Nanotechnology and you

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Teaching emerging sciences

Common Questions:

- How does it fit the syllabus I am meant to teach?
- If these are so high-tech, how can I do hands on activities with my students?
- How can I teach this when I don’t understand it anyway?

Two case studies

- Nanotechnology
- Synchrotron Science

Myths of nanotechnology

- instant desktop assembly of cheese sandwiches from wood or waste
- nanotechnology is midget submarines or robots (nanobots) that swim in the human bloodstream to repair people
- Nanotechnology will let people live forever
- nanotechnology is about making things smaller
- nanotechnology is science fiction

The promise of nanotechnology

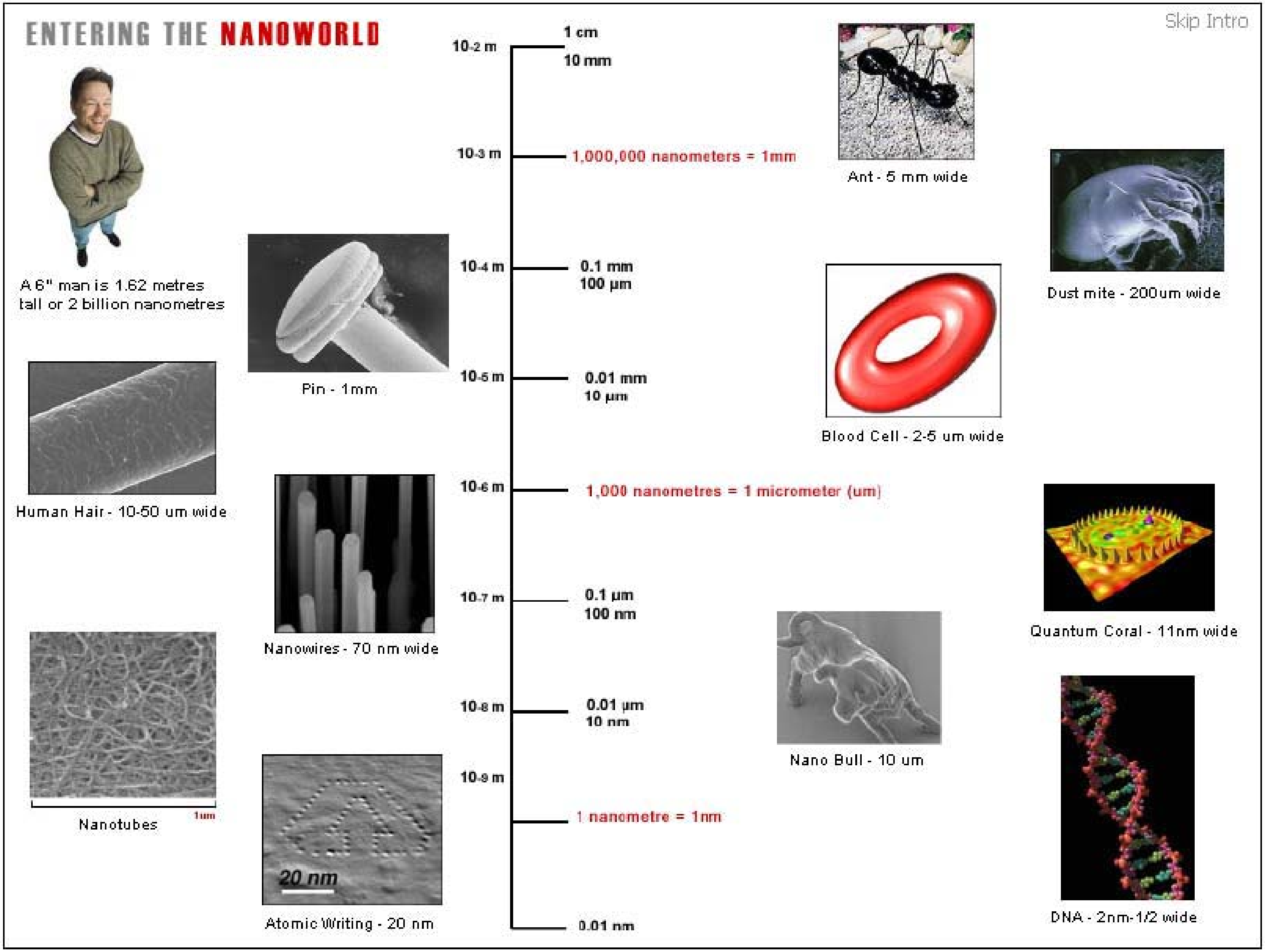
- smaller
- lighter
- cheaper
- faster
- quieter
- cleaner
- better

possible applications of nanotechnology

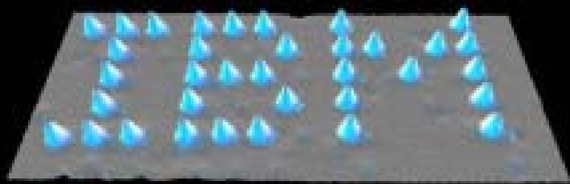
- Food and food packaging
- health and medicine
- paints, pigments and coatings
- cosmetics
- clothing
- solar power
- military, security and space
- computers

What is nanoscience?

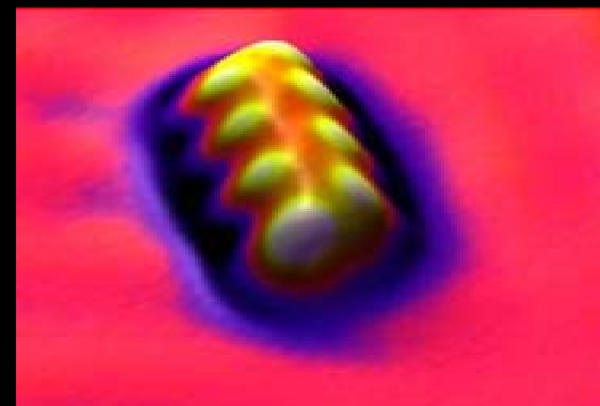
- Nano is derived from ancient Greek: nano~ = “dwarf”
- nanoscience: the domain where Physics, Chemistry and Biology meet
- nanoscience is the study of materials and events at the 10^{-9} m level


ENTERING THE NANOWORLD
Skip Intro
A 6" man is 1.62 metres tall or 2 billion nanometres
Human Hair - 10-50 um wide
Nanotubes
1um
Pin - 1mm
Nanowires - 70 nm wide
20 nm
Atomic Writing - 20 nm
10-2 m
1 cm
10 mm
10-3 m
1,000,000 nanometers = 1mm
10-4 m
0.1 mm
100 µm
10-5 m
0.01 mm
10 µm
10-6 m
1,000 nanometres = 1 micrometer (um)
10-7 m
0.1 µm
100 nm
10-8 m
0.01 µm
10 nm
10-9 m
1 nanometre = 1nm
0.01 nm
Ant - 5 mm wide
Dust mite - 200um wide
Blood Cell - 2-5 um wide
Quantum Coral - 11nm wide
Nano Bull - 10 um
DNA - 2nm-1/2 wide

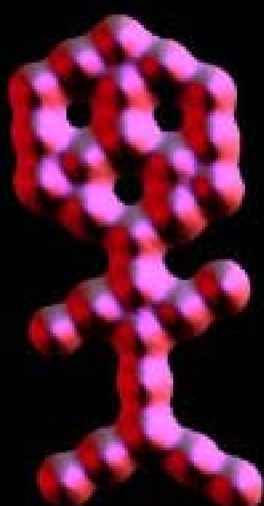
Limits of Nanotechnology



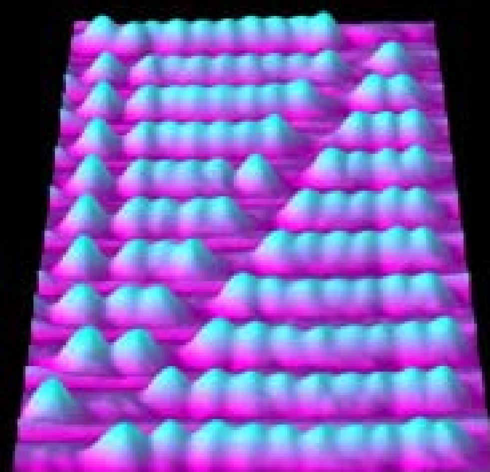
Xenon on Nickel (110)



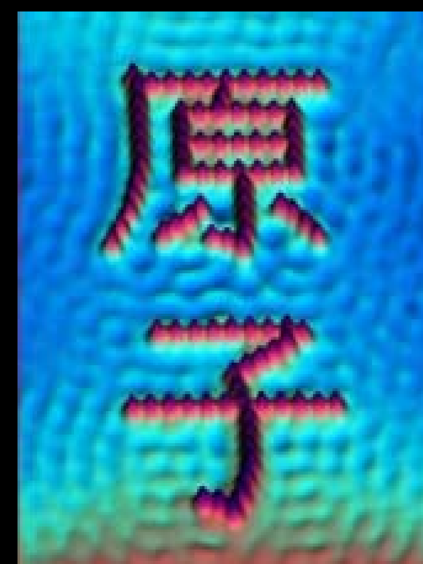
Cesium & Iodine on Copper (111)



Carbon Monoxide on Platinum (111)



C_{60} on Copper



Iron on Copper (111)

http://www.almaden.ibm.com/vis/stm/atomo.html; http://www.zurich.ibm.com/pub/hug/PR/Abacus/

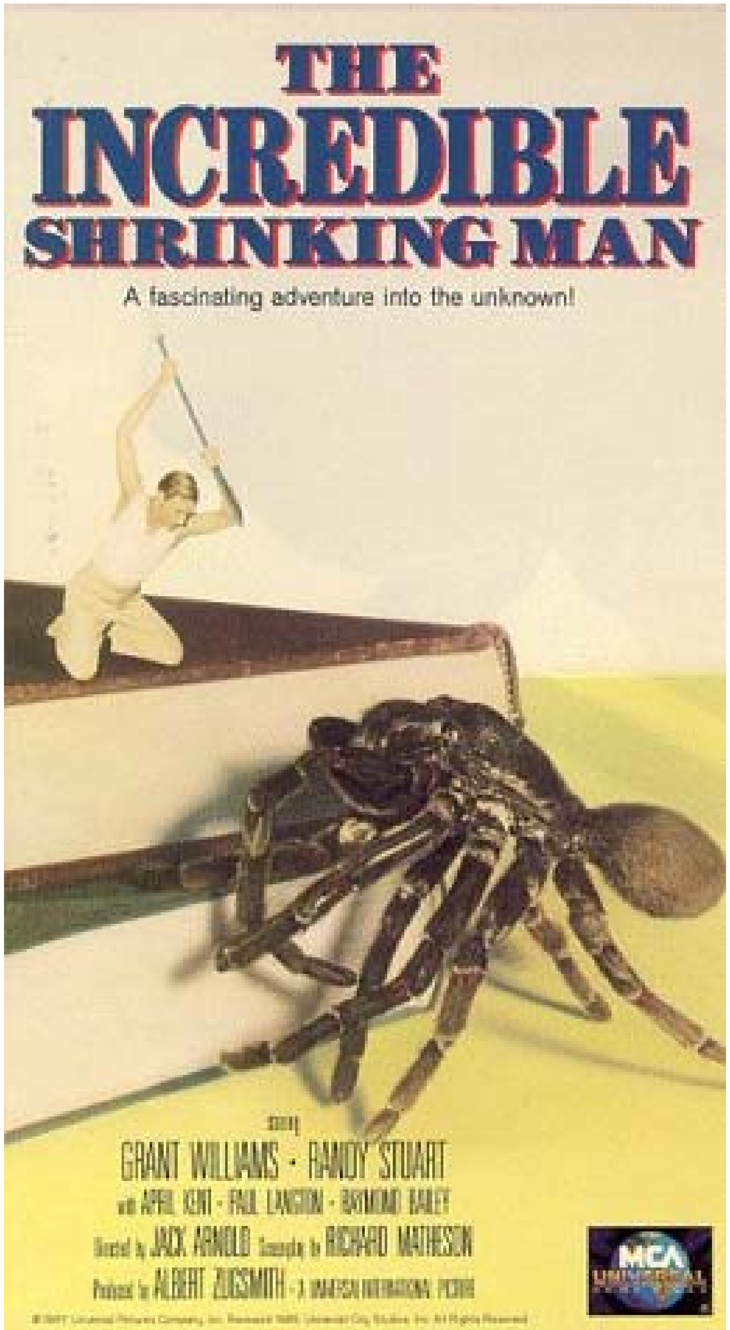
Why is Nano Research Important?

At the nano scale, properties and behaviours of everyday materials significantly change

Nanoparticles exhibit size dependent properties that are profoundly different from the corresponding bulk material.

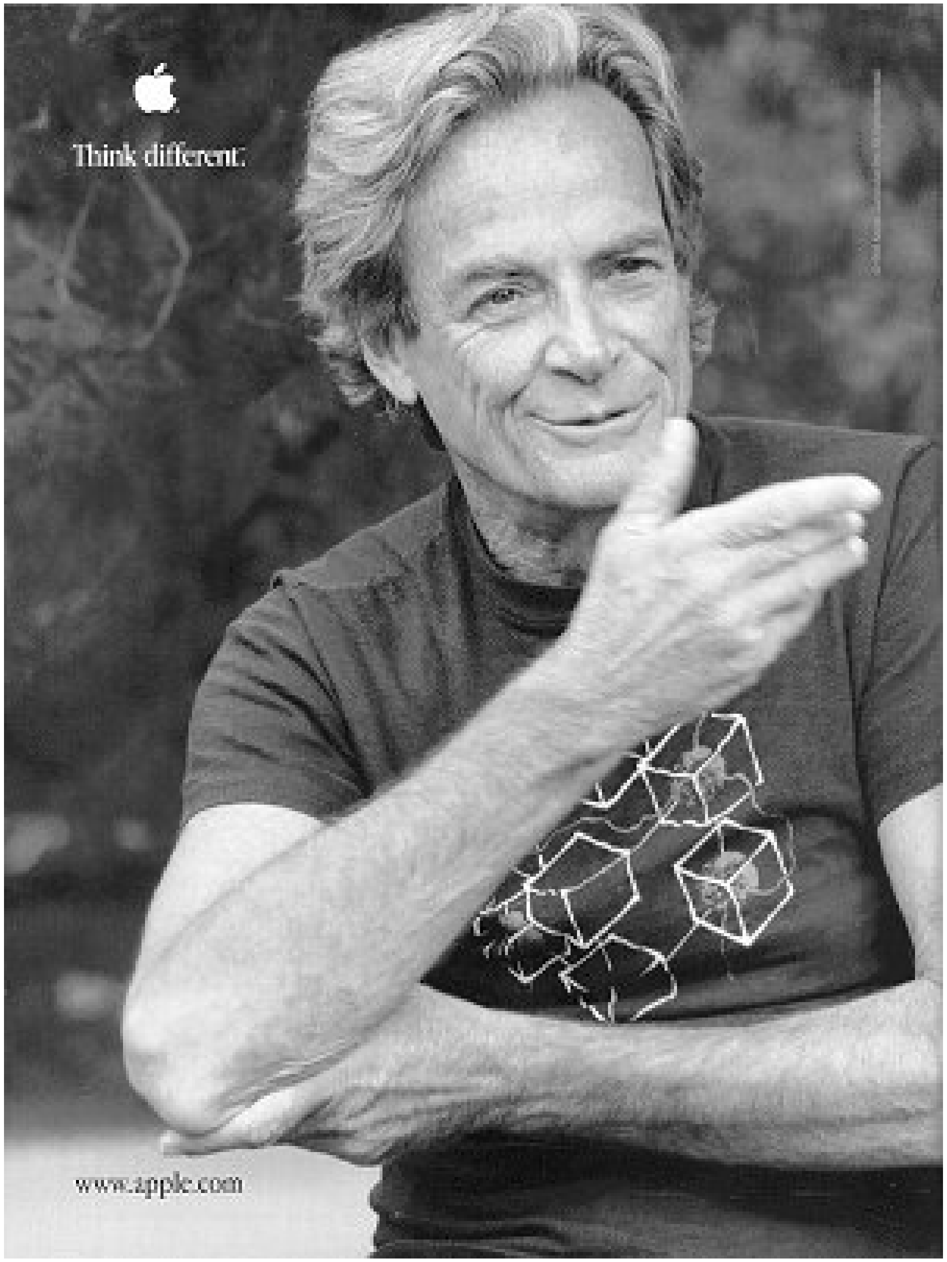
Electrical	higher electrical conductivity in ceramics and magnetic nanocomposites; higher resistivity in metals
Magnetic	increase in magnetic coercivity down to a critical size in the nanoscale regime; below critical crystalline size, decrease in the coercivity leading to superparamagnetic behavior
Mechanical	increase in hardness and strength of metals and alloys; enhanced ductility, toughness and formability of ceramics; super strength and superplasticity
Optical	increase in luminescent efficiency of semiconductors; transparency of nanoparticles
Chemical	Substantial increase in catalytic properties and reaction rates

History of nanotechnology



1957

After being exposed to a radioactive cloud, Scott Carey slowly shrinks to atomic size



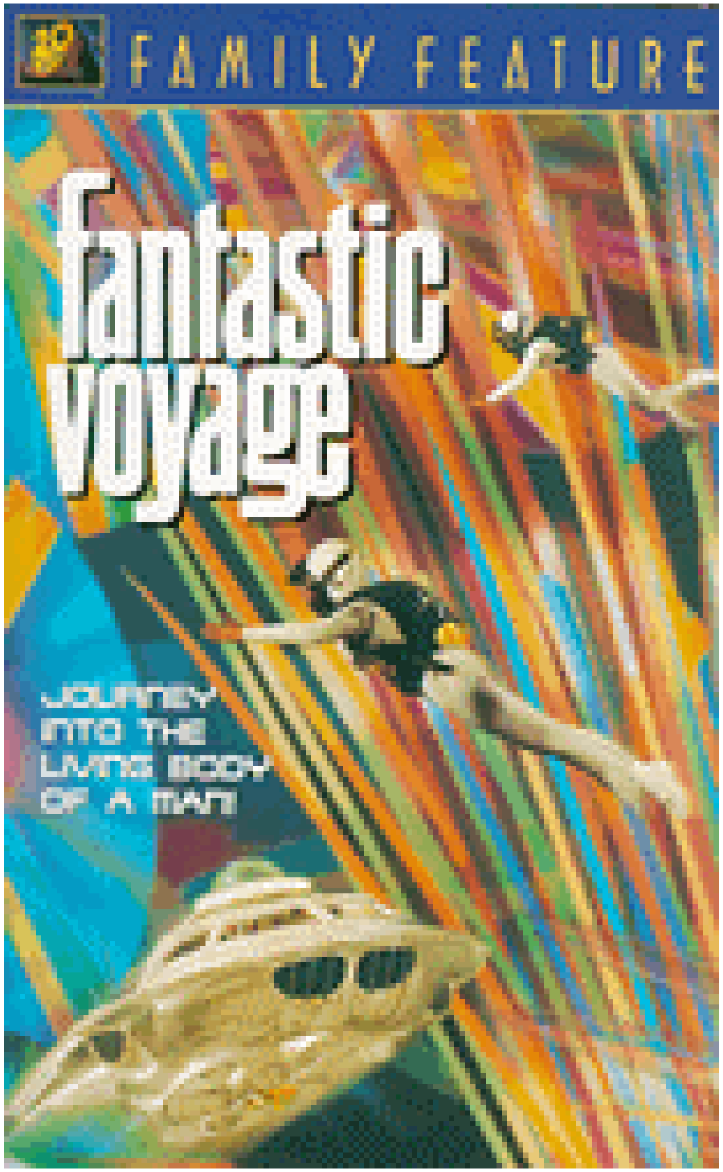
There's Plenty of Room at the Bottom

An Invitation to Enter a New Field of Physics

by Richard P. Feynman

December 29th 1959

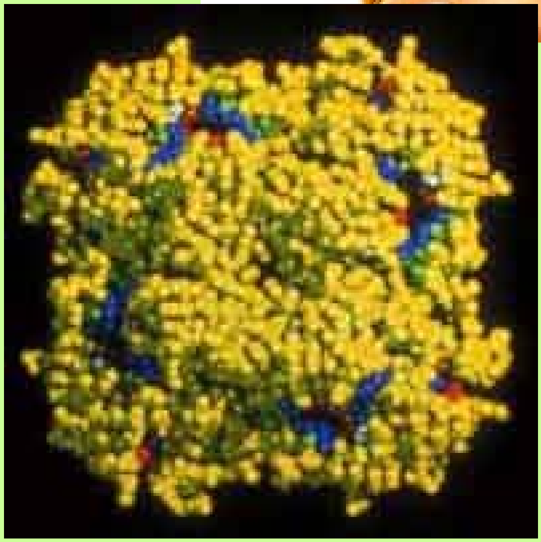
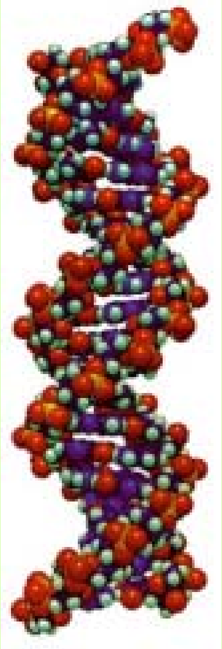
(1966) Fantastic Voyage



FORESIGHT INSTITUTE

Eric Drexler -
“Engines of
Creation” (1985)




-3×10^9 years nature

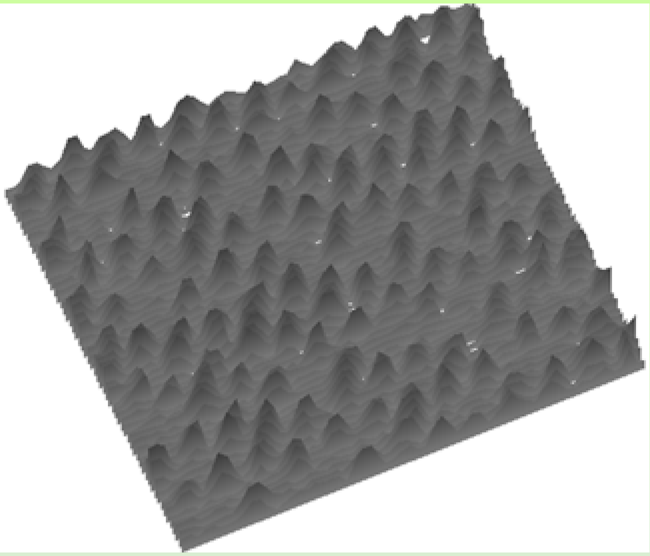
What is nanotechnology?

Many things to many people but two aspects are common:

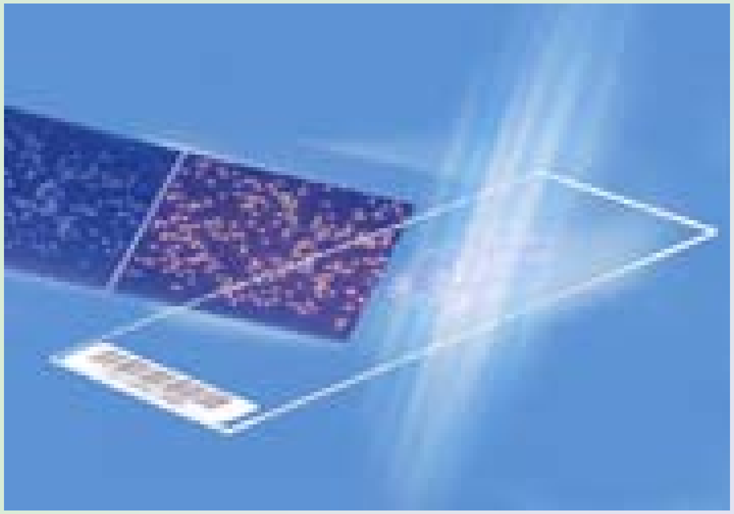
- Creation of “new” materials and devices from being able to manipulate properties at the level of atoms.
- Exploitation of strange and new properties of materials of less than 100 nm - such as nanopowders and nano-crystals.

nanotechnology products

- CD-ROMS
- transparent zinc oxide sunscreen
- "nano" cosmetics
- Crush resistant eyeglasses with scratch resistance



- plastic and clear beer bottles
- biochip arrays for DNA & medical testing
- nanocomposites in new tennis balls



Two approaches to nanotechnology

Top-down approach
Start with large block of material and make smaller. Eg grinding TiO_2 to a nano-fine powder

Bottom up approach
Position atoms exactly where we want them

Both approaches have problems

wasteful

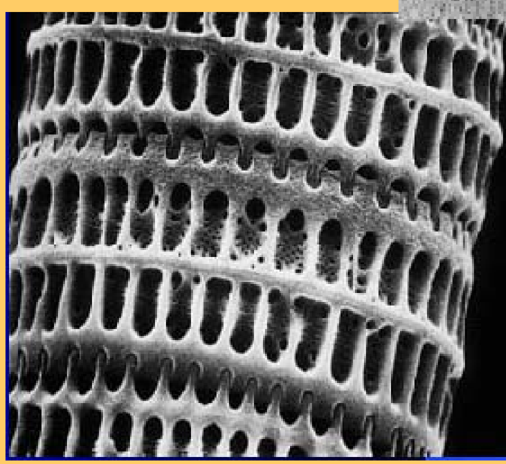
time consuming, slow and expensive.

self assembly

Modern integrated circuits and chips are made by top-down approaches. Start with silicon wafers and use masks and etching to create micron sized features

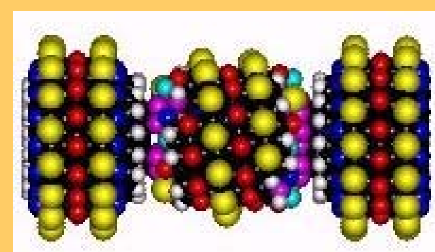
self assembly in nature

DNA 2-5 nm



diatom – 100nm.

ultimate goal of nanotechnology is a bottom-up process that looks after itself… self assembly

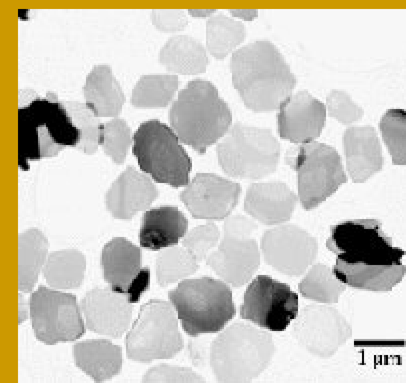


PRODUCT CASE STUDIES

Transparent Zinc Creme

transparent zinc crème was invented in Australia in 98/99. Predicted to be 50% of market in 2002/03 summer

Normal ZnO sunscreen particles both absorb and scatter light, so zinc cream looks white.



grind TiO_2 and ZnO particles to 100 nm diameter – small enough to let visible light pass through without absorption and scattering.

nano-fine TiO2 and ZnO absorb 2x UV radiation of traditional sunscreens and are effective for longer

Other applications are varnishes, paints and plastic additives - anywhere where increased sun protection is wanted without changing appearance.

nanosomes: transport devices across the skin barrier

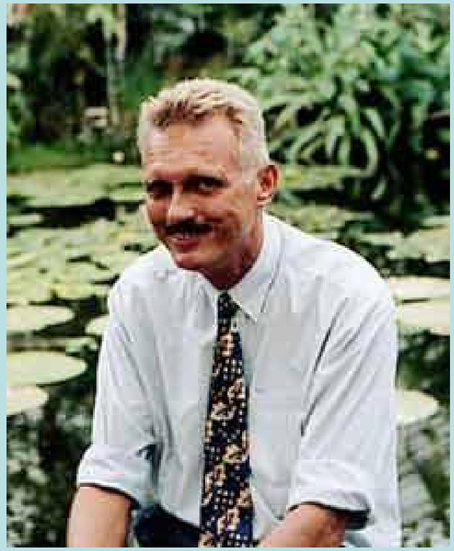
Human skin has 100 nm interstices.

Nanosomes are 30-50 nm wide vesicles that can transport and protect lipophilic active agents through the skin

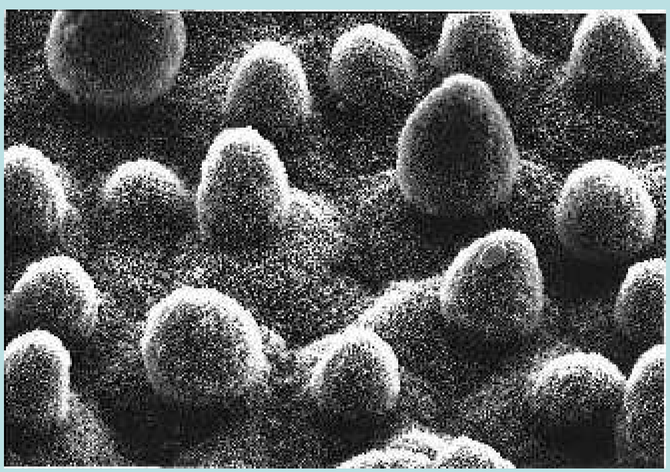
L'Oreal developed nanosomes to transport pure Vitamin E or Pro Retinol A through the outer skin for release into inner skin layers.

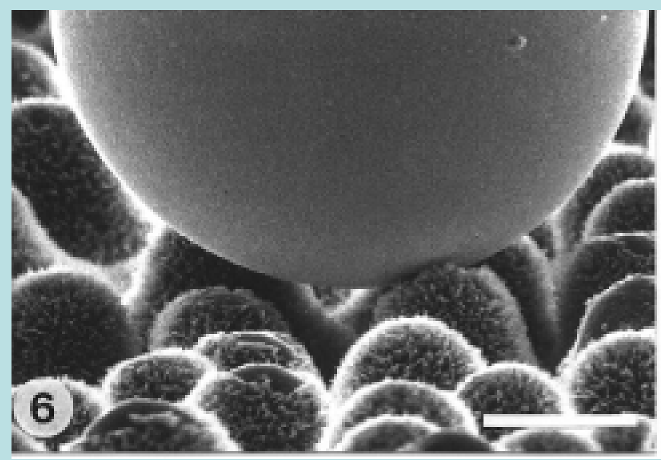
MIKA Pharma spraygel-technology delivers drugs across membranes (eg heparin to reduce blood clotting and swelling after injuries)

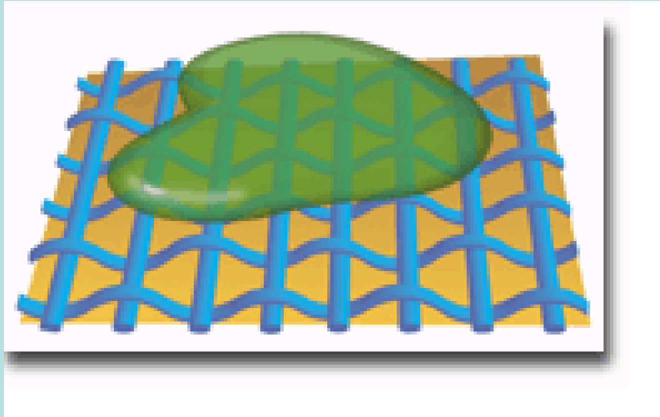
The lotus effect - biomimicry in action



Dr Wilhelm Barthlott





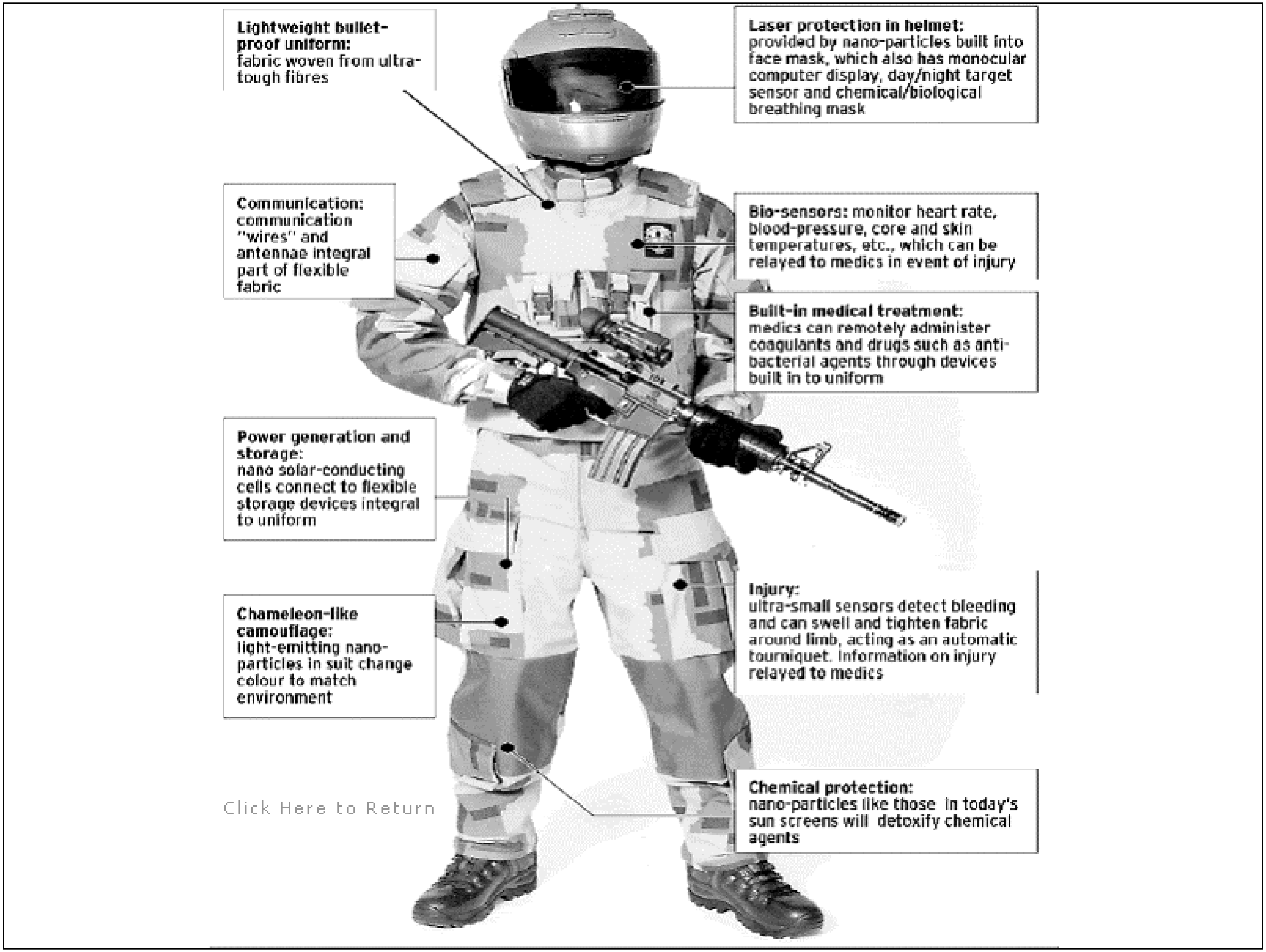


“nano-whiskers” 1/1000th the diameter of a cotton fibre are attached to the fabric surface

washing without detergent removes dirt!

Other applications: bathroom chromes, paints and the “non wash car”

marketed by Lee jeans as “Performance Khakis with“nano-care”.


Lightweight bullet-proof uniform: fabric woven from ultra-tough fibres
Laser protection in helmet: provided by nano-particles built into face mask, which also has monocular computer display, day/night target sensor and chemical/biological breathing mask
Communication: communication "wires" and antennae integral part of flexible fabric
Bio-sensors: monitor heart rate, blood-pressure, core and skin temperatures, etc., which can be relayed to medics in event of injury
Built-in medical treatment: medics can remotely administer coagulants and drugs such as anti-bacterial agents through devices built in to uniform
Power generation and storage: nano solar-conducting cells connect to flexible storage devices integral to uniform
Injury: ultra-small sensors detect bleeding and can swell and tighten fabric around limb, acting as an automatic tourniquet. Information on injury relayed to medics
Chameleon-like camouflage: light-emitting nano-particles in suit change colour to match environment
Chemical protection: nano-particles like those in today's sun screens will detoxify chemical agents
Click Here to Return

Self cleaning glass

Photo-catalysis of surface dirt & organics to smaller particles

Hydrophilic surface attracts water, washing off particles

nano-fine TiO_2 is attached to the surface of the glass during the processing. Nano-particle is smaller than wavelength of light so is transparent.

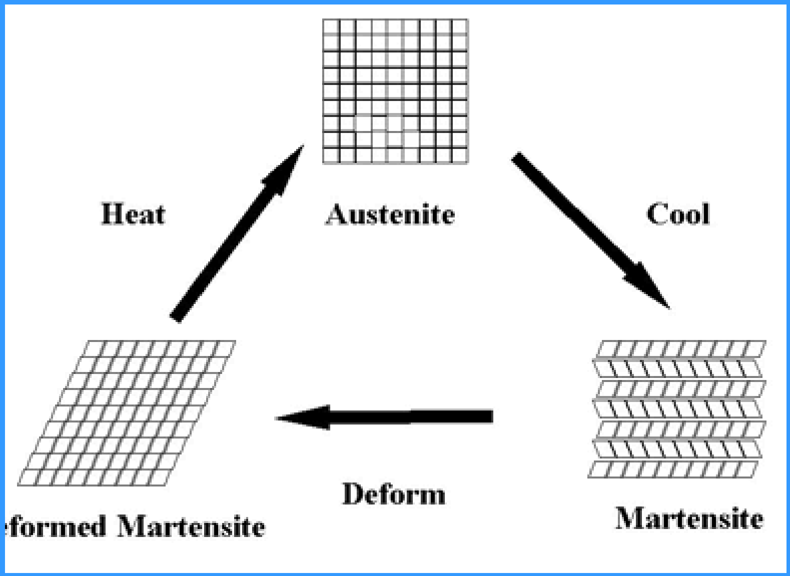
R& D into paint surfaces - especially for car bodies

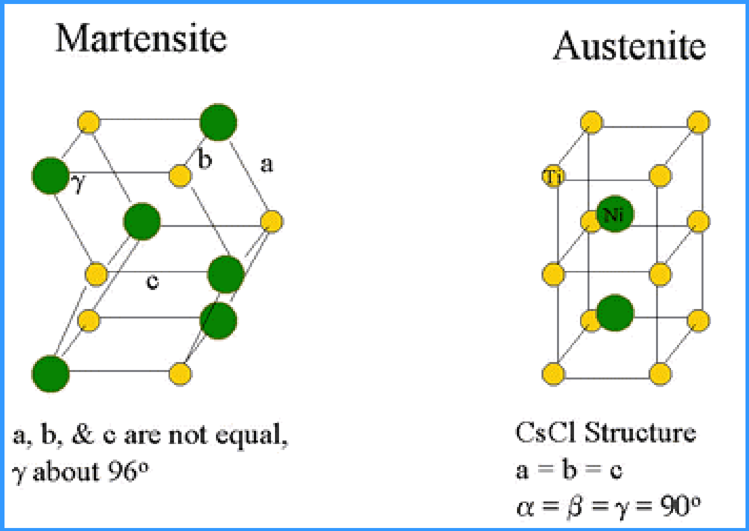
memory metal

NiTi alloy (nitol) developed by US navy

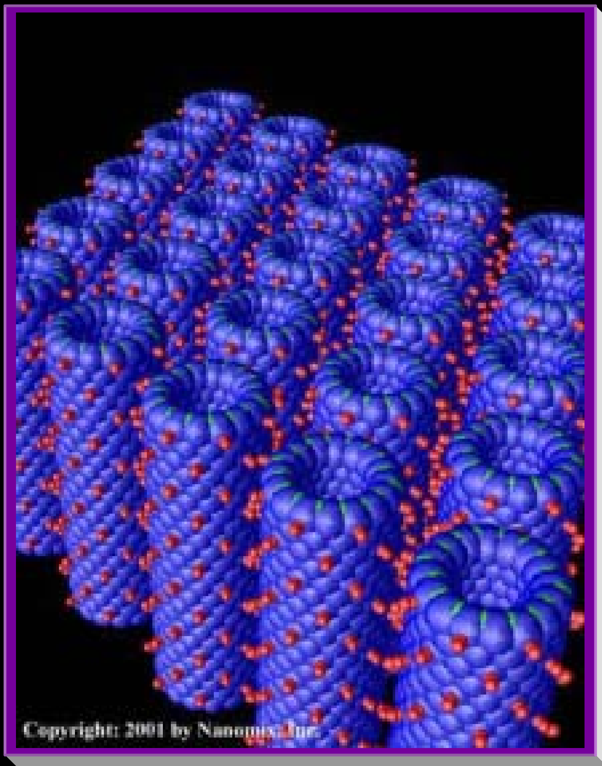
Can deform shape of alloy. Heat in warm water and alloy returns to original shape

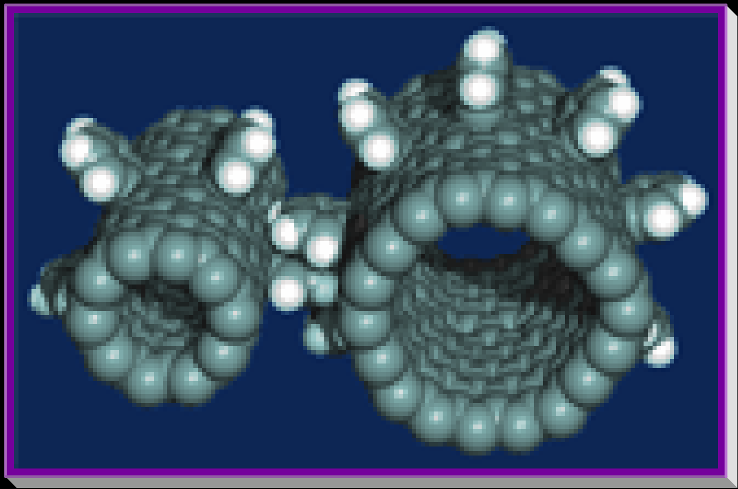
Link 1

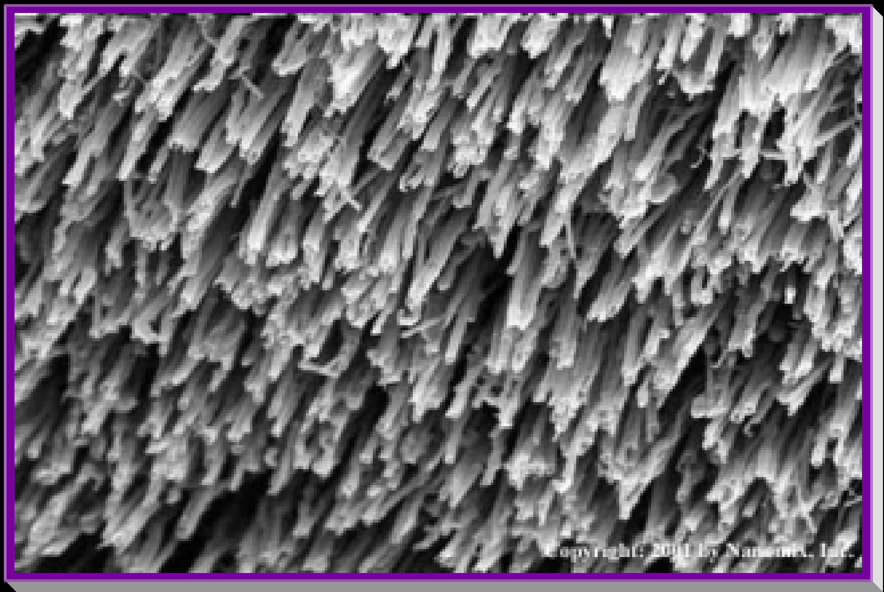




Carbon Nanotube Technology



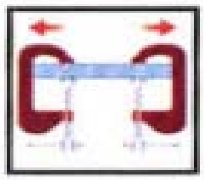
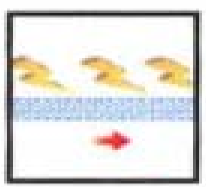




http://www.ipt.arc.nasa.gov/gallery.html; http://www.nano.com/an-pg-body.html

Physical Properties of Carbon Nanotubes

Going to Extremes

	PROPERTY	SINGLE-WALLED NANOTUBES	BY COMPARISON
	Density	1.33 to 1.40 grams per cubic centimeter	Aluminum has a density of 2.7 g/cm³
	Tensile Strength	45 billion pascals	High-strength steel alloys break at about 2 billion Pa
	Resilience	Can be bent at large angles and restraightened without damage	Metals and carbon fibers fracture at grain boundaries
	Current Carrying Capacity	Estimated at 1 billion amps per square centimeter	Copper wires burn out at about 1 million A/cm²

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NASA Langley Research Center

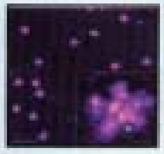
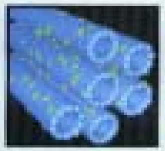
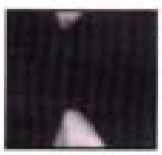
Grace, L. in “Nanotubes for Electronics,” P. G. Collins and P. Avouris, Scientific American, 283(6), pp. 62 ff, Dec, 2000.

Applications of Carbon Nanotubes

Other Uses for Nanotubes

Beyond Electronics

Feasibility Ratings
0 = Science Fiction
2 = Demonstrated
4 = Ready for Market

		THE IDEA	OBSTACLES	FEASIBILITY
	**Sharper Scanning Microscope** Individual IgM antibodies	Attached to the tip of a scanning probe microscope, nanotubes can boost the instruments' lateral resolution by a factor of 10 or more, allowing clearer views of proteins and other large molecules.	Although commercially available, each tip is still made individually. The nanotube tips don't improve vertical resolution, but they do allow imaging deep pits in nanostructures that were previously hidden.	4
	**Supersensitive Sensors** Oxygen sticks to tubes	Semiconducting nanotubes change their electrical resistance dramatically when exposed to alkalis, halogens and other gases at room temperature, raising hopes for better chemical sensors.	Nanotubes are exquisitely sensitive to so many things (including oxygen and water) that they may not be able to distinguish one chemical or gas from another.	3
	**Mechanical Memory** Nonvolatile RAM	A screen of nanotubes laid on support blocks has been tested as a binary memory device, with voltages forcing some tubes to contact (the "on" state) and others to separate (the "off" state).	The switching speed of the device was not measured, but the speed limit for a mechanical memory is probably around one megahertz, which is much slower than conventional memory chips.	2
	**Superstrong Materials** Nanotube stress test	Embedded into a composite, nanotubes have enormous resilience and tensile strength and could be used to make cars that bounce in a wreck or buildings that sway rather than crack in an earthquake.	Nanotubes still cost 10 to 1,000 times more than the carbon fibers currently used in composites. And nanotubes are so smooth that they slip out of the matrix, allowing it to fracture easily.	0

Compiled by W. Wayt Gibbs, staff writer

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Grace, L. in "Nanotubes for Electronics," P. G. Collins and P. Avouris, Scientific American, 283(6), pp. 62 ff, Dec, 2000.

The (near) future (1-3 years)

- High speed computing (Intel's 10Ghz chip, 100 G-flop proteomic analysis computer)
- Applications for C_{60}, single and multi-walled carbon nanotubes
- Sensors (chemical, biological & diagnostics)
- DNA separation & sequencing (microfluidics/nanoseparations)
- Bio/silicon interfaces (DNA chips, biochips)
- Nanostructured flat panel displays

The future (5-15 years)

- Self assembled materials, devices & systems
- Biological semiconductors; artificial photosynthesis
- Miniature terabit data storage
- Mass produced sensors for home diagnostics
- Molecular motors and gears, portable fuel cells

Grace, L. in "Nanotubes for Electronics," P. G. Collins and P. Avouris, Scientific American, 283(6), pp. 62 ff, Dec, 2000.

- Artificial

Social implications

Regardless of benefits … nanotechnology is a very disruptive technology

Applications positive for consumer and citizen – but not good for many existing occupations

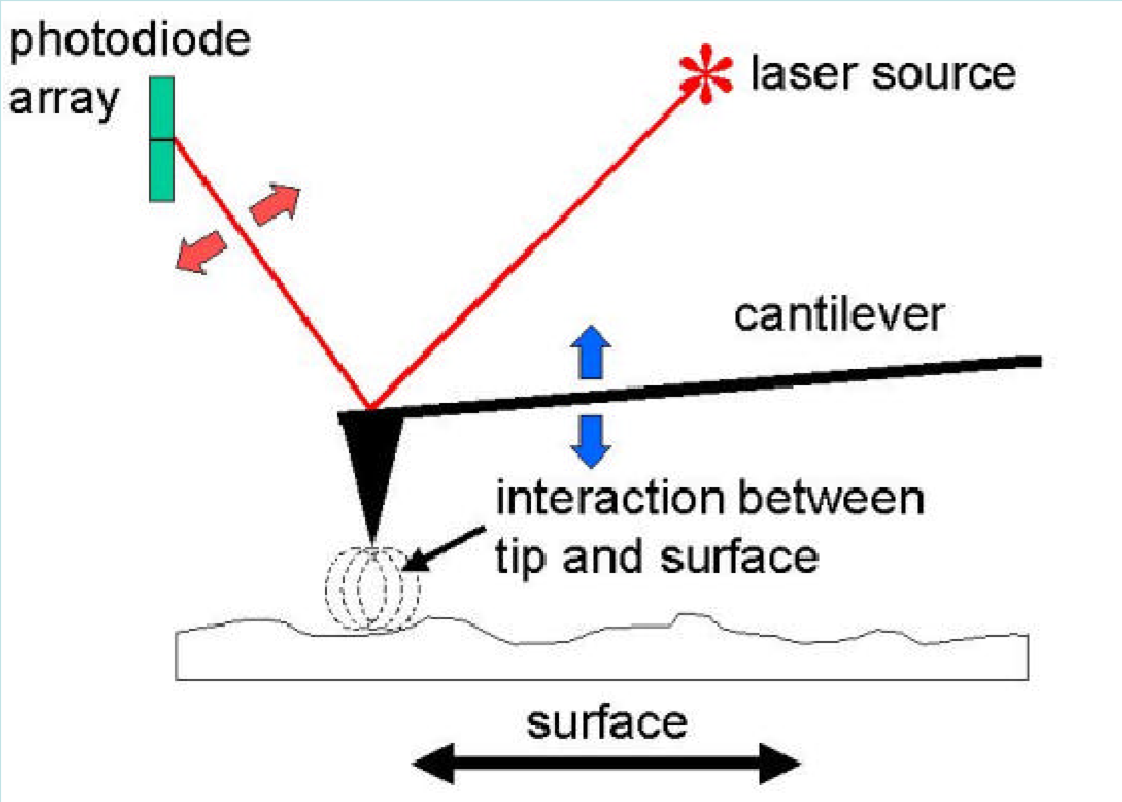
current developments threaten future livelihood of pathologists, dry cleaners, textile workers, window washers, car washers, food handlers, etc

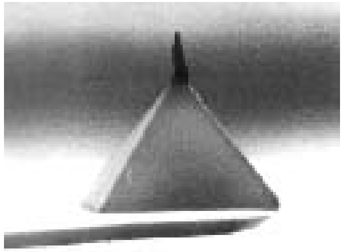
toolkit of the nanotechnologist

Major elements of the toolkit:

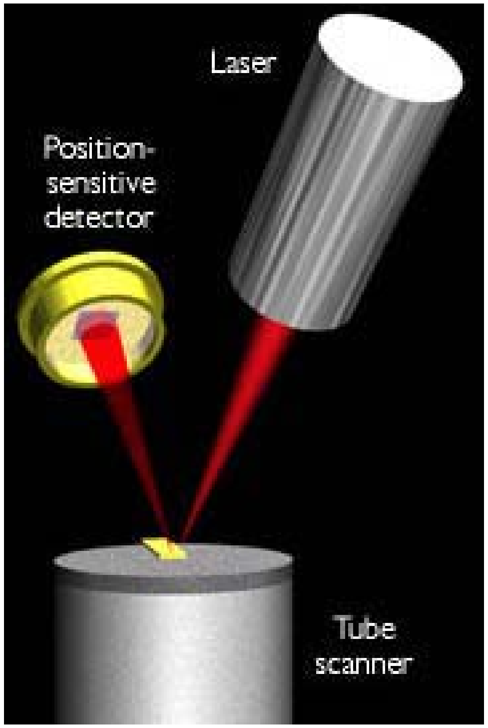
- Atomic Force microscope
- Atomic magnetic microscope
- Tunnelling electron microscope
- Synchrotron radiation

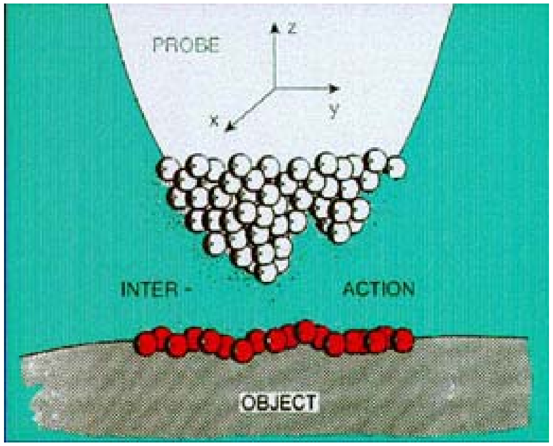
Atomic Force Microscope Principles



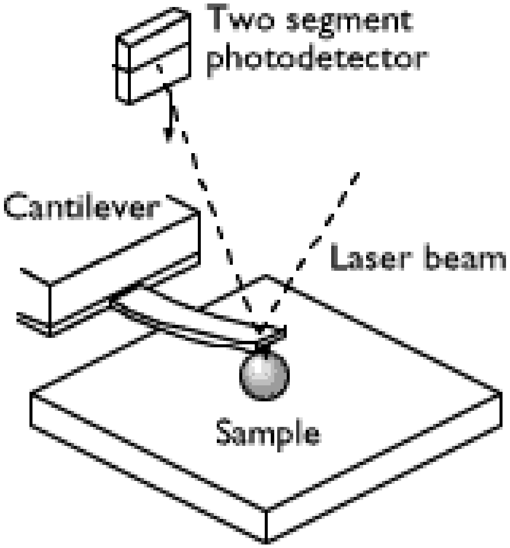


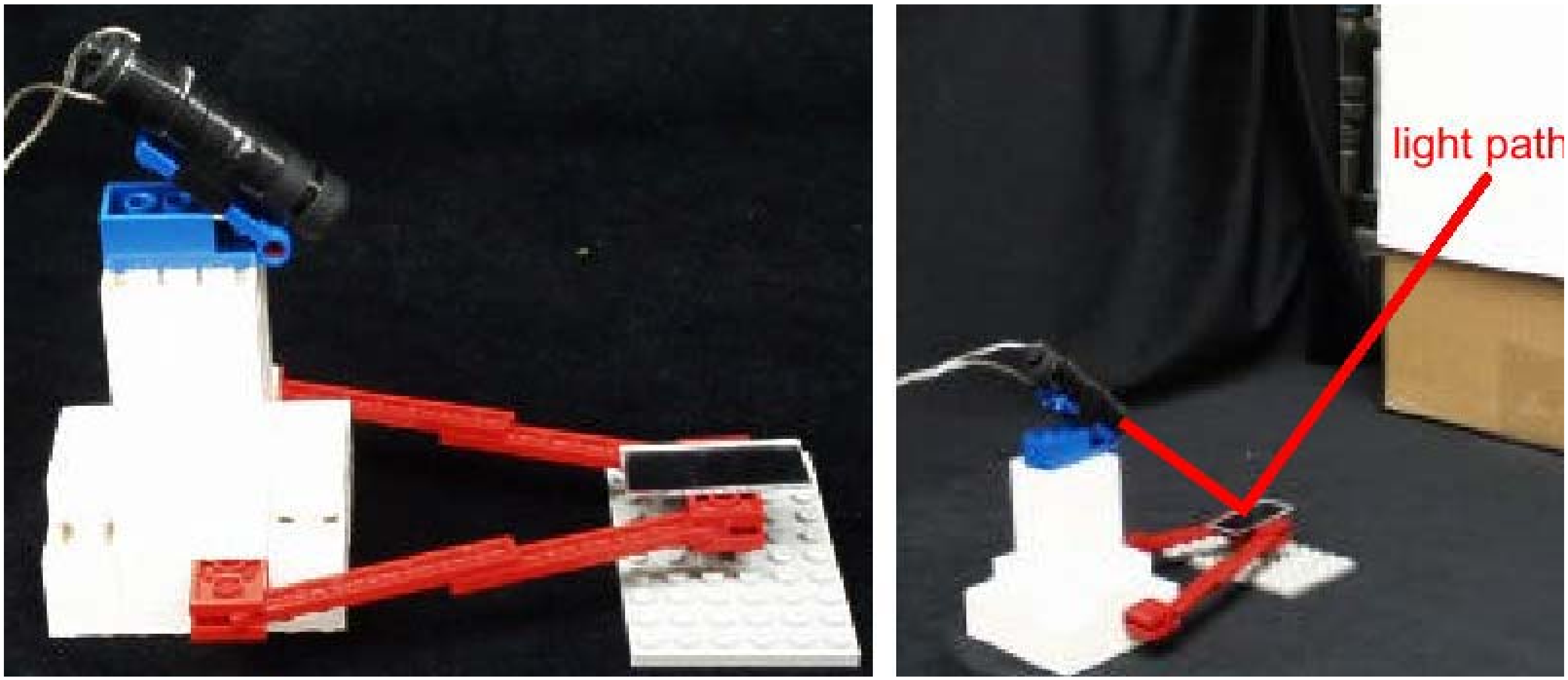
AFM supertip3 µm tall





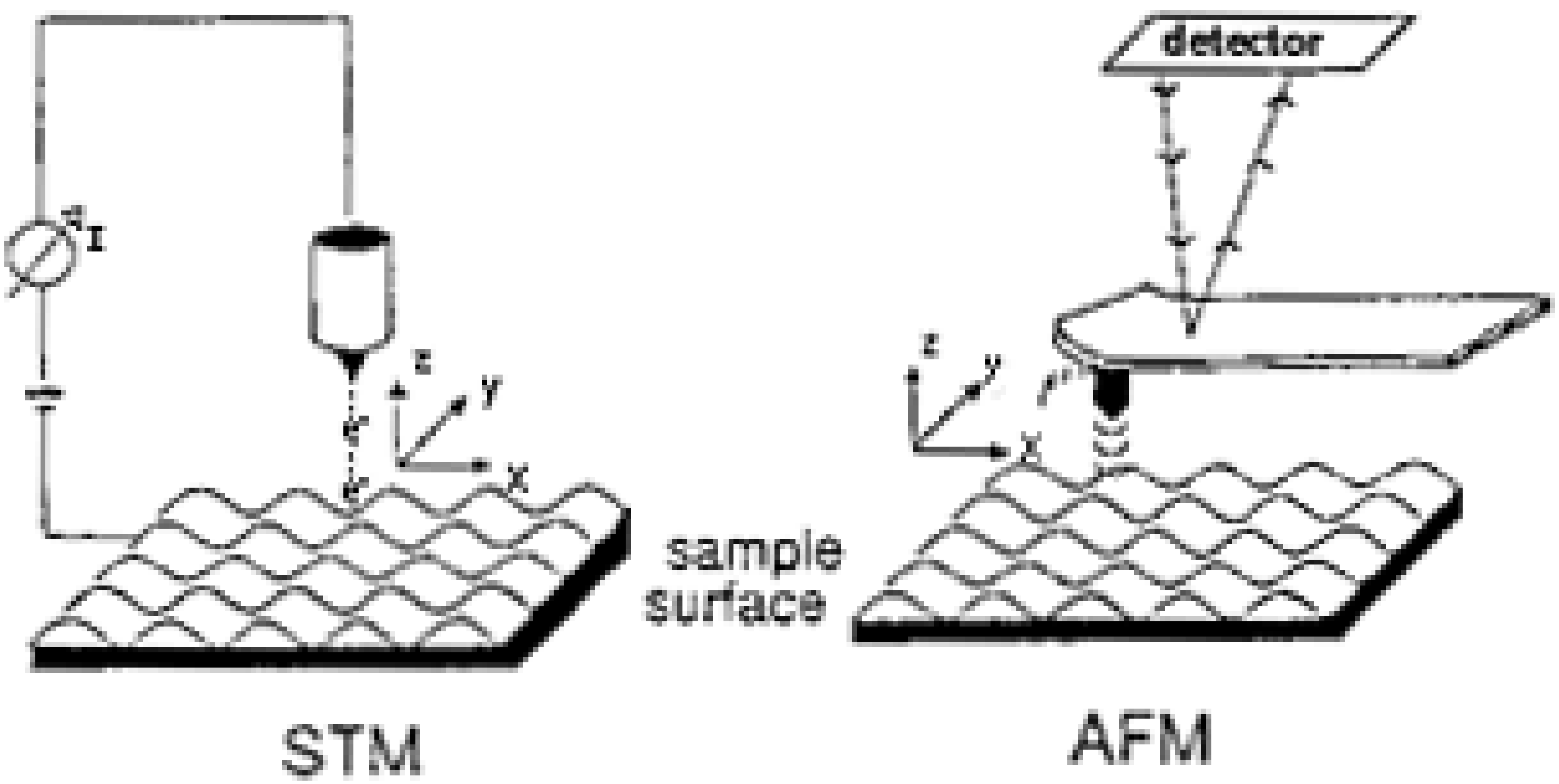
Atomic force microscopy



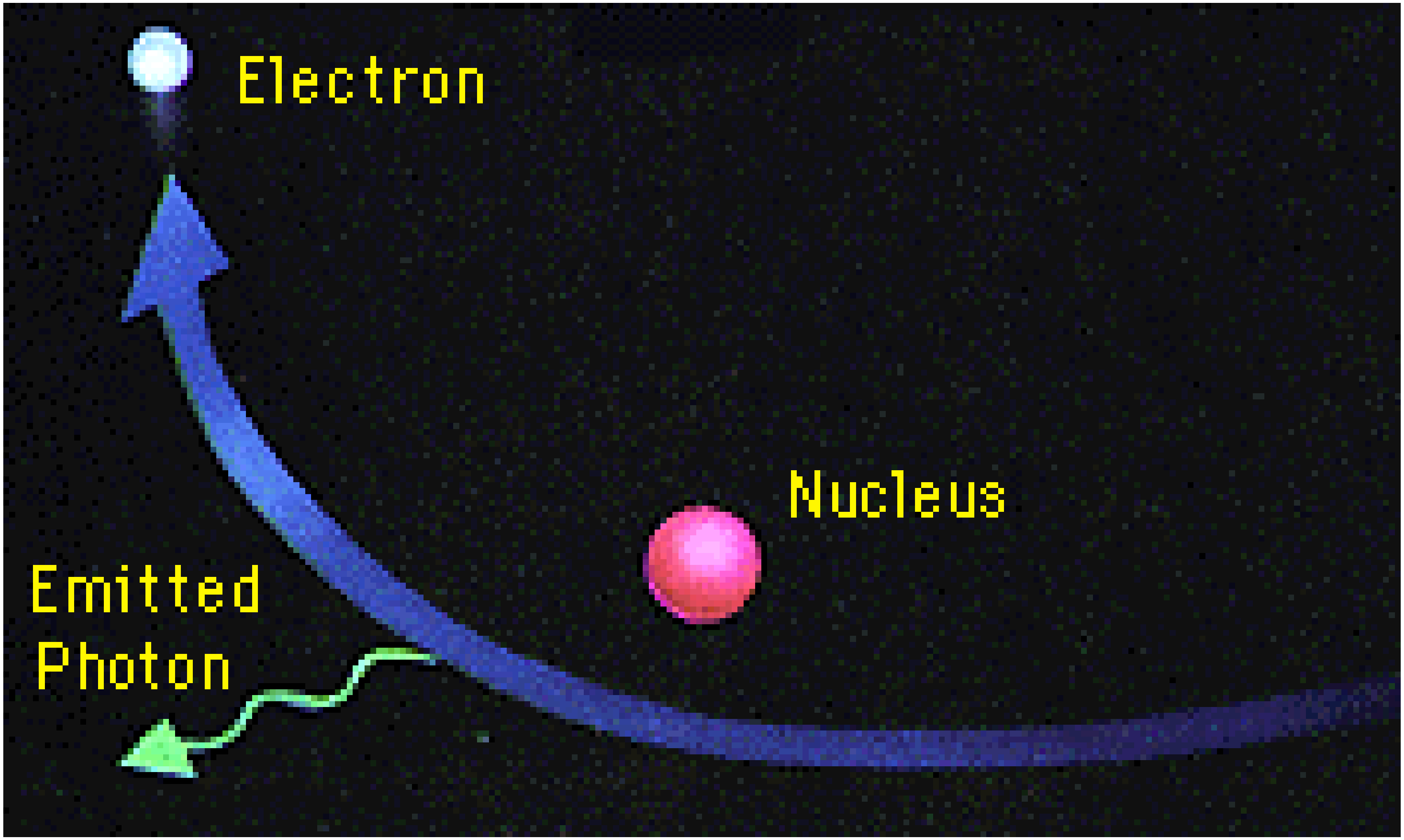

light path

More power....

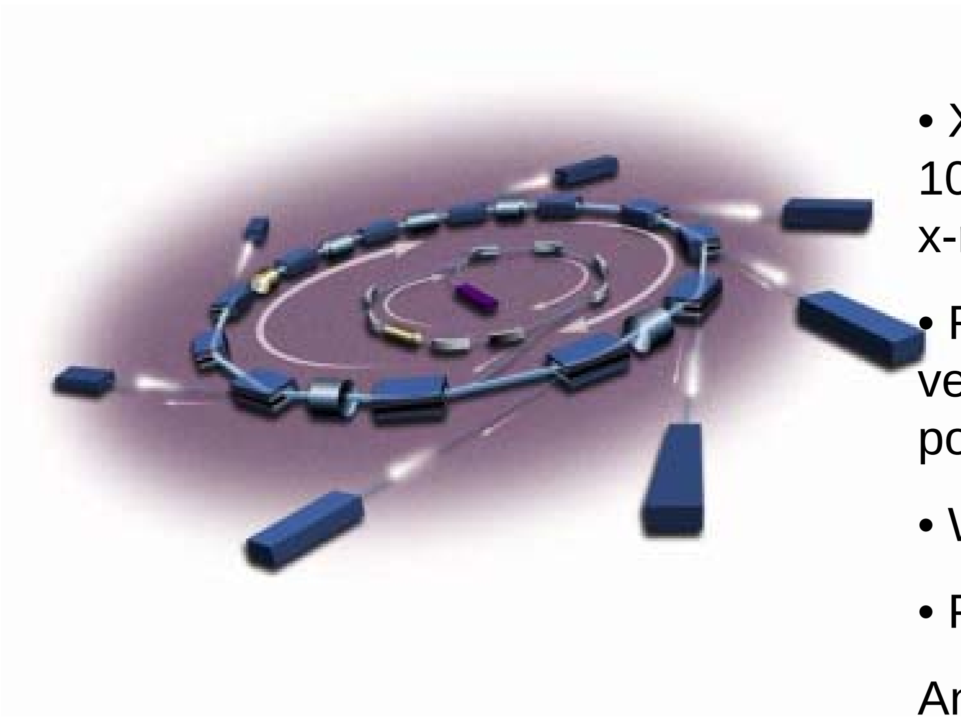
atomic microscopy



Photons are produced when electrons are accelerated / decelerated



Synchrotron radiation



• X-ray radiation of high intensity: 10^{19} photons/s/mm^2/mrad^2 opening x-ray tube is 10^5 photons/s/mm^2/mrad^2

• Radiation is non-monochromatic but very coherent (ie non-divergent) – linear polarization

• Wide spectrum and high flux

• Pulsed structure

Analysis is by:

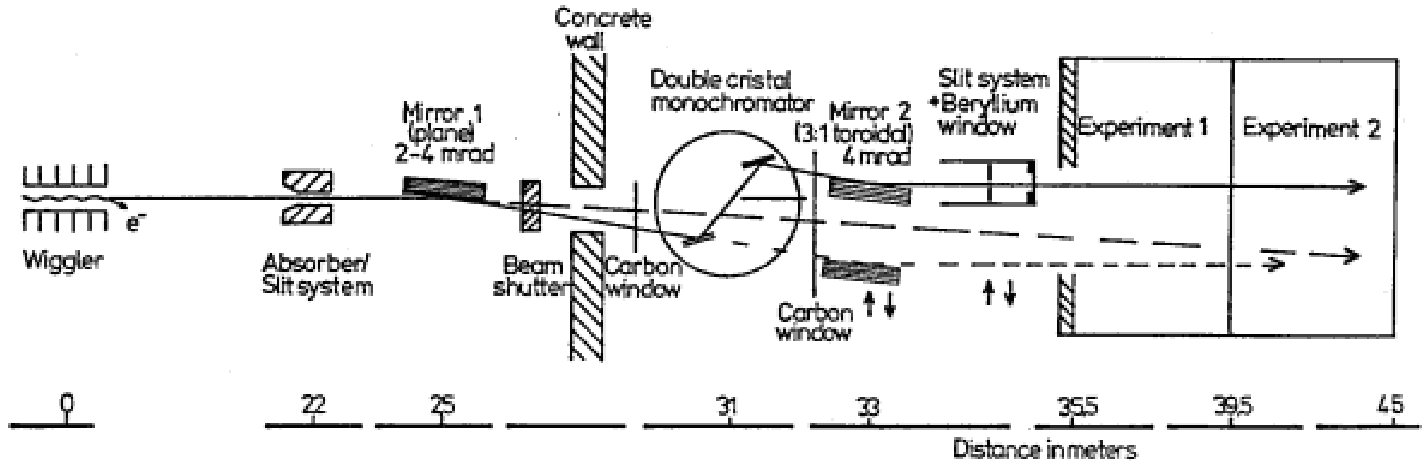
• X-ray diffraction (Braggs law)

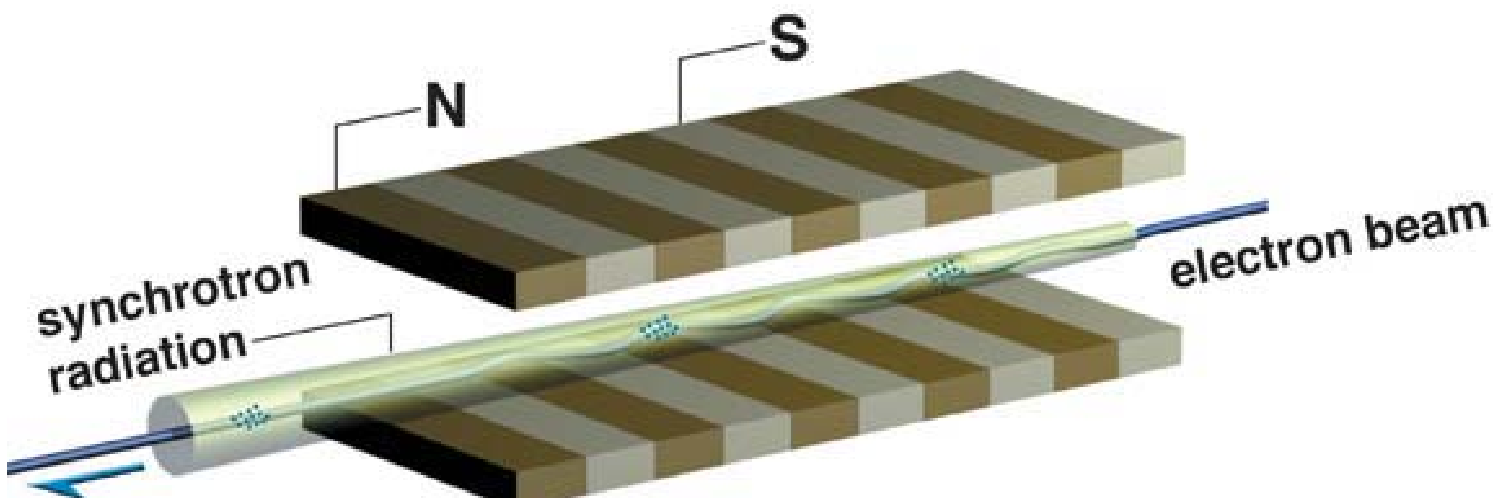
• X-ray scattering

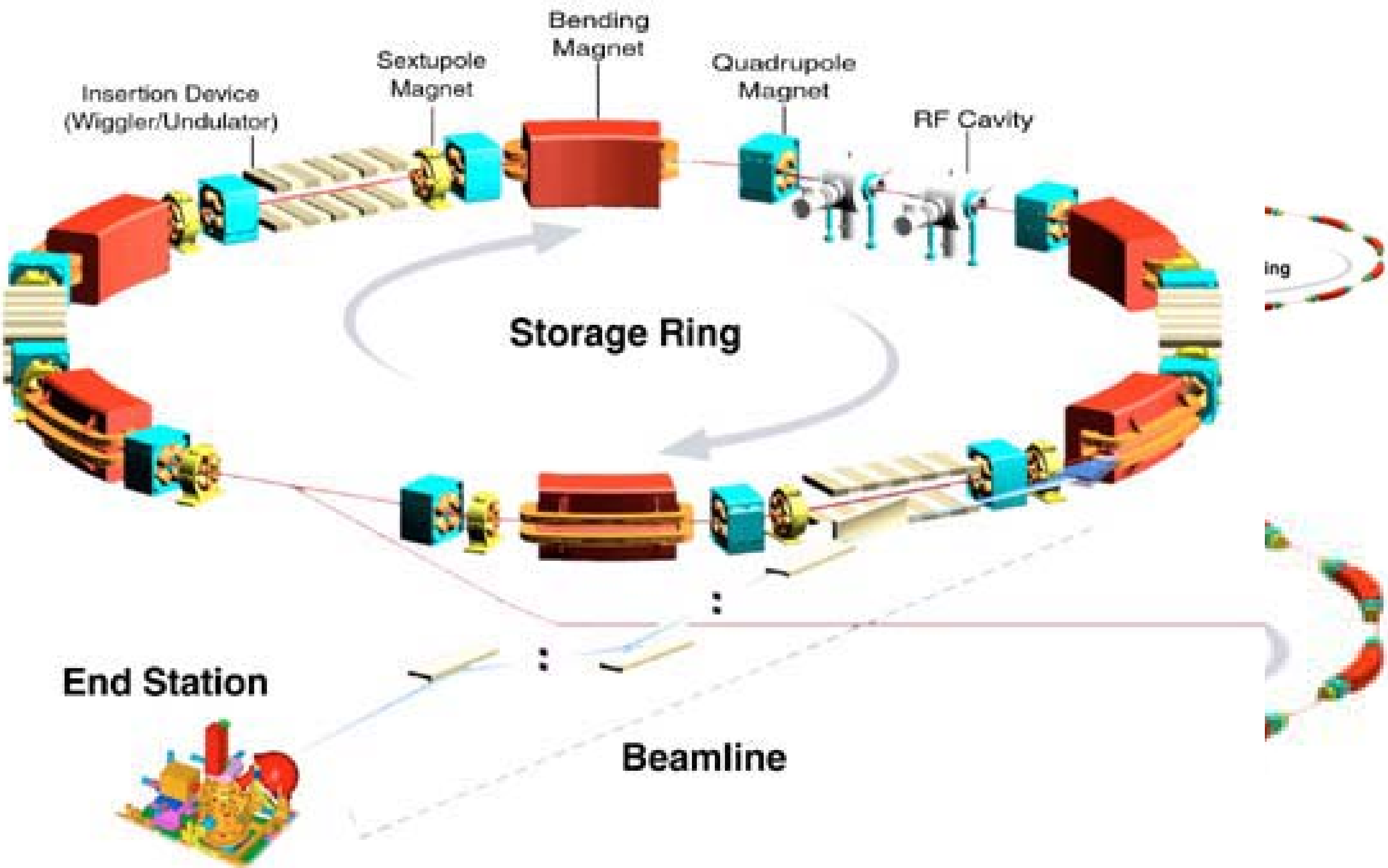
• Absorption, emission (fluorescence) and photoemission

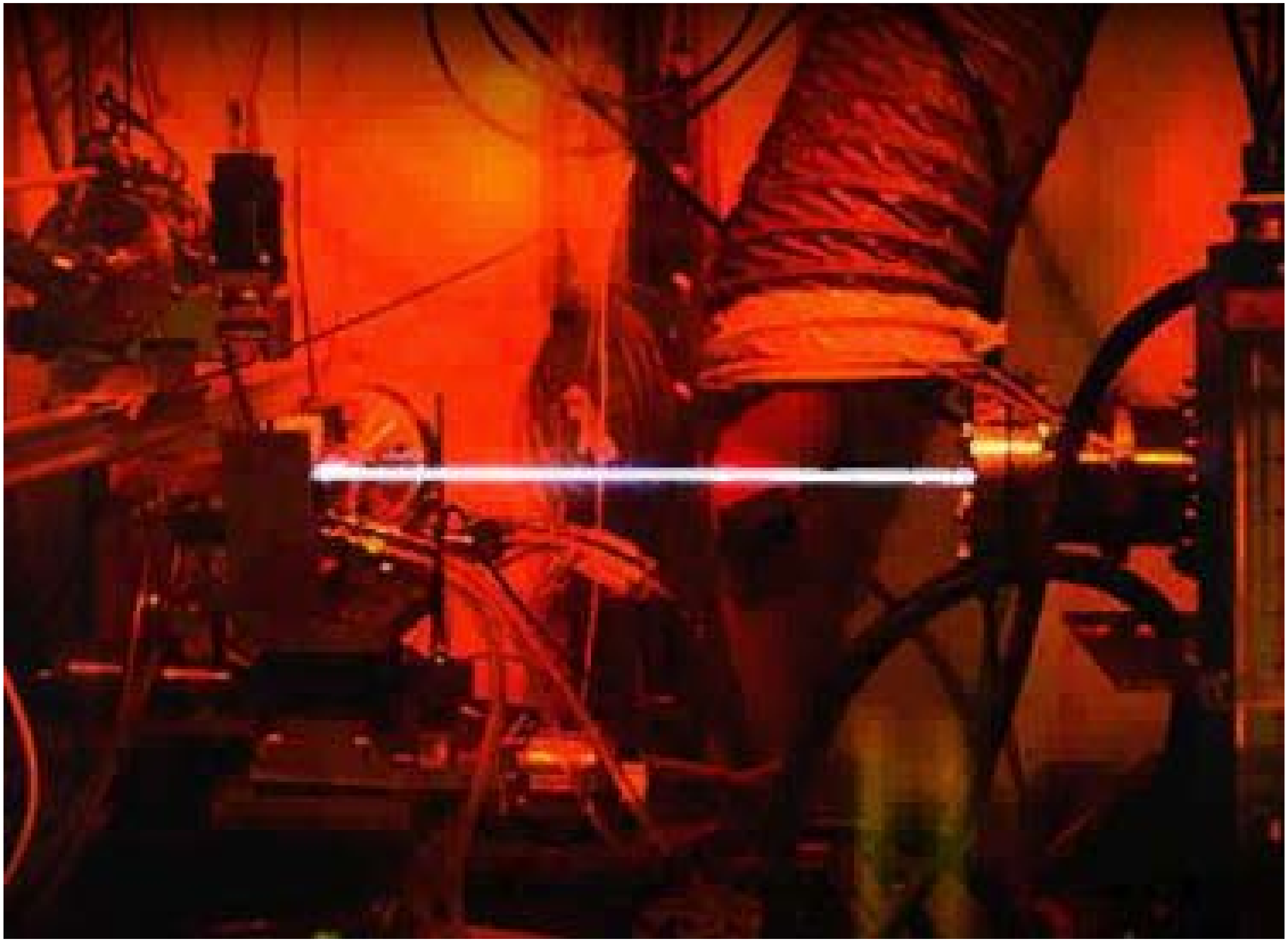
Yet more power, Igor....

More power: wigglers and undulators

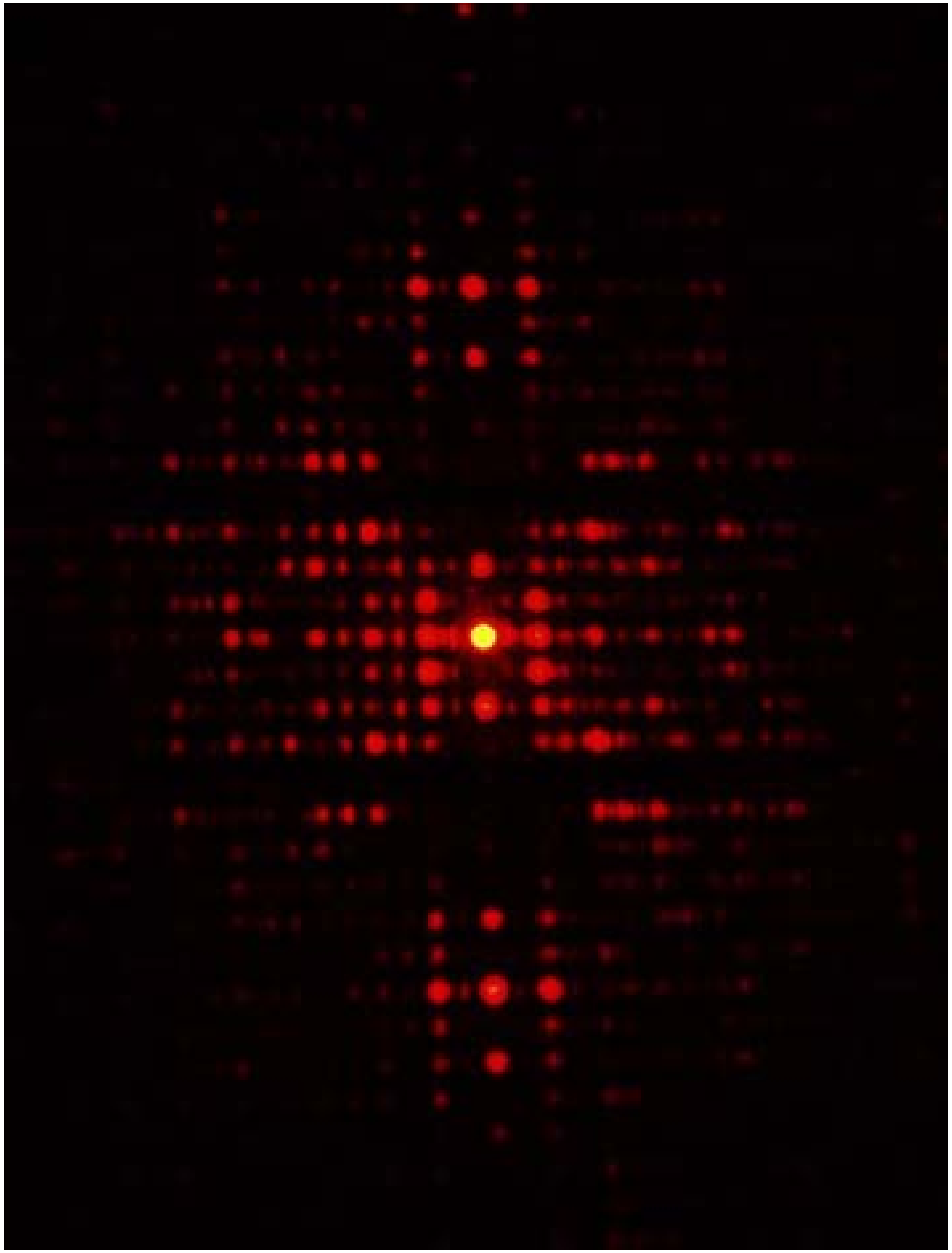


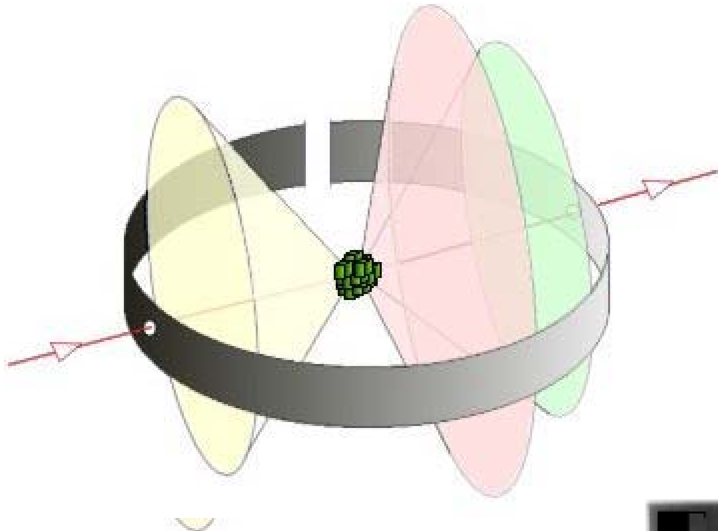


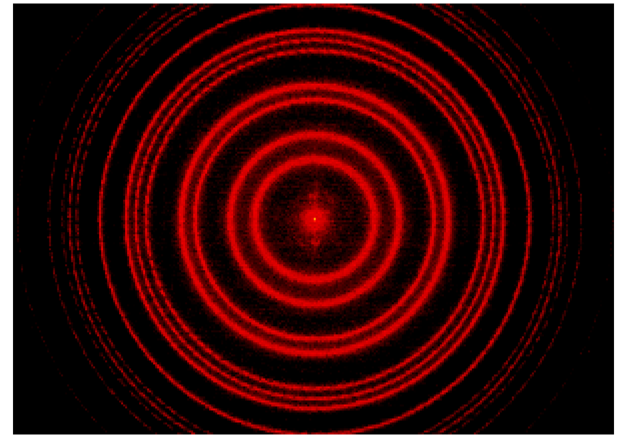

Bending
Magnet
Sextupole
Magnet
Quadrupole
Magnet
Insertion Device
(Wiggler/Undulator)
RF Cavity
Storage Ring
End Station
Beamline

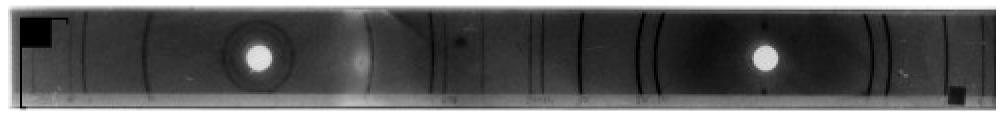


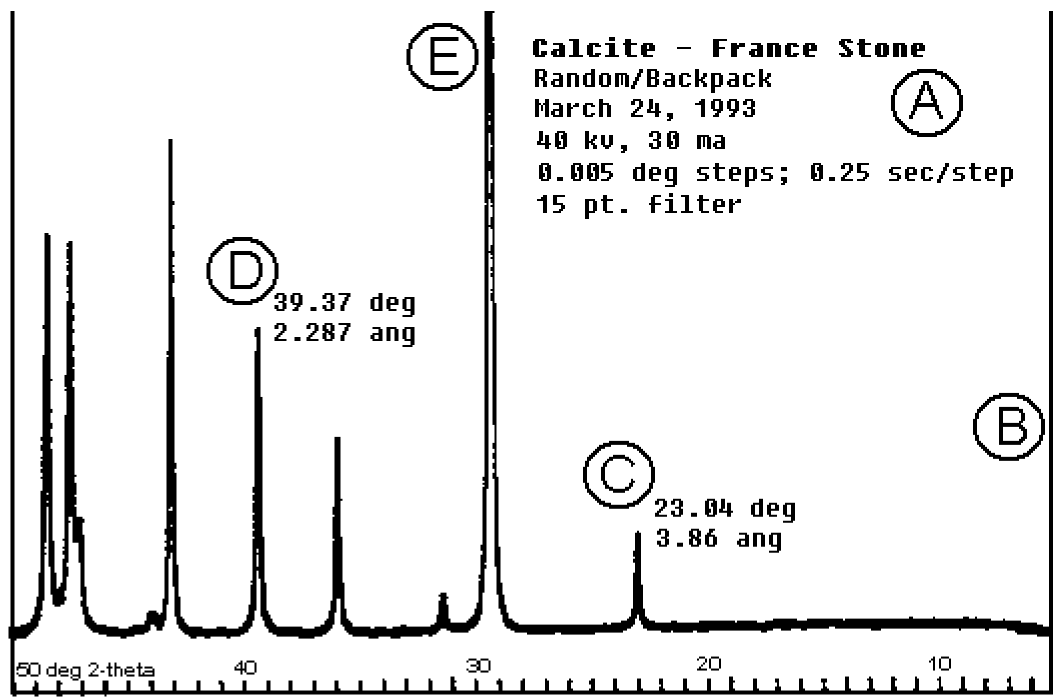
DIFFRACTION PATTERN OF DNA











Calcite - France Stone
Random/Backpack
March 24, 1993
40 kv, 30 ma
0.005 deg steps; 0.25 sec/step
15 pt. filter
A
B
C
23.04 deg
3.86 ang
D
39.37 deg
2.287 ang
E
50 deg 2-theta
40
30
20
10

Biomimetics/Nanotechnology Training in a Perfect World

Biomimetics/ Nanotechnology

Math
Calculus
Differential Equations
Linear Algebra

Physics
Classical Mechanics
Electromagnetism
Basic Quantum Mechanics
Solid State Physics

Chemistry
Thermodynamics
Statistical Mechanics
Organic Chemistry
Chemical Kinetics
Quantum Chemistry

Engineering
Systems Engineering
Solid Mechanics
Systems Dynamics
Control Theory
Electronic Circuit Design
Micro-fabrication
Quantum Electronics

Materials Science
Mechanics of Materials

Computer Science
Numerical Simulation
Parallel Computing
Interface Design

Biology
Biochemistry
Biomechanics
Biophysics

Curriculum coherence for nanotechnology

Chemical science **6.5 ext. SCCS0605**

Describe the production and uses of substances with unusual and specialised properties.

* report on the production, uses and impact on society of a chosen substance
* describe the production of the substance outlining reaction conditions and chemical equations
* describe the properties of the substance explaining why they are unusual or specialised
* relate the uses of the substance to its properties.

Sample Activities:

* Report on novel substance- eg nanotubes, biomimetic paint & fibers, Kevlar, TiO_2 surfaces
* Construction and testing model force microscope
* Production of nanopowders
* investigation of memory metal
* Consumer testing stain resistance of fabrics including lotus-effect materials

Chemical science 5.4 SCCS0504

Relate simple procedures for preparing and separating mixtures to medical and industrial procedures.

* describe a range of techniques for separating and concentrating mixtures
* describe the formation of colloids, including emulsions
* describe medical and industrial applications of separation techniques

Sample Activities:

* Production of colloidal gold and investigation of differences in properties based on size
* Production of monolayers
* Construction and use of biochips to separate mixtures based capillary action
* Lithography – modelling and photolithography

http://www.mrsec.wisc.edu/edetc/index.html

Chemical science Level 4

Substances: structure, properties and uses SCCS0401

Relate properties of common substances to their suitability for particular use.

* compare observable physical properties of common substances
* describe the properties of everyday materials
* link the properties of substances to their suitability for particular uses.

Sample Activities:

* Measurement of rate of chocolate dissolving
* Composites – recycling paper, mud bricks
* Elasticity testing

* http://www.nbtc.cornell.edu/education/lesson_plans.html

Curriculum coherence for Synchrotron

Years 9 & 10
Level 6: Physical science
Energy and its uses
6.1 SCPS0601
Relate the behaviors of light, such as reflection, refraction, absorption and polarization, to uses in technology

VCE Physics – New Study Design
Unit 3 Detailed Study 1
4 week study of principles and applications of synchrotron light. Real time analysis of ceramic powder sample using (eg) x-ray diffraction

Opportunities for teachers

- Working with the VCAA and DIIRD, schools have an opportunity to participate in the development and trial of curriculum materials and activities in Synchrotron Science or nanotechnology
- See www.netspace.net.au/~werry/indexb.htm