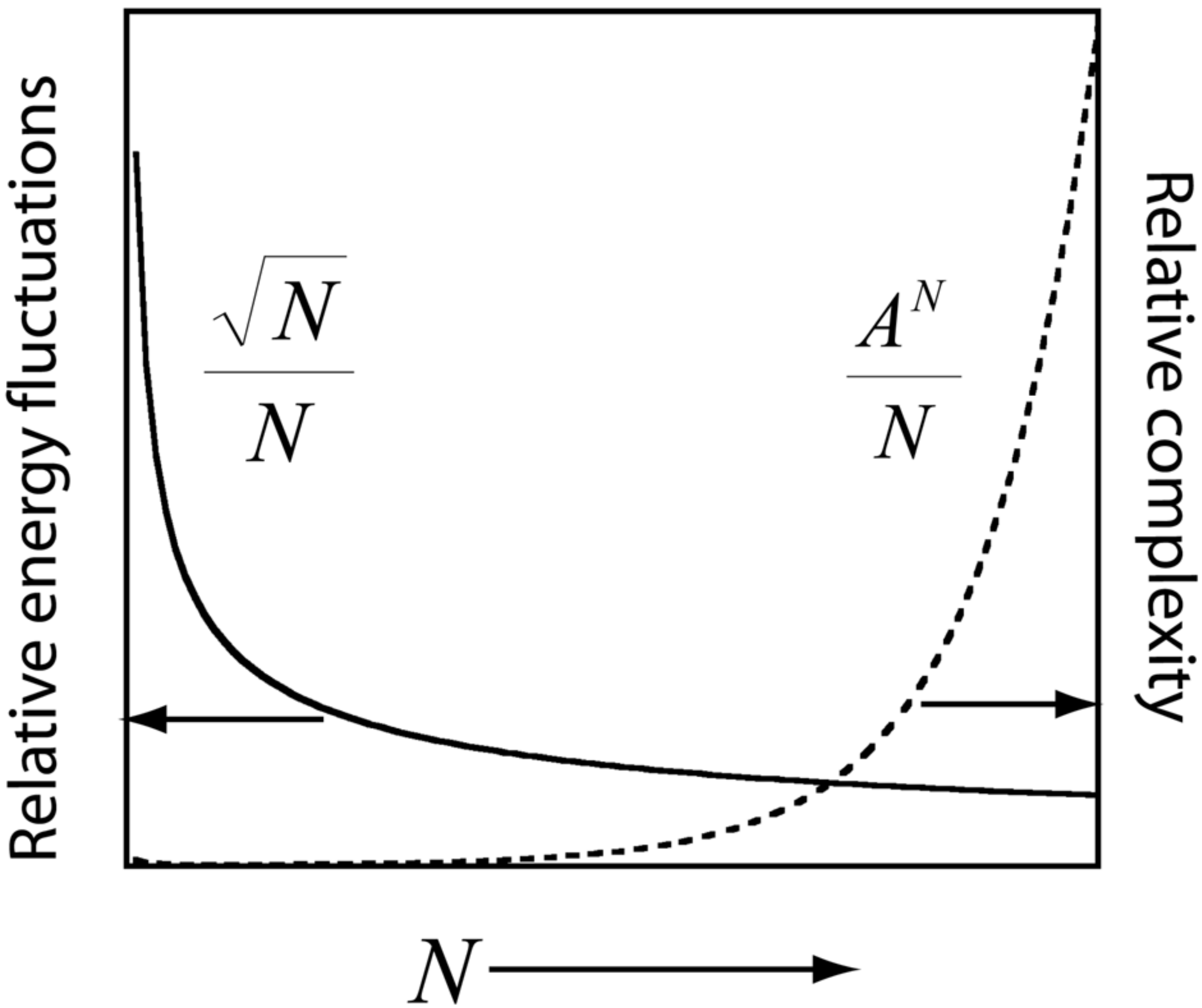
Fluctuations

- $\sqrt{N}/N \rightarrow 1$ in small systems
- Complexity increases with N exponentially

Emergent Phenomena

- Adequate complexity and fluctuations
- Electron transfer in chemical reactions – occurs on the nanoscale
- Proteins fold and unfold, …

S.M. Lindsay, Introduction to Nanoscience, Oxford University Press, 2010

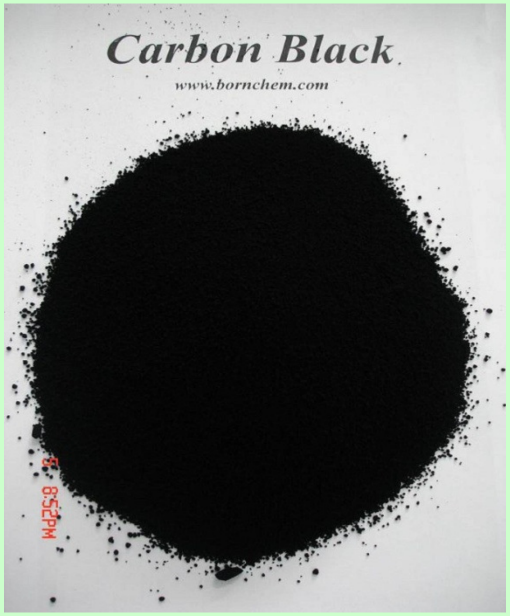


In order to make statements about the present and future, it is worthwhile to consider the past

much confusion in the general public and the social sciences comes from misconceptions about recent emergence of nanoscience

So are nanoscience and -engineering new? Are they dangerous? Are they disruptive, …, are they very different from classical engineering in the sense that classical physics is very different from quantum physics?

Indian Ink (masi), since about 4th century BC (the times of Alexander the Great)



+

Gum Arabic

also known as gum acacia, chaar gund, char goond or meska

Acacia Senegal, F. E. Köhler, Köhler's Medizinal-Pflanzen (1887)…

commonly known as soot, pure carbon

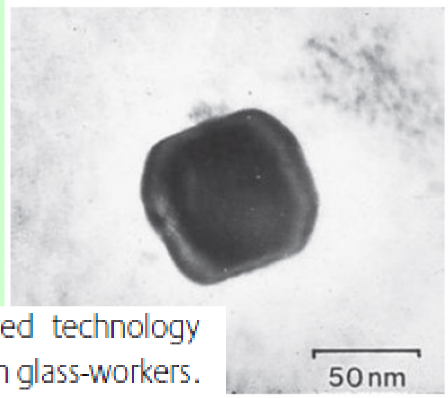
complex mixture of polysaccharides and glycoproteins

+

Indian wootz steel (from about 300 BC onwards) and Damascus swords (from about 900 AD until the special Indian iron ore sources with conducive impurity content became depleted around 1700) contain (crystalline) nanowires of the mineral cementite that may have grown from carbon nanotubes, see M. Reibold *et al.* *Nature* **444**, 286 (2006).

The Lycurgus Cup – A Roman Nanotechnology

Figure 4
Transmission electron microscopy (TEM) image of a silver-gold alloy particle within the glass of the Lycurgus Cup [21]. © The Trustees of the British Museum.



The Lycurgus Cup demonstrates a short-lived technology developed in the fourth century A.D. by Roman glass-workers. They discovered that glass could be coloured red and unusual colour change effects generated by the addition of a precious metal bearing material when the glass was molten. We now understand that these effects are due to the development of nanoparticles in the glass. However, the inability to control the colourant process meant that relatively few glasses of this type were produced, and even fewer survive. The Cup is the outstanding example of this technology in every respect – its outstanding cut work and red-green dichroism render it a unique record.

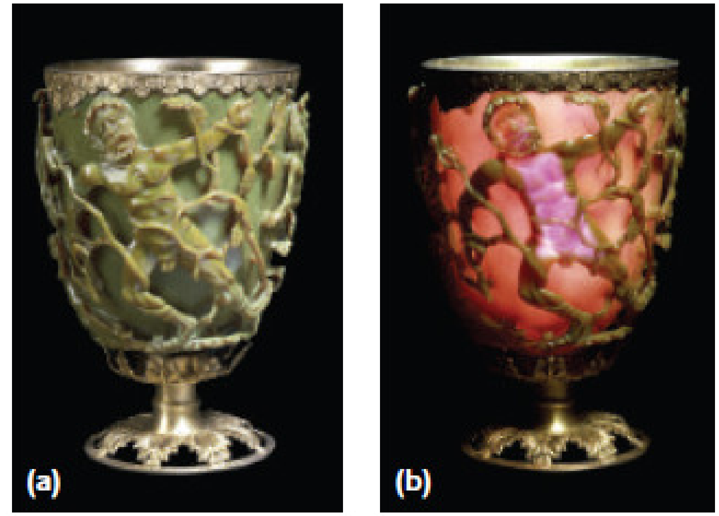
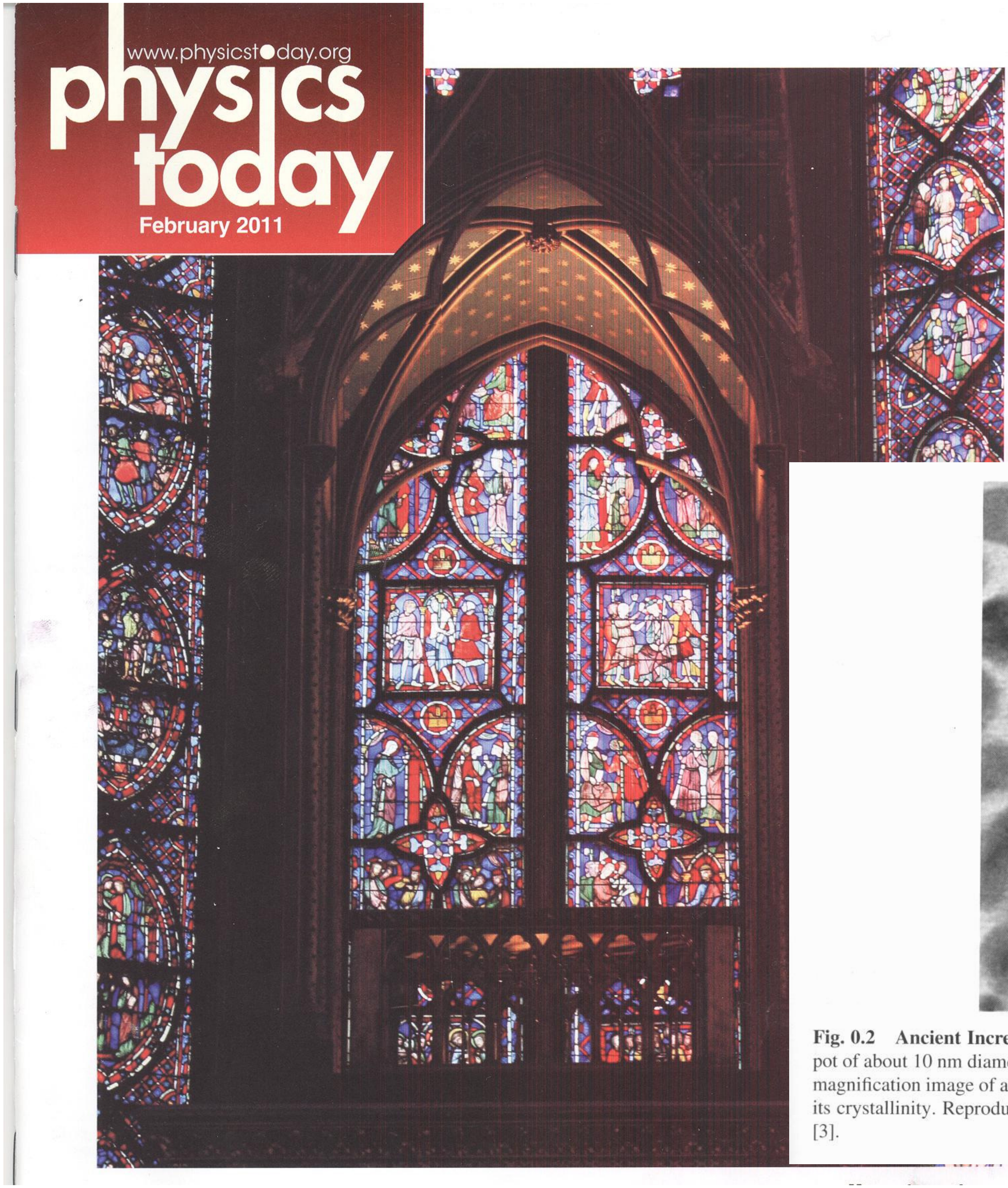


Figure 1 (a and b)
The Lycurgus Cup *1958,1202.1 in reflected (a) and transmitted (b) light. Scene showing Lycurgus being enmeshed by Ambrosia, now transformed into a vine-shoot. Department of Prehistory and Europe, The British Museum. Height: 16.5 cm (with modern metal mounts), diameter: 13.2 cm. © The Trustees of the British Museum*

Well, without a nano-(materials) science, some nanotechnologies were either short lived, or depended on the availability of conducive raw materials



To be explained by plasmonics and Mie scattering

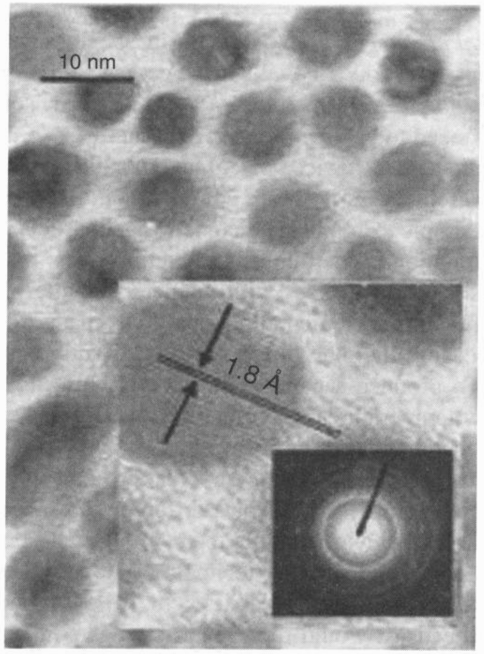
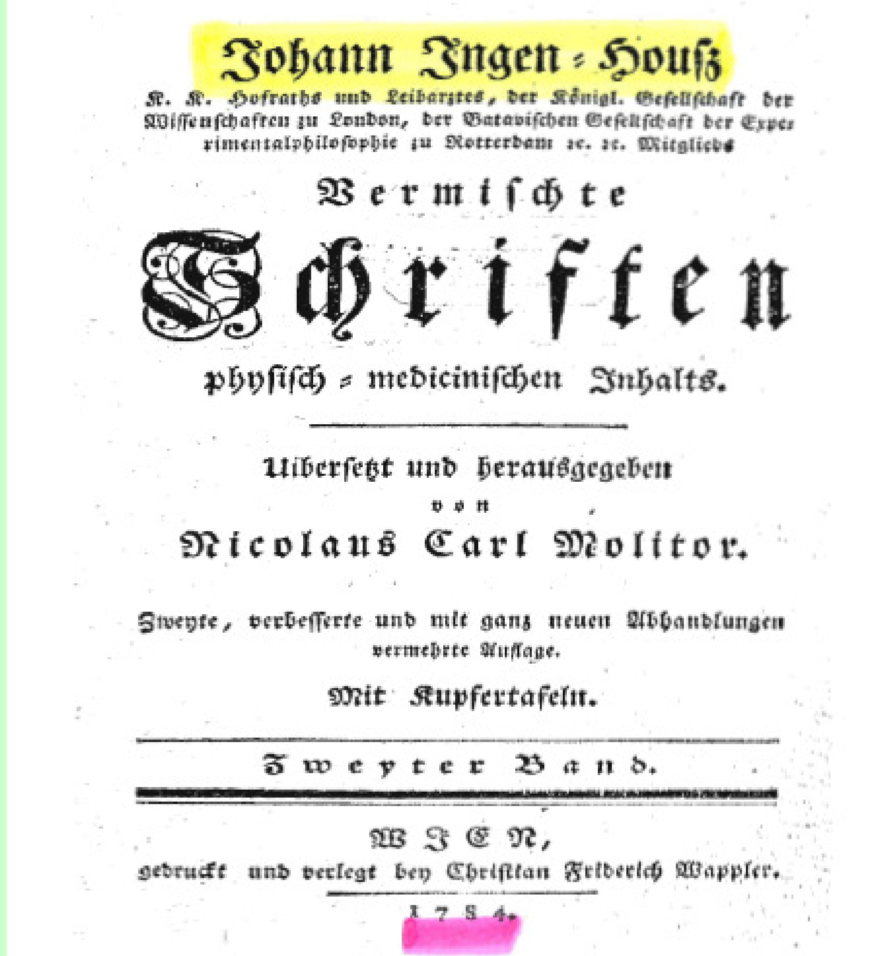


Fig. 0.2 Ancient Incremental Nanotechnology. Copper nanocrystals on a 10th century pot of about 10 nm diameter used to produce a surface luster. The inset shows an increased magnification image of a single 7 nm diameter particle with atomic planes visible revealing its crystallinity. Reproduced with the permission of Elsevier Science from I. Borgia et al. [3].

Jan Ingen-Housz (1730-1799)



Johann Ingen-Housz

K. K. Hofraths und Leibarztes, der Königl. Gesellschaft der Wissenschaften zu London, der Batavischen Gesellschaft der Experimentalphilosophie zu Rotterdam ꝛc. ꝛc. Mitglieds

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gedruckt und verlegt bey Christian Friderich Wappler.

1784.

To see clearly how one can deceive one's mind on this point if one is not careful, one only has to place a drop of alcohol in the focal point of a microscope and introduce a little finely ground charcoal therein, and one will see these corpuscules in a confused, continuous and violent motion, as if they were animalcules which move rapidly around.

http://www.aip.org/history/einstein/brownian.htm

FIG. 1.10 *The slide depicting Faraday's gold sol was used in his lecture on nanogold, titled* On the Relation of Gold to Light, *on June 12, 1856. The slide has a reddish-purple color, indicating particles on the order of 20–40 nm in diameter on the average.*

Source: Image reprinted with permission from the Whipple Museum of the History of Science, Cambridge University.

Michael Faraday, Experimental relations of gold (and other metals) to light; the Bakerian lecture, *Phil. Trans. Royal Soc. London*, vol. 147, pp. 145-181, **1857**

Faraday's conjecture on size dependency of a physical property

"… a mere variation in the size of the particles gave rise to a variety of resultant colours …"

So qualitative nanoscience is some 150 years old !

Leading eventually to improved silver based photography, colloids, sols and gels, polymers **(collectively soft materials), catalysts, … are all nanoengineered products**

from 1905/1906 onwards Nanoscience becomes quantitative

Einstein, Albert (1905), *A new determination of molecular dimensions*. PhD thesis, ETH Zürich, completed April 30, submitted July 20, published (after update) in Annalen der Physik, Feb. 8, 1906, PhD booklet of 16 pages, Buchdruckerei K. J. Wyss, Bern, 1906

"A NEW DETERMINATION OF MOLECULAR DIMENSIONS"

"It will be shown in this paper that the size of molecules of substances dissolved in an undissociated dilute solution can be determined from the internal viscosity of the solution and of the pure solvent, and from the diffusion rate of the solute within the solvent provided that the volume of a solute molecule is large compared to the volume of a solvent molecule."

Final result of theory, two equations in two unknowns, $NP^3 = (3M/10p)\ (m^*/m - 1)$ *and* $NP = RT / 6pm\ D$

"… We will carry out the calculation for an aqueous solution of sugar. From the data on the viscosity of the sugar solution cited earlier, it follows that at 20°C, $NP^3 = 80$. *…*
We obtain $NL = 2.08 \cdot 10^{16}$*. Neglecting the differences between the values of a at 9.5° and 20°, the values found for* NP^3 *and NP yield*
$P = 9.9 \cdot 10^{-8}$ *cm*
$N = 3.3 \cdot 10^{23}$. *(in 1911 corrected to* $6.56\ 10^{23}$*)*
… The value found for N shows satisfactory agreement, in order of magnitude, with values found for this quantity by other methods. (Bern, 30 April, 1905)"

from 1905/1906 onwards Nanoscience becomes quantitative, published February 8, 1906

ANNALEN

DER

PHYSIK.

BEGRÜNDET UND FORTGEFÜHRT DURCH

F. A. C. GREN, L. W. GILBERT, J. C. POGGENDORFF, G. UND E. WIEDEMANN.

VIERTE FOLGE.

BAND 19.

DER GANZEN REIHE 324. BAND.

KURATORIUM:

F. KOHLRAUSCH, M. PLANCK, G. QUINCKE,
W. C. RÖNTGEN, E. WARBURG.

UNTER MITWIRKUNG

DER DEUTSCHEN PHYSIKALISCHEN GESELLSCHAFT

UND INSBESONDERE VON

M. PLANCK

HERAUSGEGEBEN VON

PAUL DRUDE.

MIT FÜNF FIGURENTAFELN.

LEIPZIG, 1906.

VERLAG VON JOHANN AMBROSIUS BARTH.

3. ***Eine neue Bestimmung der Moleküldimensionen; von A. Einstein.***

Die ältesten Bestimmungen der wahren Größe der Moleküle hat die kinetische Theorie der Gase ermöglicht, während die an Flüssigkeiten beobachteten physikalischen Phänomene bis jetzt zur Bestimmung der Molekülgrößen nicht gedient haben. Es liegt dies ohne Zweifel an den bisher unüberwindlichen Schwierigkeiten, welche der Entwickelung einer ins einzelne gehenden molekularkinetischen Theorie der Flüssigkeiten entgegenstehen. In dieser Arbeit soll nun gezeigt werden, daß man die Größe der Moleküle des gelösten Stoffs in einer nicht dissoziierten verdünnten Lösung aus der inneren Reibung der Lösung und des reinen Lösungsmittels und aus der Diffusion des gelösten Stoffes im Lösungsmittel ermitteln kann, wenn das Volumen eines Moleküls des gelösten Stoffs groß ist gegen das Volumen eines Moleküls des Lösungsmittels. Ein derartiges gelöstes Molekül wird sich nämlich bezüglich seiner Beweglichkeit im Lösungsmittel und bezüglich seiner Beeinflussung der inneren Reibung des letzteren annähernd wie ein im Lösungsmittel suspendierter fester Körper verhalten, und es wird erlaubt sein, auf die Bewegung des Lösungsmittels in unmittelbarer Nähe eines Moleküls die hydrodynamischen Gleichungen anzuwenden, in welchen die Flüssigkeit als homogen betrachtet, eine molekulare Struktur derselben also nicht berücksichtigt wird. Als Form der festen Körper, welche die gelösten Moleküle darstellen sollen, wählen wir die Kugelform.

§ 1. Über die Beeinflussung der Bewegung einer Flüssigkeit durch eine sehr kleine in derselben suspendierte Kugel.

Es liege eine inkompressible homogene Flüssigkeit mit dem Reibungskoeffizienten k der Betrachtung zugrunde, deren Geschwindigkeitskomponenten u, v, w als Funktionen der Koordinaten x, y, z und der Zeit gegeben seien. Von einem beliebigen Punkt x_0, y_0, z_0 aus denken wir uns die Funktionen u, v, w als Funktionen von $x - x_0$, $y - y_0$, $z - z_0$ nach

Wir wollen die Rechnung für wässerige Zuckerlösung durchführen. Nach den oben mitgeteilten Angaben über die innere Reibung der Zuckerlösung folgt zunächst für 20° C.:

$$N P^3 = 200\,.$$

Nach Versuchen von Graham (berechnet von Stefan) ist der Diffusionskoeffizient von Zucker in Wasser bei 9,5° C. 0,384, wenn der Tag als Zeiteinheit gewählt wird. Die Zähigkeit des Wassers bei 9,5° ist 0,0135. Wir wollen diese Daten in unsere Formel für den Diffusionskoeffizienten einsetzen, trotzdem sie an 10 proz. Lösungen gewonnen sind und eine genaue Gültigkeit unserer Formel bei so hohen Konzentrationen nicht zu erwarten ist. Wir erhalten

$$N P = 2{,}08 \,.\, 10^{16}.$$

Aus den für $N P^3$ und $N P$ gefundenen Werten folgt, wenn wir die Verschiedenheit von P bei 9,5° und 20° vernachlässigen,

$$P = 9{,}9 \,.\, 10^{-8} \text{ cm},$$

$$N = 2{,}1 \,.\, 10^{23}.$$

Der für N gefundene Wert stimmt der Größenordnung nach mit den durch andere Methoden gefundenen Werten für diese Größe befriedigend überein.

Bern, den 30. April 1905.

(Eingegangen 19. August 1905.)

A. Einstein, "Eine neue Bestimmung der Moleküldimensionen", *Annalen der Physik*, vol. **19**, pp. 289-306, 1906

11. ***Berichtigung zu meiner Arbeit: „Eine neue Bestimmung der Moleküldimensionen“[1]; von A. Einstein.***

ibid vol. **34**, pp. 591-592, 1911

Vor einigen Wochen teilte mir Hr. Bacelin, der auf Veranlassung von Hrn. Perrin eine Experimentaluntersuchung über die Viskosität von Suspensionen ausführte, brieflich mit, daß der Viskositätskoeffizient von Suspensionen nach seinen Resultaten erheblich größer sei, als der in § 2 meiner Arbeit entwickelten Formel entspricht. Ich ersuchte deshalb Hrn. Hopf, meine Rechnungen nachzuprüfen, und er fand in der Tat einen Rechenfehler, der das Resultat erheblich fälscht. Diesen Fehler will ich im folgenden berichtigen.

Legt man die berichtigte Formel zugrunde, so erhält man für das Volumen von 1 g in Wasser gelöstem Zucker statt des in § 3 angegebenen Wertes 2,45 cm³ den Wert 0,98, also einen vom Volumen 0,61 von 1 g festem Zucker erheblich weniger abweichenden Wert. Endlich erhält man aus der inneren Reibung und Diffusion von verdünnten Zuckerlösungen statt des im Anhange jener Arbeit angegebenen Wertes $N = 4{,}15 \,.\, 10^{23}$ für die Anzahl der Moleküle im Grammolekül den Wert $6{,}56 \,.\, 10^{23}$.

Zürich, Januar 1911.

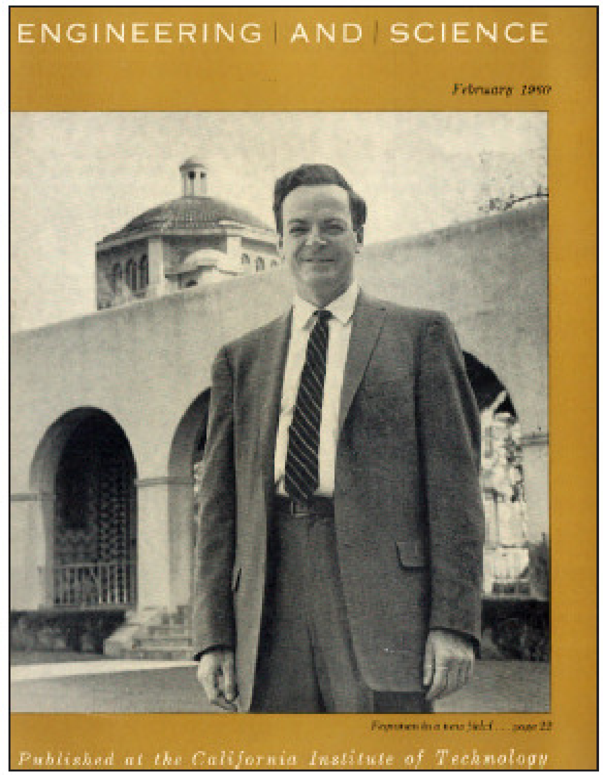
(Eingegangen 21. Januar 1911.)

Arthur von Hippel's **1956** vision for the then emerging field of materials science and engineering

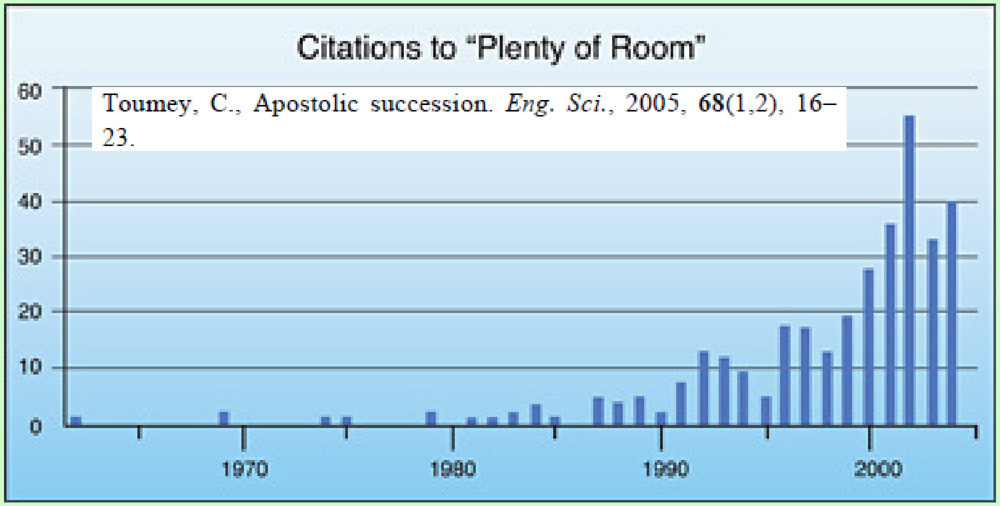
"… instead of taking prefabricated materials and trying to devise engineering applications consistent with their macroscopic properties, one builds materials from their atoms and molecules for the purpose at hand."

A. R. von Hippel, "Molecular Engineering", *Science*, vol. 123 (issue 3191), pp. 315-317, 1956; MIT *Techn. Rep*. 101, October 1955; *Molecular Science and Molecular Engineering*, Technology Press of MIT Press and Wiley & Sons, New York, 1959.

There's plenty …



Eng. Sci. **23**(5) 22-36, 1960

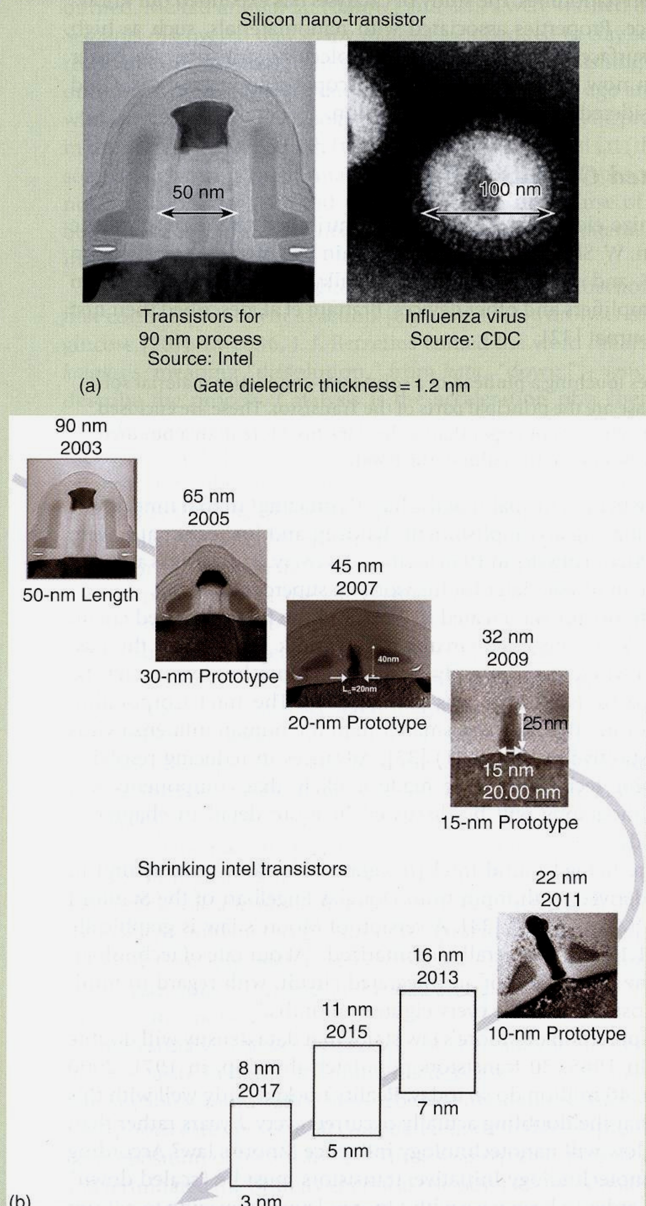


"I am not inventing antigravity, which is possible someday only if the laws are not what we think. I am telling you what could be possible if the laws are what we think; ***we are not doing it simply because we haven't gotten around to it****."*

"… ***"it is an unwritten rule on Nature Nanotechnology that Richard Feynman's famous 1959 lecture 'There's Plenty of room at the Bottom' should not be referred to at the start of articles unless absolutely necessary,"*** wrote editor in chief Peter Rodgers in the December 2009 isue …
Not that Rodgers has anything against the talk, he went on to say—he'd simply like to see a little variety in his opening lines. (He forbids references to Moore's law for the same reason.) …"

DS (might be Sara DiPalma, copy editor of ***Engineering and Science*** Volume LXXIII, Number 1, WINTER 2010)
http://calteches.library.caltech.edu/705/1/ES73.1.2010.pdf

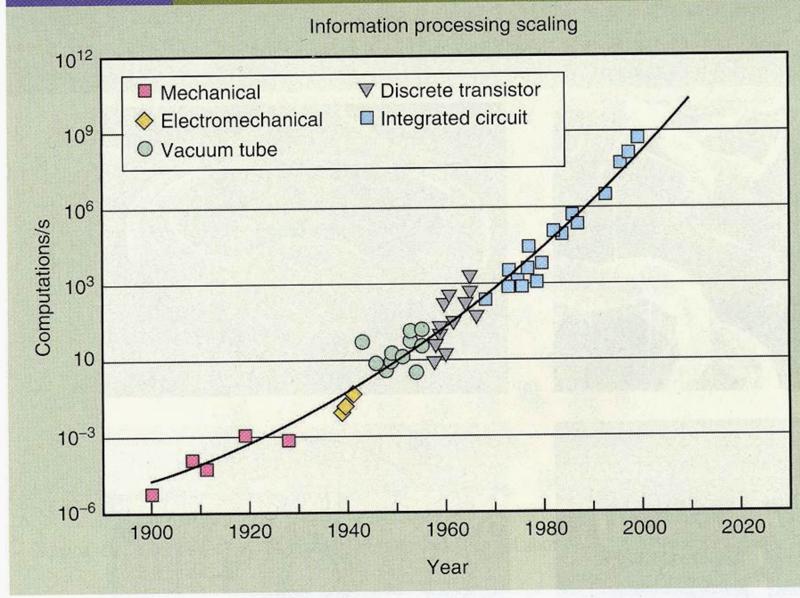
Fig. 1.11 *(a) A vintage 2003 transistor fabricated by the Intel Corporation is compared to the human influenza virus. We are now able to make devices smaller than one of the smallest "complete" biological structures. (b) The decreasing trend in transistor size is shown. By 2017, transistors under 10 nm in size are expected to be components in chips.*



Source: Images reprinted with permission of George Thompson, Intel Corporation.

Gordon Moore's 1st law, 1965 (1975), the number of components (transistors) on a chip doubles every 1 (to 2 years) (18 months?), while chip size increases; 2nd law: investment required to set up a new semiconductor factory also grows exponentially, this may limit the industry

Fig. 1.12 *An adaptation of Moore's law shows how computing power has increased since the onset of the first mechanical computing devices.*



Source: Image courtesy of the IBM Corporation. With permission.

Bandwidth of information that can be transmitted through optical fibers doubles every 6 months, Internet

Human beings have difficulties comprehending exponential growth

- There is some lake where sea roses grow, their growth is exponential
- It took 5 months for the sea roses to cover an area equivalent to one quarter of that lake
- How long will it take before that lake will be covered completely by sea roses ??? (and the exponential growth stops)

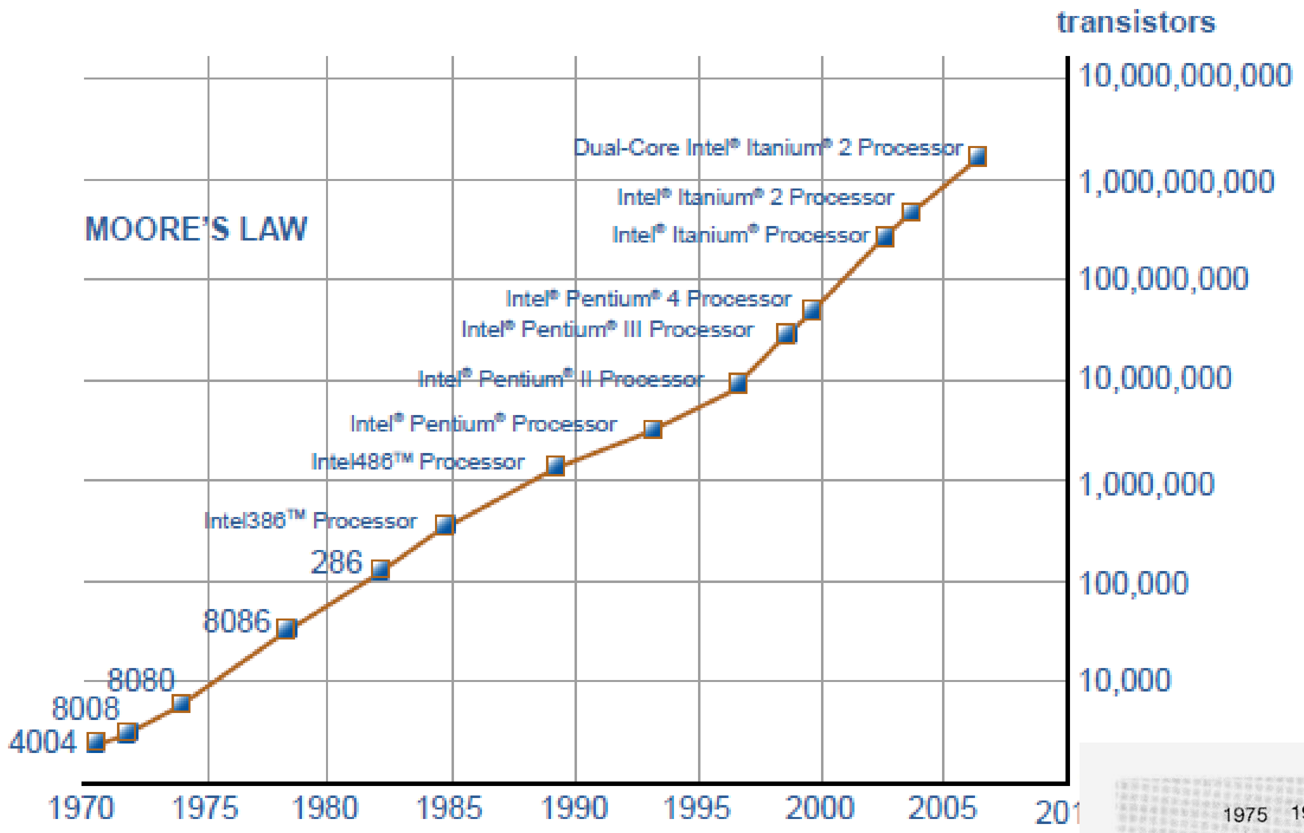


Figure 1.1. Moore's law predicts rapid miniaturization c
printed with permission from Intel Corporation © Copyrig
poration.]

New version" number of transistors with time = $2^{time(t)}$ (since 1962, while keeping the chip size constant) if t = 1 year, 2^{10} = 1024 fold increase in 10 years, if t = 2 years, only 32 fold increase if t = 1.5 years, 101.6 fold increase

Moore himself: "I never said 18 month, I said 1 year and then 2 years, Moore's law has been the name given to everything that changes exponentially. … if Gore invented the Internet, I invented the exponential."

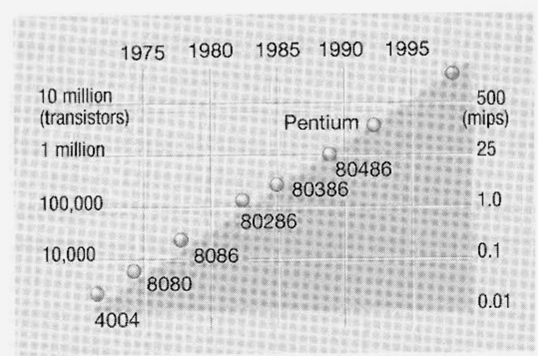
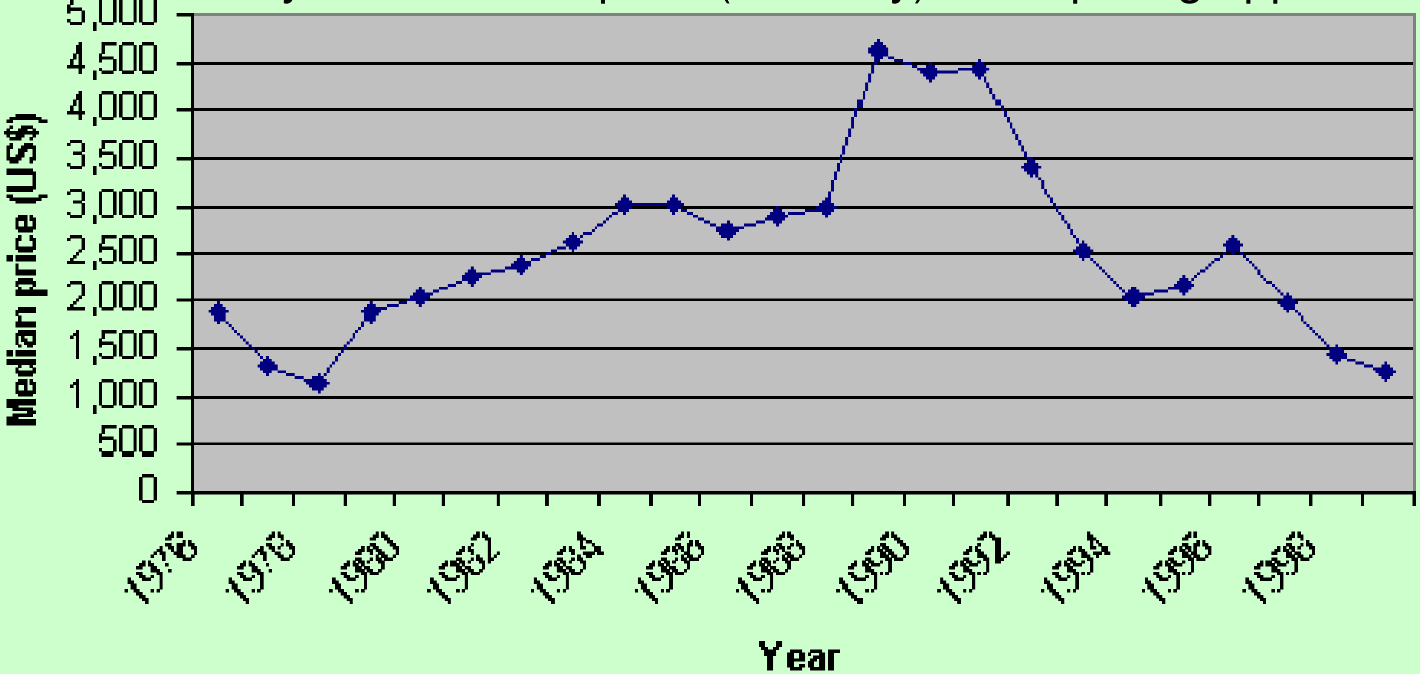


Figure 1.2 Moore's Law. [6]. The number of transistors in successive generations of computer chips has risen exponentially, doubling every 1.5 years or so. The notation "mips" on right ordinate is "million instructions per second". Gordon Moore, co-founder of Intel, Inc. predicted this growth pattern in 1965, when a silicon chip contained only 30 transistors! The number of Dynamic Random Access Memory (DRAM) cells follows a similar growth pattern. The growth is largely due to continuing reduction in the size of key elements in the devices, to about 100 nm, with improvements in optical photolithography. Clock speeds have similarly increased, presently around 2 GHz. For a summary, see [7].

wait 18 months and you get a computer that is twice as powerful as today for the same price (as today)? Comparing apples and oranges?



"Quality adjusted PC prices" actually halved every 53 month between 1995 and 2000

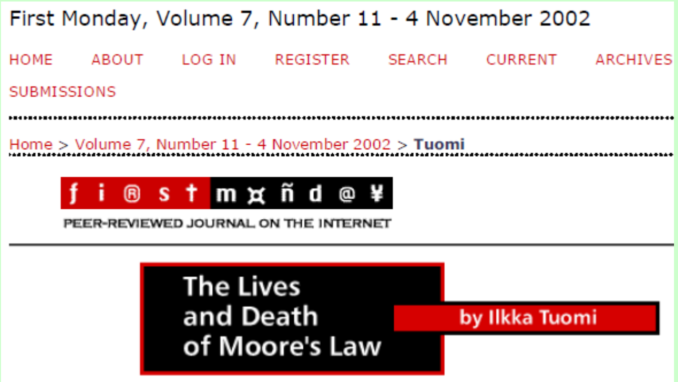
www.nber.org/papers/w8715

Median price for desktop computers sold in the U.S.

Source: http://firstmonday.org/htbin/cgiwrap/bin/ojs/index.php/fm/article/view/1000/921

Gordon Moore himself: ***"Fortunately, the software industry has been able to take advantage of whatever speed and memory we could give them. They have taken more than we gave, in fact. I used to run Windows 3.1 on a 60 megahertz 486, and things worked pretty well. Now I have a 196 megahertz Pentium running Windows 95, and a lot of things take longer than they used to on the slower machine. There's just that much more software, I guess."***

Wirth's law: "Software gets slower faster than hardware gets faster."



http://firstmonday.org/htbin/cgiwrap/bin/ojs/index.php/fm/article/view/1000/921

“We found that Moore changed his interpretations of Moore’s Law during the 1960s and 1970s, and that its subsequent extensions have added qualitatively new and important aspects to it. Whereas the original formulations of Moore’s Law focused on counting components on integrated circuits, its extensions made claims of exponential increase in processing power and exponentially dropping quality–adjusted prices of computing. **We reviewed the available empirical evidence for these different versions of Moore’s Law and found that they have little empirical support.** **Semiconductor technology has not developed according to Moore’s Law. The claims that future developments in semiconductors, computer technology, or information processing would be determined by the continuation of Moore’s Law are, therefore, obviously invalid.**

This result is either trivial or quite illuminating. It is trivial in the sense that no one has seriously been arguing that Moore’s Law would be a deterministic natural law. It is supposed to be a rule–of–thumb that tries to give an overall picture of the dynamics of development in semiconductor technology and, more generally, in computer technology and information society.

The result, however, is also far from trivial. It implies that references to Moore’s Law qualitatively miss the character of development in semiconductor technology and the information society.

Moore's Law gave us a compact and a deceptively exact way to express beliefs in technological determinism. Later it became transformed to economic determinism, which argued that people would buy computers because they will be ridiculously cheap. Moore's Law also provided a convincing basis for arguing that the development of economies and societies is at the hands of technical experts. The fact that Moore's Law has so often been misrepresented and used together with contradictory evidence indicates that it has expressed strong and fundamental convictions about the nature of progress. **Contrary to what its users have often claimed to say — that the history of semiconductors and computing has followed a well–defined exponential path — the rhetoric point of Moore's Law has been directed towards the future**, determined by technological development and understood by the speaker.

…

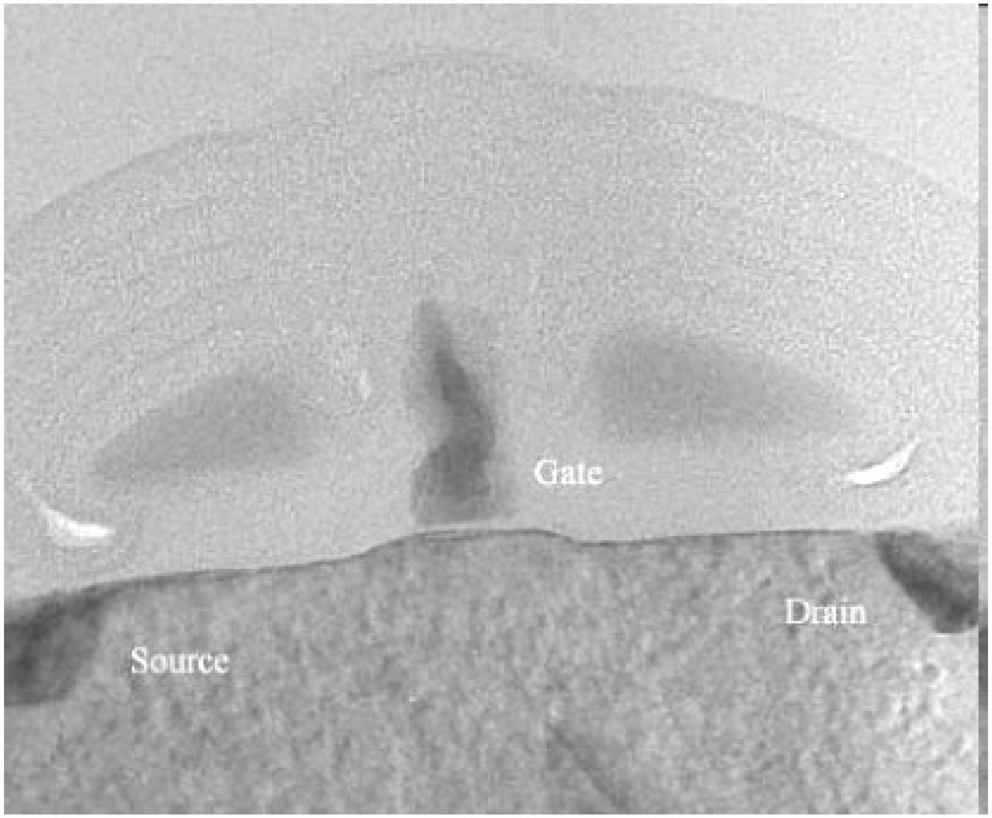
In a way his prediction, however, was too successful. It allowed technologists, economists, and politicians to neglect important factors that have been driving social, technical, and economic development during the last decades. Although the increasing use of computing technology has made people more aware of, for example, social, cultural, organizational, political, ethical, and cognitive issues related to information processing, **physics is still commonly seen as the hard core of future developments**. As a result, many discussions on the future of Moore's Law have focused on physical limits. In recent years economic considerations have gained legitimacy also in this context, partly because Moore himself has frequently predicted that the increases in chip complexity will not be limited by physics but by the exponentially increasing costs of manufacturing plants."

Micro-electronic was so successful for precisely the same reasons as nanoelectronics is going to be,

There is “plenty of room at the bottom”, for “mircometer-electronics” say there is a factor 10^6 in comparison to our human length scale

For “nanometer-electronics” this factor is going to be 10^9 also new opportunities arise from “going quantum”

Prototype Intel 20 nm transistor



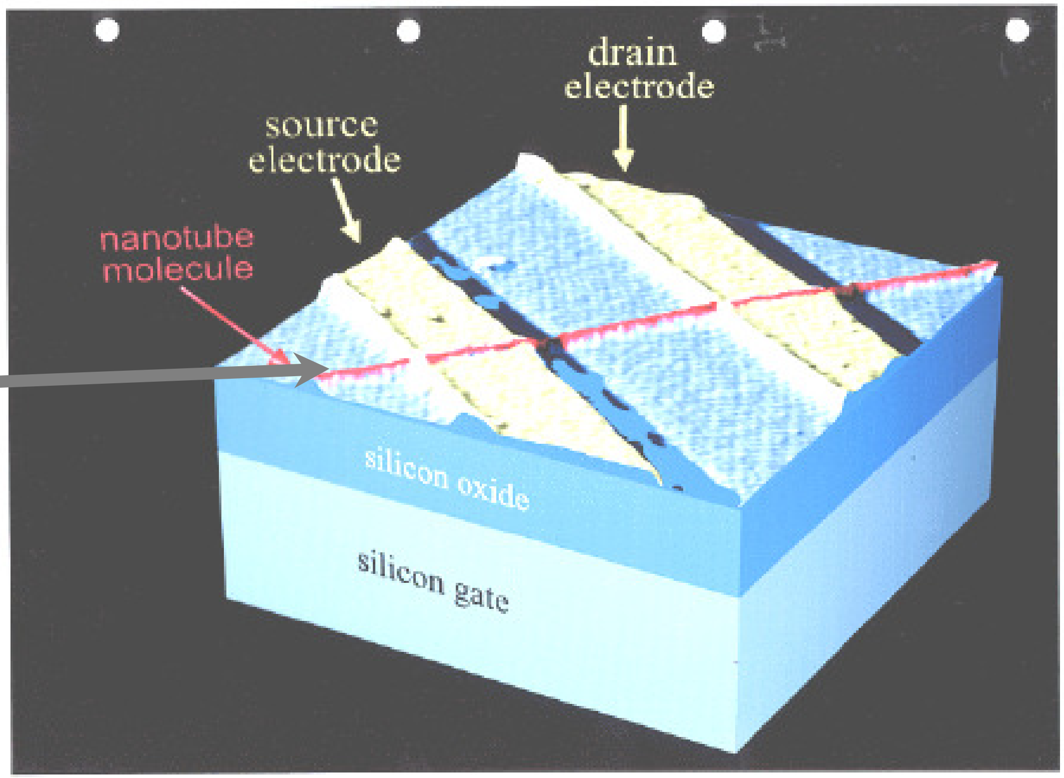
TEM image

Already in 2002, the number of all transistors in DRAMs produced in the world in that year was greater than the number of grains of rice produced !!

The cost of producing one transistor in a DRAM was about 1/100 of the cost of producing one grain of rice !

C. Dekker, TU Delft: <1 nm SWCNT transistor

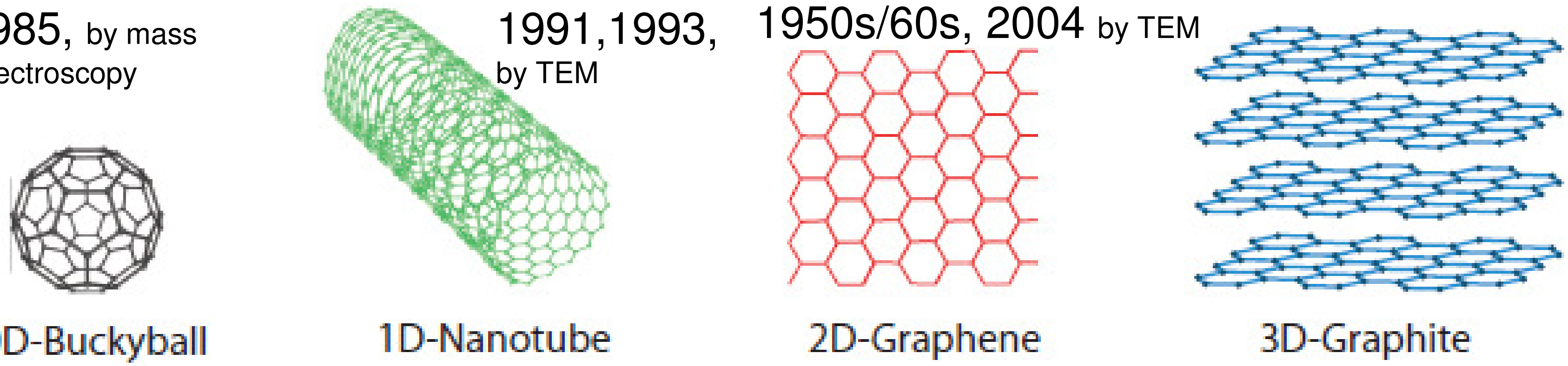
About 2 nm diameter



1985, by mass spectroscopy

1991,1993, by TEM

1950s/60s, 2004 by TEM



Nobel prize chemistry 1996

2004 production by exfoliation, physical properties measured, Nobel prize physics 2010

Figure 9.4. Graphene is a 2D building material for carbon materials of all other dimensionalities. It can be wrapped up into 0D buckyballs, rolled into 1D nanotubes or stacked into 3D graphite.

Graphene: the new “electronic wonder-material”, loosely speaking kind of nearly all what nanotubes can do, graphene could possibly do better, there is no chirality problem and associated variability of physical properties as there are with mass produced nanotubes,

Before there was graphene by exfoliation or epitaxial SiC growth with subsequent desorption of Si, researchers would slice nanotubes open to have a nano-ribbon

Graphene is unique with respect to its linear E(k) dispersion relation, effective mass of electron and hole are zero, $v_{fermi} \approx 1/300\ c$

$$E = \pm \left| \hbar \vec{k} \right| \cdot v_{Fermi}$$

The only other system that has a linear dispersion relation is photons in free space !! E = p c !

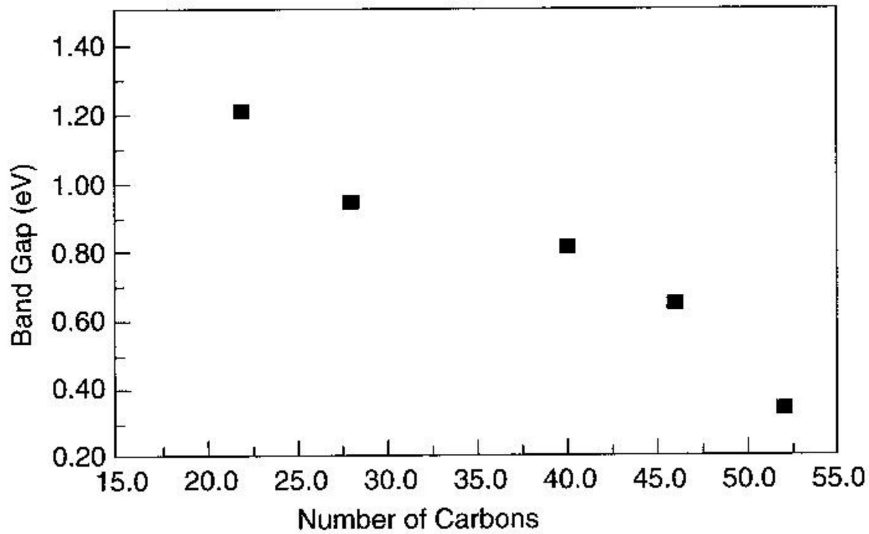


Figure 10.52. Calculated bandgap at $K = 0$ for graphene ribbon versus the number of carbons in the ribbon. [Adapted from F. J. Owens, *Molec. Phys.* **104**, 3107 (2006).]

$$E_{gap} = \alpha / (W - W^*)$$

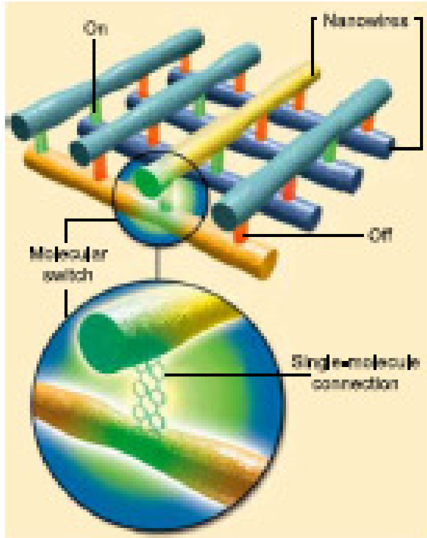
α ≈ 0.2 eV nm

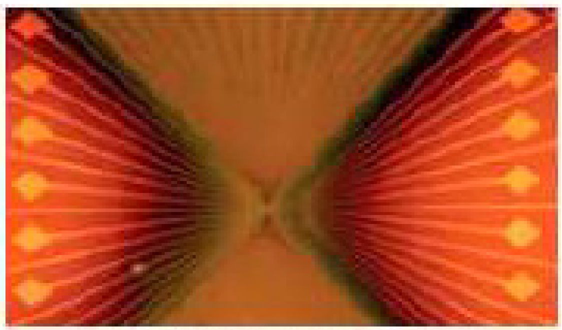
W* ≈ 16 nm

are fitting constants from experiment

Bandgap of graphene can be tuned by widths of the nanoribbon (nm size in one dimension, μm size in the other dimension, so it can be a metal, a semiconductor, or an isolator just in dependence of its widths and the back-gated voltage, a smaller widths semiconductor nanoribbon region could be contacted by a larger widths metallic region (avoiding the electric contract problems of nanotubes

There could be different kinds of organic molecule at different interjections





FAN-OUT WIRES from crossbar to test pads.

Figure 1.9. Left: Schematic showing how the switch is formed at the junction between two crossing nanowires that are separated by a single monolayer of molecules. Right: Picture of fan-out wires that connect the nanoscale circuits to the microscale. [Reprinted with permission from P. J. Kuekes, G. S. Snider and R. S. Williams, *Scientific American*, November 2005, 72. Copyright © 2005 by Scientific American, Inc. All rights reserved.]

Science 17 December 2010:
Vol. 330 no. 6011 p. 1604
DOI: 10.1126/science.330.6011.1604

Breakthrough of the Year **First Quantum Machine**

Adrian Cho

Summary

Until now, all machines have moved according to the not-surprising laws of classical mechanics, which govern the motion of everyday objects. In contrast, a tiny machine unveiled this year jiggles in ways explicable only by the weird rules of quantum mechanics, which ordinarily govern molecules, atoms, and subatomic particles. The proto-quantum machine opens the way to myriad experimental devices and perhaps tests of our sense of reality. That potential and the ingenuity of the experiment make it the Breakthrough of the Year.

http://www.sciencemag.org/site/special/insights2010/

FIG. 1.20 *The wavelength of quantum resonance fluorescence emission of cadmium selenide quantum dots is related to the size of the nanoparticle. The emission of longer wavelengths is indicative of larger size.*

Size matters !!

Source: Image reprinted with permission from Professor Zhiqun Lin, Department of Materials S University.

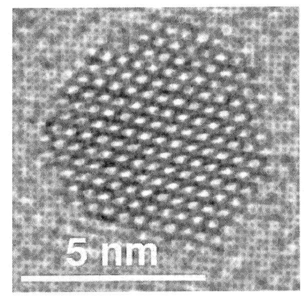


Figure 1.3 Transmission Electron Micrograph (TEM) Image of one 5 nm CdSe quantum dot particle, courtesy Andreas Kornowski, University of Hamburg, Germany.

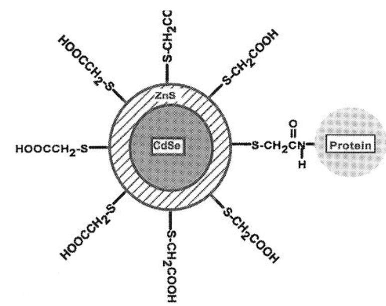


Figure 1.4 Schematic of quantum dot with coatings suitable to assure water solubility, for application in biological tissue. This ZnS-capped CdSe quantum dot is covalently coupled to a protein by mercaptoacetic acid. The typical QD core size is 4.2 nm. [8]

Isolated quantum dots in a solution, their color depends just on the size (independent on the semiconductor material), have also been called “artificial atoms” because they have discrete and well separated energy level, just like atoms, may be modeled as particles in a box if different sizes.

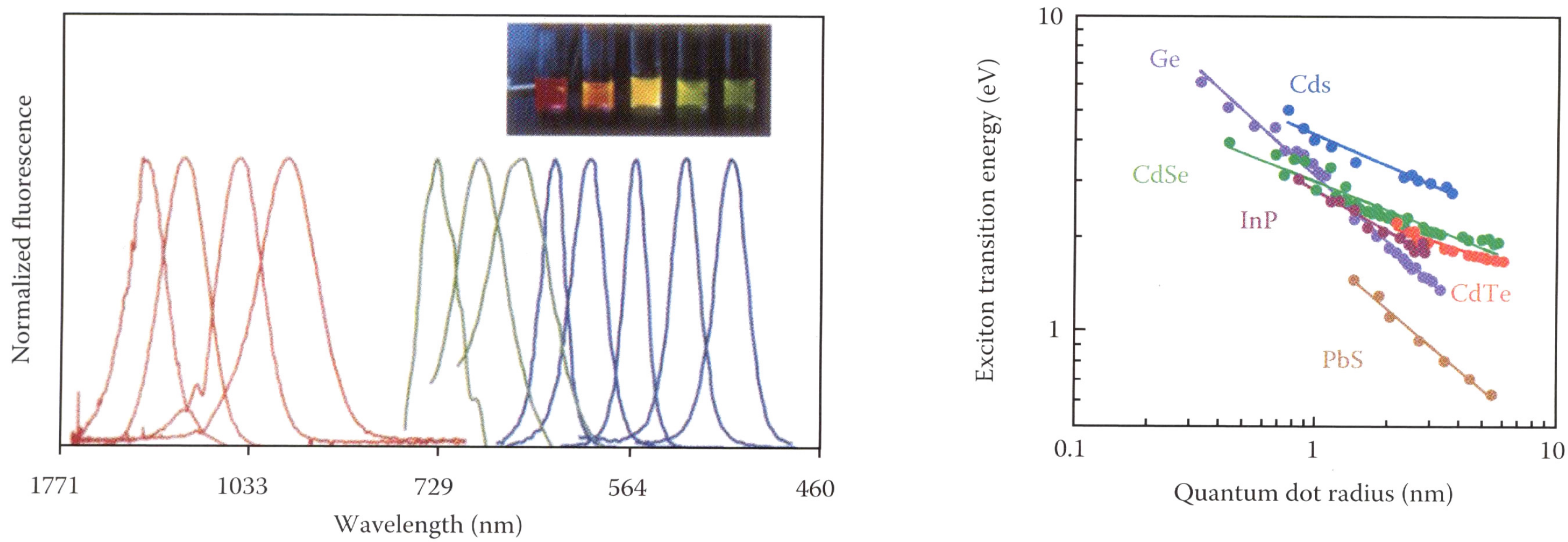


Figure 3.8 Left: Size- and material-dependent fluorescence spectra of semiconductor nanocrystals. Blue lines: CdSe nanocrystals with diameters of 2.1, 2.4, 3.1, 3.6, and 4.6 nm (from right to left). Green lines: InP nanocrystals with diameters of 3.0, 3.5, and 4.6 nm. Red lines: InAs nanocrystals with diameters of 2.8, 3.6, 4.6, and 6.0 nm. Inset: Images of a series of silica-coated core (CdSe) shell (ZnS or CdS) nanocrystals. (Reprinted from M. Bruchez et al., *Science* 281, 1998, 2013. With permission.) Right: Size-dependent exciton energies for quantum dots of various semiconducting materials. (Reprinted from G.D. Scholes and G. Rumbles, *Nat. Mater.* 5, 2006, 683. With permission.)

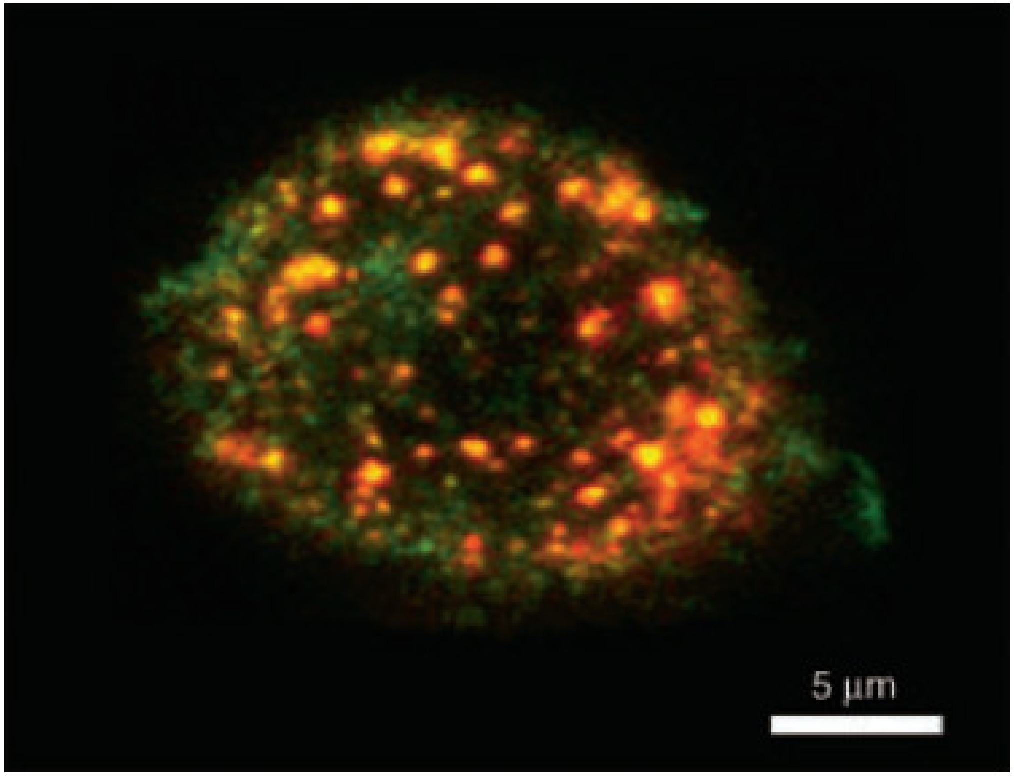
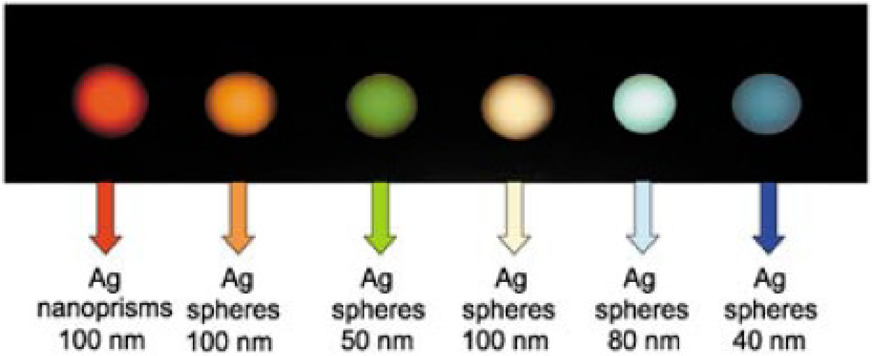


Figure 4. Image of a mammalian cell labeled with fluorescent, surfactant-stabilized, semiconductor quantum dots.[82] The resistance of these nanostructures to photobleaching makes them attractive in applications in which the sensitivity of molecular fluorophores to the exciting light is a serious impediment to their use.



Shape matters !!

— 200nm (the same for all the images)

Figure 1. Size, shape, and composition matters. This statement is illustrated here by considering the Rayleigh light-scattering properties of various nanoparticles (quoted nanoparticle sizes are all approximate).

The Beginning of a *Small* Revolution

*Chad A. Mirkin**

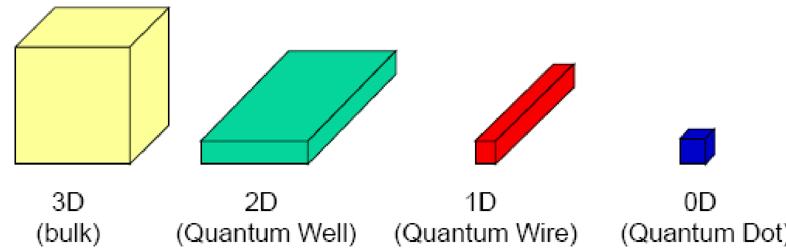
small 2005, 1, No. 1

$$I = I_0 \frac{8\pi^2\alpha^2}{\lambda^4 R^2}(1+\cos^2\Theta)$$

characteristic length smaller than λ visible light

Density of electronic states as a function of dimensionality, at least one dimension should be below about 100 nm

C. W. Shong, S. C. Haur, A. T. S. Wee, *Science at the Nanoscale, An Introductory Textbook*, Pan Stanford, 2010.



Dimensionality matters !!

When the size is small, shape matters as well

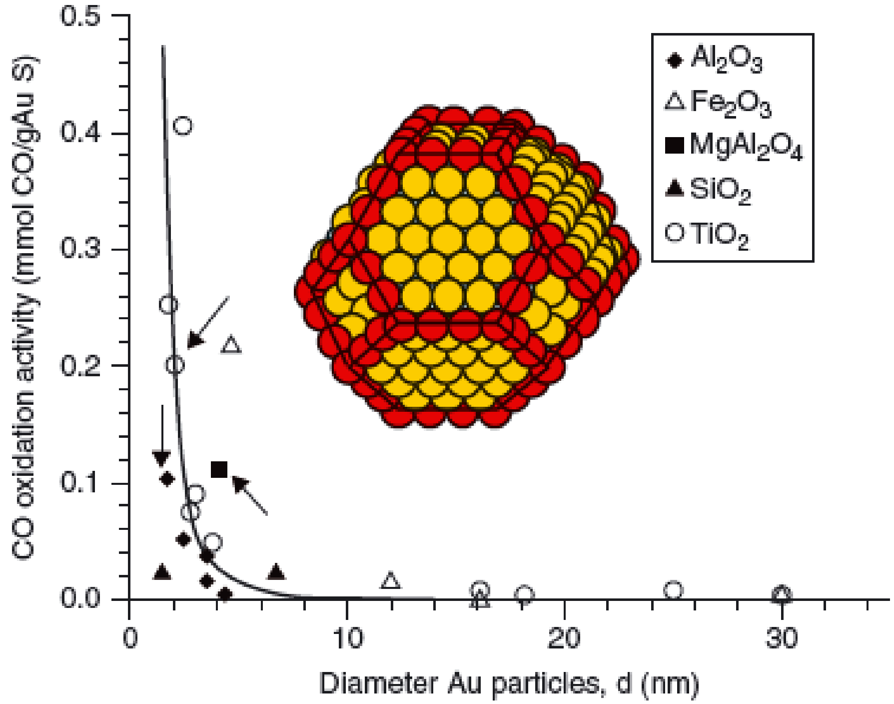


Fig. 1.13 Reactivity of gold nanoparticles. Measured activities of gold nanoparticles on various supports (box) for carbon monoxide oxidation as a function of particle size. The black line is a fit using a $1/d^3$ law and is seen to broadly represent the variation indicating that the dominant effect size effect is the proportion of gold atoms that are at a corner between facets at the surface (see text). Such atoms are highlighted in red on the nanoparticle shown. Reproduced with the permission of Elsevier Science from N. Lopez et al. [16].

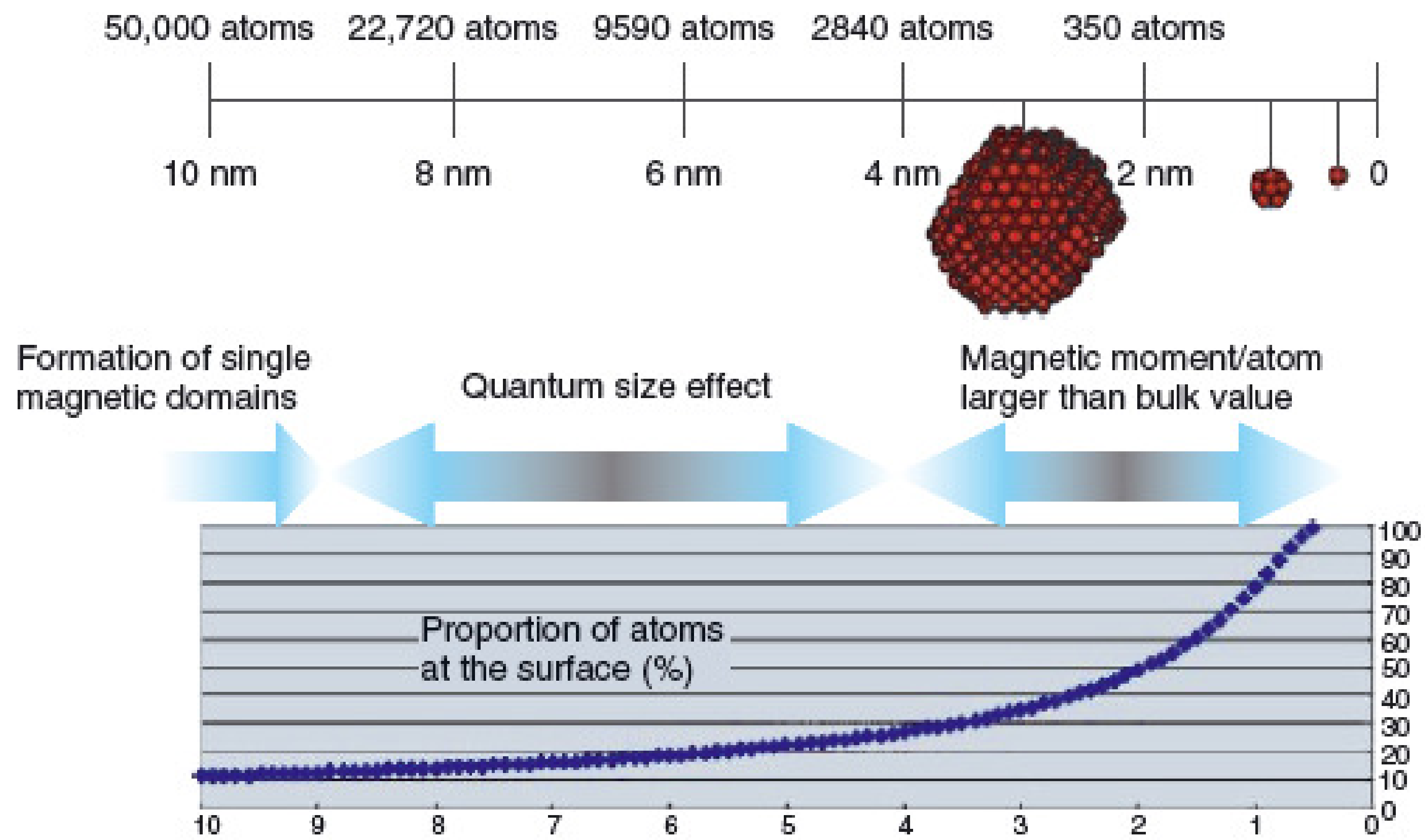


Fig. 1.6 Size-dependent behavior in nanoparticles. For particles smaller than 10 nm, quantum effects start to become apparent. In this size range the proportion of atoms that constitute the surface layer starts to become significant reaching 50% in 2 nm diameter particles. Below about 3 nm the strength of magnetism per atom starts to increase.

Physical properties that are size dependent

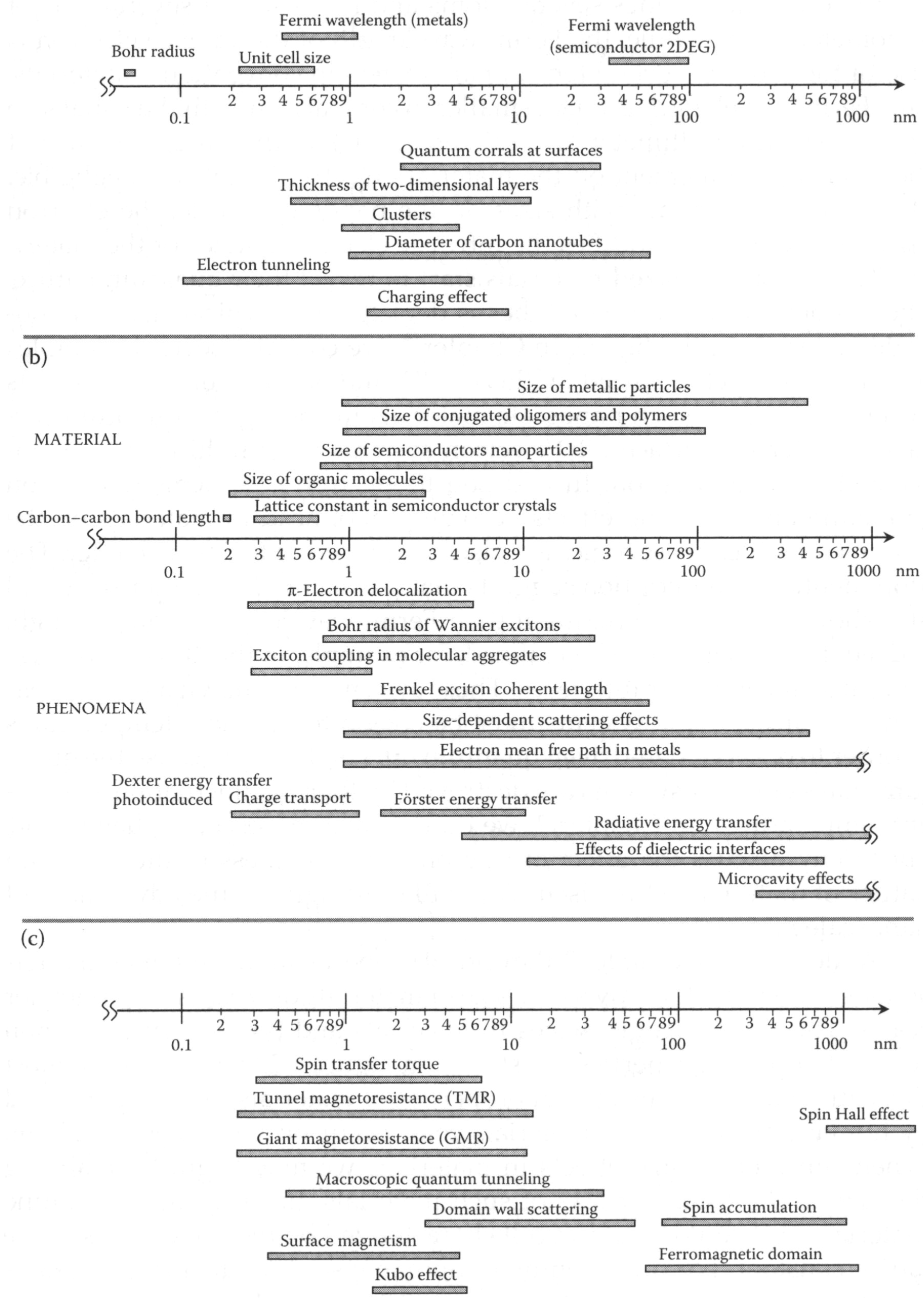


Figure 1.23 Material properties with respect to characteristic size of nano-structures: (a) eletronic properties; (b) optical properties; (c) magnetic properties.

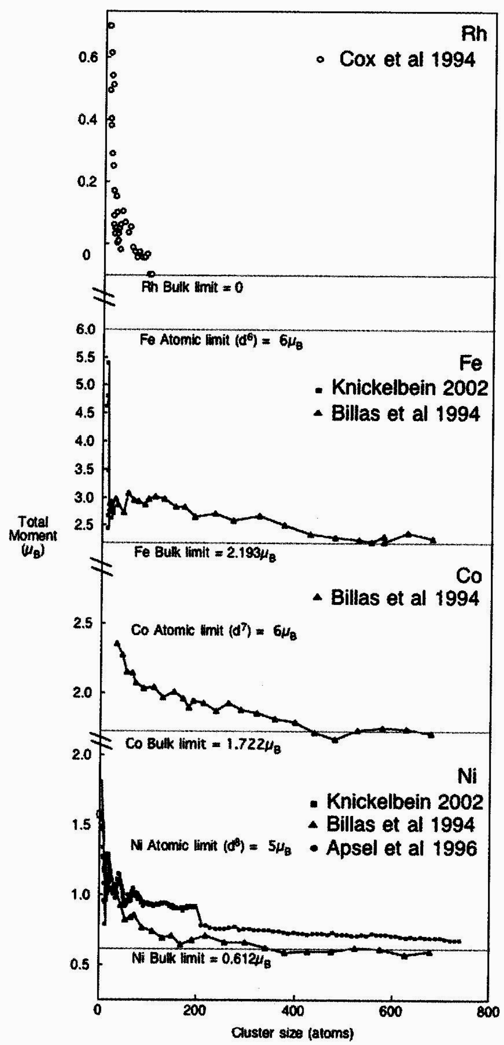


Fig. 1.8 Measured magnetic moments per atom in magnetic nanoparticles. Experimental measurements of the magnetic moment per atom in iron, cobalt, nickel and rhodium (a non-magnetic metal in the bulk) nanoparticles as a function of the number of atoms in the particle. For iron, cobalt and nickel, there is a significant increase in the magnetic moment per atom over the bulk value for particles containing less than about 600 atoms. Rhodium becomes magnetic in particles containing less than about 100 atoms. Note the very dramatic change in the magnetic moment of iron particles in going from a 12-atom particle to a 13-atom particle. Reproduced with the permission of the American Association for the Advancement of Science (AAAS) from I. M. L. Billas et al. [4], permission of the American Physical Society from A. J. Cox et al. [5] and S. Apset et al. [6], Copyright 1994 and 1996 and permission of Elsevier Science from M. B. Knickelbein [7].

Example magnetic properties, Fe, ferromagnetism, the super paramagnetic limit, smaller than super paramagnetic limit

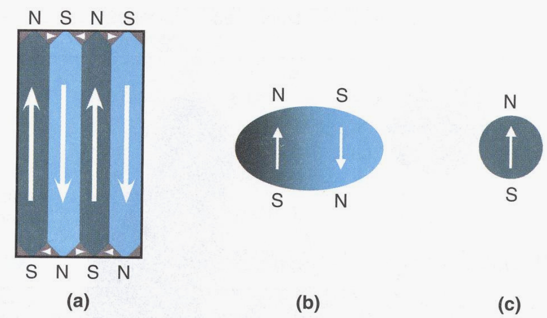


Fig. 1.4 Single-domain particles. Domain formation in iron to minimize energy. Below a critical size (approx. 100 nm), the energy balance favors just a single domain and the piece of iron stays permanently and fully magnetized.

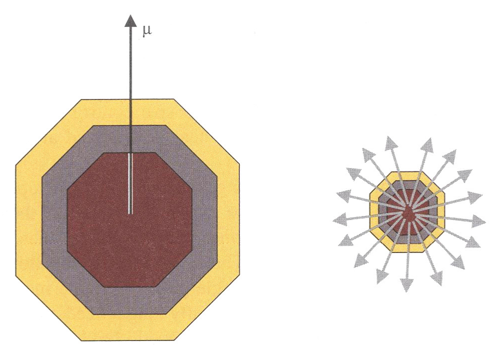


Fig. 6.11 Superparamagnetic and blocked magnetic nanoparticles. Illustration of a magnetic nanoparticle that is large enough (>10 nm diameter) to be magnetically blocked at blood temperature so it is permanently magnetized in one direction compared to a smaller superparamagnetic nanoparticle in which thermal energy flips the moment around randomly at high frequency.

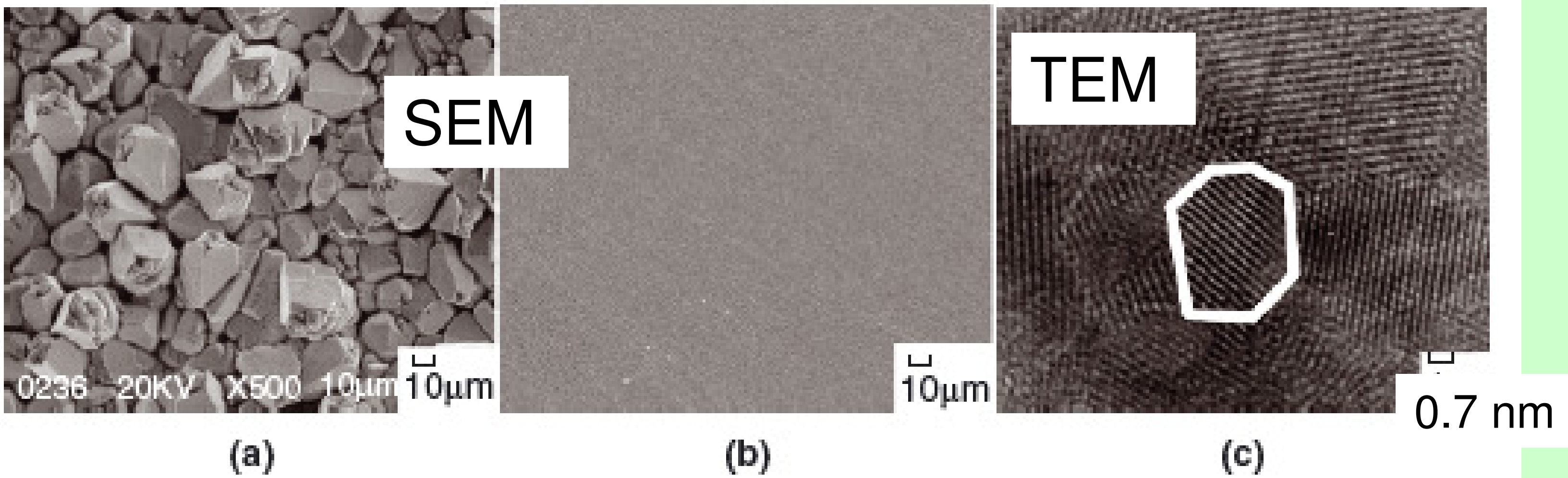


Fig. 1.11 Grain size in nanostructured materials. Electron microscope images showing a comparison of the grain structure in conventional and nanostructured materials. (a) Conventionally processed material (tin) showing a typical grain size of about 20 µm. (b) Nanovate™ nanostructured nickel based coating produced by Integran Technologies Inc. On the same scale as (a) the material appears homogenous. (c) Increasing the magnification by a factor of 15,000 reveals the nano-sized grains. The lines in the picture are atomic planes and the edges of the grains are revealed by changes in the direction of the planes as indicated for one of the grains. Reproduced with permission from Integran Technologies Inc. (http://www.integran.com).

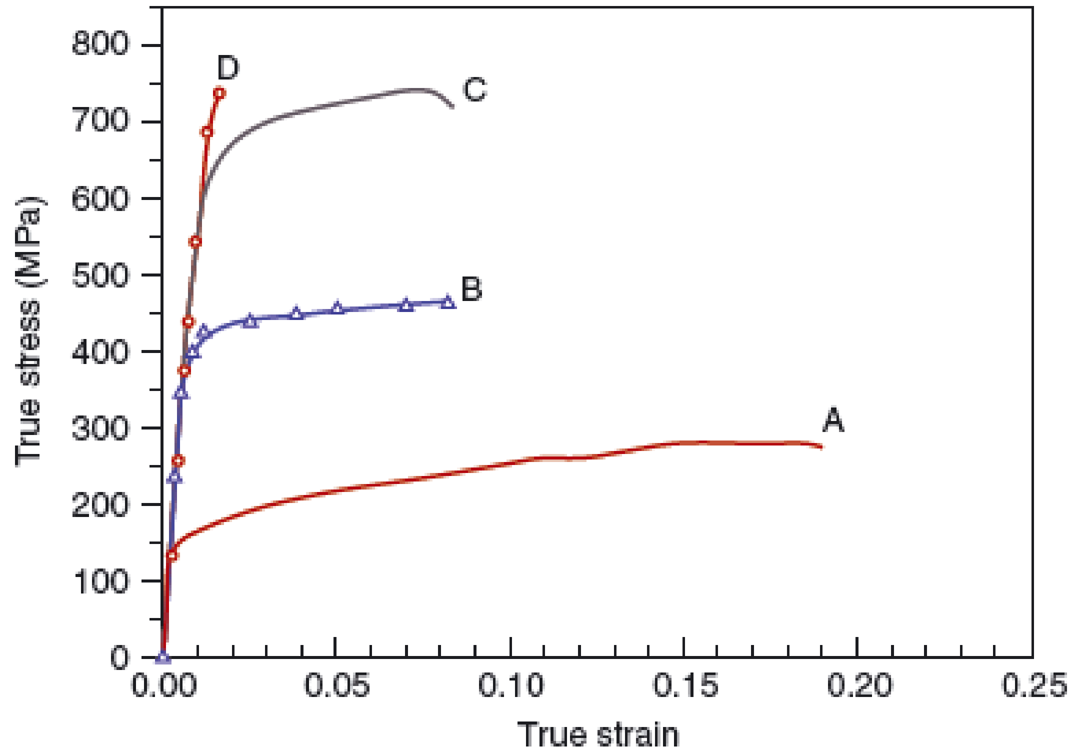
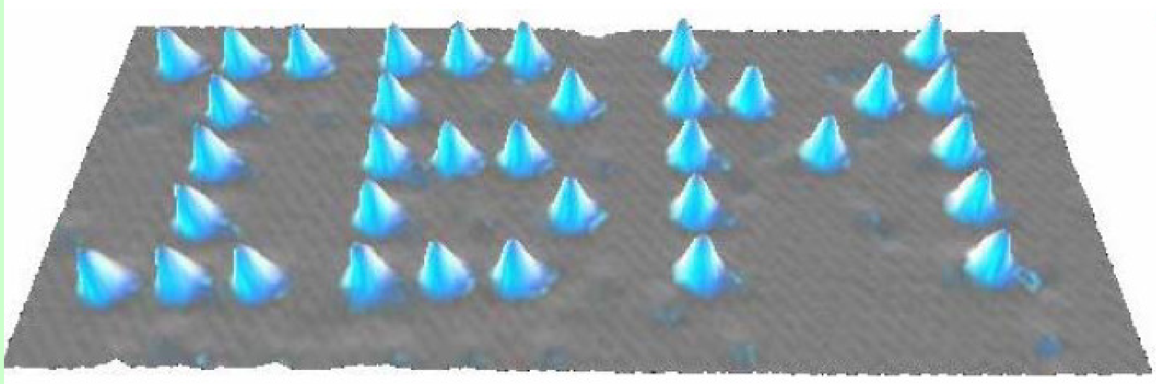


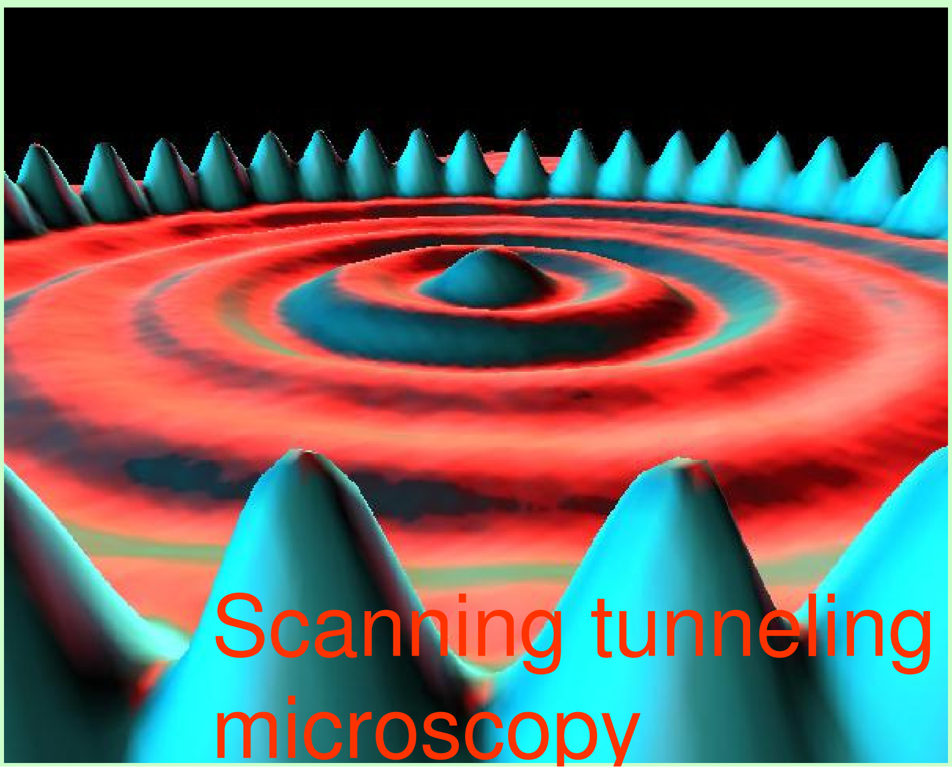
Fig. 1.12 Yield strength of aluminium alloys. Comparison of Deformation (Strain) vs. Load (Stress) for aluminium alloys with different grain sizes. A normal aluminium alloy (coarse-grained). $B - D$ nanostructured aluminium alloy containing grains of size ~30 nm produced by various processes. The plastic limit occurs at the point where the slope changes and the nanostructured materials have a value that is up to four times higher that the conventional alloy. Reproduced with the permission of Elsevier Science from K. M. Youssef et al. [14].

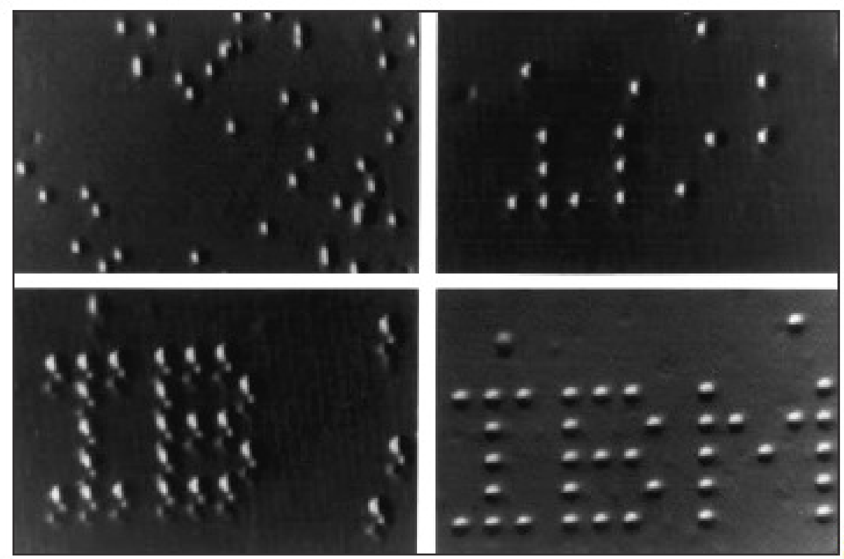
D.M. Eigler IBM - 1989

http://www.youtube.com/watch?v=YcqvJI8J6Lc&feature=fvwrel



what we actually see is either the square of the wave functions of individual atoms or of an electron that is trapped at the surface by the potential energy distribution of the specially arranged surface atoms





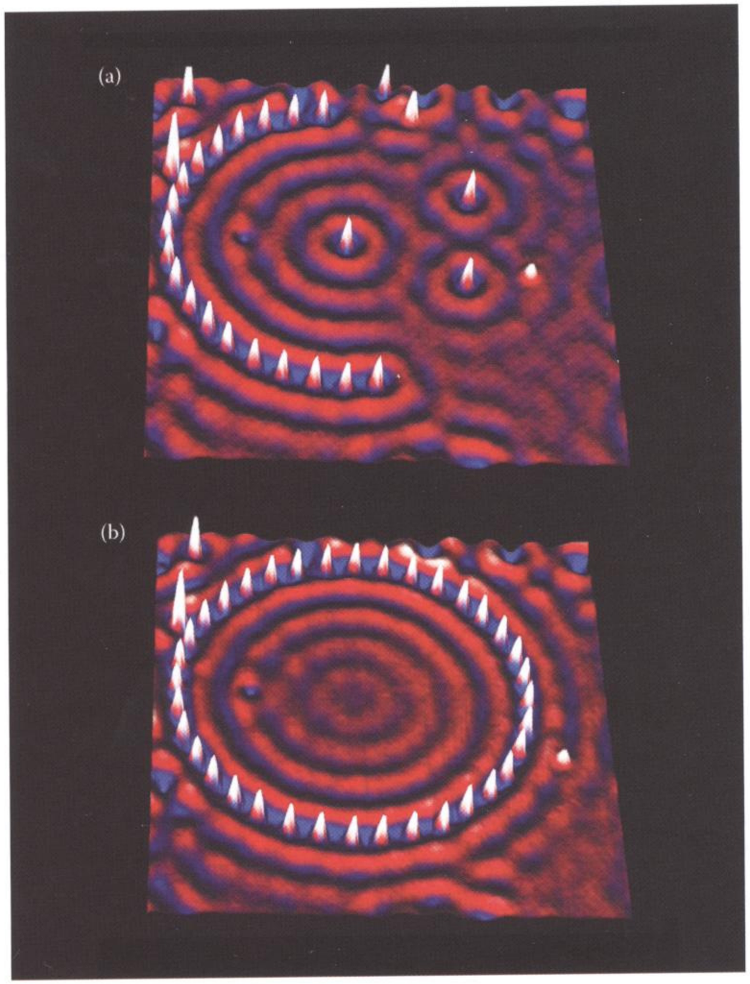
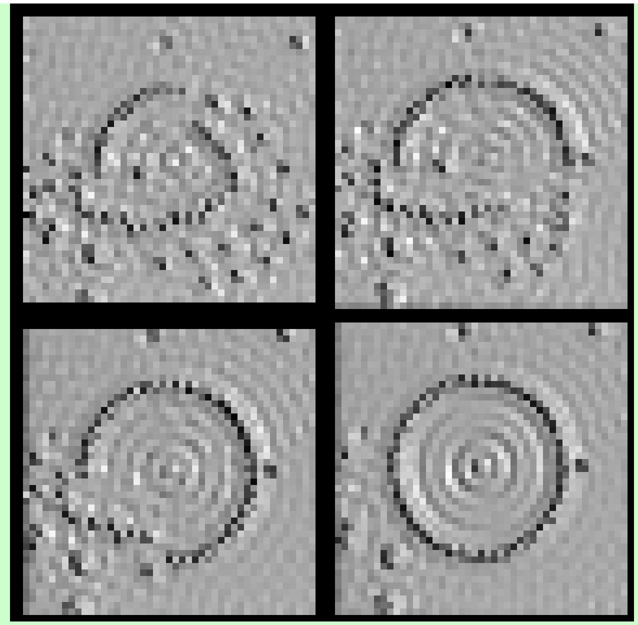
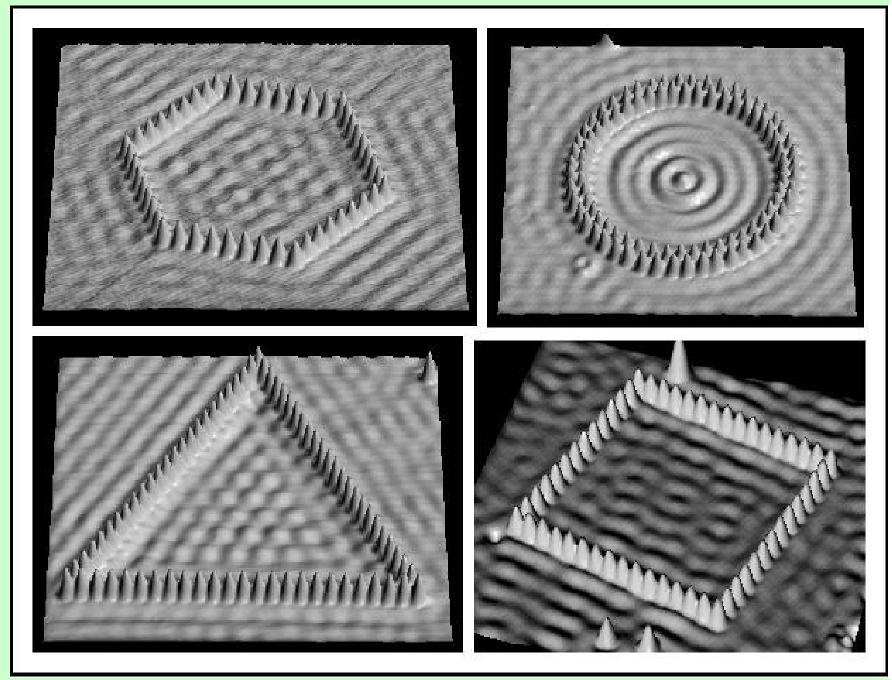


Figure 2.17 Construction of a 2D cylindrical well using STM (a) during the construction and (b) the completed cylindrical well. (Reprinted from S. Hla, K. Braum, and K.H. Rieder, *Phys. Rev. B* 67, 2003, 201402. With permission.)





http://www.youtube.com/watch?v=NJxobgkPEAo less than 3 minutes

http://www.youtube.com/watch?v=D3fOXt4MrOM&NR=1 less than 4 min, DNA

Soft Machines: Thoughts on the future of nanotechnology from Richard Jones: http://www.softmachines.org/wordpress/

Francis Crick, Central dogma

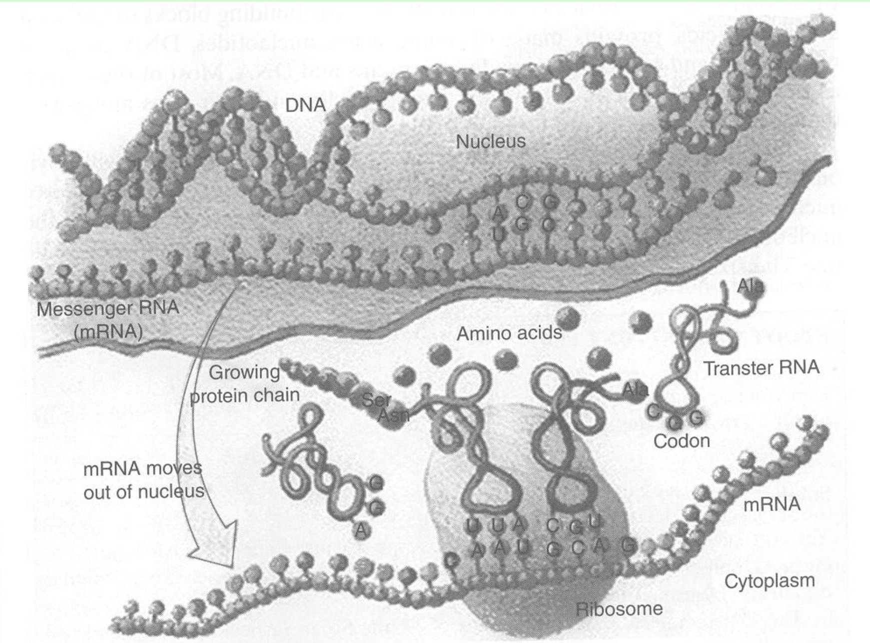


Figure 11.11. An illustration of the central dogma of molecular biology. Courtesy of the Genomone Management System, Oak Ridge National Laboratory.

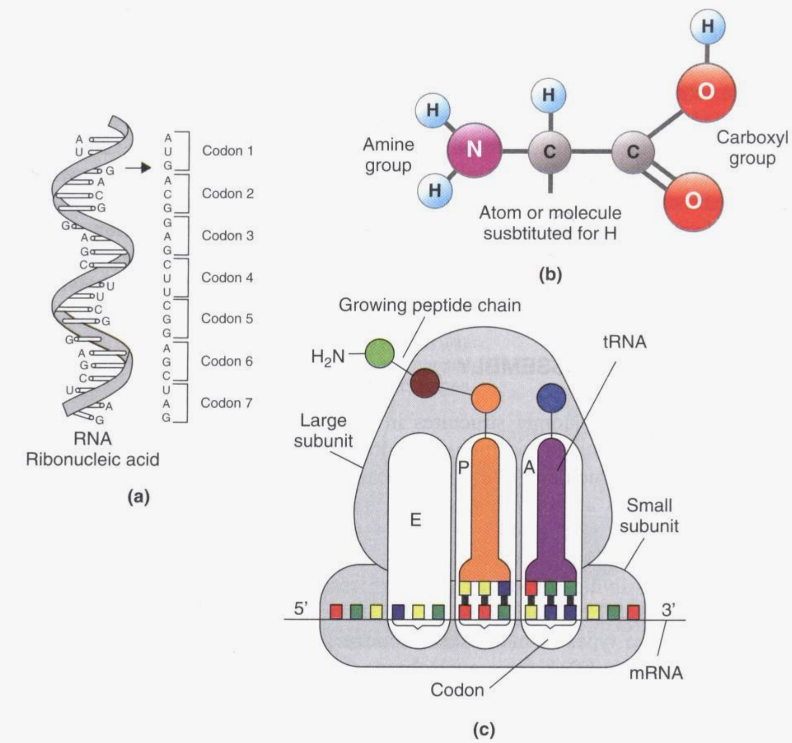


Fig. 7.8 Protein assembly by ribosomes. (a) A section of RNA in which a set of four bases, labeled 'A' (adenine), 'G' (guanine), 'C' (cytosine) and 'U' (uracil) are strung along a phosphate backbone. The bases are arranged in groups of 3 where each group is known as a *codon* and is a label for a specific amino acid. Reproduced from Wikipedia web page: http://en.wikipedia.org/wiki/Genetic_code (b) The generic structure of an amino acid. Reproduced from Wikipedia web page: http://en.wikipedia.org/wiki/Amino_acid (c) Schematic of a ribosome showing the 3 docking positions for transfer RNA (tRNA). The ribosome has started making a chain of amino acids represented by the colored circles and a tRNA carrying the next one (blue circle) as coded by the mRNA has just docked. Its amino acid will be added to the chain after which the mRNA and tRNA will translocate by one codon so that the tRNA at P moves to E (exit) the one at A moves to P and the next codon is exposed at dock A and waits for a tRNA carrying the correct amino acid. Reproduced with permission from Prof. J. Frank, Columbia University.

Note the look and key specifics to what nature has been building for a couple of billion years

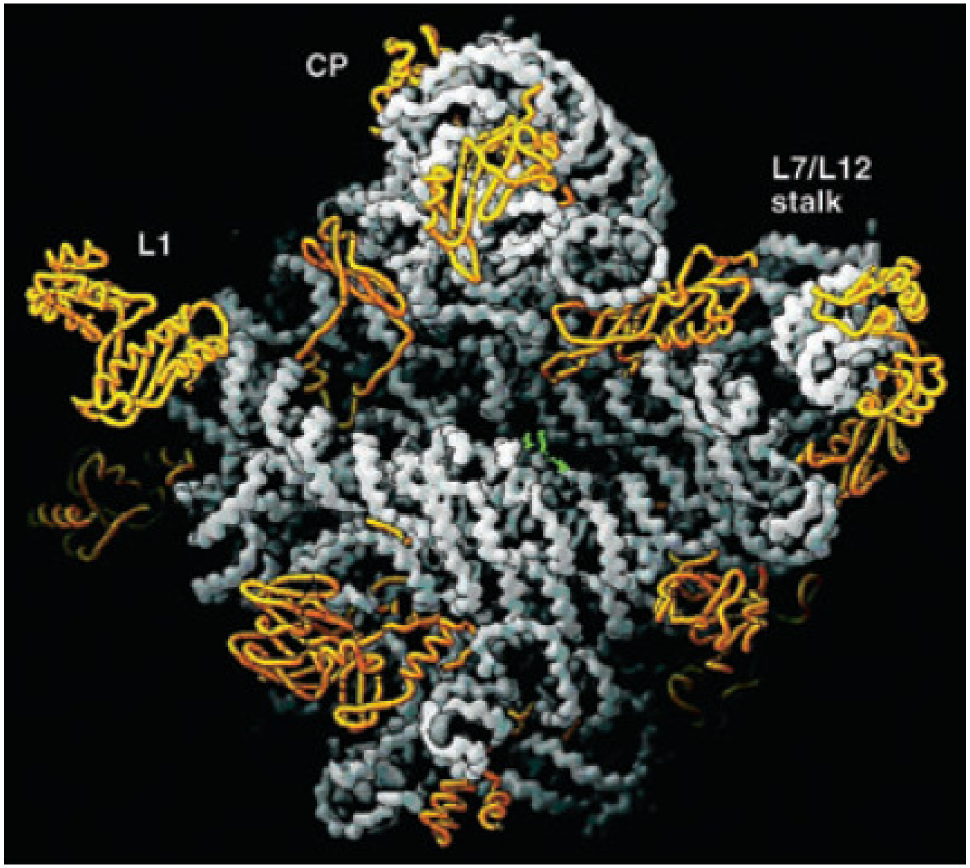


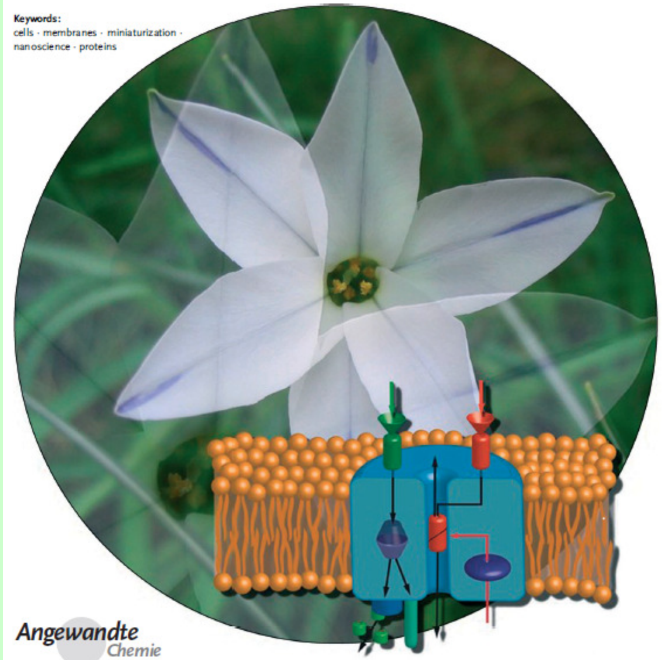
Figure 1. The *H. marismortui* large ribosomal subunit. RNA is shown in gray, the protein backbones are rendered in gold. The particle is approximately 25 nm across.[78] The macromolecular structures that populate the cell are functional nanostructures—"nanomachines"—with a sophistication much greater than that of the nanostructures now available by synthesis and/or fabrication. The principles by which these three-dimensional structures are generated rely heavily on self-assembly, starting with linear precursors, and are very different from those familiar in microelectronics or materials science.

Artificial Life
DOI: 10.1002/anie.200705538

Life as a Nanoscale Phenomenon**

*Stephen Mann**

Keywords:
cells · membranes · miniaturization · nanoscience · proteins



Stephen Mann is Professor of Chemistry and Director of the Centre for Organized Matter Chemistry in the School of Chemistry at the University of Bristol, UK. He is interested in the self-assembly, biomimetic synthesis, and chemical emergence of complex forms of organized matter across extended length scales, and has published over 350 papers and a book entitled Biomineralization: Principles and Concepts in Bioinorganic Materials Chemistry. He has obtained numerous awards, including most recently the RSC J. Chatt Medal and Lectureship (2007). He is a Fellow of the Royal Society and a member of the editorial and advisory boards of several journals including Advanced Materials and Angewandte Chemie.

Working nanoscale rotation motor, soft matter/ biological system evolved over a very long time, nature came up with the basic design just once, about a billion years ago.

One can attach this motor to some suitable surface in a MEMS, as long as one feeds it with ATP, it will be a very efficient local source of energy

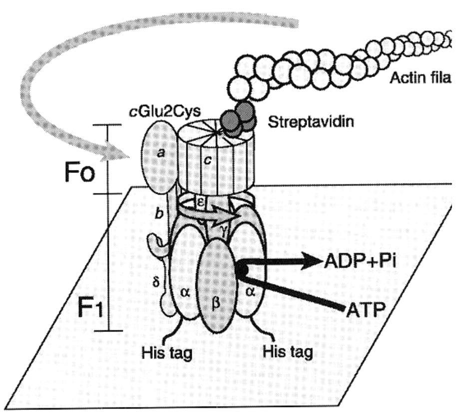


Figure 3.3 Fluorescently labeled actin filament permits observation of rotation of the c subunit in ATP Synthase (F_0F_1) [20]. A c subunit of Glu^2 was replaced by cysteine and then biotinylated to bind streptavidin and the actin filament. The γ, ε, and c units are thus shown to be a rotor, while the α, β, δ, a, and b complex is the stator. The rotation rate of the actin filament in the viscous medium was found to depend upon its length. Rotational rates in the range 0.5 Hz – 10 Hz were measured, consistent with a torque τ of 40 pN·nm.

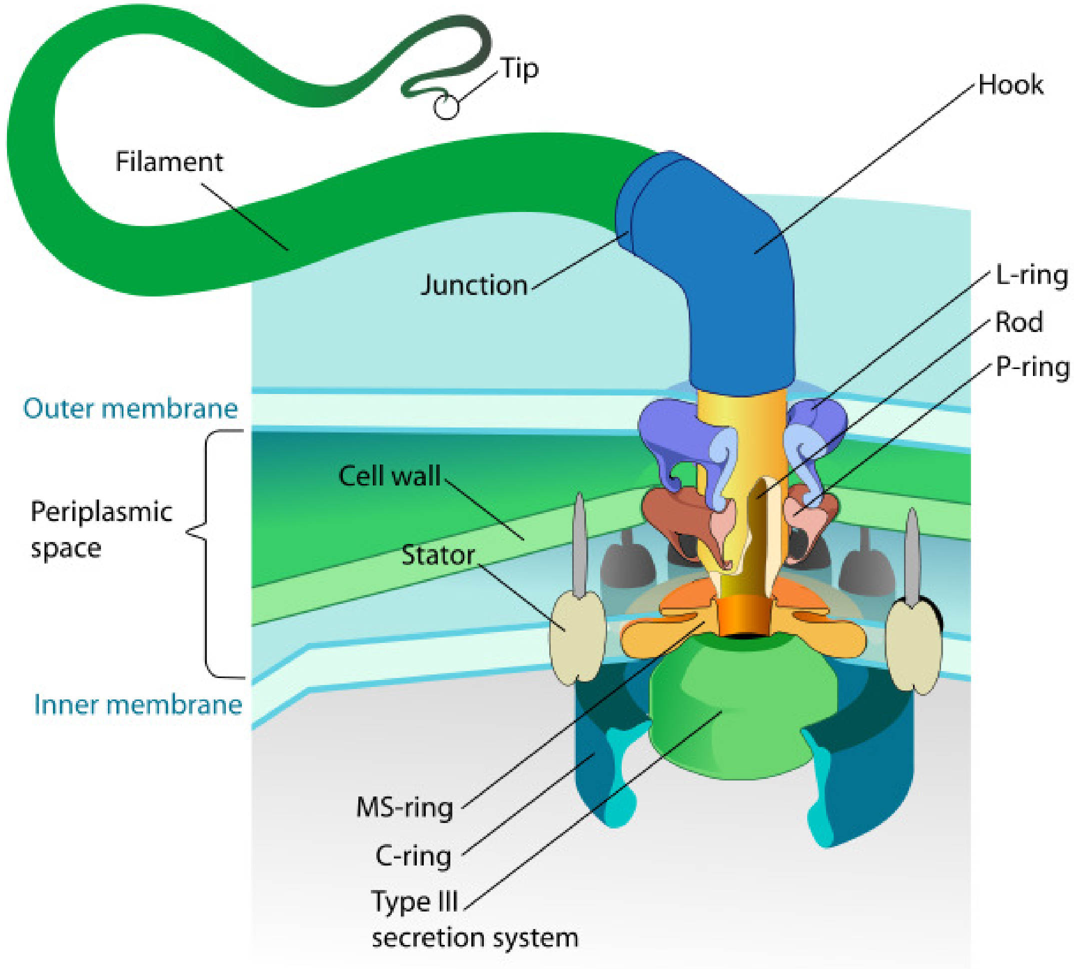


Fig. 7.6 Flagellum and motor of a Gram-negative bacterium. The flagellum is composed of the protein flagellin, which forms tubular structures and has a diameter of ~20 nm and a length of up to 10 μm. The hook near the cell membrane produces a sharp bend in the flagellum so that when it is rotated it moves in a helix to produce thrust. A straight shaft attached to the hook passes through four protein rings (labeled L, P, MS and C) that act as bearings and in addition, the lower two are thought to provide the torque to drive the flagellum [14]. The energy to operate the motor is derived from hydrogen ions (protons) crossing the cell membrane as a result of their electrostatic interaction and concentration gradient. The latter can be controlled by the cell's metabolism to vary the rotational speed of the motor. Reproduced from Wikipedia web page: http://en.wikipedia.org/wiki/Flagellum.

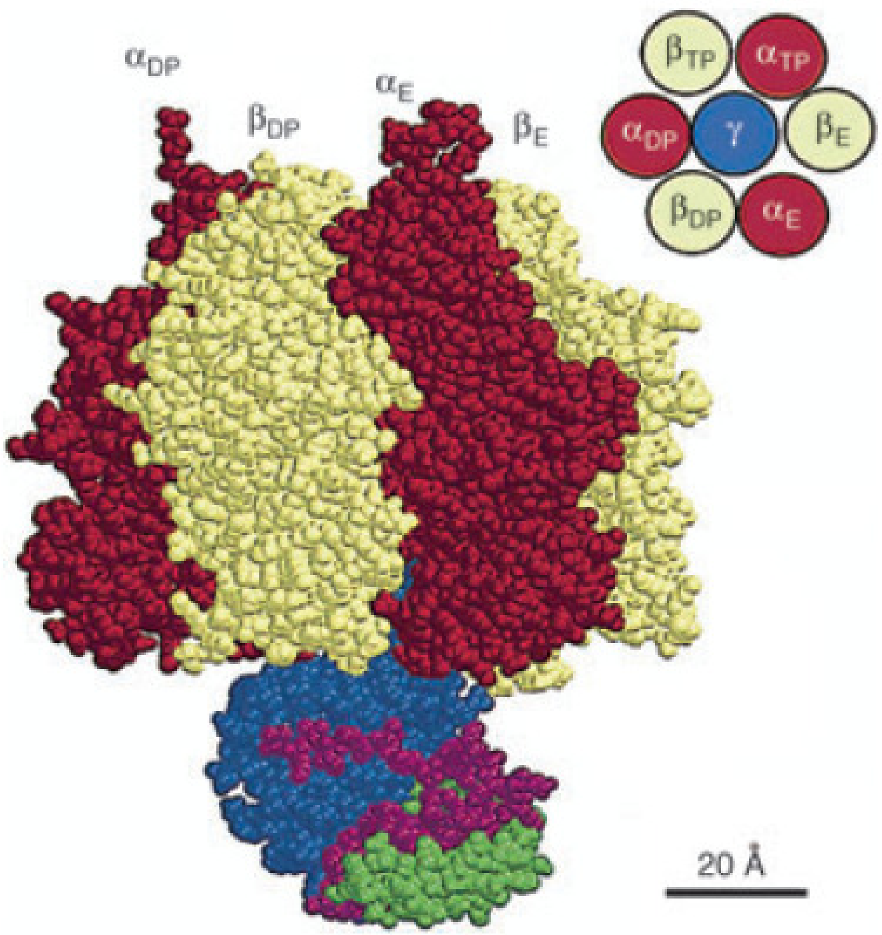


Figure 7. The crystal structure of the central stalk in bovine F1-ATPase at 2.4-Å resolution.[84] This structure represents a biological solution to a rotary machine. Although it superficially resembles a conventional electrical motor in that it has a rotating "shaft" and a "stator", its mechanism of operation depends on conformational changes in proteins and ion currents rather than on magnetic fields and electrical currents.

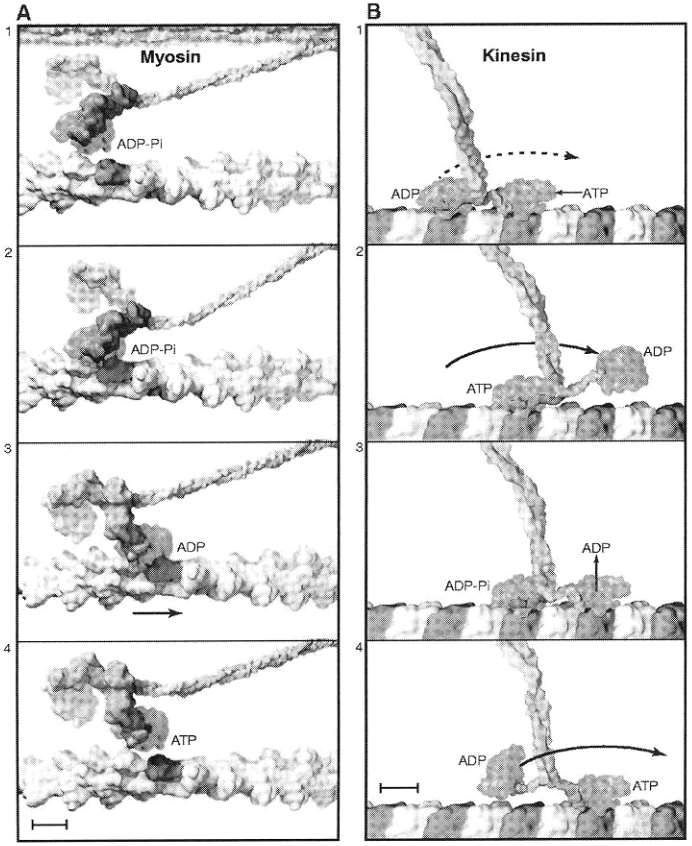


Figure 3.2 Models of the motion of muscle myosin and conventional kinesin [8]. (A). Frame 1: Muscle myosin is a dimer of two identical motor heads, anchored to a thick filament (top). Frames 2–4 show docking of heads on actin filament (lower), which serves to move the actin. The motion is about 10 nm per ATP hydrolyzed. (B). The two heads of the kinesin dimer move along a tubulin filament as indicated in Frames 1–4. In these frames the coiled coil extends to the top and to the attached cargo. The step length is about 8 nm. The head motion is associated with hydrolysis of ATP to ADP. The scale bar in A is 6 nm; that in B is 4 nm. (Taken from [8])

Efficiency about 60 %

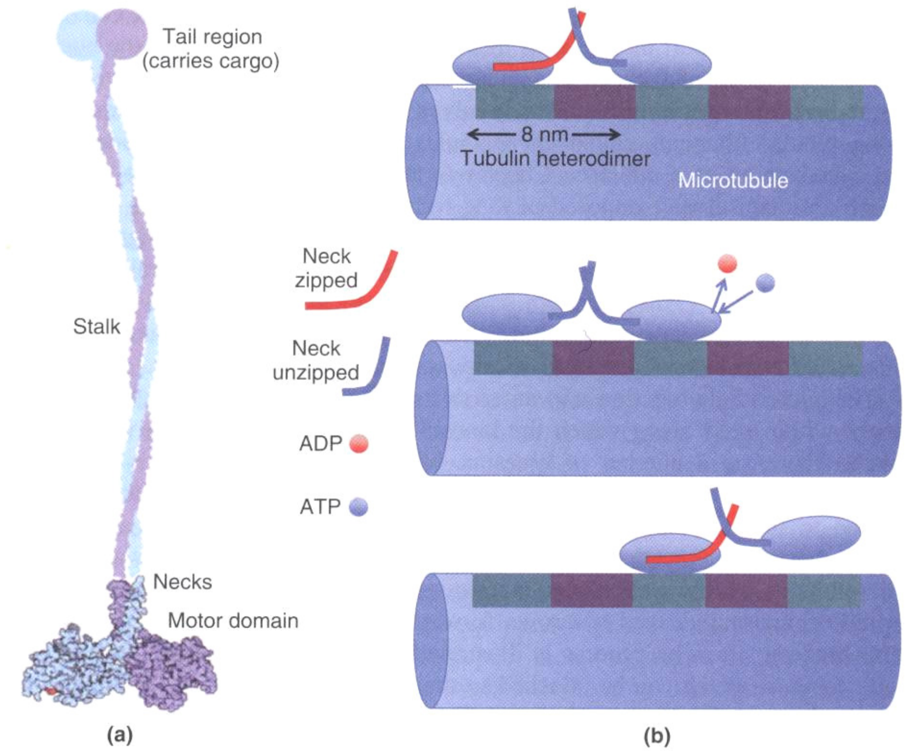
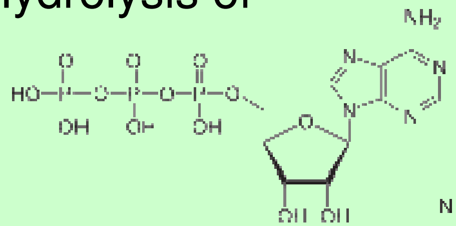


Fig. 7.1 Kinesin transport along microtubule. (a) Generic kinesin structure showing the two heads and necks in the motor domain a long stalk and the tail region onto which the cargo is attached. Reproduced from Wikipedia web page: (http://en.wikipedia.org/wiki/Kinesin) (b) Schematic of translational mechanism. In the top image both heads are attached to protein subunits (green) of the protein heterodimers that compose the protofilaments of the microtubule. The neck of the trailing head is zippered. In the next step (middle image) the trailing head hydrolyzes adenosine triphosphate (ATP) and releases phosphate that causes it to release from the microtubule and its neck to unzipper. The forward head releases an adenosine diphosphate (ADP) molecule and absorbs an adenosine triphosphate (ATP) molecule, which causes its neck to zipper throwing the rear head forward. This then binds onto the next protein subunits along the protofilament and the roles of the two heads reverses.

Linear motors, moving along a track of some 5 nm diameter and 1 – 4 μm in length

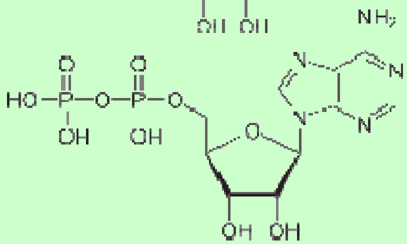
http://www.youtube.com/watch?v=CUm1RAHt860

Hydrolysis of



ATP, Adenosine triphosphate

to



ADP, Adenosine diphosphate

+ an orthophosphate
+ chemical energy

Table 3.1 Cellular engines of biology [6]. The performance of various cellular engines is compared with thermal energy (kT) and a typical automobile engine. Calculations for the specific power are based on the molecular weight of the smallest unit of the engine. Thus, molecular motors and polymerization-based engines are more powerful than the cellular structures in which they are found; for example, compare myosin to striated muscle

Engine	Velocity ($\mu m\ s^{-1}$)	Force (dynes)	Specific Power (erg s^{-1} g^{-1})
kT (thermal energy)	–	4×10^{-7} dyne nm	–
Actin polymerization [9]	1.0	1×10^{-6}	1×10^{9}
Microtubule polymerization [10]	0.02	4×10^{-7}	5×10^{8}
Myosin II [11]	4.0	1×10^{-6}	2×10^{8}
Kinesin [12]	1.0	6×10^{-7}	7×10^{7}
Vorticellid spasmoneme [13]	8×10^{4}	1×10^{-3}	4×10^{7}
Automobile engine, typical [14]			3×10^{6}
Striated muscle [14]			2×10^{6}
Bacterial flagellar motor [15,16]	100 Hz	4.5×10^{-11} dyne cm	1×10^{6}
Thyone acrosomal reaction [17]	6–9	5×10^{-4}	1×10^{5}
Limulus acrosome reaction	10	1×10^{-6}	1×10^{4}
Eukaryotic flagellum [14]	–		3×10^{2}
Mitotic spindle [14]	2.0	1×10^{-5}	

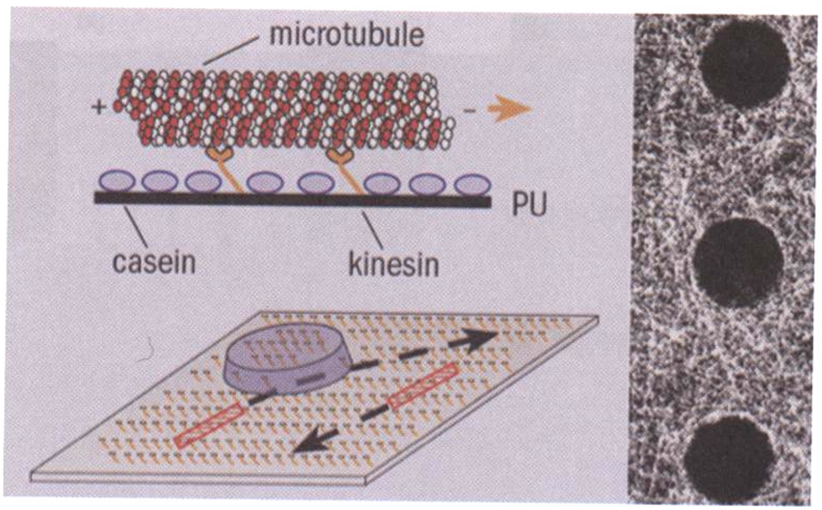


Fig. 7.2 Random motion of crowd-surfing tubules on a kinesin covered surface. Kinesin immobilized by its tail groups on a polyurethane surface pre-coated with casein will move microtubules randomly over the surface. The surface was patterned with pillars 10 μm in diameter and 1 μm high. The right image shows a sum of 500 frames taken every 5 s by an optical microscope of the fluorescently labeled tubules. The entire image is covered by random light spots apart from the pillars, which the microtubules are unable to climb due to their stiffness. Reprinted with permission from [5]. © 2002 by the American Chemical Society.

Ion channels, act like a transistor, also driven by ATP hydrolysis, also about 1 billion years old

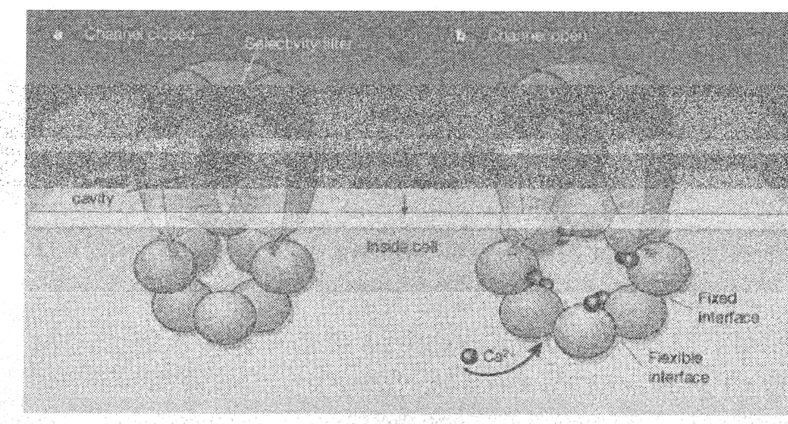


Figure 3.5 Model for Ca^{++}-gated K channel, after [22]

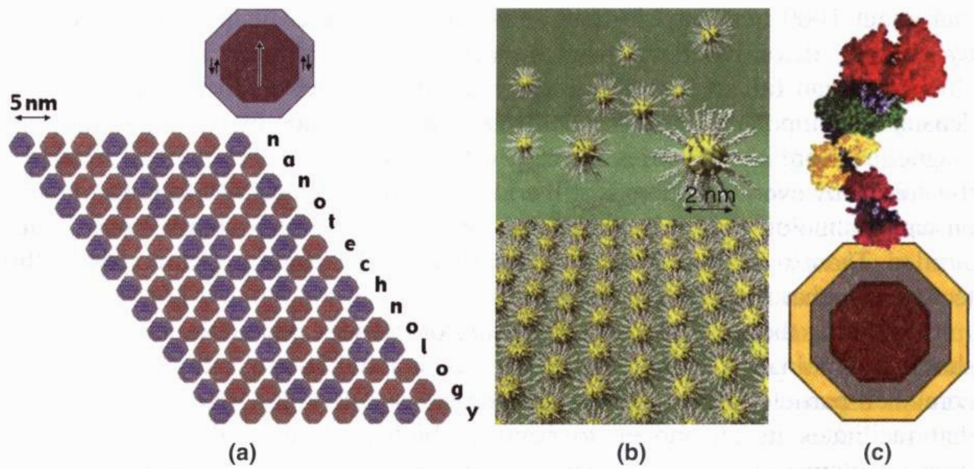


Fig. 0.3 Functionalized nanoparticles. (a) A "core-shell" magnetic nanoparticles consisting of a ferromagnetic metal core (e.g. iron or cobalt) surrounded by an antiferromagnetic shell, e.g. cobalt-oxide or manganese) that is specialized to record a single bit of information encoded by the direction of the core magnetization (see Chapter 5, Section 5.1). The lower picture shows an array storing the word 'nanotechnology' in ASCII format with blue representing down magnetization or '0' and red representing up magnetization or '1'. Writing at this density would enable the storage of about two million books (a large University library) on an area the size of a postage stamp. (b) Gold nanoparticles with attached thiol molecules. Each nanoparticle can behave as a transistor and the thiols can bond onto other thiol-coated gold nanoparticles via electrically resistive or capacitive links to build circuits with a component density 1000 times greater than existing devices (see Chapter 5, Section 5.3). Reproduced with the permission of Dr. Mark Everard from [4]. (c) A core-shell magnetic nanoparticle (as in (a)) with a second shell of gold that makes it easy to attach biological molecules such as proteins or antibodies, or drugs. The magnetic core of the particle can be utilized to steer the attached molecule to specific areas of the body by external fields for targeted drug delivery. Alternatively, the attached biological molecule could be used to target specific cells (e.g. tumor cells) that could then be heated and killed by a weak external radio-frequency magnetic field that is harmless to healthy tissue (see Chapter 6, Section 6.2.2).

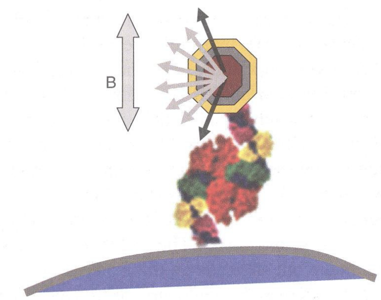


Fig. 6.12 Heating blocked magnetic nanoparticles by an applied AC magnetic field. A blocked magnetic nanoparticle with attached targeting molecule latched onto the membrane of a target cell. An alternating magnetic field forces the magnetization to switch back and forth producing heat in the nanoparticle (see Advanced Reading Box 6.3).

Big challenge is how to make these kinds of nanocrystals with a clever surface coating self-assemble

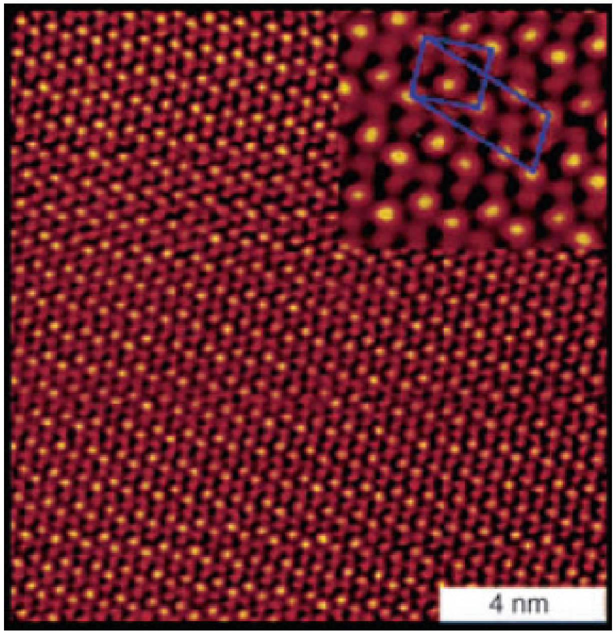


Figure 5. Scanning tunneling microscope image of a self-assembled monolayer (SAM) of decanethiol on gold.[83] The scanning probe microscopes make it possible to view nanostructures in molecular detail, and have revolutionized surface science. SAMs represent a class of material in which properties such as wetting and biocompatibility can be engineered at the molecular level; many other examples of materials engineered at the nanoscale are now emerging from nanoscience.

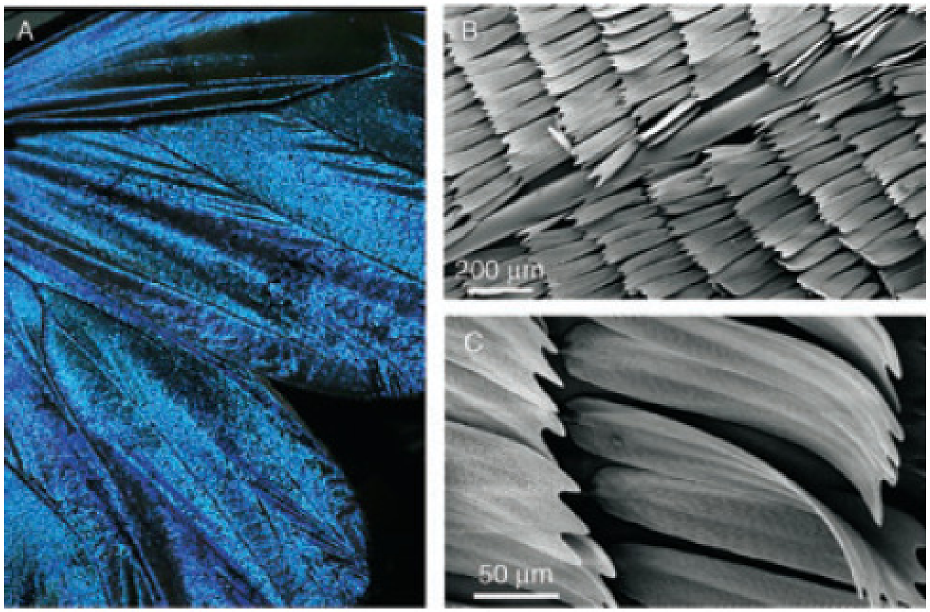
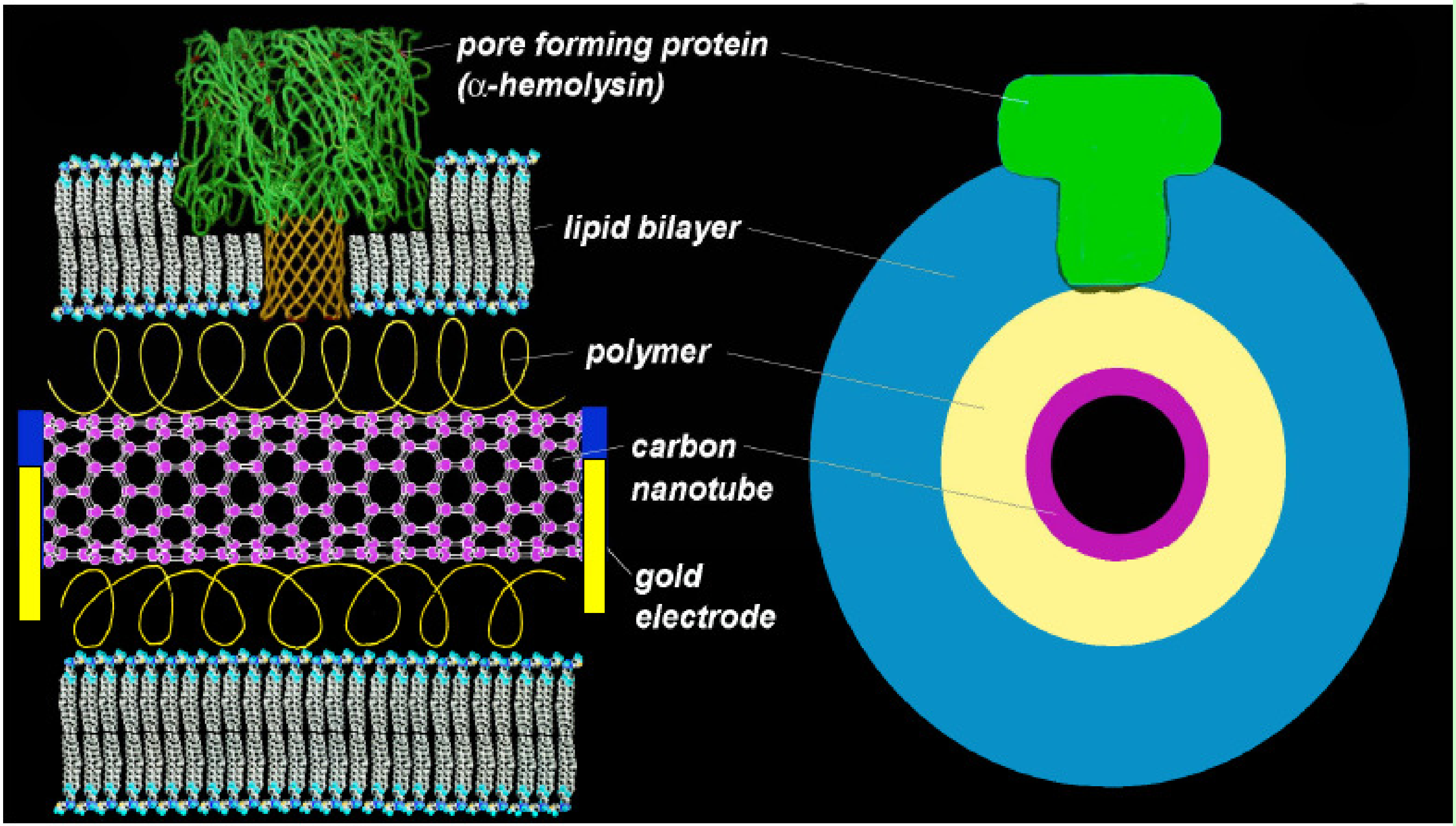


Figure 6. Photograph (A) and SEM images (B,C) of the wing of the *morpho* butterfly (images by Felice Frankel). The brilliant blue reflection from the wing of this butterfly is due to the operation of a remarkable, optically sophisticated photonic bandgap structure, which not only is wavelength selective, but also reflects over a broad range of angles of incidence and observation. Biology presents examples of functional nanostructures of a wide range of types, and has much to teach nanoscience and nanotechnology.

Nanotubes can be used as sensors



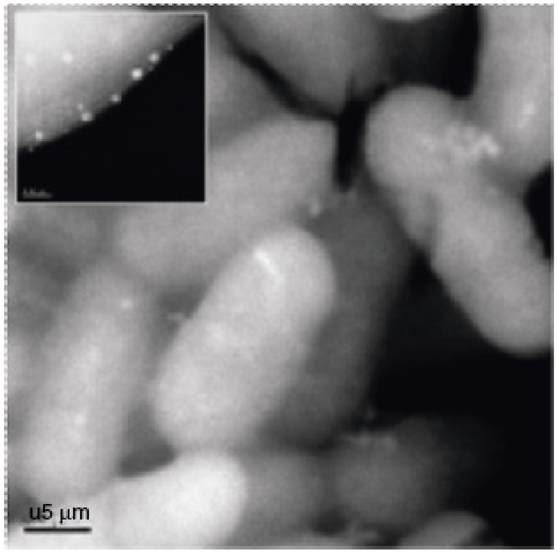
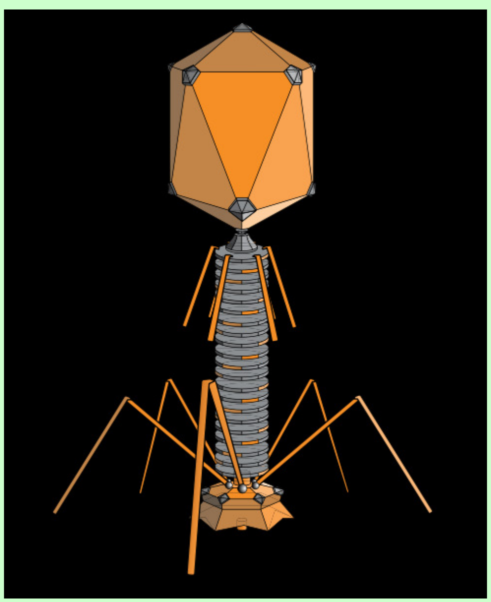


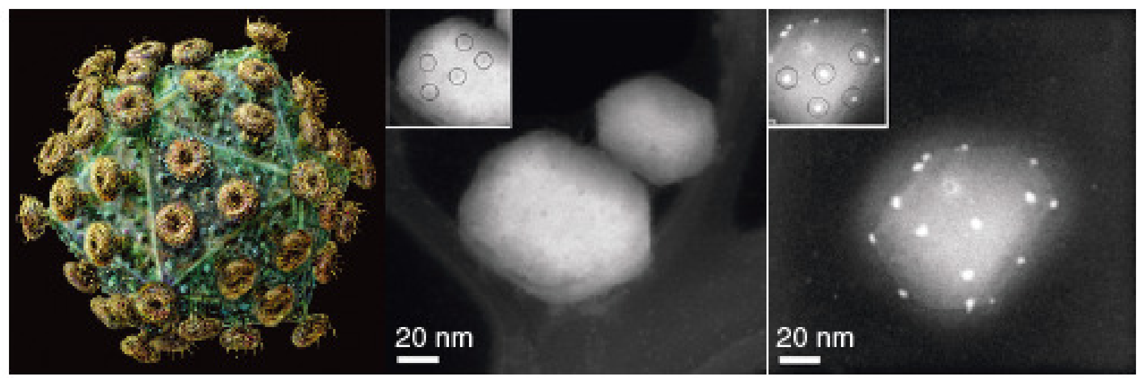
Fig. 1.14 Silver nanoparticles attacking bacteria. Electron microscope image of P.aeruginosa[4] bacteria after exposure to silver nanoparticles. The particles with size ranges 1–10 nm are active in disrupting the cell function. The inset shows a high-resolution image of some particles attached to the cell outer membrane. Reproduced with the permission of the Institute of Physics from J. R. Morones et al. [18].

- kills bacteria and odor, e.g. impregnated socks, but may get released into the environment and end up in fish

Viruses are typically below 100 nm, while bacteria are typically at least one order of magnitude larger

Bacteriophages, sketch bottom left, are viruses that attack bacteria





(a) (b) (c)

Fig. 1.15 Silver nanoparticles attached to HIV-1 virus. (a) Computer generated image of HIV virus, showing glycoprotein 'knobs' (Reproduced with permission from www.virology.net/Big_Virology/BVretro.html). (b) Electron microscope image, with inset superimposing position of knobs. (c) Electron microscope image of virus after attachment of silver nanoparticles. Reproduced with the permission of BioMed Central from J. L. Elechoguerra et al [19].

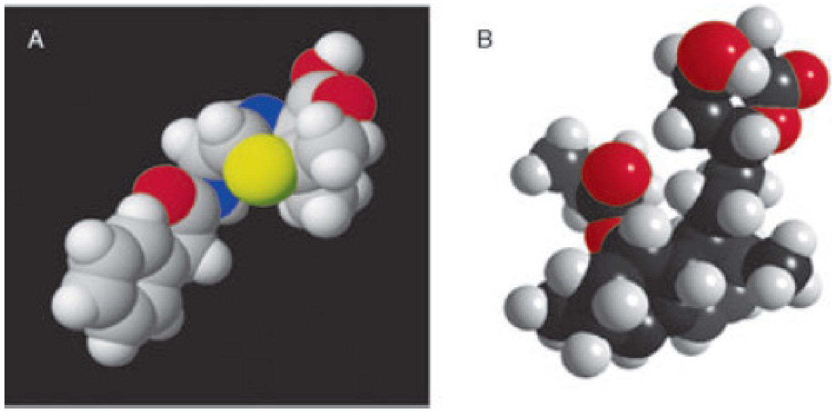


Figure 3. Space-filling molecular models of penicillin (A) and lovastatin (B).[80,81] Penicillin marked the beginning of rational approaches to the treatment of bacterial disease; lovastatin is equally important in the treatment of cardiovascular disease. Both can be regarded as engineered nanostructures, which act to shut down the activities of larger catalytically functional nanostructures—enzymes—in cells.

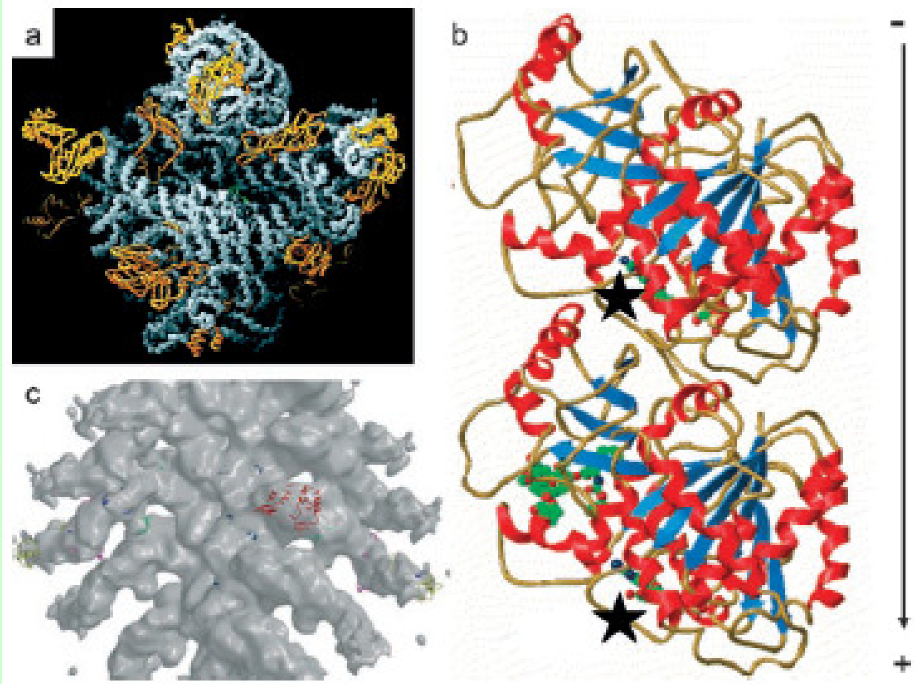


Figure 5. Modular assembly using globular nanoobjects. a) High-resolution structure of the 50S ribosome subunit of *H. marismortui*. The interface with the smaller 30S subunit is in the foreground. RNA (space-filled, gray) and ordered proteins (backbone, gold) are shown. The assembled nanostructure is about 25 nm across. From ref. [71]. b) Ribbon diagram showing orientation of α- (top) and β- (bottom) tubulin subunits in a microtubule protofilament (arrow indicates microtubule axis). The GTP/GDP binding sites are indicated (asterisk). From ref. [81]. c) Surface representation of actin filament in association with protruding myosin S1 cross-bridges (upper 50 kDa head domain). The closing of the actin-binding cleft is structurally coupled to the opening of the nucleotide-binding pocket. From ref. [82].

UP: Nanostructures we can assemble right now

RIGHT: Nanostructures nature assembles without us

Importance of structural biology

Nanotech can be classified as incremental, evolutionary, and radical (all direct quotes from C. Binns, Introduction to Nanoscience and Nanotechnology, Wiley, 2010)

- "**incremental** nanotechnology can .. be considered to be a re-branding of other, more traditional lines of research such as **materials science**
- **evolutionary** nanotechnology attempts to build nanoparticles that individually perform some kind of useful function
- **radical** nanotechnology … is the construction of machines whose mechanical components are the size of molecules"

My comments: while incremental nanotech is indeed an established part of materials science and –engineering (MSE), evolutionary nanotech is best developed within the nano-MSE framework.

Man-made (Drexlerian) radical nanotech (building everything from atoms and small molecules upwards) may be an illusion and remain so if one does not embrace **physical biology** (micro-/structural/quantum-biology) and starts building from specific molecules (utilizing look and key mechanisms, …) for very specific purposes

Alternatively, one may use **Vincenzo Balzani's classification scheme**, V. Balzani, *small* 1(3) 278-283 (2005)

First distinguish between Top–Down and Bottom–Up Approaches

Lump all kinds of materials problems that need to be solved for top-down miniaturization (as currently in the microelectronics industry) into ***incremental nano***

Within the Bottom–Up Approaches, distinguish between

"Case 1: Nanoscale "objects" are very simple from a chemical viewpoint and do not exhibit any specific intrinsic function (atoms, clusters of atoms, small molecules). Function arises from ensembles of such objects."

incremental and evolutionary nano?

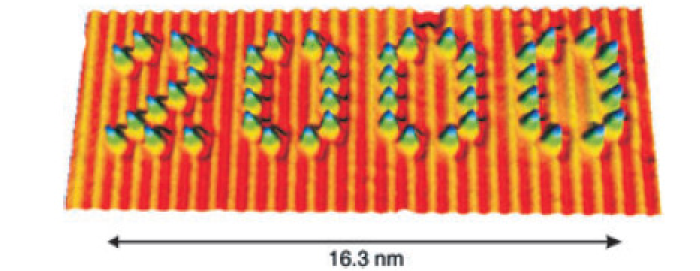


Figure 1. The number 2000, celebrating the new millennium, has been written by using 47 CO single molecules. Each protrusion represents an individual CO molecule and the background vertical lines are the intrinsic Cu surface step edges.[5]

"Case 2: Nanoscale "objects" have complex chemical composition (supramolecular of multicomponent systems), exhibit characteristic structures, show peculiar properties, and perform specific functions. All of the artificial molecular devices and machines belong to this category."

evolutionary and radical nano?

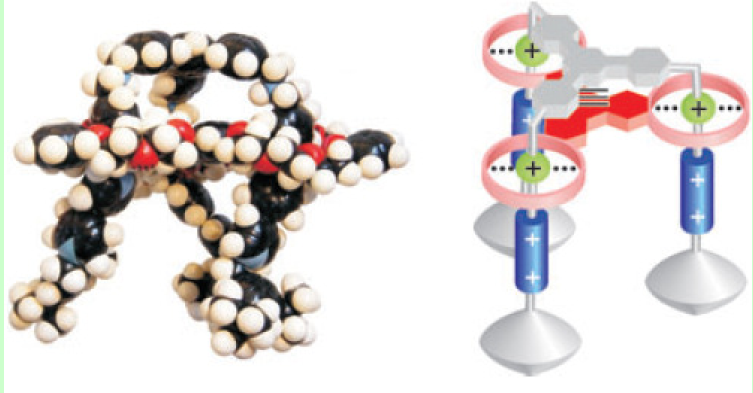


Figure 4. A molecular elevator: the red platform moves up and down upon the addition of acid and base, respectively.[14]

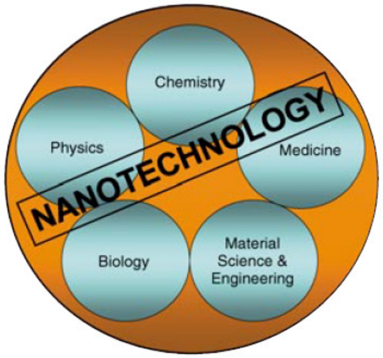
Introduction to Nano-Materials Science and Engineering: An elective course within an Applied Physics PhD program

Peter Moeck
Department of Physics, Portland State University, Portland, OR 97207-0751 & Oregon Nanoscience and Microtechnologies Institute, Email: pmoeck@pdx.edu

WIDER CONTEXT OF THE COURSE

The INMSE course is outlined at a dedicated website [6]. The wider context of this course is classical materials science and engineering. Materials science and engineering (MSE) courses are in so far unique in the curriculum of higher education that they consider their subject as a double discipline, where applied science and engineering are both taught on an equal footing. The INMSE course emulates this tradition and an attempt is made to give balanced introductions to all four corners and six edges of the Materials Science and Engineering Tetrahedron as introduced in an influential study that defined the whole field [7], Fig. 1.

The Beginning of a *Small* Revolution
*Chad A. Mirkin**
small 2005, 1, No. 1



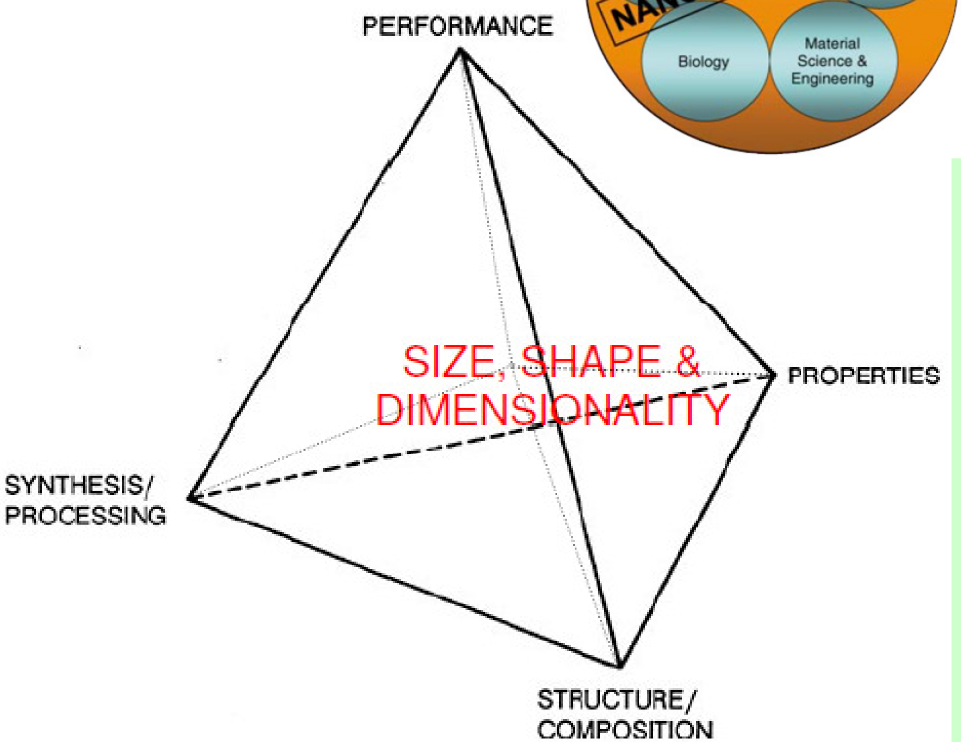
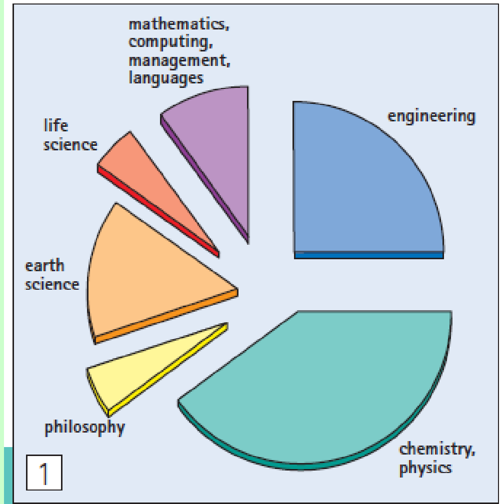


Fig. 1 The well known Materials Science and Engineering (MSE) Tetrahedron (taken from ref. [7] and sketched with five full and one dotted line) with **Size, Shape & Dimensionality** added as inset right at its center.

[6] web.pdx.edu/~pmoeck/nanoMSE.htm.
[7] *Materials Science and Engineering for the 1990s: Maintaining Competitiveness in the Age of Materials*, A National Academies Study, National Academy Press, Washington, D.C., 1989, chapter 2, p. 29, http://www.nap.edu/openbook.php?record_id=758&page=19.

Harry Bhadeshia Materials World November 2000 10-12



An approximate illustration of the components of materials science

idea is to incorporate biology, next step nano-bio tech

G. M. Whiteside, A. P. Wong, MRS Bulletin **31** (2006) 19-27

"individual materials scientist must learn biology"

Nanoscience and Nanotechnology: Evolving Definitions and Growing Footprint on the Scientific Landscape

*Michael L. Grieneisen and Minghua Zhang** DOI: 10.1002/smll.201100387

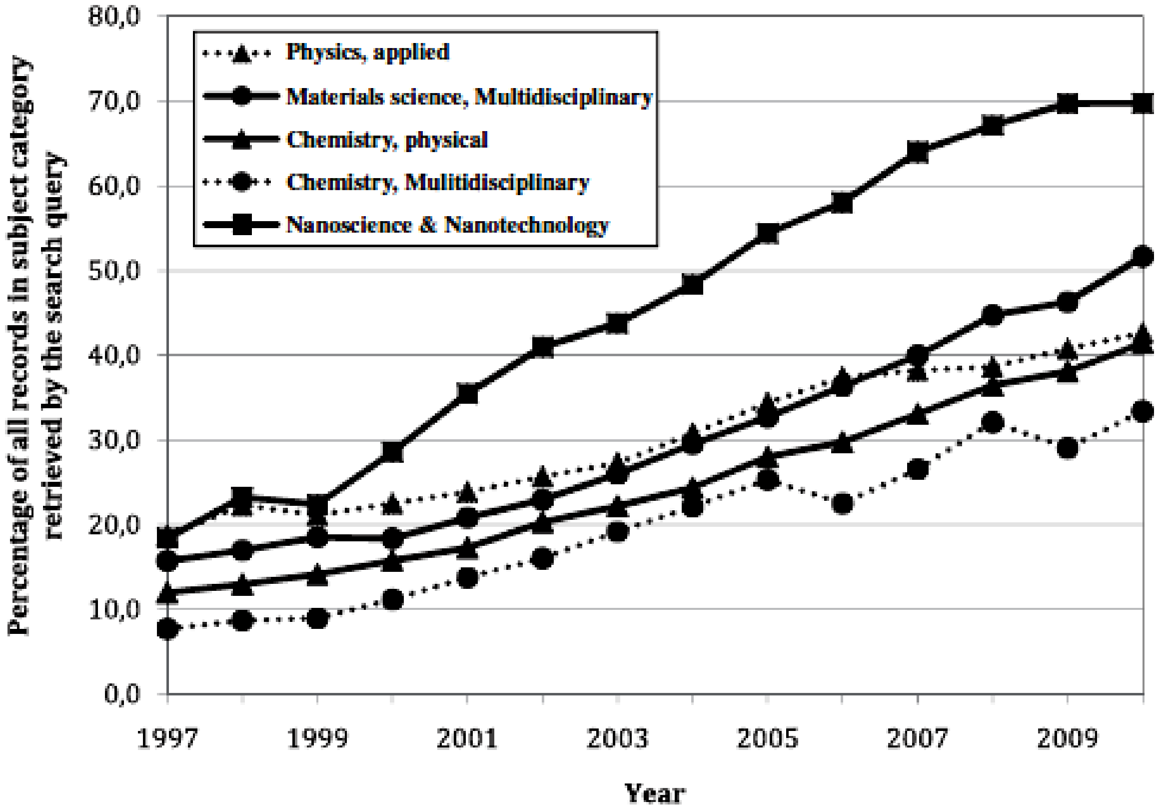
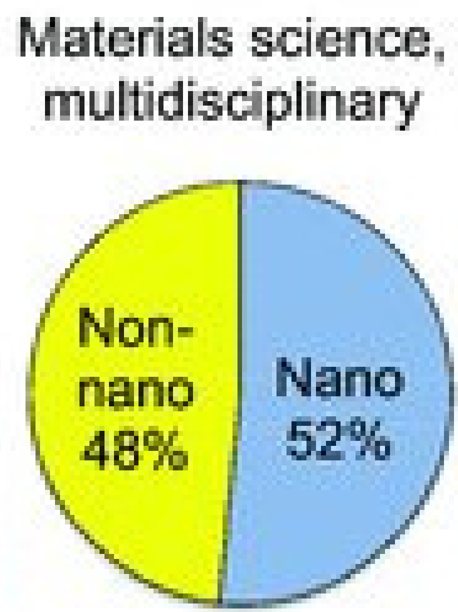


Figure 2. Percentage of all records in 5 top Web of Science subject categories which were retrieved by the search query in Table 1. These subject categories had the highest number of records retrieved by the search query for PY 2009. Because these are percentages, data for the partial year of 2010 are included. The footprint of nanoscience and nanotechnology within these fields has grown dramatically in just the past 13 years.

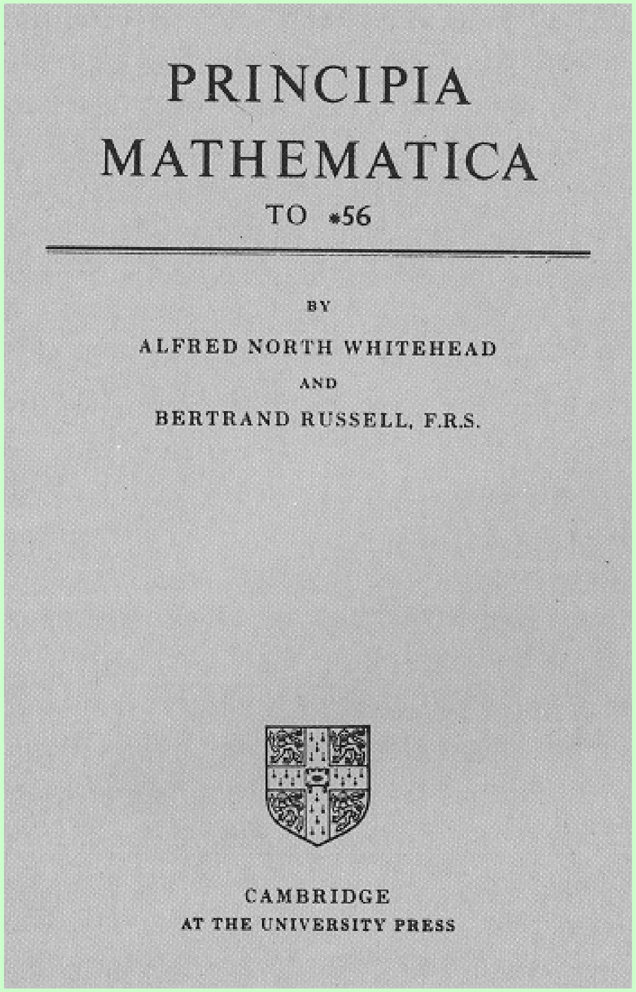


When nanotech is considered within the materials science and –engineering context, there are **NO *SPECIAL* PROBLEMS** concerning implications, responsibilities, …, that context always had to make sure that new products are acceptable to society in order for a company to stay in business

Why do we have the genetically modified food debate (more in Europe than in the US)? Was it not because Monsanto and others overdid it, creating seeds that were resistant to their brand of herbicides but also no longer capable of germination???

major proponents of the implications, responsibilities, …., moral acceptability of nanotech are International Council on Nontechnology (ICON) at Rice University (offshoot of NSF Center for Biological and Environmental Nanotechnology (also at Rice),

Ideas of starting a whole new scientific field: ***"Predictive nanotoxicology", "predict effects – adverse or desirable – of engineered nanoparticles upon interaction with biological system"***



Everybody basically knows: ***"The notion of complete understanding controlling action is an ideal in the clouds, grotesquely at variance with practical life."***
Alfred North Whitehead, Adventures of Ideas, Mac Millan, New York, 1956, 114-115

there sure is potential for "nano-things" to go wrong, …

“There is something civil servants have that the private sector doesn’t. And that is the duty of loyalty to the greater good – the duty of loyalty to the collective best interest of all rather than the interest of the few. Companies have duties of loyalty to their shareholders not to the country.”

David. M. Walker, comptroller general of the United States,

quoted from an article by S. Shane and R. Nixon, “In Washington, Contractors Take the Biggest Role Ever”, **New York Times**, February 4, 2007

Problems: Much of what the public thinks will be shaped by the media, that will also be what some of the incoming student expect, ***so we have to fight both <u>scaremongers</u> and unrealistic visionaries***

II

So since we have to provide ***nanoeducation***,

And nanotech is according to NNI more or less technology and research development at the length scale of 1 to 100 nm, ***to provide*** a fundamental understanding of phenomena and materials at the nanoscale and ***to create*** and use structures, devices and systems that have novel properties and functions because of their small and/or intermediate size.

i.e. both nanoscience and nanoengineering, we have to strike a balance, in my opinion, science first, engineering second

Clarifying the deep connection between nanoscience and nanoengineering shall allow the students to develop a realistic perception of risks !!!

whoever pays for the piper calls the tune? Who is one of the main sponsors of international conferences on the implications and moral acceptance of nanotech?

Swiss Re, a reinsurer which is heavily invested in insuring companies that have investments in the genetically modified food business

E. McCarthy and C. Kelty, "Responsibility and nanotechnology", *Social Studies of Science*, vol. 40, pp. 405-432, 2010. http://sss.sagepub.com/content/40/3/405

What to do about this?

If you are working on "hard nanoscience", tell your students, friends, and kids, …, but one needs to have knowledge of the real problem, so called Folk Theories are of limited utility (A. Rip, "Folk Theories of Nanotechnologists", *Science as Culture*, vol.15, pp. 349-365, 2006.)

e.g. is not simply true that fear arises from ignorance, that public acceptance of nanotech will rise as people learn more about the technology !

So called "hierarchical individualists" who like free markets and respect the authority of social elites find more to approve on in nanotech as they grow more familiar with it, conversely, more information seems to give so called "egalitarian communitarians" more to be concerned about. R.A.L. Jones, **Soft Machines** blog,
ttp://www.nature.com/news/2008/081209/full/news.2008.1290.html

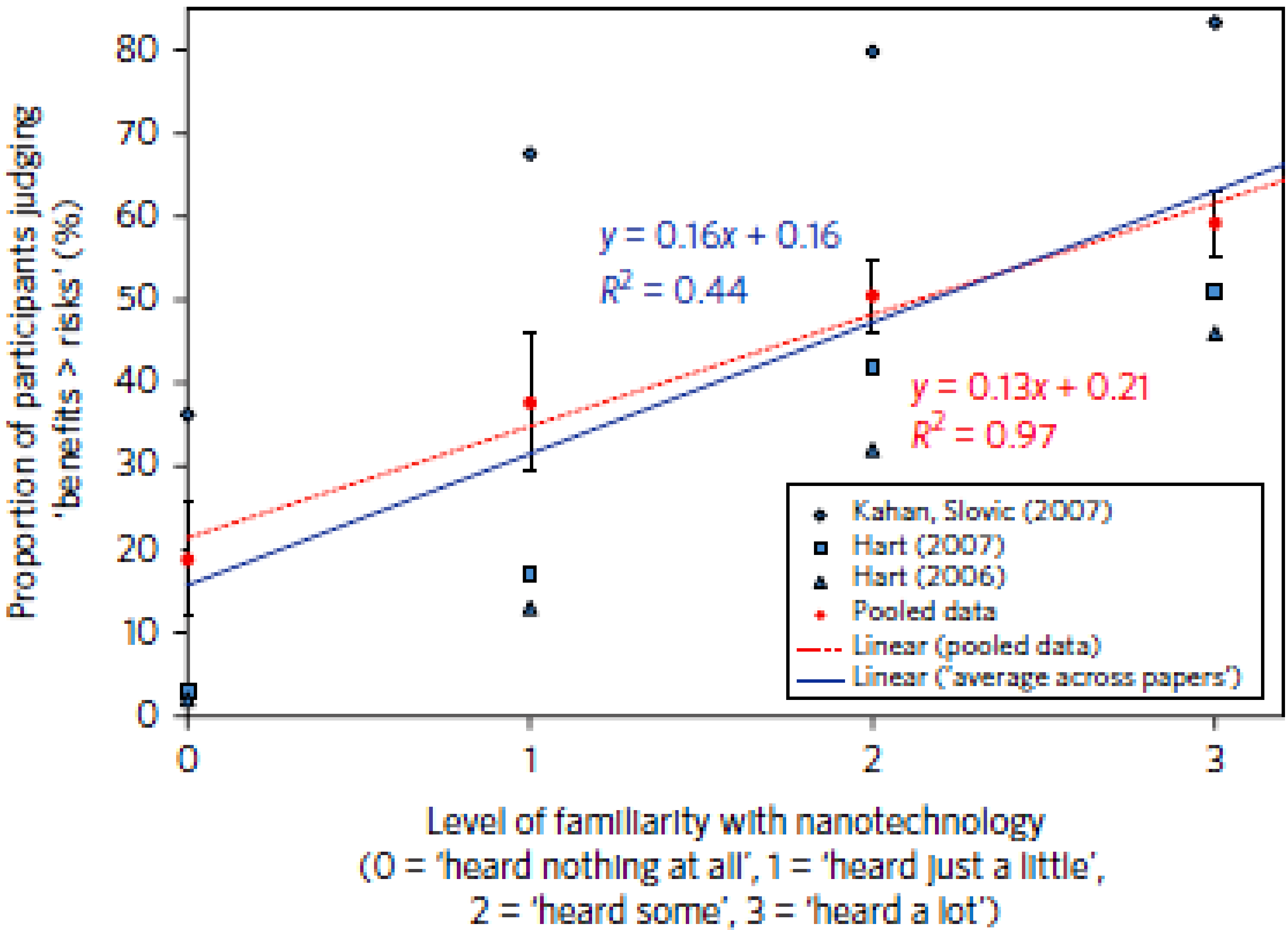
NATURE NANOTECHNOLOGY | VOL 4 | NOVEMBER 2009 | www.nature.com/naturenanotechnology 752

Anticipating the perceived risk of nanotechnologies

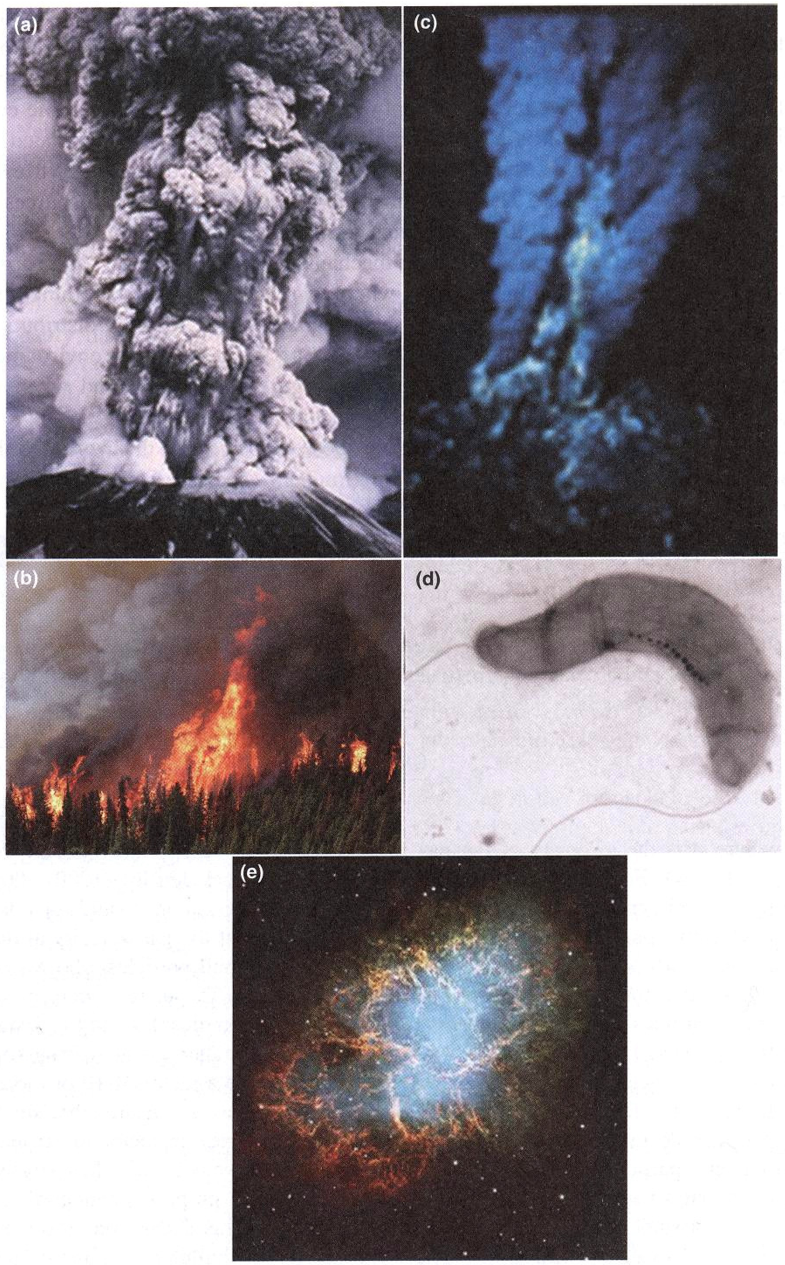
Terre Satterfield[1]*, Milind Kandlikar[2], Christian E. H. Beaudrie[1], Joseph Conti[3] and Barbara Herr Harthorn[3]

Understanding emerging trends in public perceptions of nanomaterials is critically important for those who regulate risks. A number of surveys have explored public perceptions of their risks and benefits. In this paper we meta-analyse these surveys to assess the extent to which the following four hypotheses derived from previous studies of new technologies might be said to be valid for nanotechnologies: risk aversion will prevail over benefit appreciation; an increase in knowledge will not result in reduced aversion to risks; judgements will be malleable and subject to persuasion given risk-centric information; and contextual, psychometric and attitudinal predictors of perceived risk from prior studies can help anticipate future perceptions of nanotechnologies. We find that half the public has at least some familiarity with nanotechnology, and those who perceive greater benefits outnumber those who perceive greater risks by 3 to 1. However, a large minority of those surveyed (44%) is unsure, suggesting that risk judgements are highly malleable. Nanotechnology risk perceptions also appear to contradict some long-standing findings. In particular, unfamiliarity with nanotechnology is, contrary to expectations, not strongly associated with risk aversion and reduced 'knowledge deficits' are correlated with positive perceptions in this early and controversy-free period. Psychometric variables, trust and affect continue to drive risk perceptions in this new context, although the influence of both trust and affect is mediated, even reversed, by demographic and cultural variables. Given the potential malleability of perceptions, novel methods for understanding future public responses to nanotechnologies will need to be developed.

[1]Institute for Resources, Environment and Sustainability, University of British Columbia, Vancouver, British Columbia, Canada V6T 1Z4, [2]Liu Institute for Global Issues and Institute of Asian Research, University of British Columbia, Vancouver, British Columbia, Canada V6T 1Z2, [3]NSF Center for Nanotechnology in Society, University of California, Santa Barbara, California 93106, USA. *e-mail: satterfd@interchange.ubc.ca


Proportion of participants judging 'benefits > risks' (%)
80
70
60
50
40
30
20
10
0
0
1
2
3
y = 0.16x + 0.16
R2 = 0.44
y = 0.13x + 0.21
R2 = 0.97
Kahan, Slovic (2007)
Hart (2007)
Hart (2006)
Pooled data
Linear (pooled data)
Linear ('average across papers')
Level of familiarity with nanotechnology
(0 = 'heard nothing at all', 1 = 'heard just a little',
2 = 'heard some', 3 = 'heard a lot')

Nanocrystals and -particles are everywhere



e.g. phytoplankton (some microscopic plants) produce nano-particle containing aerosols, which influence the climate along with man-made nanoparticles from air planes, diesel engines, worn off tires, …

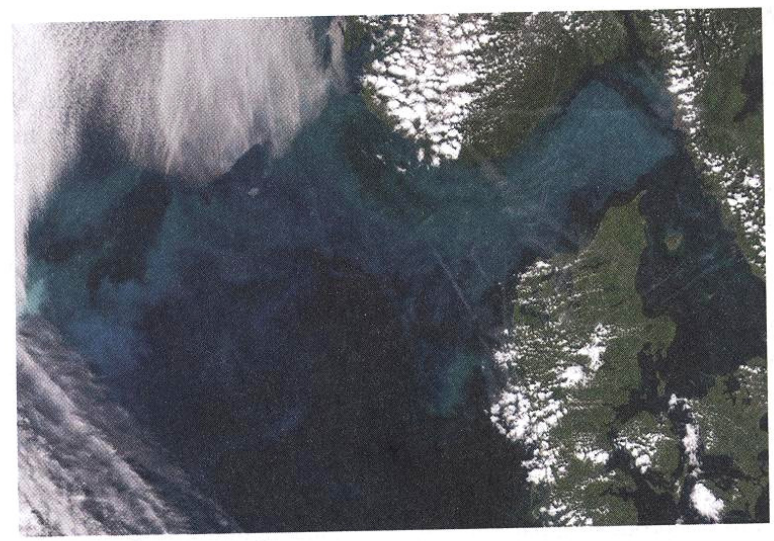


Fig. 2.6 Phytoplankton bloom in the North Sea. Clouds of phytoplankton are the turquoise colored patches in this image acquired on June 27th 2003 by the MODIS instrument on NASA's Terra satellite. The land mass at the top right is Norway and Denmark is on the bottom right. Phytoplankton grow in nutrient-rich waters, and multiply very quickly; blooms big enough to be seen from space, like this one, can take only days to appear. Also visible are a number of streaky airplane contrails. Image reproduced courtesy of NASA (http://visibleearth.nasa.gov).

Man has been making fires/nano-particles from some 0.5 to 1.5 million years and probably evolved to deal with the consequences, sure more children have asthma these days

Carbon black is an assortment of nanoparticles in tires, have been in use for about 100 years, sure too short for humans to evolve, …

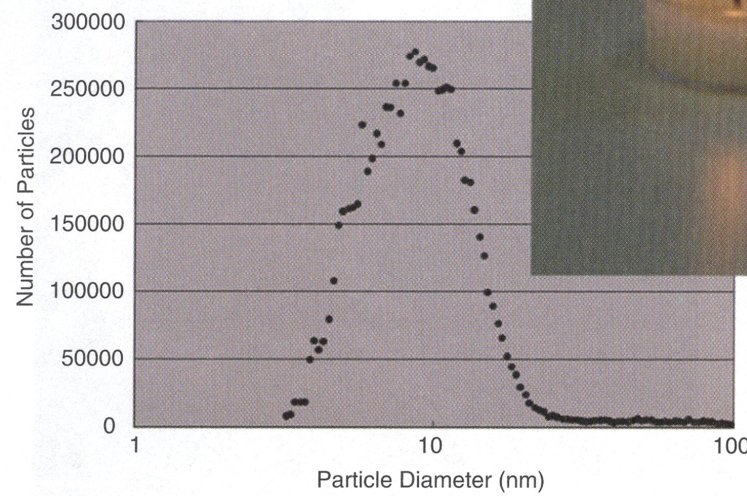


Fig. 2.3 Nanoparticles produced by candles. Size distribution of particles produced by combustion from a standard 'nightlite' type candle. The distribution was measured using an aerosol particle sizer and if plotted as the number density, consists mostly of nanoparticles with diameters around 10 nm. These are predominantly carbon particles. The method used to measure the size distribution is described in Chapter 4, Section 4.1.6.

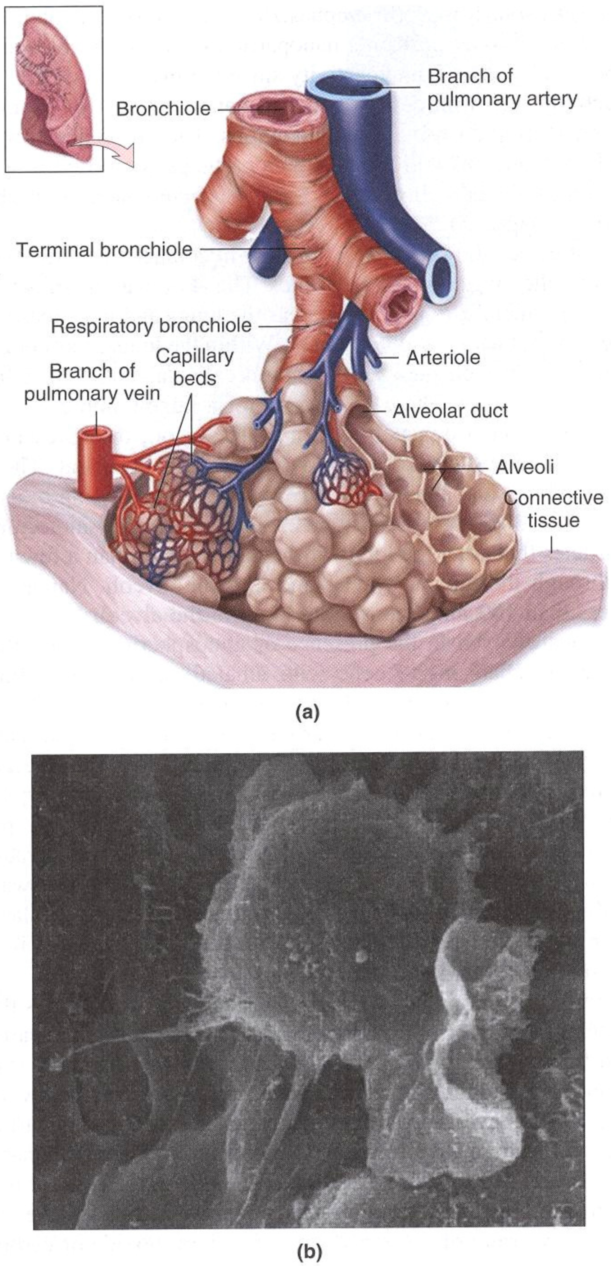


Fig. 2.4 Nanoparticles and the lungs. (a) Lung structure showing the ends of the finest bronchial tubes terminating in clusters of tiny sacs (alveoli) 0.2 mm across and wrapped in blood vessels. The adult lung contains about 500 million of these with a total surface area of about 100 m^2. Across a significant proportion of this surface the tissue separating air and blood is as thin as 300 nm and allows gas molecules to diffuse across. Reproduced with permission of McGraw-Hill from *Human Anatomy* by McKinley and O'Loughlin, 2006. (b) Alveolar macrophages, typically 1–2 μm across that occupy the lungs including the alveoli. They ingest particles by a process called phagocytosis and are carried up through the lung system by a slow mucus flow called the mucociliary escalator. They are eventually swallowed and pass out through the digestive system.

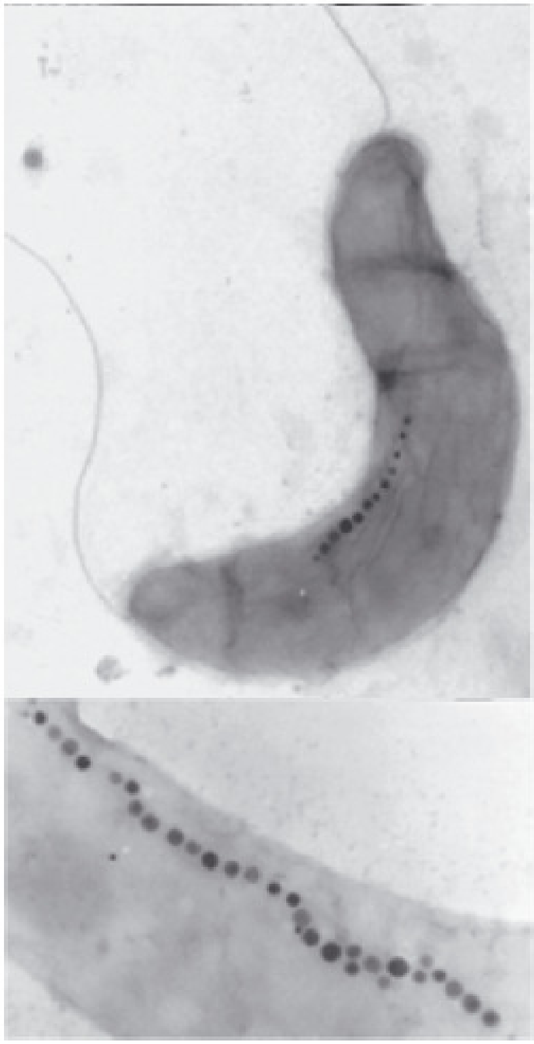


Fig. 1.5 Magnetic bacterium using single-domain particles. The Magnetic bacterium (*magnetospirillum gryphiswaldense*) from river sediments in Northern Germany. The lines of (permanently magnetized) single-domain magnetic nanoparticles, appearing as dark dots, align the body of the bacterium along the local direction of the Earth's magnetic field, which in Germany is inclined at 55° from horizontal. This means that the bacterium will always swim downwards towards the sediments where it feeds. Reproduced with With kind permission of Springer Science and Business Media from D. Schüler [2].

Magnetite is ferrimagnetic (two opposing ferromagnetic spin system arrangements of unequal strength which leave a reasonably large total magnetic moment)

The bacterial produce the nanocrystals by themselves, do have the genes to do the synthesis, do it all at low temperatures in special cells, man-made crystal growth is very different

There are attempts to grow these kinds of bacteria in order to get the magnetite nanocrystals out of them for magnetic hypothermia treatments of cancer cells

In my personal opinion, it all hinges on precise definitions, …, imprecise definitions tend to lead to confusion, … so what is nanotechnology??

"… In other words, there is no such thing as nanotechnology. Nanotechnology is now the buzzword and an umbrella term to designate nothing less than the state-of-the-art in science and technology in what is the normal progression and evolution of the relationship of humankind with its habitat and environment."

Dannie Jost, Nanotechnology for Policymakers, An Introduction from the Physical Science Perspective, World Trade Institute, University of Bern, April 2009,

“Magic Nano Story” of 2006

company Kleinmann GmbH of Sonnenbühl/Germany (a subsidiary of Illinois Tool Works Inc. of Glenview/Illinois) distributed a bath and toilet (glass and ceramic) cleaner/ sealant as “Magic Nano”

which they did not develop by themselves and that did *not* actually contain nanometer-scaled materials for the intended purpose of creating a hydrophobic surface sealing after a thorough cleaning

cleaner/sealant was supposed to be sprayed from a can

It is believed that the solvents in the sprayed aerosol caused respiratory irritations for about one hundred customers when the product was used in enclosed spaces such as bathrooms.

Product was recalled, incident led to an “nano-hype media-field day” in 2006; (renewed call for a world-wide moratorium on the development of nanoproducts by a non-governmental organization).

Had the synthesis/processing corner and most importantly the “nano-center” of the nano-MSE Tetrahedron, been duly considered as part of the scaling up to industrial production, different properties and the intended product performance would have resulted and the whole incidence would probably not have happened!

Manufacturer (which was neither Kleinmann GmbH nor Illinois Tool Works Inc.) did not follow through with implementing the synthesis/processing procedures as prescribed by the developers from academia so that the beneficial nanoparticles simply fell out of solution and never made it into the final product.

Spray can was replaced by aerosol pump in new product.

I do not know if there are now nanoparticles in the new product and if they are now doing their intended job.

Nanotech has been classified as incremental, evolutionary, and radical (all direct quotes from C. Binns, Introduction to Nanoscience and Nanotechnology, Wiley, 2010)

- "**incremental** nanotechnology can .. be considered to be a re-branding of other, more traditional lines of research such as **materials science**
- **evolutionary** nanotechnology attempts to build nanoparticles that individually perform some kind of useful function
- **radical** nanotechnology … is the construction of machines whose mechanical components are the size of molecules"

State of Oregon created in 2003 the **Oregon Nanoscience and Microtechnologies Institute (ONAMI),**

which ***puts*** ***"nanotechnology to work in microsystems".***

motto clarifies nature of "nanotech" developments that Oregon supports

Functional nanostructured materials and devices on their basis, (i.e. mainly *incremental* and *evolutionary* (but only some radical) "nanotech",), are developed within a materials science and engineering context in order to enhance the functionality of existing and novel microsystems.

ONAMI
OREGON NANOSCIENCE AND MICROTECHNOLOGIES INSTITUTE

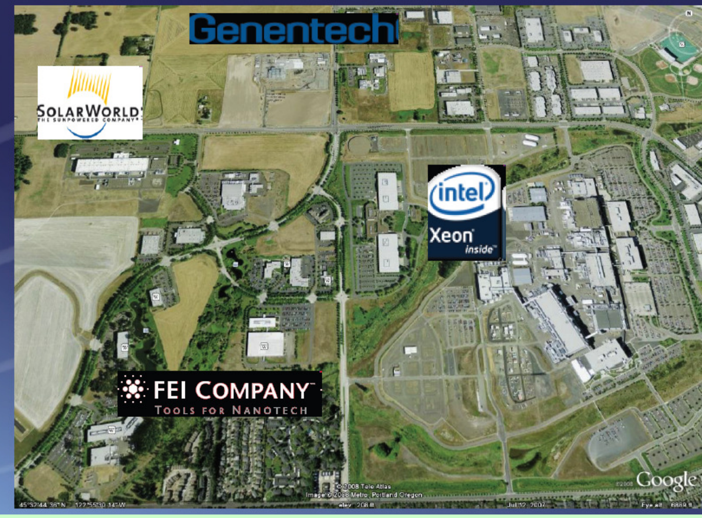
ONAMI's Four Collaborative Research Thrusts

- *Microtechnology-based Energy and Chemical Systems*
- *Green Nanomaterials and Nanomanufacturing*
- *Nanolaminates and Transparent Electronics*
- *Nanoscale Metrology and Nanoelectronics*

So these are the general directions our graduate students will do their research in, for the greater good of Oregon's industry

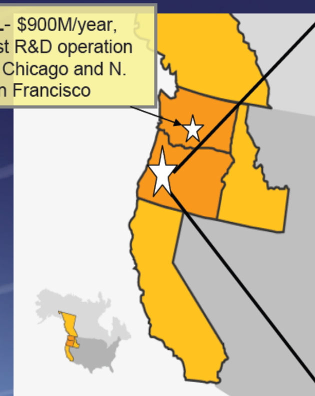
Silicon Forest: Hillsboro, Beaverton WW "Nano Central"?

- Intel
- FEI
- ESI
- Triquint
- IDT
- Genentech
- Solarworld
- Acrymed
- NexPlanar
- Voxtel
- *many more..*



"Silicon Forest": The Surprise World Leader in Industrial "Small Tech" R&D Assets!

PNNL- $900M/year, largest R&D operation W. of Chicago and N. of San Francisco



INTEL: #1 Nanotech application and R&D
- 15,000 Employees In Oregon
- HQ Semiconductor Process Engr. ($11B capex, 90/65/45 nm R&D and lead production)

HP: #1 MEMs application and R&D
- HP Ink Jet HQ (MEMs & nanometer technology)
- Largest HP technology site – 2000 people.
- 25% of all HP patents here, #1 nano patent portfolio

FEI: World leader in tools for nanotechnology;

INVITROGEN: World Leader in Quantum Dots

TriQuint: World leader in GaAs ICs

ESI: World leader in laser micromachining

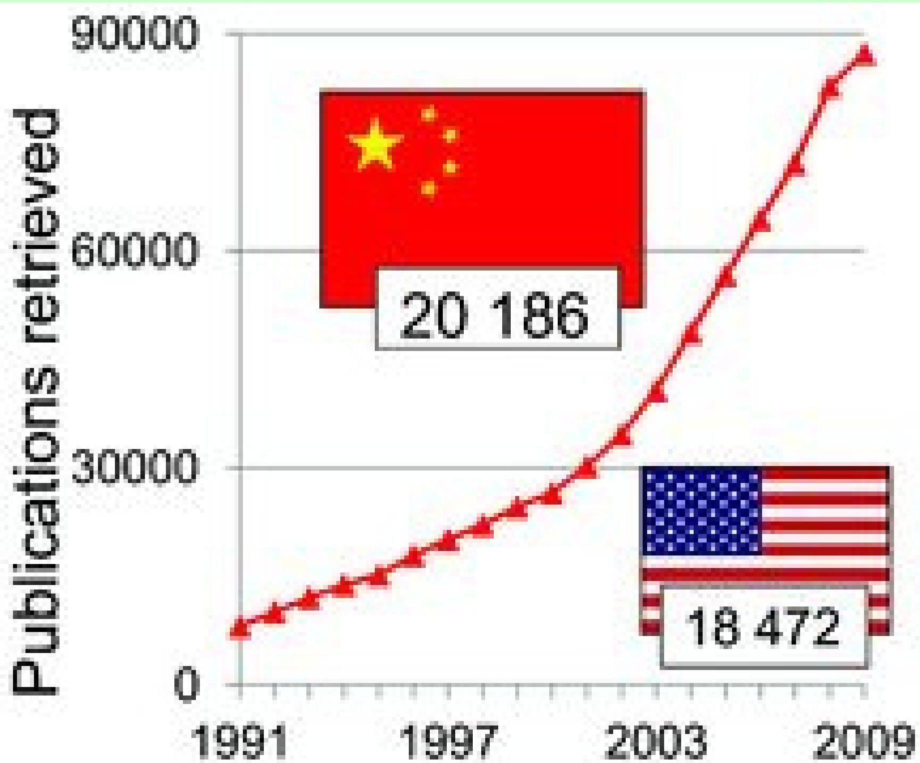
Tektronix, Xerox, ON Semi/Nantero, Applied Materials, Novellus, nLIGHT, IDT, Microchip, IDT, Siltronic, SEH, Wafertech, Sharp…

"You already have what everyone else wants"
Dr. John Marburger, Presidential Science Advisor

Nanoscience and Nanotechnology: Evolving Definitions and Growing Footprint on the Scientific Landscape

*Michael L. Grieneisen and Minghua Zhang**

DOI: 10.1002/smll.201100387



Web of Science now adds nearly 90 000 nanotechnology articles per year

Country	Total country records	Records retrieved	% of all country records
Singapore	9324	1530	16.41
China	131 742	20 186	15.32
South Korea	40 515	5278	13.03
Iran	16 072	1892	11.77
India	40 748	4682	11.49
Taiwan	24 476	2778	11.35
Romania	6389	676	10.58
Russia	23 662	2306	9.75
Japan	77 544	6556	8.45
Germany	97 374	6546	6.72
Portugal	9571	639	6.68
France	66 727	4420	6.62
Poland	18 265	1195	6.54
Czech Republic	9068	580	6.40
Mexico	9092	578	6.36
Spain	47 957	2792	5.82
Israel	12 509	719	5.75
Switzerland	24 404	1378	5.65
Finland	10 229	550	5.38
EU-27	475 745	24 932	5.24
Austria	13 072	668	5.11
Belgium	18 504	938	5.07
Italy	56597	2806	4.96
Sweden	21 150	1041	4.92
Greece	11 424	551	4.82
USA	404 226	18 472	4.57
Brazil	31 038	1381	4.45
Denmark	12 779	543	4.25
Australia	43 526	1748	4.02
Turkey	22 558	876	3.88
England	97 784	3576	3.66
Netherlands	34 705	1266	3.65
Canada	60 912	2117	3.48

The energy challenge, nano-materials science and engineering has much to contribute

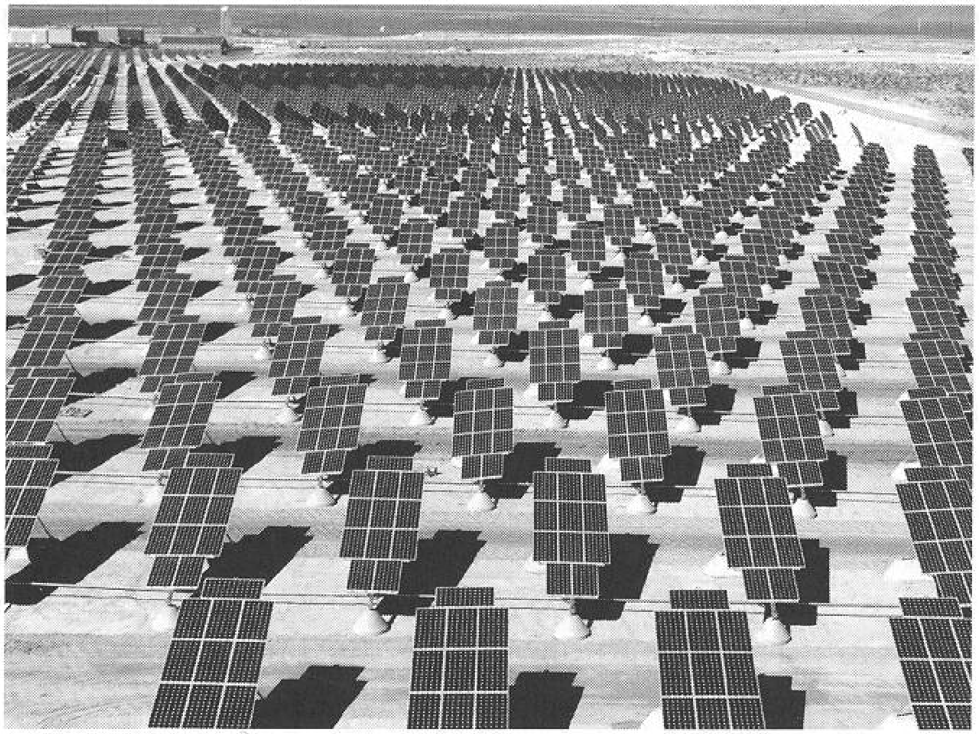


Figure 11.14. The largest photovoltaic solar power plant in the United States is at Nellis Air Force Base with the size of 70,000 solar panels worth 15 mega watt of power. Using about 140 acres of unused land. Courtesy of the U.S. Air Force, Neils Air Base.

if all of Arizona, without Phoenix, Flagstaff, Tucson, and the Great Canyon, were covered by PC could power all of the US

Summary and Conclusions

nanoeducation challenge has been quoted

aspects of nature of the nanoscience and –engineering "beast" has been elucidated

specifics of desirable educational focus of graduate (and undergraduate) education for Oregon's high tech industries were briefly touched

focusing on *nanoscience* as well as *incremental and evolutionary nanoengineering* seems to be sensible

embedding the course topic into the general materials science and engineering approach (as exemplified by a tetrahedron) is practical, at least for an introductory 1 quarter course

every instructor has to come up with his or her own course material, at least there are now a couple of good textbooks and lots of free material e.g. http://nanohub.org, http://community.nsee.us, web.pdx.edu/~pmoeck/nanoMSE.htm