Nano Science

Course Code:PH303

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Syllabus

Introduction and Classification of nano-structured materials: Nanoscience and Nanotechnology, Brief History and future scope, Gleiter's classification of nano-structured materials, Classification of nanostructures by dimensionality. Properties of Fullerene, Nanotubes, Graphene. Crystal Structure and Size Effects.

Conceptual background: Concept of matter waves, Schrodinger wave equation, confinement, particle in a potential box, barrier penetration and tunneling effects, concept of density of states.

Size effects and properties of nano-structured materials: Concept of characteristic time and length scales of physical phenomena, Definition and types of size effects, extended internal surface, increasing surface energy and tension, Grain boundaries, classical and quantum size effects, size dependent thermal, mechanical, electrical, magnetic and optical properties of nano-structured materials e.g. Reduction of lattice parameter, decrease in melting point, decreasing thermal conductivity, diffusion enhancement, increasing plastic yield strength and hardness, blue shift, broadening of energy bands, phase transitions in ferromagnetic and ferroelectric materials.

Techniques for synthesis of Nanostructures: Top-down and Bottom approaches, Vapor – phase synthesis, Liquid phase synthesis, Sol-gel technique, Solid – state phase synthesis, consolidation of nano-powders.

Basic characterization and microscopy of Nanostructure materials: X-ray diffraction (XRD), UV- visible, FTIR, TGA, Scanning Electron microscopy (SEM), Transmission electron Microscopy (TEM), Scanning probe microscopy, Scanning tunneling Microscopy (STM) and Atomic Force microscopy (AFM).

Nanotechnology Applications: Applications of Nanostructures for diversified fields of Engineering.

Books

Text Books:

- Nano Structures & Nano Materials, Synthesis, Properties & Applications by Guozhong Cao, Imperial College Press.
- Nanomaterials and Nanocomposites, R . K. Goyal, Taylor and Francis.
- Concept of modern Physics by Arthur Beiser, 6 th Edison, McGraw-Hill.

Reference Books:

- Solid State Physics by S O Pillai
- Nanoscale materials in chemistry, 2 nd edition, by Kenneth J. Klabunde and Ryan M. Richards, John Wiley & Sons.

Course Outcomes: At the end of the course student will be able to:

Course Outcome	Description	Bloom Level
CO1	Outline the concept of nanoscience, its history, nanotechnology applications and relation between quantum mechanics and nanomaterials.	BL1
CO2	Classify and interpret the nanomaterials, crystal structure density of states, and energy states.	BL2
CO3	Apply Top down and bottom-up approaches of preparation to synthesis nanomaterial by different chemical and physical processes.	BL3
CO4	Analyze the nanomaterials with different characterization techniques for different properties	BL4
CO5	Determine different physical properties of nanomaterials with their bulk counterpart for applications in devices	BL4

Why this course is important for Computer Science students

Miniaturization of Devices: The computer chips that power your phone or laptop are built at the *nanoscale*. Understanding how materials behave at this scale helps CS students grasp hardware limitations and future potentials like quantum computing and neuromorphic chips.

Next-Gen Storage & Memory: Technologies like *memristors*, *nanomagnetic memory*, and *spintronics* are set to replace traditional RAM and SSDs. A background in nanoscience gives CS students an edge in **hardware-aware software design**.

Quantum & Molecular Computing: Concepts like *quantum bits (qubits)* and *molecular switches* arise from nanoscience. These are the backbone of **quantum computing**, which will change how we solve problems in AI, cryptography, and big data.

Bioinformatics & Sensors: Many modern devices involve **nanobiosensors** and wearables that interact with the cloud or embedded systems. CS students involved in **IoT, embedded systems, or health tech** benefit from understanding how these sensors work.

Interdisciplinary Innovation: Tomorrow’s innovations won't come from one field. A nanoscience background encourages **interdisciplinary thinking**, blending software, hardware, and materials science to develop smarter, more efficient tech.

Silicon to Quantum Dots"Traditional silicon technology is approaching its physical limits. **The industry is now looking at nanomaterials like graphene, carbon nanotubes, and quantum dots for the next generation of computing**.""This opens up areas like spintronics (using electron spin to store information) or **neuromorphic computing, which mimics how the brain works – all powered by nanoscale engineering."**

Syllabus

Unit 1: Introduction and Classification of nano-structured materials: Nanoscience and Nanotechnology, Brief History and future scope, Gleiter's classification of nano-structured materials, Classification of nanostructures by dimensionality. Properties of Fullerene, Nanotubes, Graphene.

Crystal Structure and Size Effects

Nano Science and Nanotechnology

- The term 'nano' originates from the Greek word for dwarf (short person). It is the billionth (10^{-9}) of a unit.
- Nanoscience primarily deals with synthesis, characterization, exploration, and utilization of nanostructured materials.
- These materials are characterized by at least one dimension in the nanometer (nm) range.
- *Nanoscience* is the study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales, where properties differ significantly from those at a larger scale.
- *Nanotechnologies* are the design, characterisation, production and application of structures, devices and systems by controlling shape and size at nanometre scale.

Bulk versus Nano

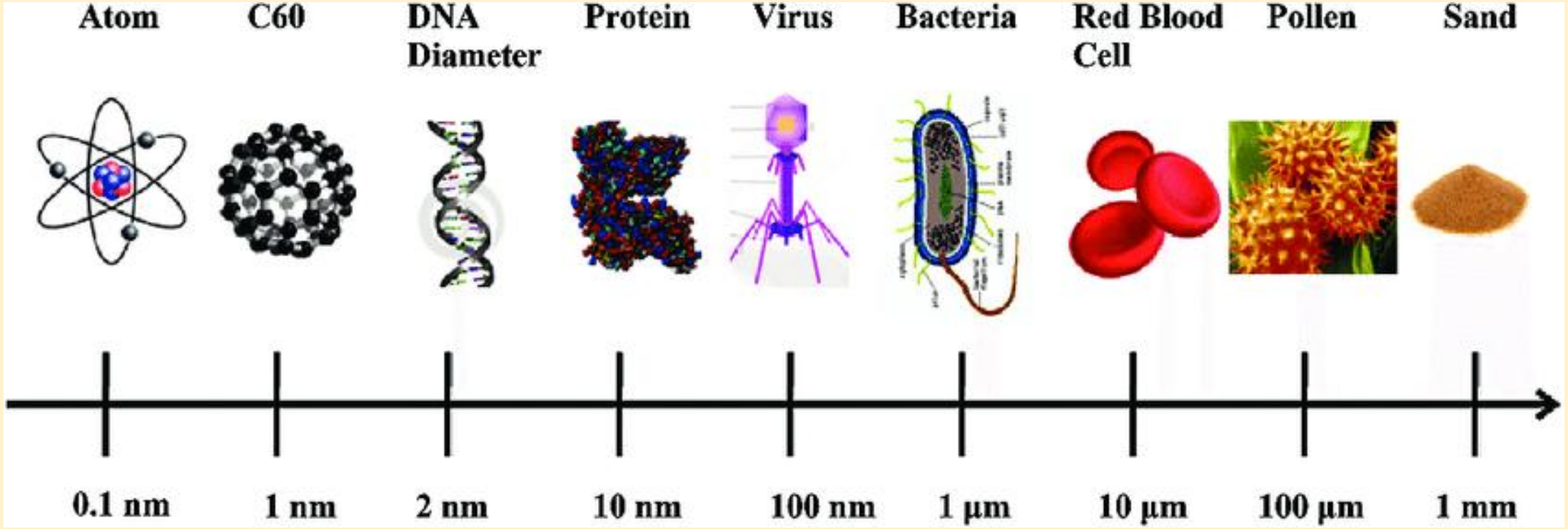
- Bulk Materials (small pieces or objects in our daily life) possess continuous (macroscopic) physical properties
- Also the same properties were found in micro sized (μm)particles (sand, powders of material etc)

- But there is big difference in properties when we go to particle sizes to nanometers(nm), because at these dimensions quantum mechanics principles governs the properties.

- Same material (such as gold or silver) have different properties at nanoscale as compared to their bulk counterpart.

Nanomaterials

- **Nanomaterials : Dimensions less than 100 nanometers (at least nanoscale in one dimension)**
- **A sheet of paper is about 100,000 nanometers thick, a human hair is around 80,000-100,000 nanometers wide**
- **We can compare some dimensions of objects:**



How small is nano?

10^8 times

10^8 times

Atom
0.1 nm

Ball
22 cm

Earth
12756 km

Some examples of nano-scaled objects encountered in daily life are as follows:

- Our fingernails grow 1nm per second
- The diameter of human hair is ~80,000 nm
- Size of a DNA molecule is ~1-2nm
- A pin head is ~one million nanometer across.
- The transistor of Pentium Core Duo processor is 45nm.

Nanotechnology

Nanometer: 10^{-9} m = 10 x 10^{-10} m = 10 atoms in a line
(one atom, $_2He^4$ ~ 10^{-10} m ~ 0.1 nm)

One nanometer is approximately the length equivalent to:
10 Helium atom
or *5* silicon atoms aligned in a line

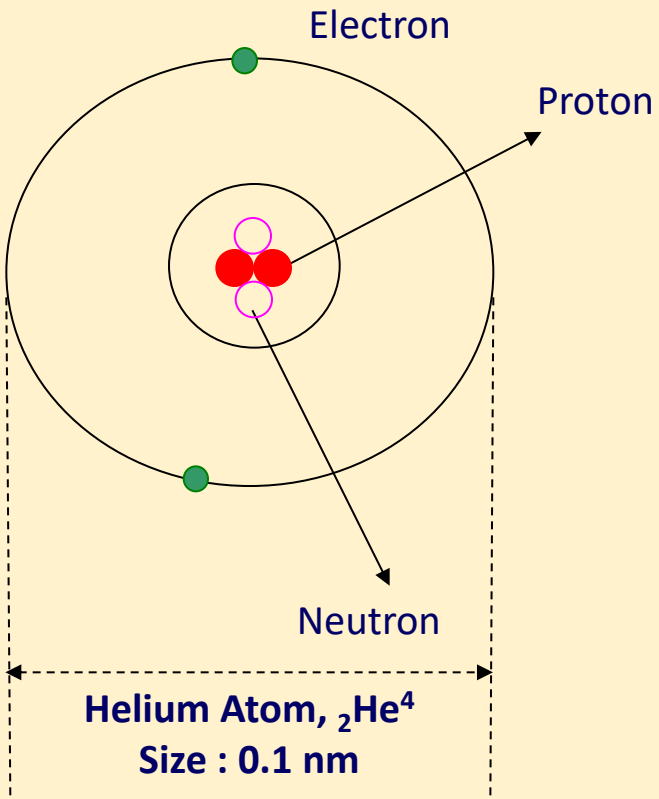
1 meter = 10^0m
1 nanometer = 10^{-9} m

Sub-Nanometer Sizes:

Electron ~1.986 x 10^{-18} m
~ 2 x 10^{-9} nm

Proton ~10^{-15} m ~ 10^{-6} nm

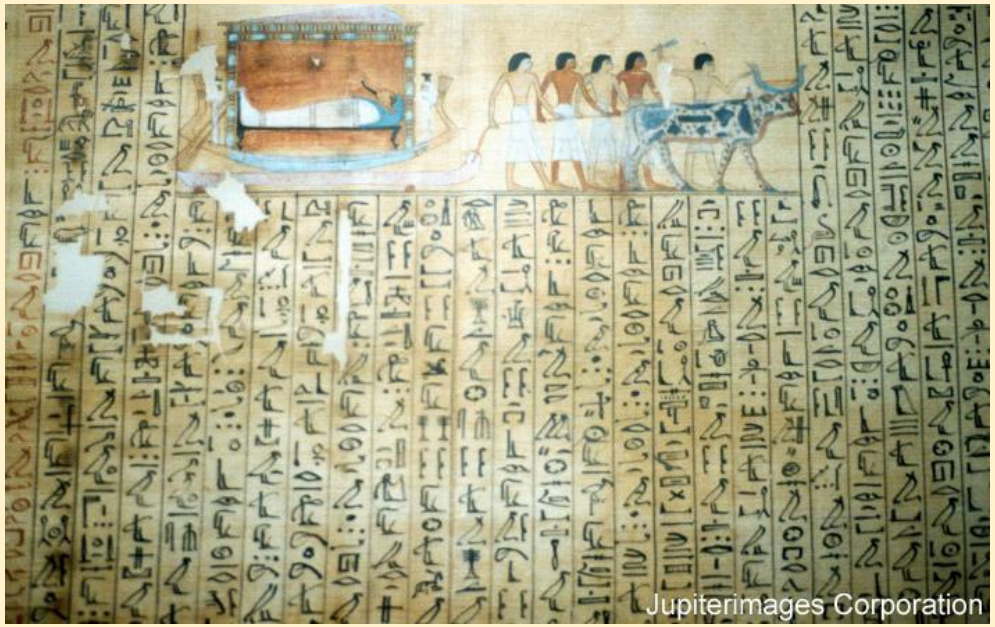
Neutron ~ 10^{-6} nm



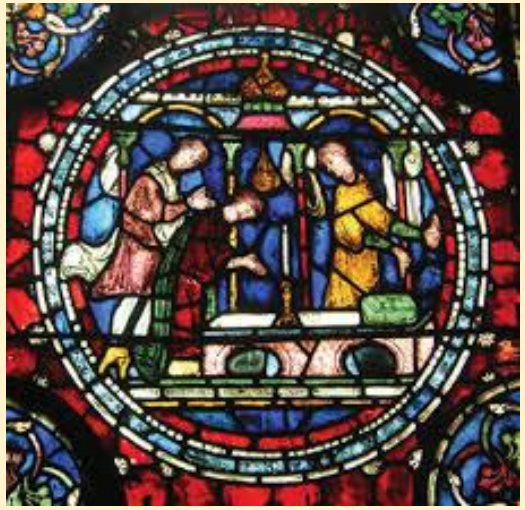
History: When did nanotechnology start?

Nanotechnology is not a new idea. Nanoparticles have in fact been used by people for thousands of years.

The Egyptians used ink containing nanoparticles of black pigment.



Nanoparticles of lead sulphide were used by the Romans to dye their hair black.



Nanoparticles of gold and silver have also been used since the 10th century to colour ceramics and stained glass.

Examples:

The stained-glass windows and Lycurgus cup are the examples of Medieval era/Roman era which consist of a few tens parts per million (ppm) of gold and silver nanoparticles in the glass matrix and exhibit unique optical properties.

The Lycurgus Cup is a 4th-century Roman glass cage cup made of a dichroic glass, which shows a different colour depending on whether or not light is passing through it: red when lit from behind and green when lit from in front.

Picture Reference: Wikipedia

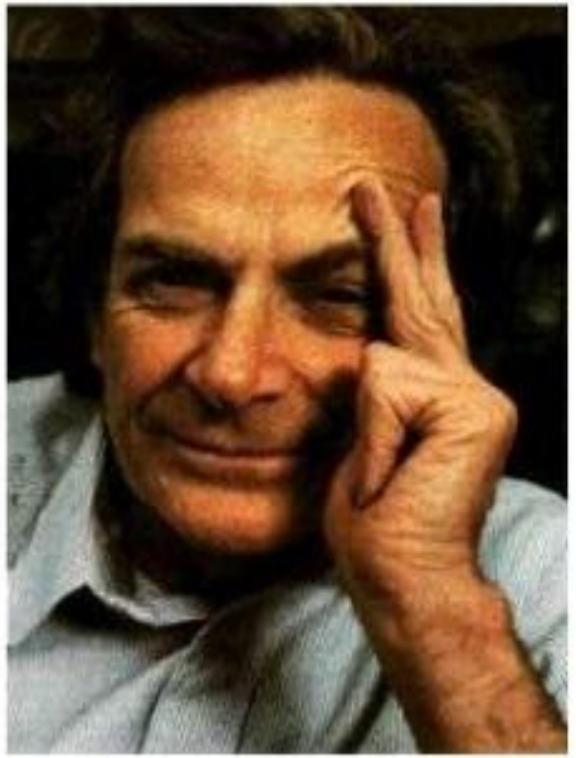
In Museum

https://en.wikipedia.org/wiki/Lycurgus_Cup

HISTORY OF NANOTECHNOLOGY

History

- The first ever concept was presented in 1959 by the famous professor of physics **Dr. Richard P.Feynman.**
- Invention of the **scanning tunneling microscope** in 1981 and the discovery of **fullerene**(C60) in 1985 lead to the emergence of **nanotechnology.**
- The term **"Nano-technology"** had been coined by Norio Taniguchi in 1974



THERE'S PLENTY OF ROOM AT THE BOTTOM

The Japanese scientist called Norio Taniguchi of Tokyo University of Science was first to use the term "nano-technology" in a 1974 conference,

Nanotechnology in ancient swords (India)

- **Damascus steel : European buy that steel from India**

Carbon nanotubes and nanowires with Steel.

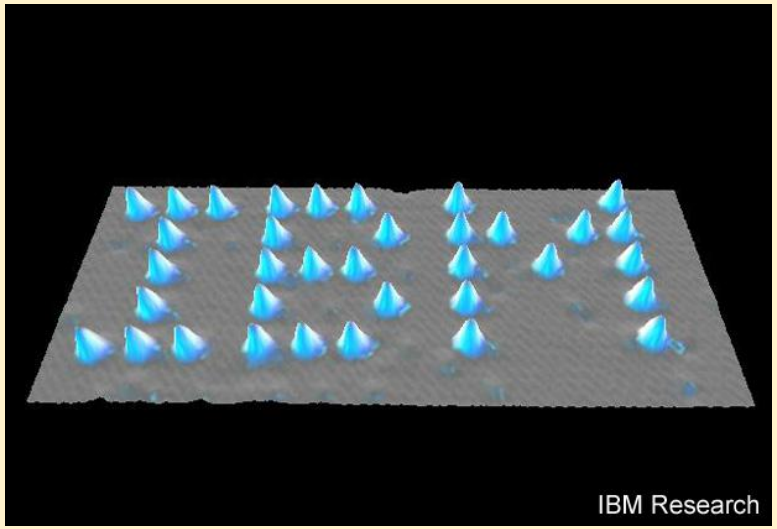
Used by south India for making weapons and swords , Tamilnadu and Kerala. (Around 17th Century)

Development of Nanotechnology

As scientists have steadily made things smaller, they have needed new equipments to help them.

In 1981, the scanning tunnelling microscope (STM) was invented and allowed scientists to see the nano-world.

Using an STM, it is possible to see individual atoms and even move them around.



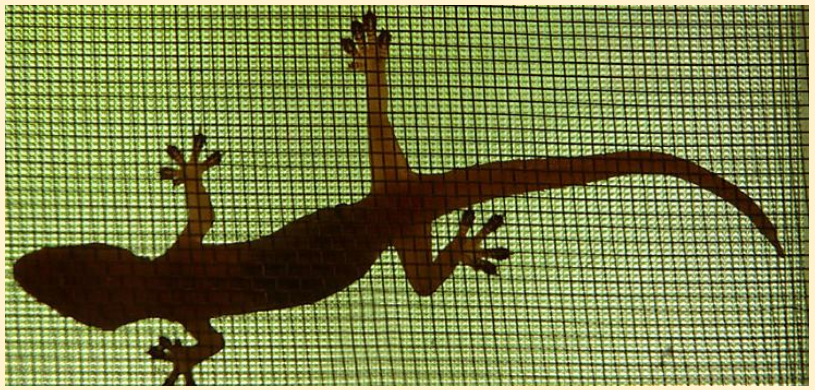
In 1989, an STM was used to move 35 xenon atoms onto a tiny piece of nickel.

The atoms spelled the name of the company: **IBM (International Business Machines Corporation).**

Are there nanoparticles in nature?

Natural nanoparticles also exist. For example:

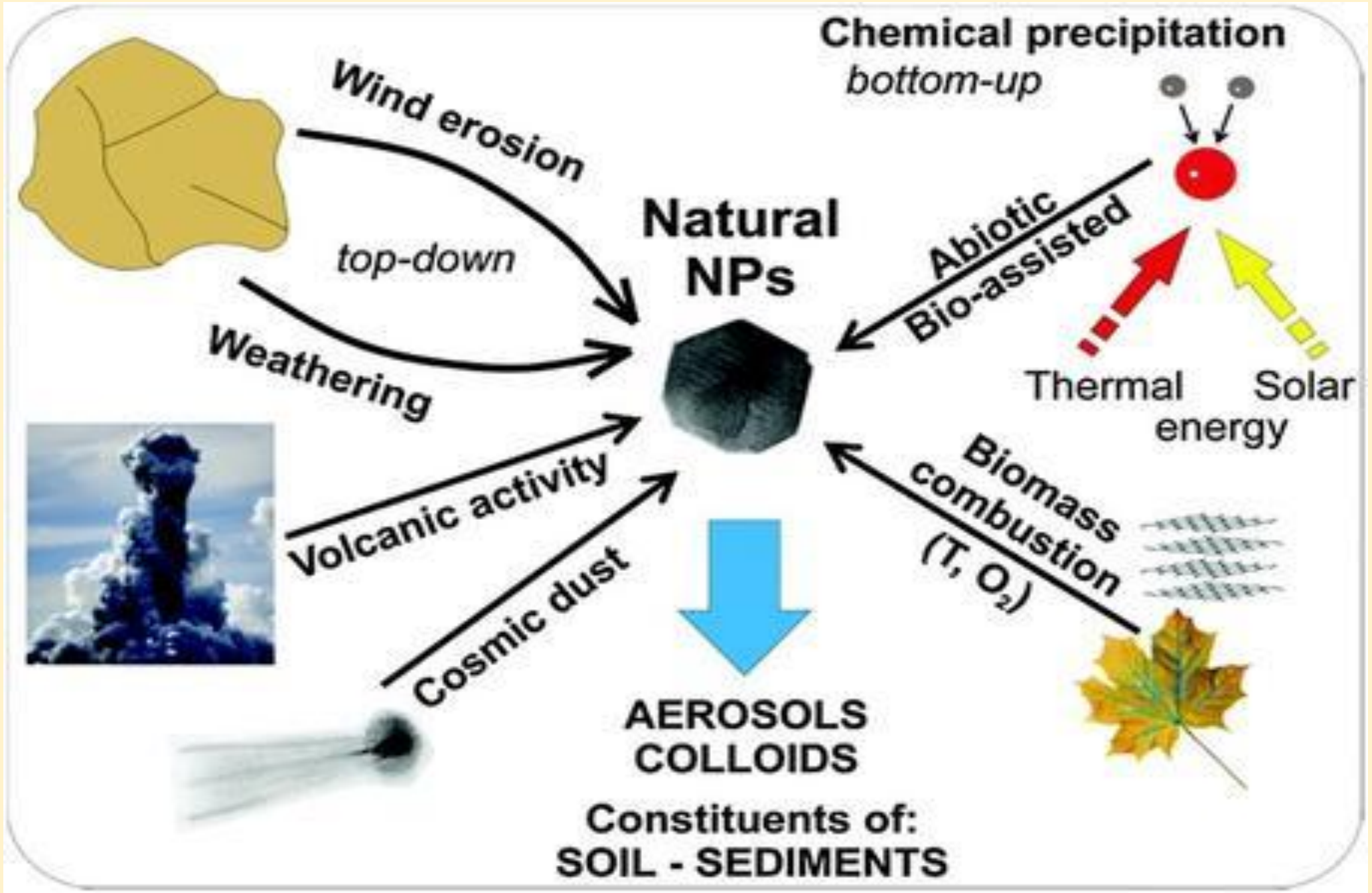
- Insects and lizards are able to stick to walls because of the nanostructures on their feet.



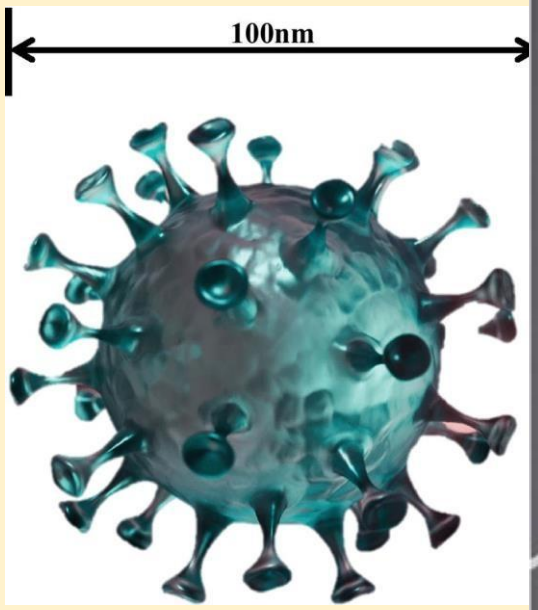
- Spiders' webs are made of super-strong nanofibers.
- Butterflies' wings contain shiny reflective nanocrystals.
- Chloroplasts in plant cells are nanofactories that harness the Sun's energy to make glucose.

Nanotechnology scientists try to copy natural nanoparticles to make new materials that are useful.

Natural Nanoparticles



Viruses



Few hundred nanometre

SARS-CoV-2

Respiratory face mask

N95, KF94,
KN95
or FFP2 mask

Particles filtered by mask
0.007 µm

Coronavirus *0.06-0.14 µm*

HIV *0.1 µm*

E. coli *2 µm*

PM 2.5 *2.5 µm*

Red blood cell *7 µm*

PM 10 *10 µm*

Pore Size of Reverse Osmosis membrane *0.0001 µm*
Pore Size of Nanofiltration membrane *0.001 µm*

1µm = 1 microns = 1000 nm = 0.001 mm

Properties of Nanomaterials

- **Nanomaterials are more reactive as compared to bulk**
- **Melting point decreases in nanomaterials**
- **They can have different colors (optical properties) depending on size of nanoparticles**
- **Changes in electric and magnetic properties**
- **Mechanical and other properties also varies in nanomaterials**

Why different properties changes at Nanoscale?

- **The material properties of nanostructures are different from the bulk due to:**

  (i) The high surface area over volume ratio and large fraction of surface atoms

  (ii) quantum effects are dominant at nanoscale (quantum confinement)

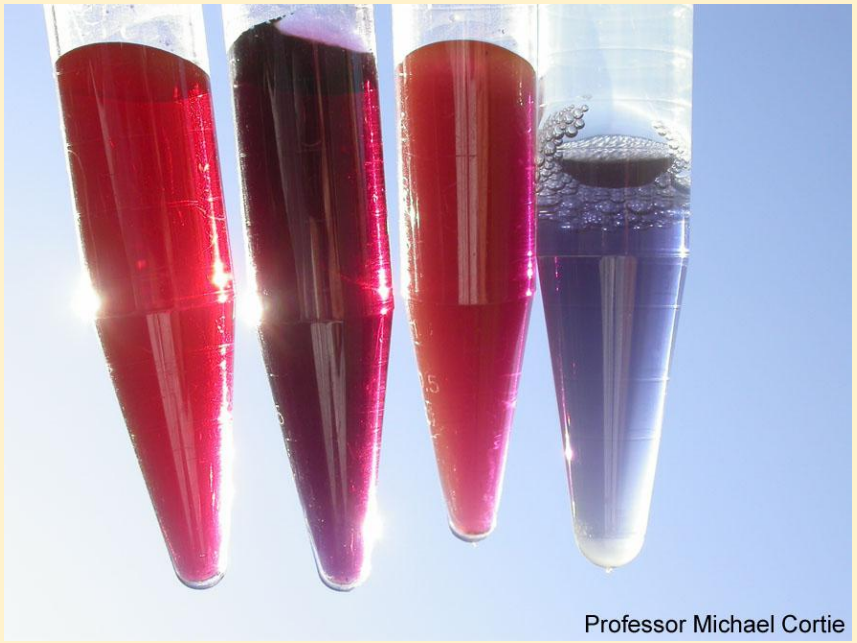
We will discuss these in next lectures on size effect and basic quantum mechanics (Particle in a box).

Properties of nanoparticles – appearance

Nanoparticles also interact differently with light.

Normally, gold metal appears yellow in colour. However, nanoparticles of gold in solution appear red and blue in colour.

Different-sized nanoparticles of gold give different coloured solutions.



Smaller nanoparticles appear red in solution, while slightly larger nanoparticles appear blue, this is due to the change in the energy band gap.

Applications of Nanotechnology

i. **Computer/Information Technology:/Communications:**
   Large memories, Nanoelectronics, Bio-molecules as transistors,
ii. **Medical and Health Care:**
   Anti-cancer drugs, Bio-sensors, Implants, Dental Pastes/Ortho
iii. **Energy:**
   Solar cell, Fuel cell, Bio-fuels, Batteries
iv. **Automobiles:**
   Lubricants, Glass Coatings, Resins, Phosphors
v. **Industry:**
   Auto, Ceramic, Insulation, Phosphors, Hard Materials, Mechanical, Spray, Sensors
vi. **Defense:**
   Special Materials, Censors, Intelligent Clothing

Applications of Nanotechnology Continued

Vii. Cosmetics:

Skin Creams ,Anti aging creams

viii. Food & Agriculture:

Food Safety, Quality Assurance, water purification

ix. Water Treatment:

Nanofiltration , Clean drinking and Waste water

x. Environment:

Filters, anti toxicants ,nano catalysts for oil spills

xi. Textiles:

Special clothes ,wrinkle and stain free, antimicrobial socks

xii. Sports:

Sunglasses, Hockey sticks ,Rackets, Tennis and Golf balls

xiii. Aerospace:

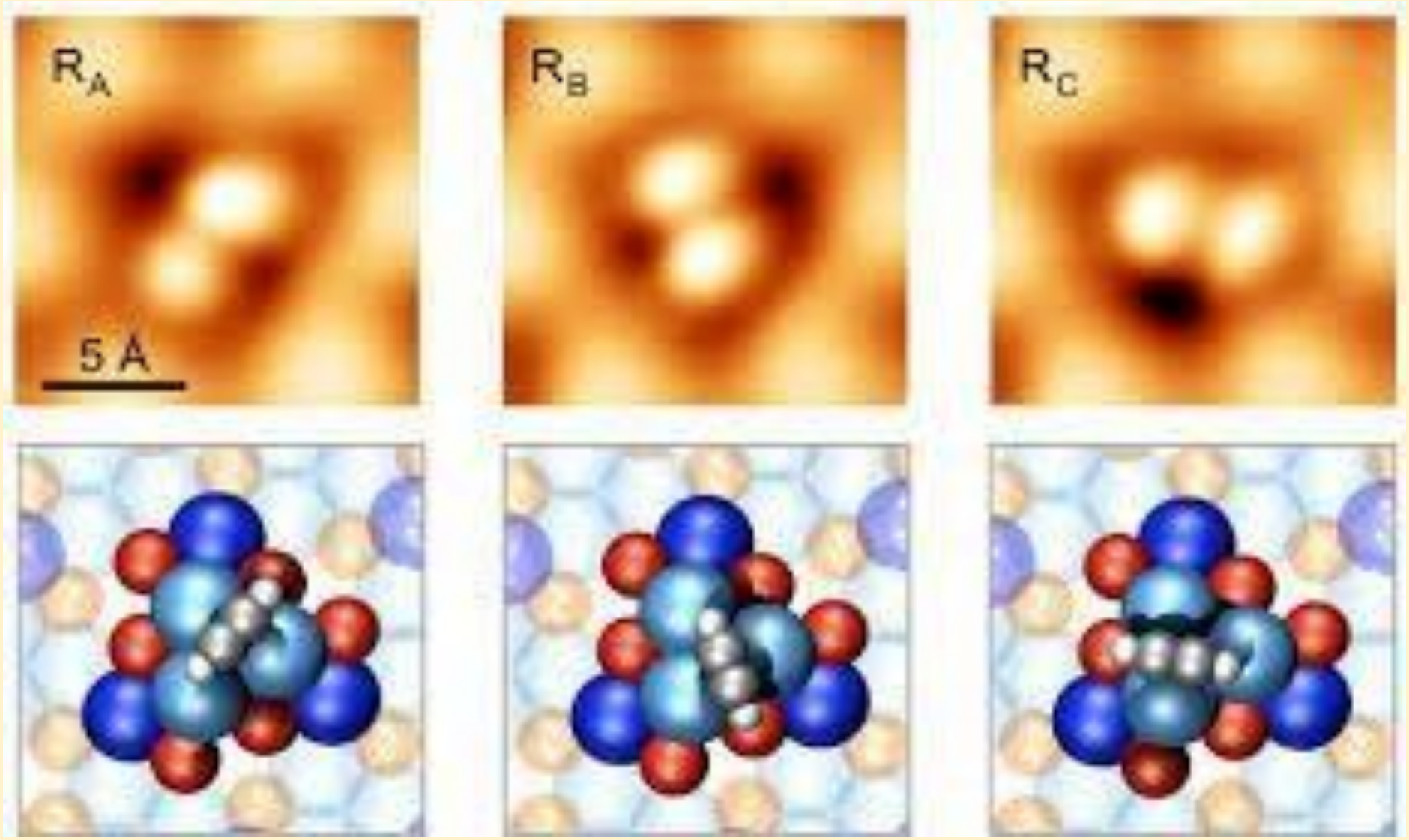
Communications, High strength light weight materials

Xiv. Oil and Gas Exploration:

50% increase in extraction from existing oil wells by using nanotechnology techniques.

World's smallest Motor: 16 atoms

A molecular motor developed by a team of researchers from Switzerland consists of just 16 atoms. June 2020



Real Device image

Atomic arrangement

Image Source: Wikipedia

Moore's law: Every eighteen months, the number of components that can exist on an integrated circuit doubles

more transistors could be packed into a chip

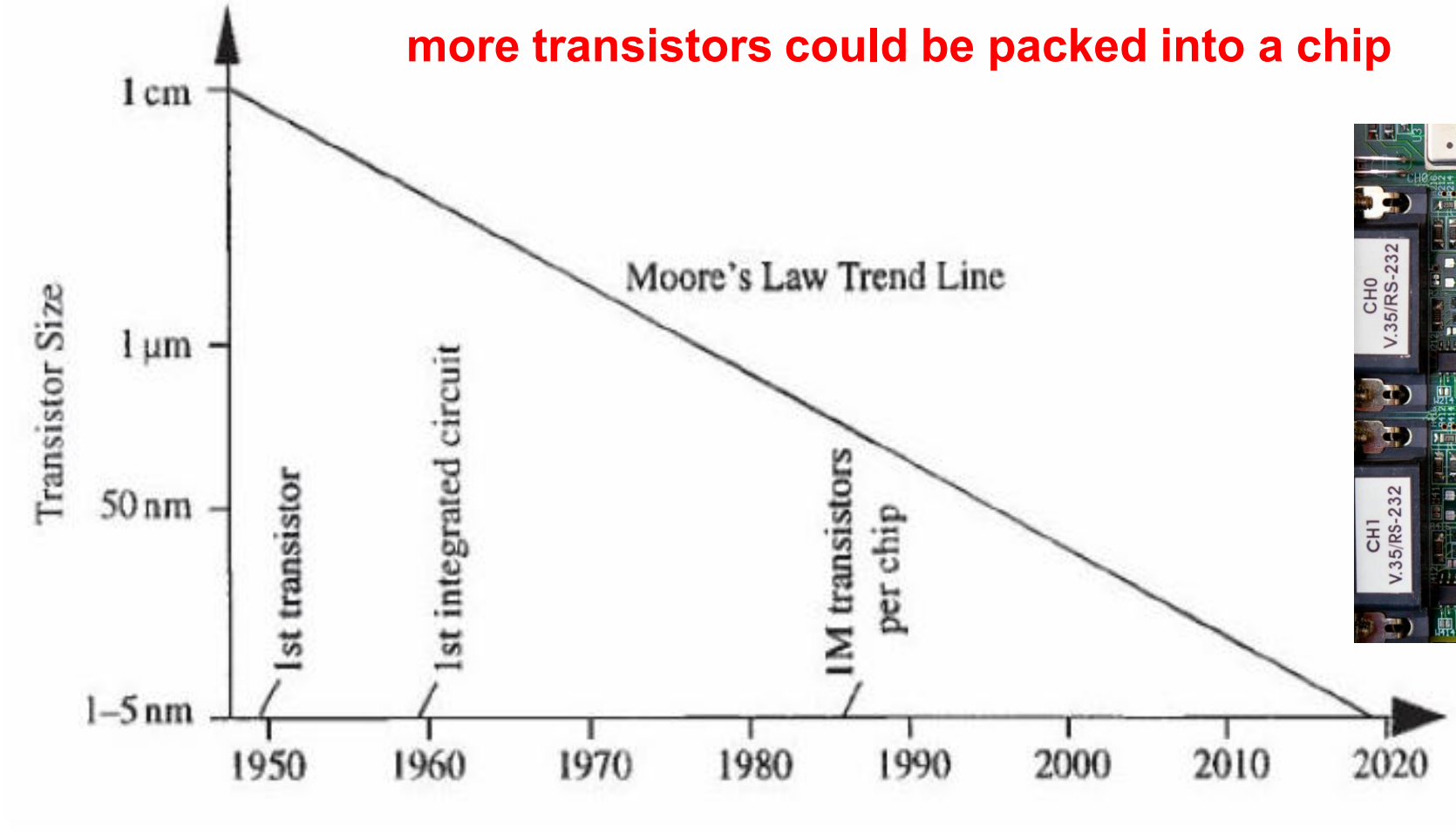
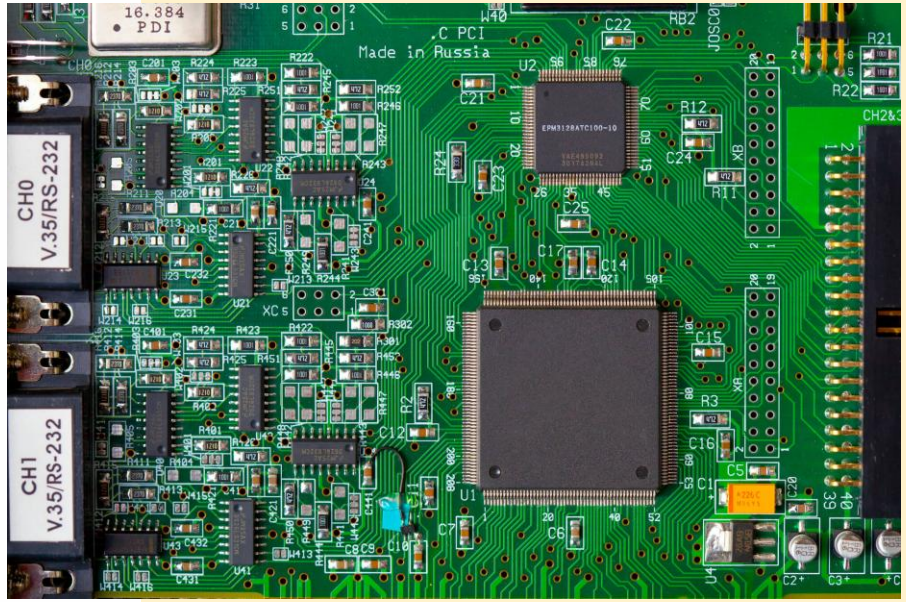


Fig. 1. "Moore's Law" plot of transistor size versus year.



But Moore suggested in 2007, that the size of transistor cant go beyond the atomic size(~ 0.1nm)

Storage Technologies

Magnetic Storage

Optical Storage

Solid State Storage

1 Byte = 8 Bit
1 Kilobyte = 1,024 Bytes,
1 Megabyte = 1,048,576 Bytes,
1 Gigabyte = 1,073,741,824 Bytes

SSD

HDD

SSD (Solid State Drive)	HDD (Hard Disk Drive)
Semiconductor memories	Magnetic Memories
Faster	Slower
Shorter life span	Longer life span
exapansive	Cheaper
Best for storing operating system, gaming apps etc	Best for storing extra data, movies, photos, documents etc.
Non mechanical (flash)	Mechanical (moving parts)

Nanotechnology Trends in 2025

1. **Nanomedicine & Theranostics**

- Smart drug delivery systems
- AI-assisted diagnosis and treatment (e.g., Nanovery, Nanobiotix)

2. Nanosensors & Smart Monitoring

- Real-time biosensors for health, agriculture, and environment
- Smartphone-compatible diagnostic tools

3. Green Nanotechnology

- Recycled nanomaterials (e.g., from plastic waste)
- Biodegradable nanocoatings (e.g., Nfinite Nanotech)

4. Nanoelectronics & Photonics

- Quantum-enabled chips, nanolasers
- Low-power, high-speed nano-optoelectronics (e.g., NcodiN)

Startups & Innovations in 2025

Noteworthy Startups:

- **Vimano (India):** Low-cost membranes for clean energy
- **Nanomatics (Singapore):** Recycled carbon nanotubes
- **Nfinite Nanotech (Canada):** Sustainable packaging coatings
- **Nanodecal (Spain):** Smartphone-based breath diagnostics
- **NcodiN (France):** Photonic-integrated nanodevices

Emerging Areas:

- DNA origami for programmable nano-structures
- Nanorobots for targeted cancer treatment
- Nanofiltration for water & air purification
- IIT Indore's quantum AI nanopore system for genetic mutation detection