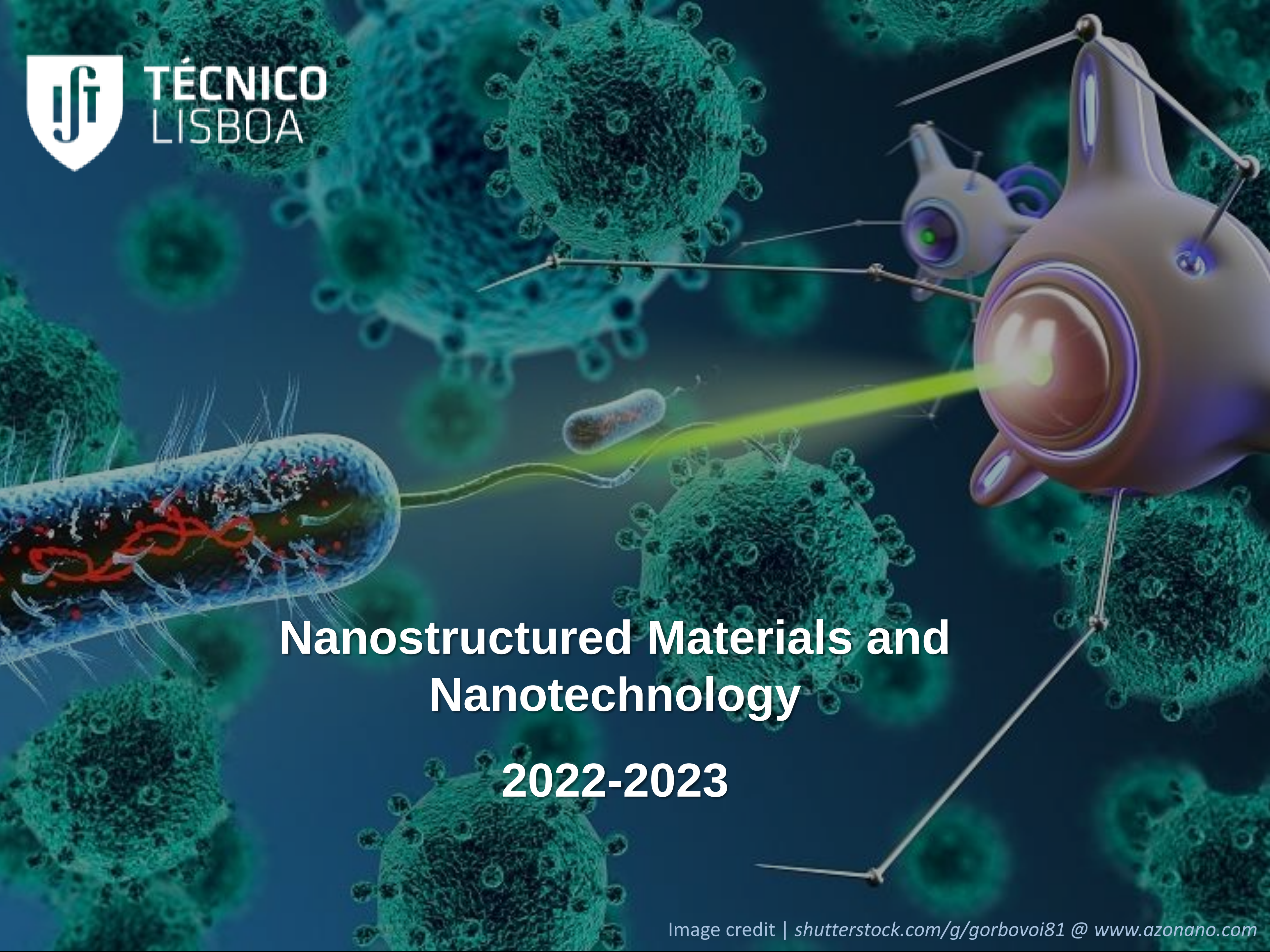

Nanostructured Materials and Nanotechnology

2022-2023

Image credit | *shutterstock.com/g/gorbovoi81 @ www.azonano.com*

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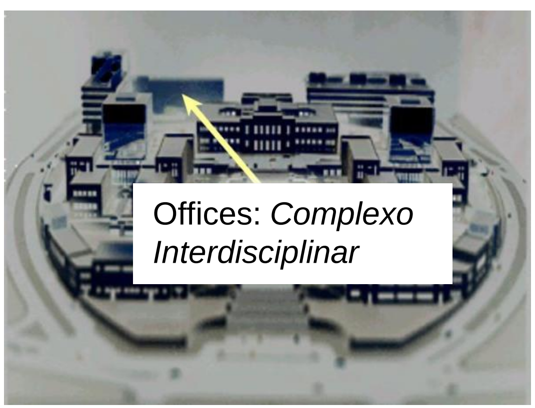

Appointments by email

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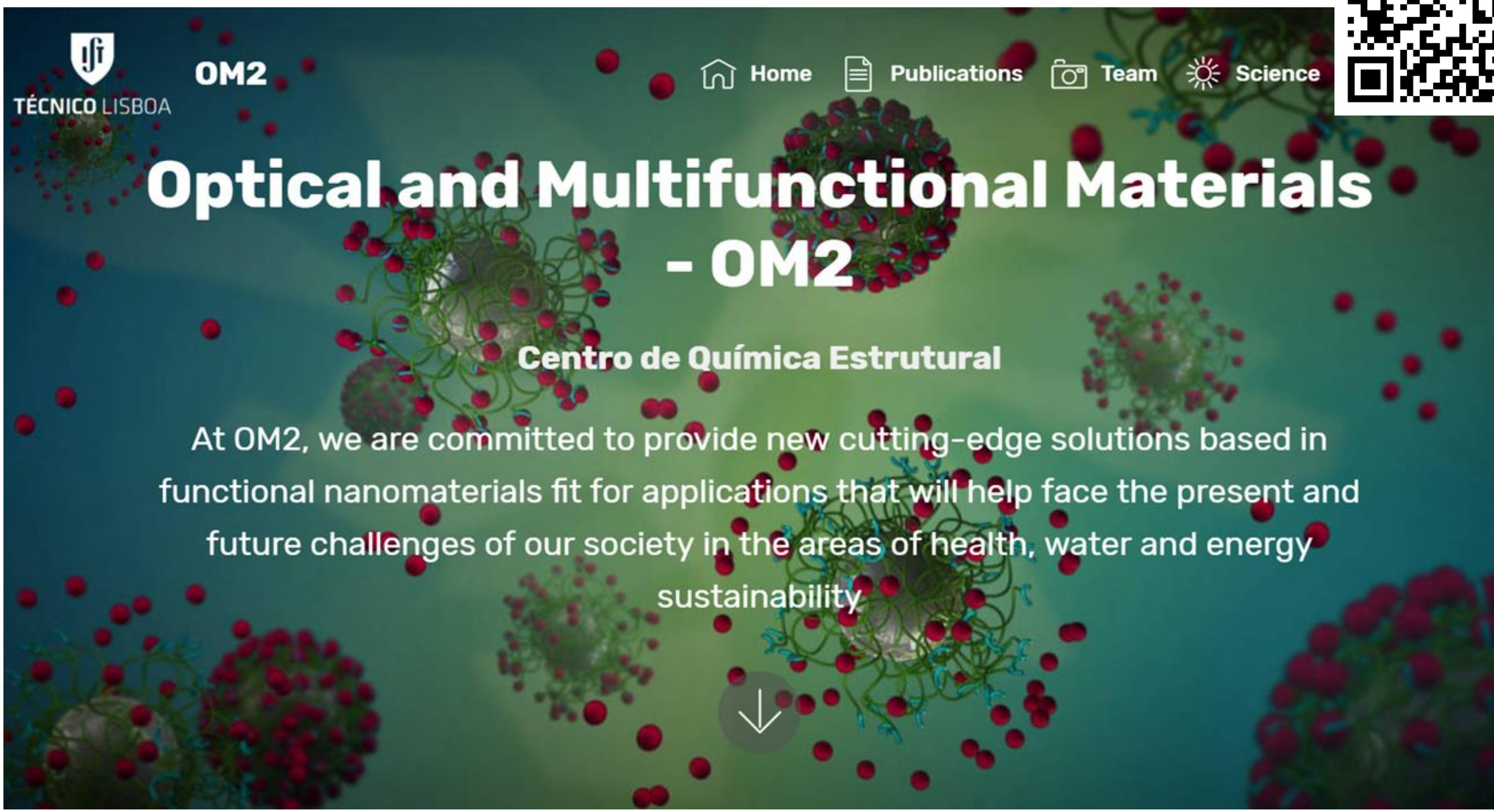
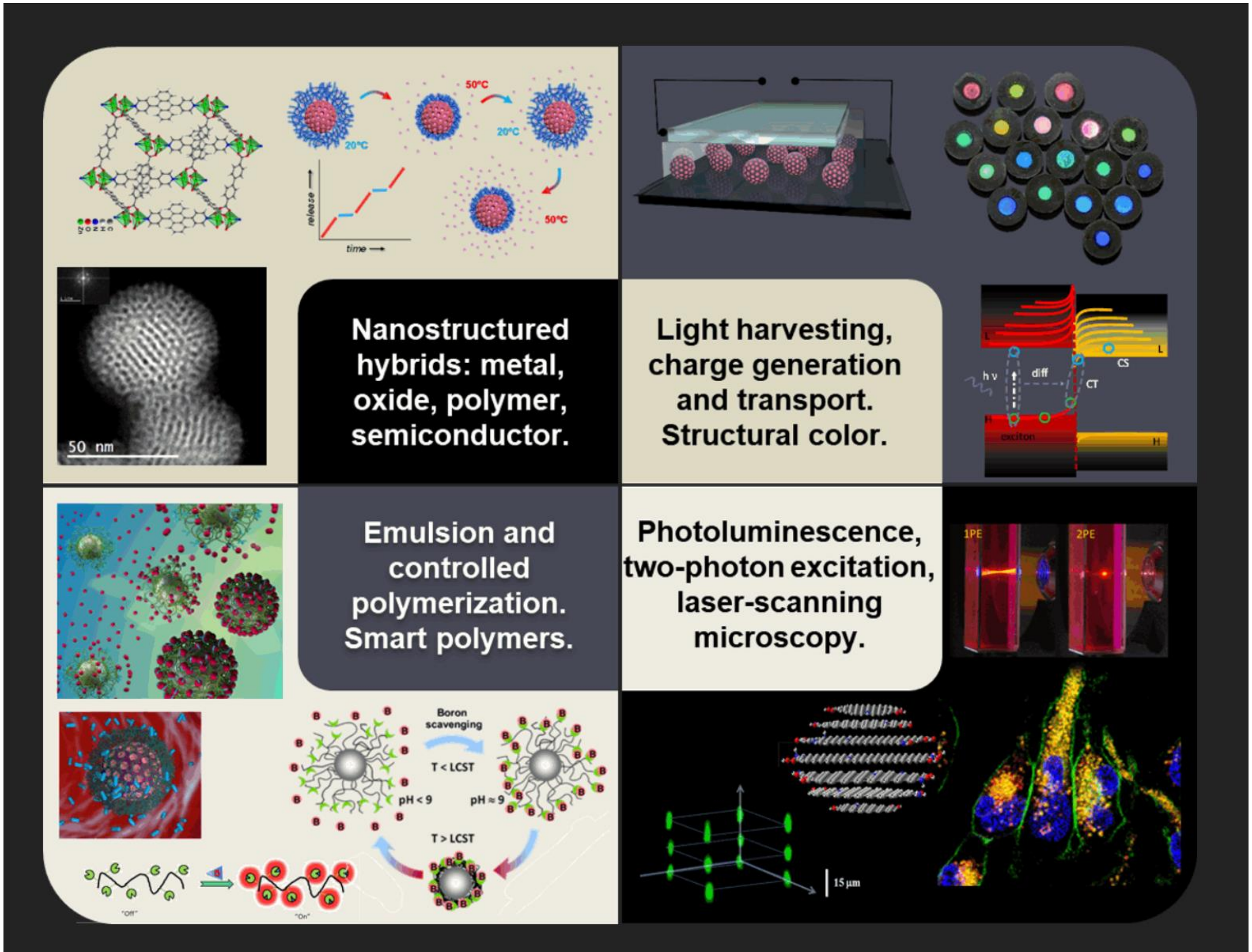
Appointments by email

OM2

Optical and Multifunctional Materials



Optical and Multifunctional Materials



Nanostructured Materials and Nanotechnology

2022-2023

Course Objectives

- Understand the concepts behind the unique properties of nanomaterials;
- Recognize the relative merits of the different techniques for the production of nanostructures;
- Master the techniques of preparation and characterization of different nanomaterials, understand their properties, and discuss their applications.

Course Contents

Introduction

Societal impact, challenges and opportunities of nano

Surfaces and interfaces at the nanoscale
Surface properties at the nano-scale
Forces and stability in dispersed nanomaterials

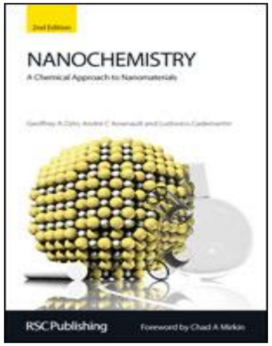
Fabrication techniques
Bottom-up (self-assembly, layer-by-layer deposition, etc.)
Top-down (cleanroom microfabrication techniques)

Preparation, properties and applications
Polymer nanomaterials
Carbon nanomaterials
Metal, semiconductor and magnetic nanoparticles
Metal oxide nanomaterials
Hybrid nanomaterials and nanocomposites

Learning Outcomes

- Relate the properties of nanomaterials with **size and quantum effects**.
- Recognize the effect of molecular and atomic **interactions in nanomaterials**.
- Understand the use of **nanofabrication techniques**, using bottom-up and top-down strategies, to produce nanostructures and devices.
- Recognize the main **properties of different nanomaterials** and how to manipulate them
- Develop **critical thinking**, question asking, problem solving and decision making in the context of nanomaterials and their applications.
- Improve critical reading and **literature search** skills.
- Discuss scientific and technological advances in nanostructured materials and nanotechnologies, and identify possible **applications**, considering their innovation, engineering, and societal impact aspects.

Bibliography



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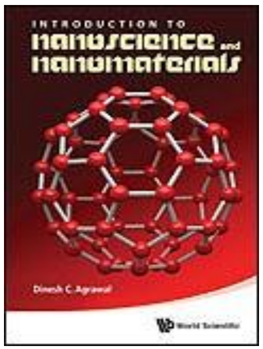

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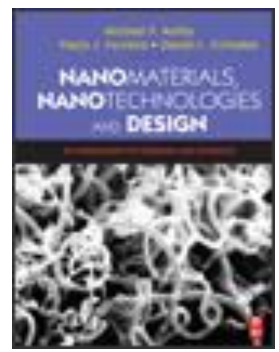

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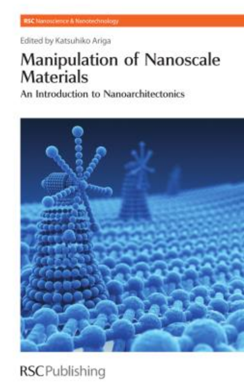
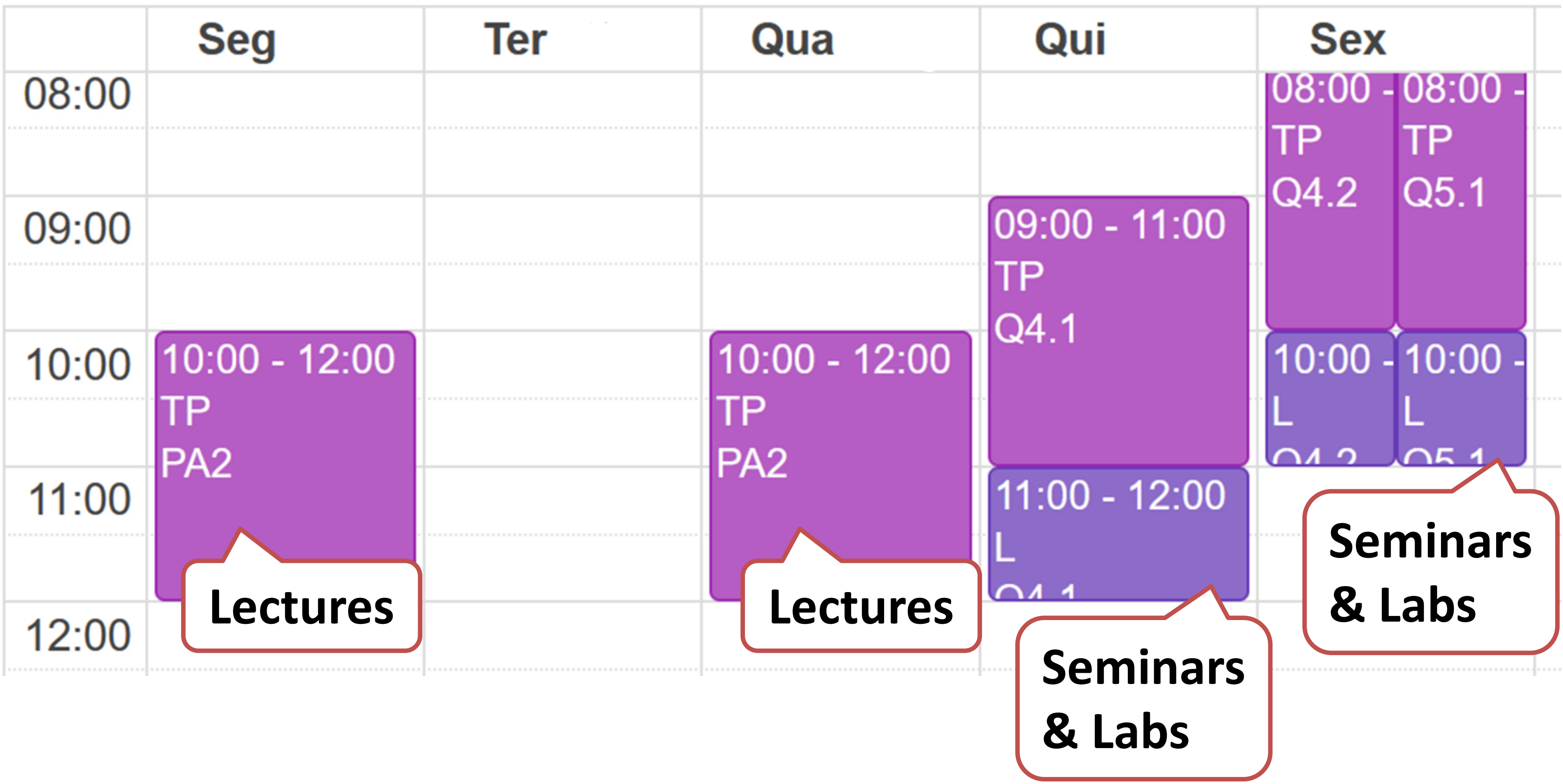


Course organization



Course organization

Lectures (Mondays & Wednesdays)

- Course content presentation
- Discussion of assignments
- Quizzes

Student seminars (Thursdays & Fridays)

- Coaching: **September 29th or 30th** (week 2)
- Presentations: **October 20th, 21th, 27th & 28th** (weeks 5 & 6)

Laboratory sessions (Thursdays & Fridays)

- Introduction, **September 22th** (or 23th)
- Nanomaterials preparation, **October 6th or 7th** (week 3)
- Characterization (DLS, NTA, SEM/TEM), **October 13th or 14th** (week 4)

Course policies and expectations

Attendance to lectures and seminars strongly recommended

Classes start 10min after the hour

Computer, tablet or cell phone is necessary in all lectures to answer quizzes

Open-mindedness, creative and risk-taking participation strongly encouraged

For out of class meetings, appointment by email

Course assessment and grading

Quizzes – 20%

Quizzes cover the content of the lectures, 15 min
Once a week. Best 5 of 7
Lecture presentations provided in advance

Seminar – 30%

On an application of the course topics. Presentation of a paper selected from 3 papers proposed by the student. Should include short introduction, goals, results, novelty and expected impact
10 min
Grading: literature review; presentation content, style and timing, answers to questions; questions during other seminars

Laboratory – 20%

Execution, report (group) and discussion

Exam – 30%

Minimum passing mark 7/20

Assignment due dates

Literature review for seminar: **September 27th** (week 2)

Seminar project: **October 12th** (week 4)

Lab. Report (group): **October 31st** (week 7)

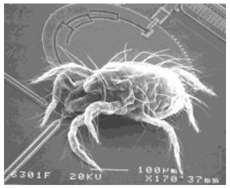
Exams

1st exam: November 14th – 18th (week 9)

2nd exam: February 6th – 10th (week 20)

The Scale of Things – Nanometers and More

Things Natural



Dust mite

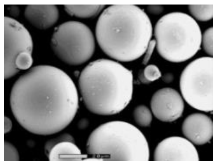
200 µm

Ant

~ 5 mm

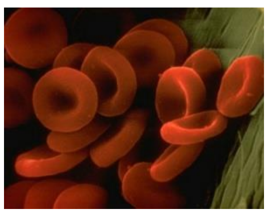
Human hair

~ 60-120 µm wide



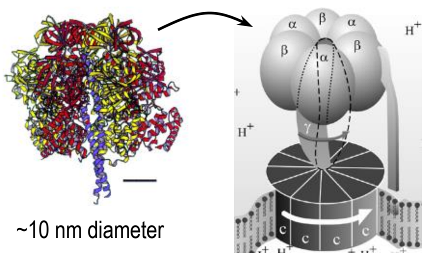
Fly ash

~ 10-20 µm



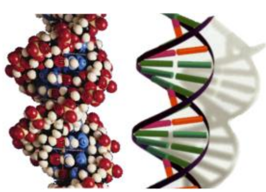
Red blood cells

(~7-8 µm)



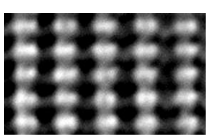
~10 nm diameter

ATP synthase



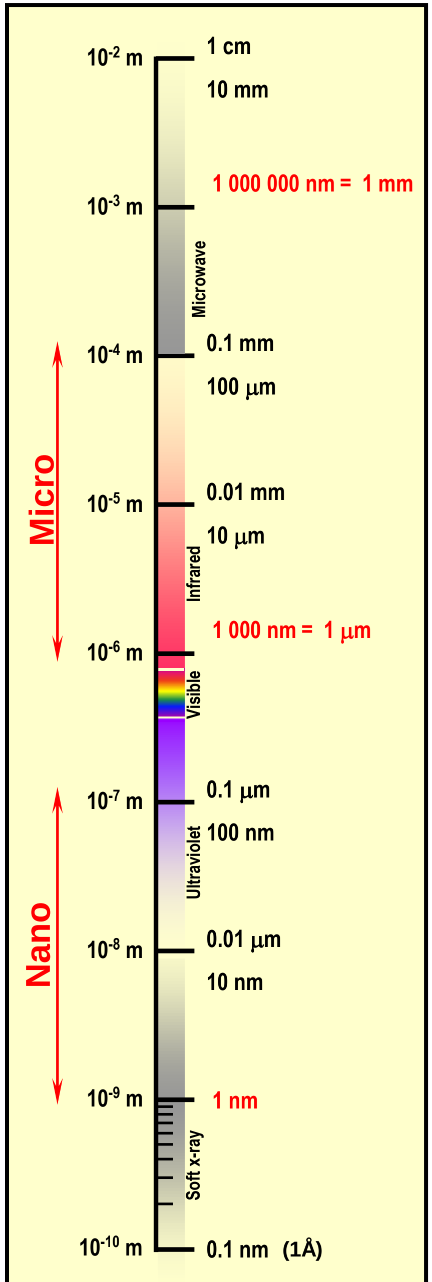
DNA

~2-1/2 nm diameter

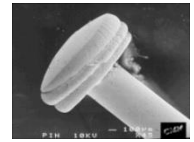


Atoms of silicon

spacing 0.078 nm

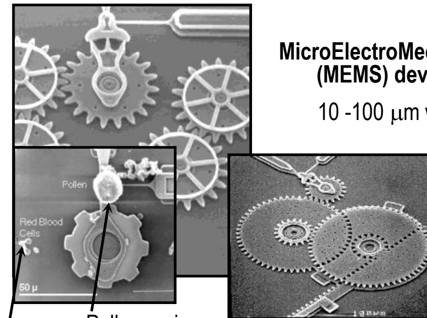


Things Manmade



Head of a pin

1-2 mm

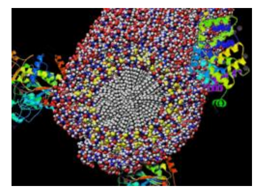


MicroElectroMechanical (MEMS) devices

10 -100 µm wide

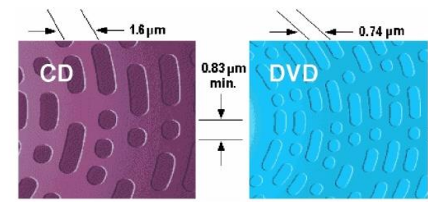
Pollen grain

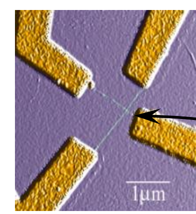
Red blood cells



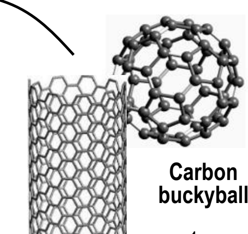
Self-assembled, Nature-inspired structure

Many 10s of nm





Nanotube electrode

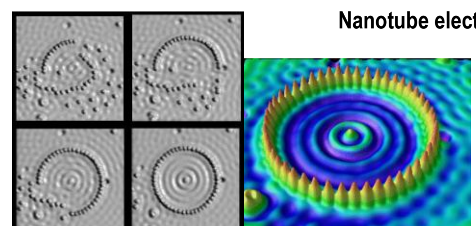


Carbon buckyball

~1 nm diameter

Carbon nanotube

~1.3 nm diameter



Quantum corral of 48 iron atoms on copper surface positioned one at a time with an STM tip

Corral diameter 14 nm

Office of Basic Energy Sciences
Office of Science, U.S. DOE

Why is "*nano*" different from "*very small*"

As the size of the system decreases

- the *surface area* to volume ratio increases drastically, changing mechanical, thermal and catalytic properties
- *quantum effects* play an important role
- Random molecular motion become more important
- Gravitational forces become negligible, electromagnetic forces dominate

Nanomaterials exhibit strong size effects that make them distinct from the corresponding bulk materials

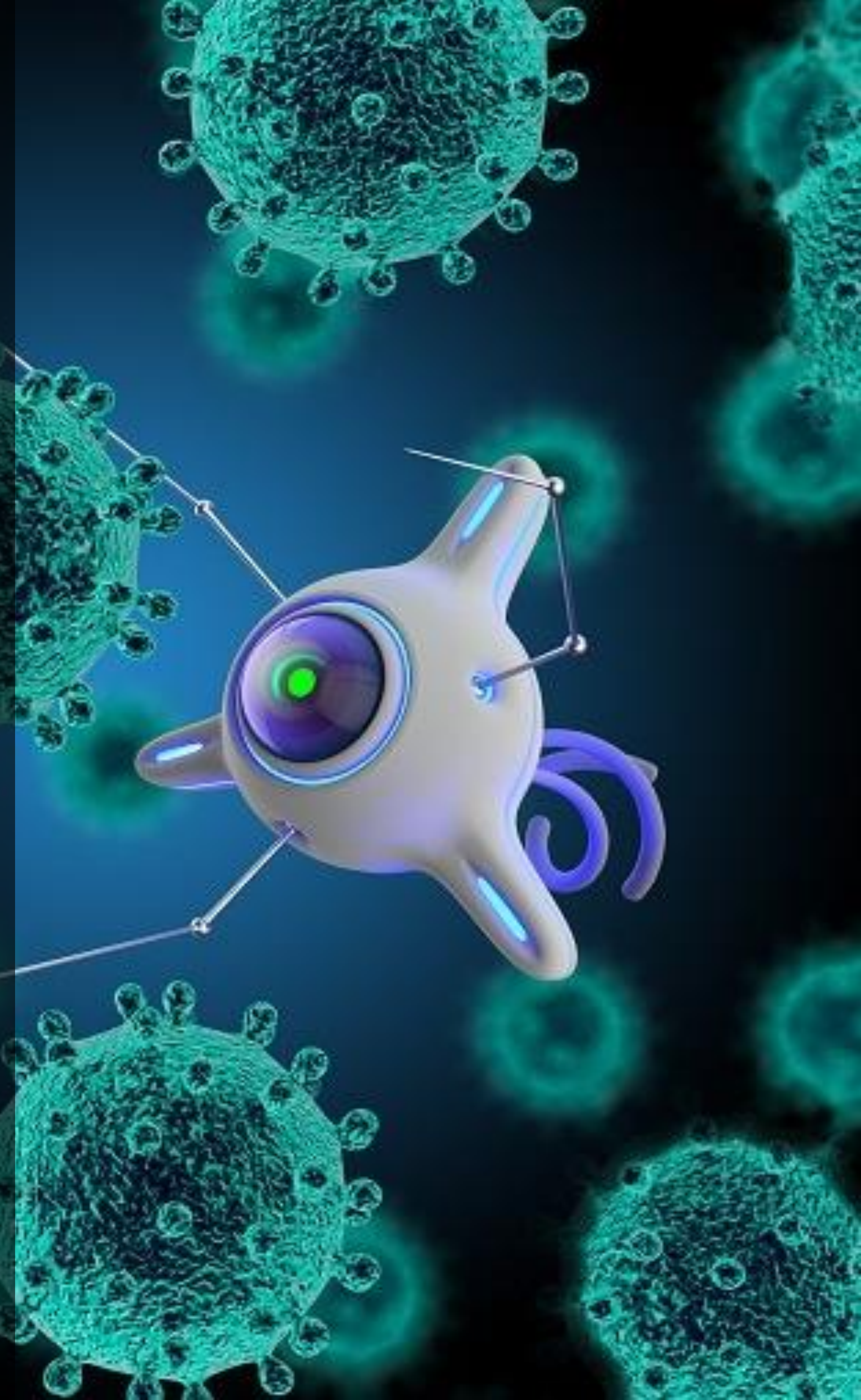
- opaque substances become transparent (*eg,* copper)
- stable materials turn combustible (*eg,* aluminum)
- metals become colored (*eg,* silver, gold)
- extreme thermal and electrical conductivities and strength (carbon)

International Organization for Standardization

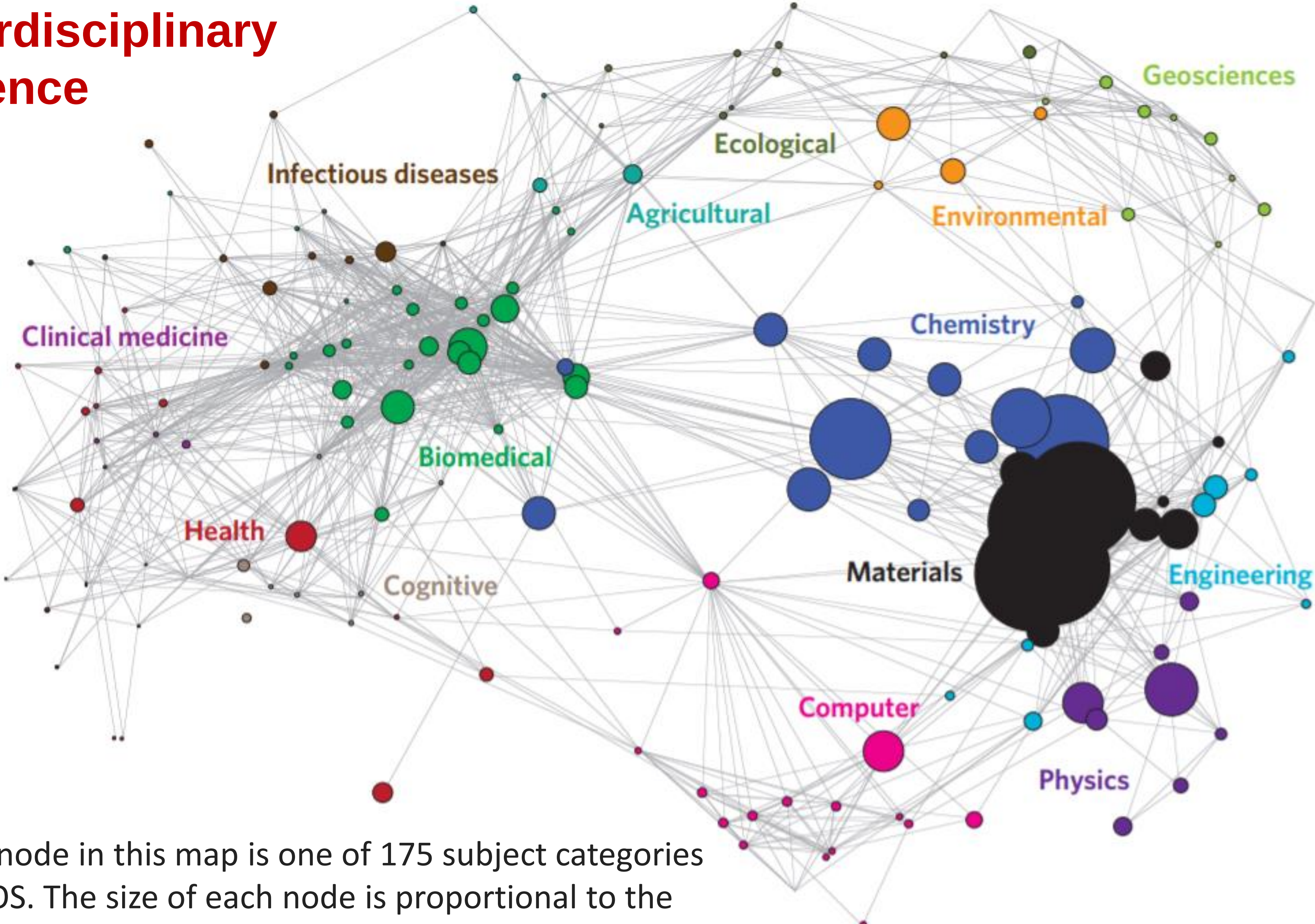
Nanotechnology

Understanding and control of matter and processes at the nanoscale, typically, but not exclusively, below 100 nanometers in one or more dimensions where the onset of size-dependent phenomena usually enables novel applications

Utilizing the properties of nanoscale materials that differ from the properties of individual atoms, molecules, and bulk matter, to create improved materials, devices, and systems that exploit these new properties



Interdisciplinary Science



Each node in this map is one of 175 subject categories in WOS. The size of each node is proportional to the number of nano papers published in journals in each subject category during the period January–July 2008.

Porter, Youtie, *Nature Nanotechnology*, 2009, 4, 534–536

What are Nanomaterials?

***Nanomaterials** are defined as materials with at least one external dimension in the size range from approximately 1-100 nanometers.*

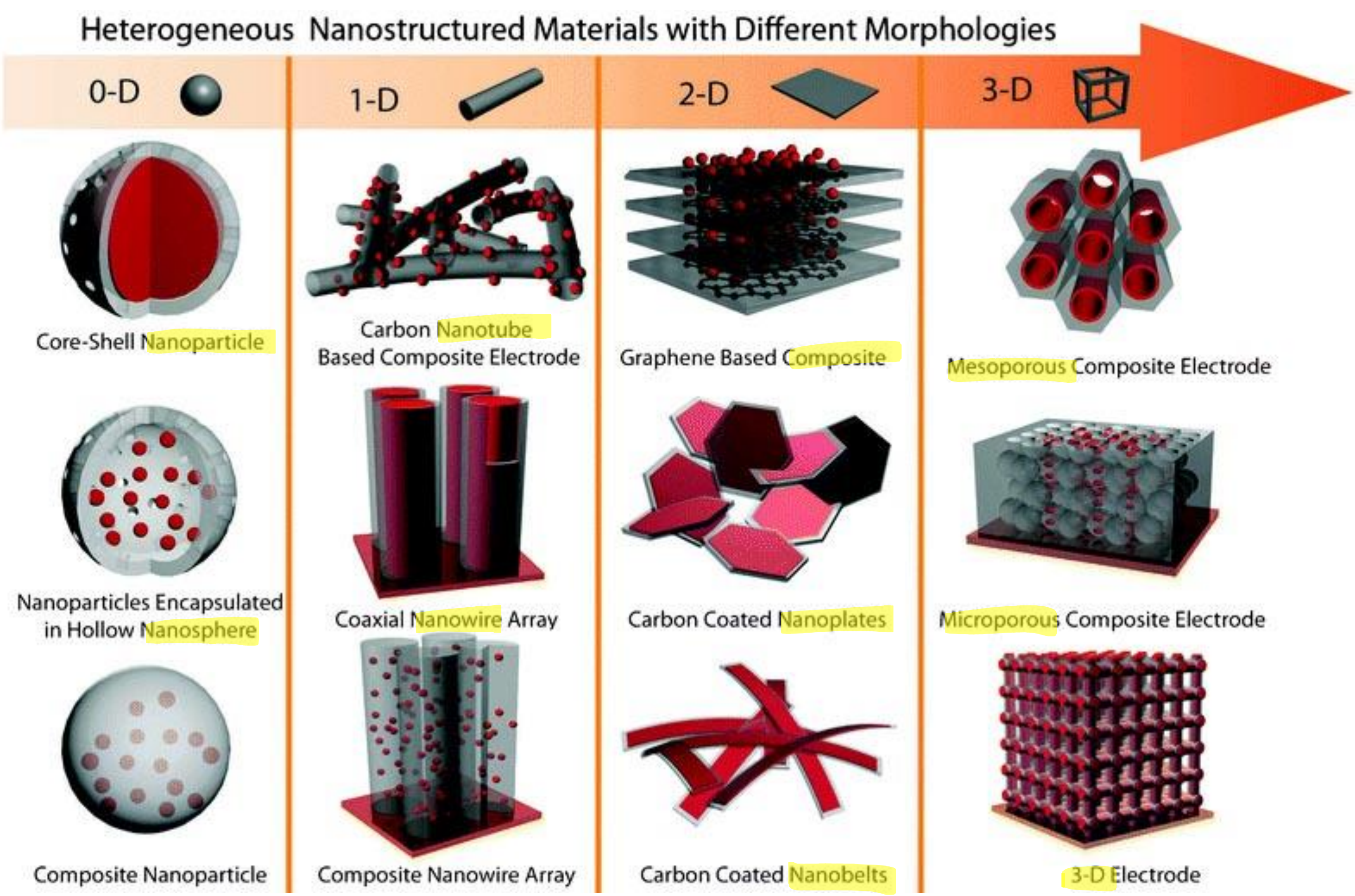
These materials exhibit strong size and surface effects that make them distinct from the bulk counterparts, often exhibiting unique optical, electronic, or mechanical properties

Example: quantum confinement effects in semiconductor nanoparticles ("quantum dots")

Cadmium red dye

Emission by CdSe QDs ca. 2-6 nm

Nanostructured materials *are materials with structure at a characteristic length scale on the order of a few nanometers (typically 1-100 nm) .*

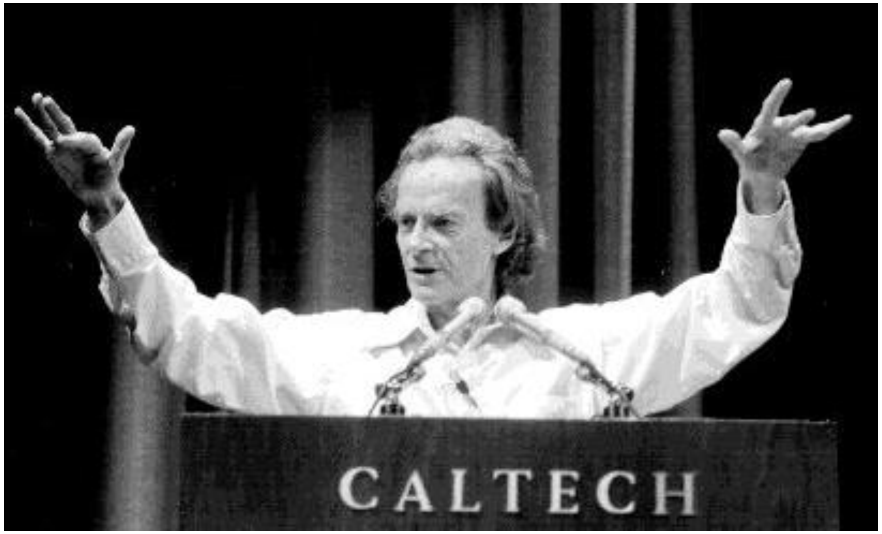


History…

A biological system can be exceedingly small. Many of the cells are very tiny, but they are very active; they manufacture various substances; they walk around; they wiggle; and they do all kinds of marvelous things - all on a very small scale (...) Consider the possibility that (...) we can manufacture an object that maneuvers at that level!

Richard Feynman

"*There's plenty of room at the bottom*" (*CalTech*, 1959)



Richard Feynman
(1918-1988)
Nobel of Physics 1965

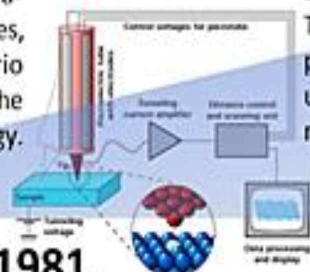
1959

1959

The ideas that define nanoscience and nanotechnology were mentioned long before the terms were coined, in a lecture by American physicist Richard Feynman "There's Plenty of Room at the Bottom" in 29, 1959. Feynman described processes that would allow scientists to manipulate and control individual atoms and molecules.

1974

While working on the development of ultra-precision machines, that Professor Norio Taniguchi coined the term nanotechnology.



1981

Gerd Binnig and Heinrich Rohrer developed the scanning tunnelling microscope (STM), that modern nanotechnology began. The STM allowed researchers to view atoms on the surface of materials for the first time ever, and since then nanotechnology began its gradual growth. However, recently the nanotechnology market has exploded and become a hotbed of innovation.

1989

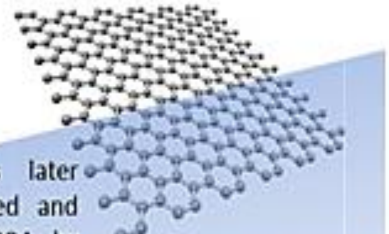
Don Eigler and Erhard Schweizer at IBM's Almaden Research Center manipulated 35 individual xenon atoms to spell out the IBM logo. This demonstration of the ability to precisely manipulate atoms ushered in the applied use of nanotechnology

1990's–2000's

Research groups and commitees formed to drive nano-related research. Consumer products making use of nanotechnology began appearing in the marketplace.

2004

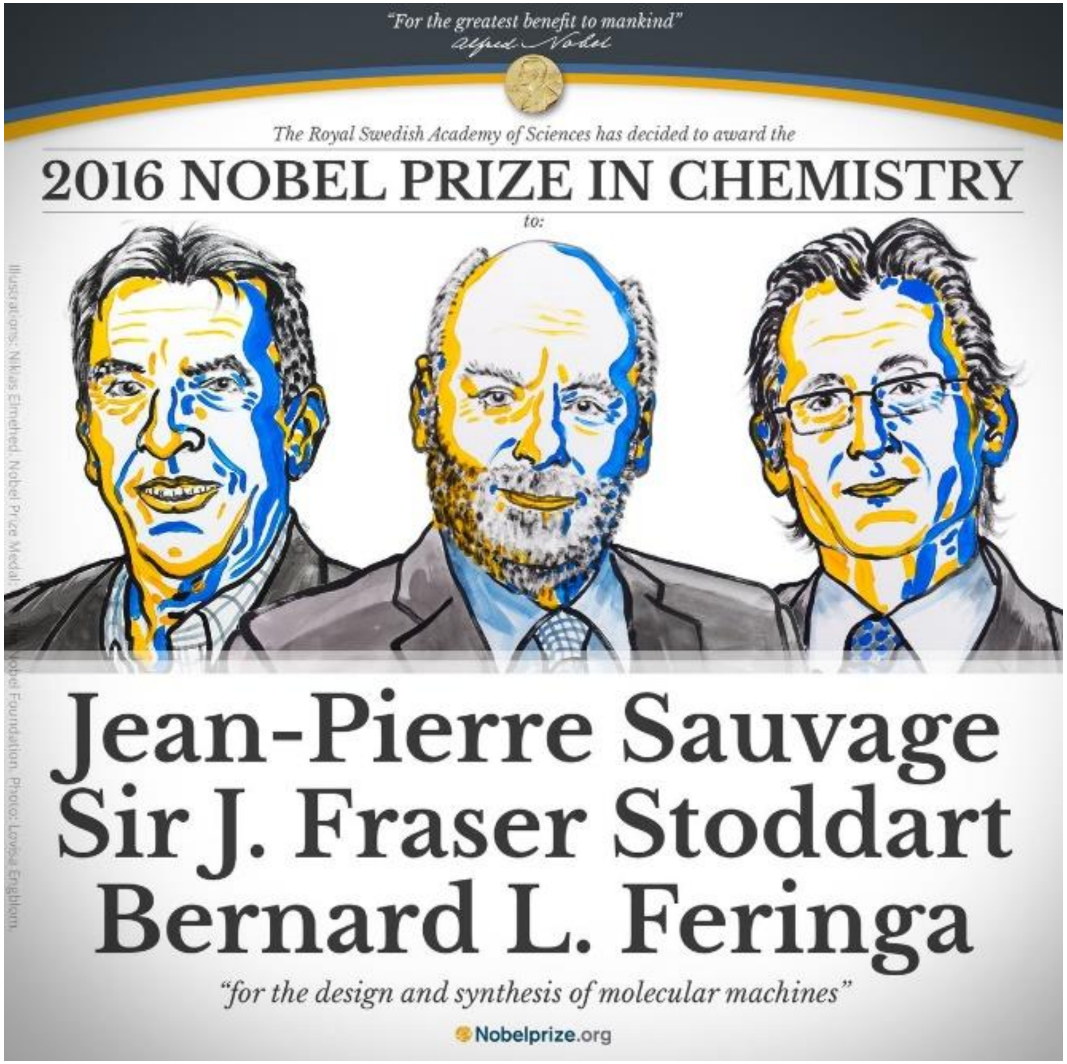
The material was later rediscovered, isolated and characterized in 2004 by Andre Geim and Konstantin Novoselov at the University of Manchester. This work won the Nobel Prize in Physics in 2010



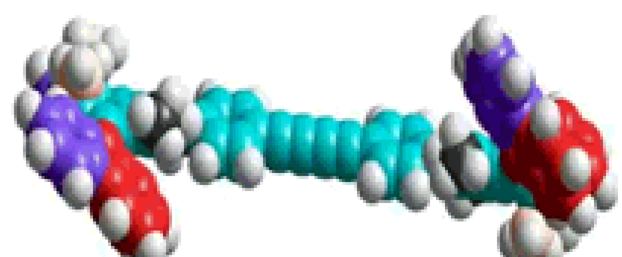
2016

Jean-Pierre Sauvage, J. Fraser Stoddart, and Bernard Feringa win the Nobel Prize in Chemistry for their research in developing Nano-scale machines including a 'nanocar'

For a more exhaustive timeline go to: https://www.nano.gov/timeline



www.youtube.com/watch?v=vELfuiUpKM0



Old nanotechnology…

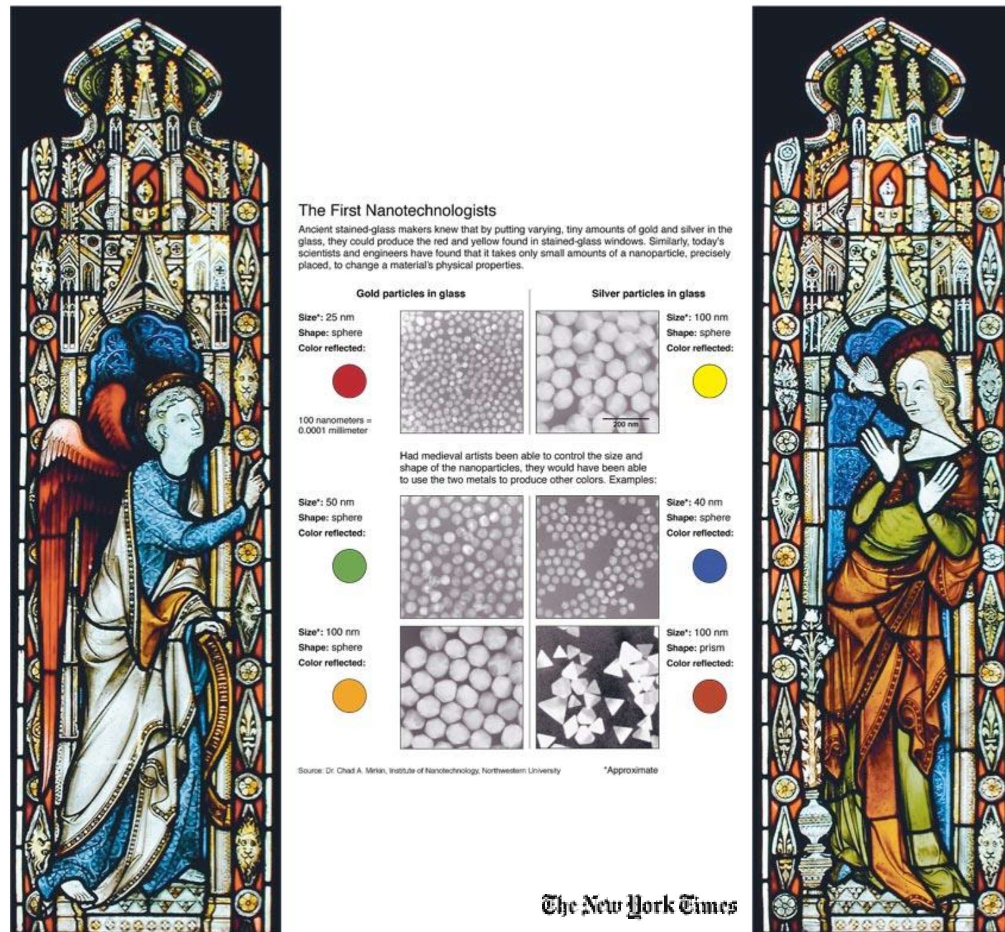
Nanomaterials have been used long before we knew what they where: gold nanoparticles, carbon nanotubes, silica nanoparticles, carbon black, etc

Lycurgus cup

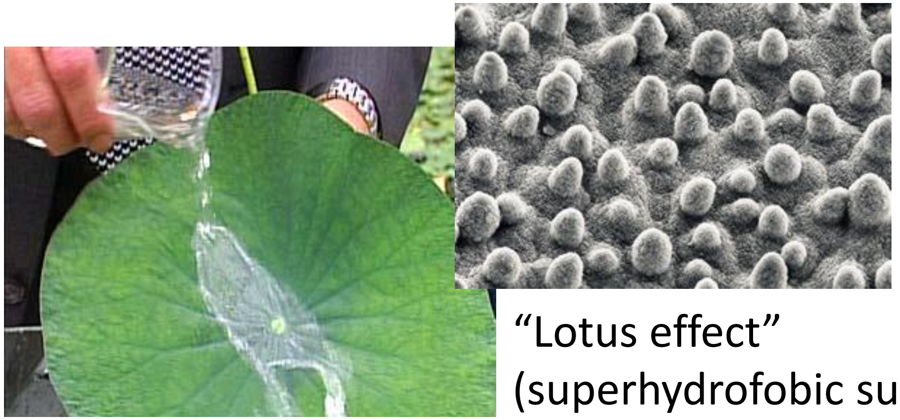
4th century Roman glass with dichroic effect given by gold and silver nanoparticles (70 nm)

Stained glass in Cathedrals

Gold nanoparticles used since the 10th century



Nanomaterials in Nature



"Lotus effect"
(superhydrofobic surface)

Gecko lyzards

Structural colors are abundant in nature. There is no such thing as a blue bird!
National Geographic

Opals. Semi-ordered aggregated silica spheres containing water

Nano all around us

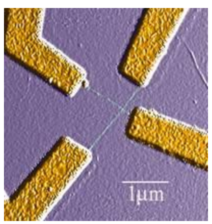
Energy

Food, Cosmetics

Coatings

Construction, transportation

IT



Nanotechnology

Defense

Sports

Textiles

Medical and environment

OECD

unitar
United Nations Institute for Training and Research

cosmetics industry

Has the most nanotechnology products on the market: anti-wrinkle creams, sunscreens, shampoos, bactericide toothpastes …

food and food production

Products (homogenize the texture, enhance the flavor, reduce fat content, etc.)

Packaging (active/intelligent packaging for longer shelf-life, thaw indicators for supply chain management, nano-coatings for oxygen/water control…)

Nutritional supplements (nano-encapsulated supplements)

Agricultural production (nano-formulation for agrochemicals and seed coatings)

environment

Environmental remediation (nanoscavengers)

Low cost, nano-sensor arrays

Low energy water desalination using nanofibers

Water filters to remove nano-sized particles (viruses and bacteria)

medical

Targeted in situ drug delivery (accumulation at the desired location)

Rapid lab-on-a-chip multisensors for diagnosis and active monitoring

Simultaneous therapeutics & diagnosis (*theranostics*), for example in insulin administration on high glucose level

Overcoming the blood–brain barrier to treat CNS diseases

Tissue engineering scaffolds and cell control

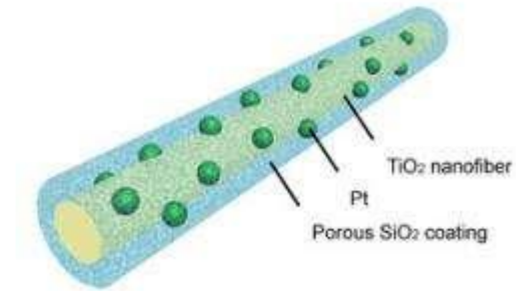
energy

Large scale, low cost nanoparticle-based solar energy

High efficiency solid state lighting

Batteries and ultra-capacitors

Membranes and nano-catalysts in fuel cells



electronics and IT

Quantum electronics, magnetic memory, spintronics

Flexible electronic and carbon nanotube based circuits

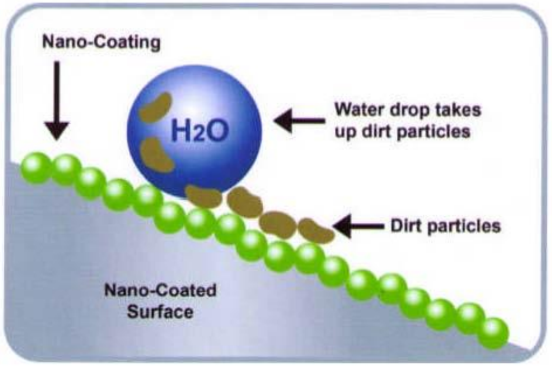
Higher speed data transmission with nanophotonic components

Nanomagnetic switches

Circuits printed with silver nanoparticles in inkjet printers

Quantum dot displays

coatings



Thin films used is floors; nanoparticles in paint, glass treated to prevent dust and dirt adhesion

construction & transportation

Automobiles: already incorporate nano-devices in sensors and use nanoparticles to enhance material performance (anti-scratch paints, antibacterial coatings, etc.)

Aerospace: nanostructured metals, polymer nanocomposites, tribological and anti-corrosion coatings

Construction: additives to cement, nanoparticles in paint, aerogel insulation

textiles

Surface structuring improving stain, water and flame resistance

Silver nanoparticles in antibacterial odor-resistant clothing

sports

Carbon and silica nanocomposites used in tennis rackets
and balls, golf clubs, bicycle frames, ski wax and kayak coatings

Weather-resistant clothing and sports shoes

defense

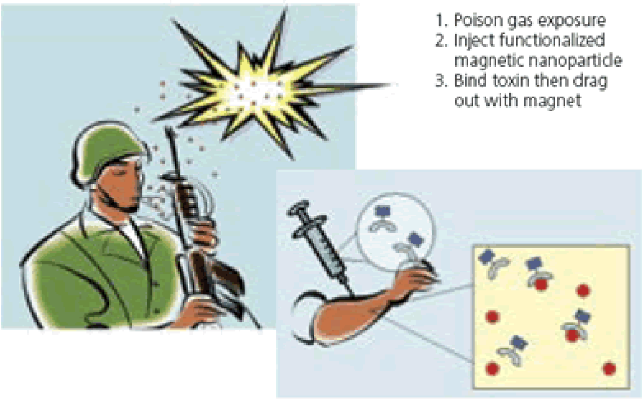
Precision missiles

Super-explosives (eg., nano-thermite)

Sensors for chemical and biological warfare

Detoxification with magnetic nanoparticles

body armor (Al-CNT, UHMWPE, etc.)



The market

The global nanotechnology market was valued at $1055 million in 2018, projected to reach $2231 million by 2025, growing at a CAGR of 10.5% in 2019 - 2025

In 2020 it was valued at $1760 million and projected to reach $33630 million by 2030, growing at a CAGR of 36.4% in 2021 - 2030

Allied Market Research https://www.alliedmarketresearch.com/nanotechnology-market

Socioeconomic impact

Expected benefits of nanotech

Cheap and clean energy

More surface area > lighter units
Conversion/storage for fuel cells, solar cells, thermo-to-electric, biomass, hydrogen, batteries, super-capacitors…

Reducing the global disease burden

Enhanced diagnosis and treatment, personalized medicine
New drug delivery systems, diagnostic devices, implants, tissue engineering…

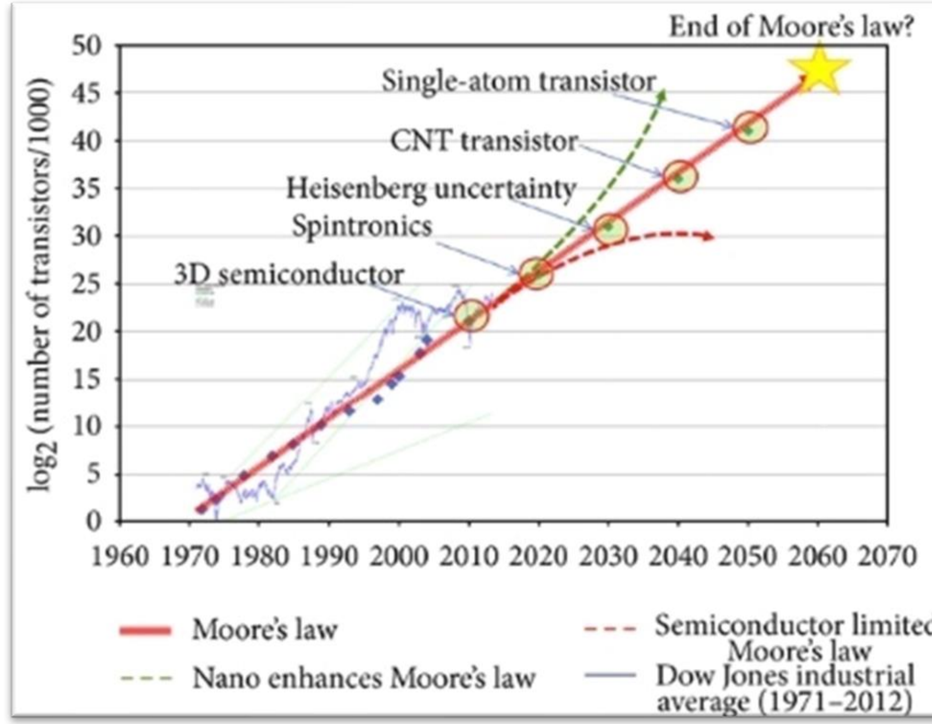
Pollution reduction and environmental progress

Less waste, longer duration, more efficient energy and resource use
Novel environmental remediation strategies (water decontamination, CO_2 capture and transformation)
Higher sustainability over the whole life cycle of products

9 INNOVATION AND INFRASTRUCTURE

Increase computation power

Keep up with Moore's law: number of transistors doubles every two years



10 REDUCED INEQUALITIES

Availability and accessibility

Geopolitics of new energy sources

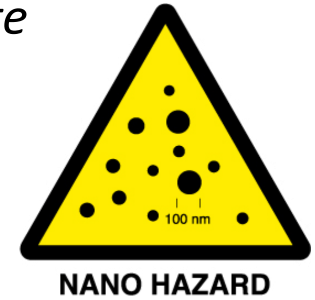
Ethical issues and plausible concerns

The properties of nanomaterials can no longer be straightforwardly extrapolated from chemical composition

→ Disruptive implications for policy and regulation

Structure-based functionality makes it difficult to regulate and control the use of nanotechnology products

Each new product may need to be assessed for environmental and health hazards



→ Nanotechnology will tend to be "invisible" to consumers, impairing individual choice

QDs

- *QDLEDs* and displays
- Biomedical, clothes, food?

Personalized medicine

Promise of improved health and expanded lifespan

→ Benefits likely to be unevenly distributed both within and between nations

→ Possible large differences in life expectancy leading to concentration of political power and social unrest

Military and surveillance

Increased security for the nations that develop the technologies

→ Impact on balance of power between citizens and governments

→ Possibility of extensive surveillance of individuals by corporations/others

What if the walls have eyes and ears?

What if sensors can be attached to me without my knowledge?

Is my health and genetic susceptibilities private information?

Human-machine interfaces for human enhancement

Should nanotechnology be used to enhance human performance?

For defense? For athletes? For children?

Who decides?

Bots – Self replicating nanomachines

Is it feasible?

Is responsible action needed?