Nanoscience and Nanotechnology

Content

- What is ***Nano scale Science****?*
- Actual physical dimensions relevant to ***Nano*** *systems*.
- Properties of ***Nanomaterial***.
- Size & Shape Dependent Properties – at ***Nano scale***.
- Applications

What is Nano ?

Nano - a prefix that means ***very, very, small*** !

- ***Question : How small is 'Nano' ?***

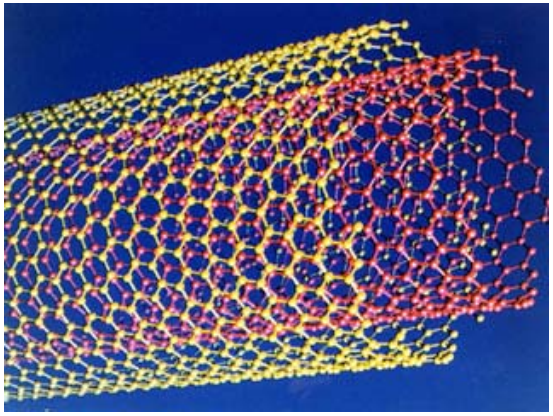
  Answer: "One billionth" of something, or 0.000000001.

$$\frac{1}{1000000000} = 10^{-9}$$

- A nanometer is ***one billionth of a meter***. *Nanoscale* is actually *Nanometer scale*.
- Nanometer scale range from approximately *100 nm to 1 nm.*

Nanoscience: Nanometer scale science

- A part of science that studies small stuff



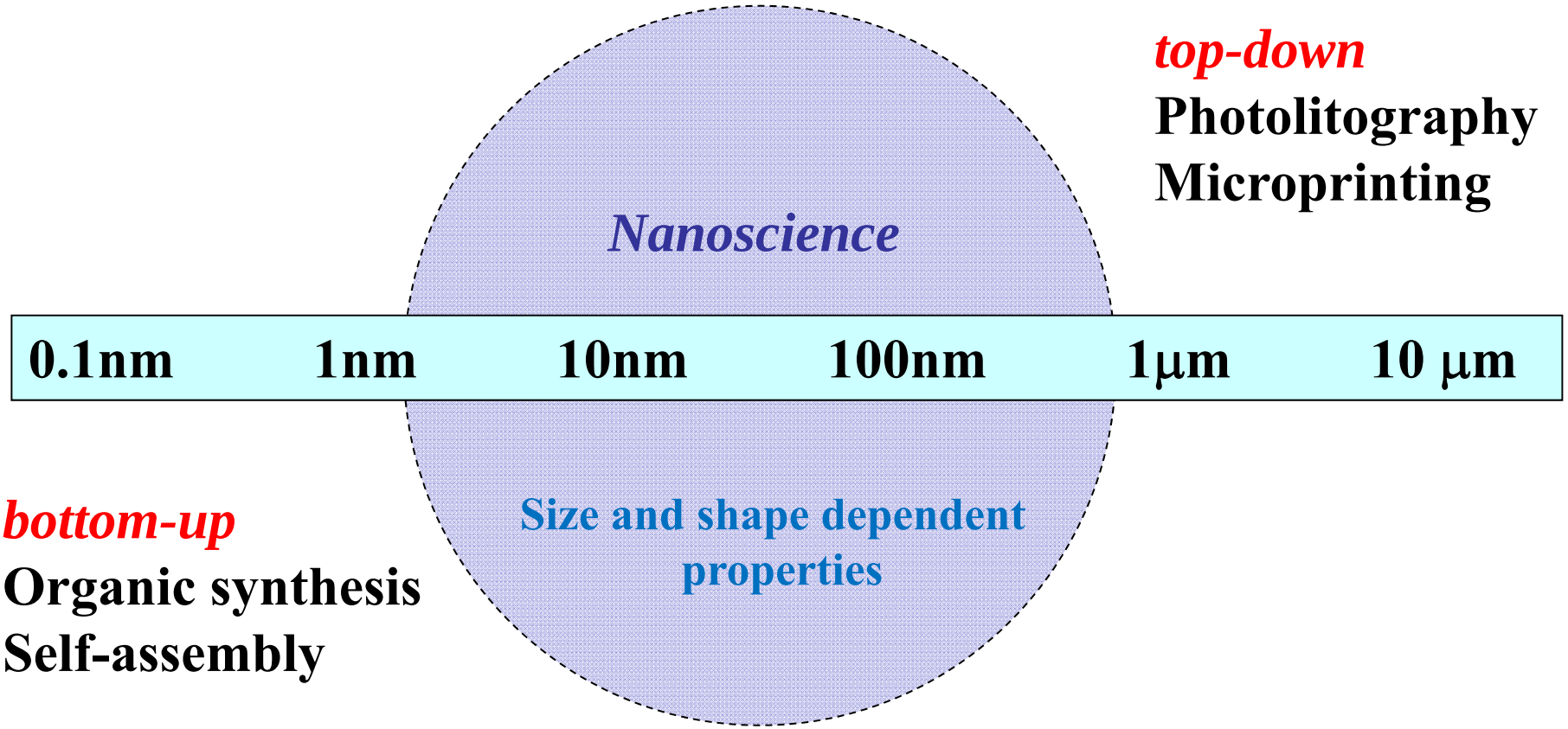
So, what is ***Nano science*** ?

- It is **not only Biology**.
- It is **not only Physics** .
- It is **not only Chemistry**.
- It is **all sciences** that work with the very small.

➢ ***Nanoscience is not physics, chemistry, engineering or biology. It is all of them.***

S.M. Lindsay, Introduction to Nanoscience, Oxford University Press (2009).

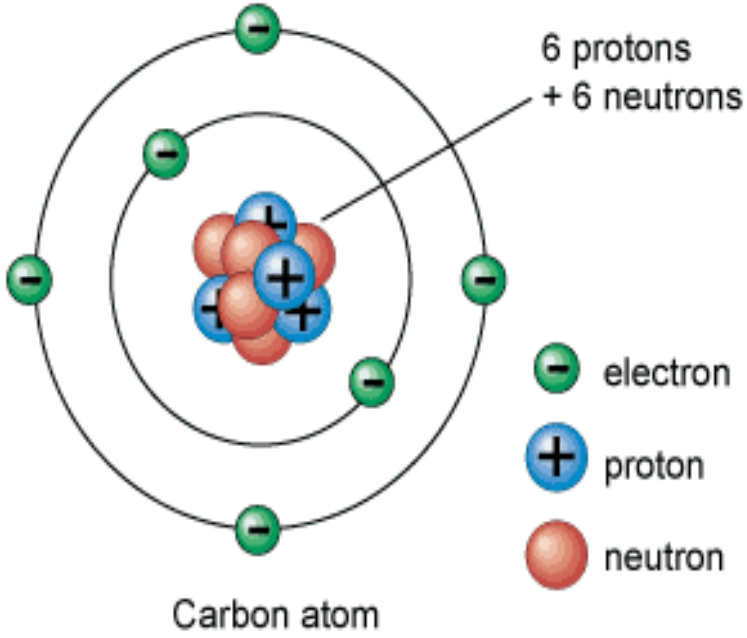
Actual physical dimensions relevant to Nanosystem



Nanometer scale : The length scale where corresponding property is size & shape dependent.

Length Scale

- Bohr radius = **0.5292Å ≈ 0.05** nm
- C atom (VdW radius)=**0.17** nm
- In a 1nm line: **3C** atoms
- In a 1nm x 1nm surface: **9C** atoms
- In a 1nm x 1nm x 1nm cube: **27 C** atoms
- In a 100 nm x 100 nm x 100 nm cube: **2.7×10^7 C** atoms



- In a 1m x 1m x 1m cube**:** **2.7×10^{28} C** atoms

Typical nanosystems may contain from hundreds to tens of thousands of atoms.

Nanosystems: % of Surface atoms

Example of Gold Nano particle:

- Sphere of radius 12.5 nm contains total approx. 480,000 atoms.
  surface contains approx. 48,000 atoms.

So, approx. ***10% atoms are on the surface*.**

- Sphere of radius 5 nm contains total approx. 32,000 atoms.
  surface contains approx. 8000 atoms.

So, approx. ***25% atoms are on the surface***.

Surface atoms have unused electrons – so very reactive
(can be used for catalysis)

What's interesting about the nanoscale?

- Nano sized particles exhibit different properties than larger particles of the same substance.

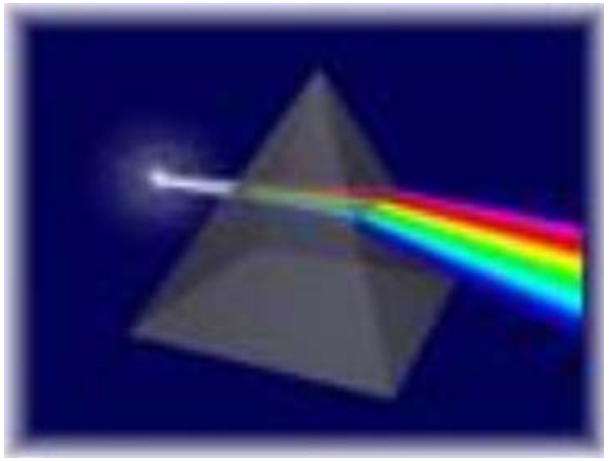
- Nano sized particle exhibit size & shape dependent properties.

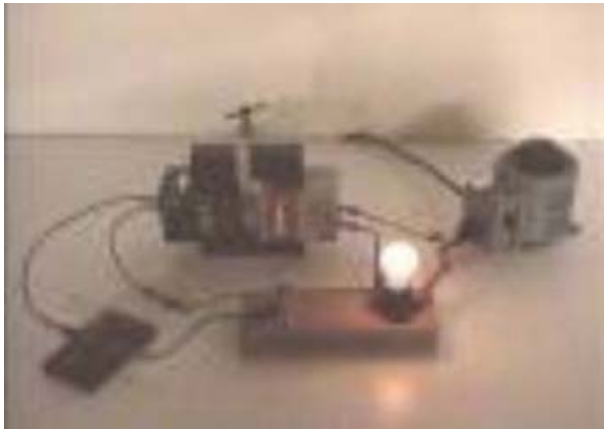
How do properties change at the Nanoscale ?

Properties of a Material

A property describes how a material acts under certain conditions.

- **Types of properties:**
  - Optical (e.g. color).
  - Electrical (e.g. conductivity).
  - Physical (e.g. melting point).
  - Chemical (e.g. reaction rate).





Optical Properties: Colour of Gold

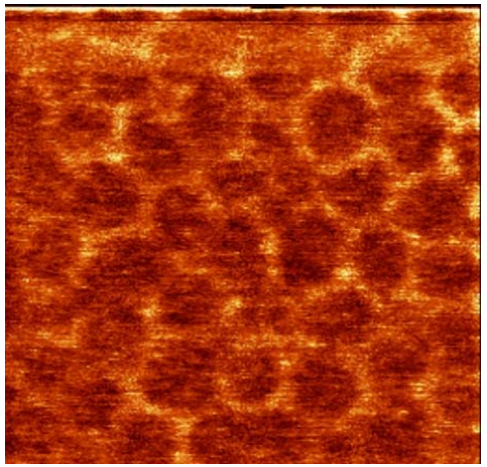
- **Bulk gold**

  appears yellow in colour.

- **Nano sized gold**

  appears red in colour.

The particles are so small that electrons are not free to move about as in bulk gold Because this movement is restricted, the particles react differently with light.

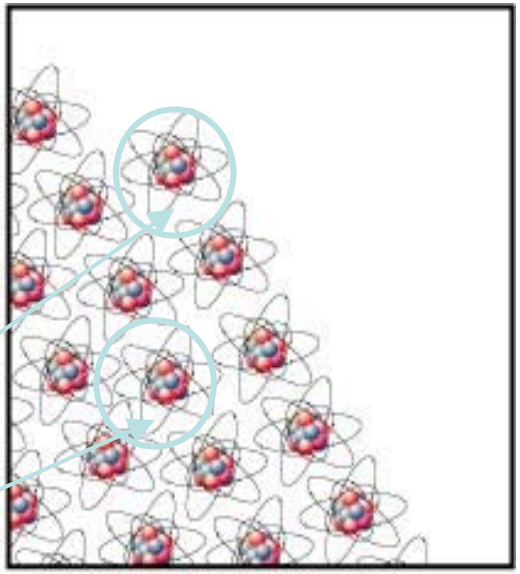


12 nanometer gold clusters of particles look red.

Sources:
http://www.sharps-jewellers.co.uk/rings/images/bien-hccncsq5.jpg
http://www.foresight.org/Conferences/MNT7/Abstracts/Levi/

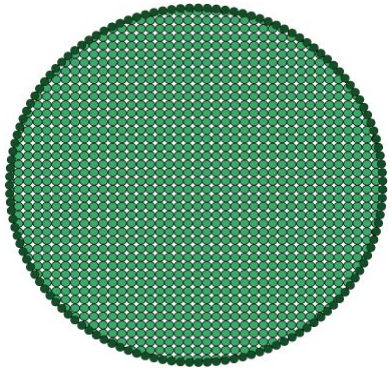
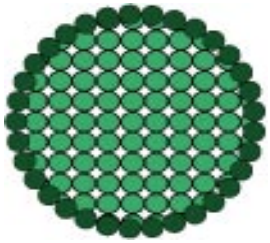
Physical Property: Melting Point of a Substance

- Melting Point (microscopic definition)
  - Temperature at which the atoms, ions, or molecules in a substance have enough energy to overcome the intermolecular forces that hold the them in a "fixed" position in a solid
  - Surface atoms require *less* energy to move because they are in contact with *fewer* atoms of the substance.



http://serc.carleton.edu/usingdata/nasaimages/index4.html

Understanding Melting Point: macro vs. nano

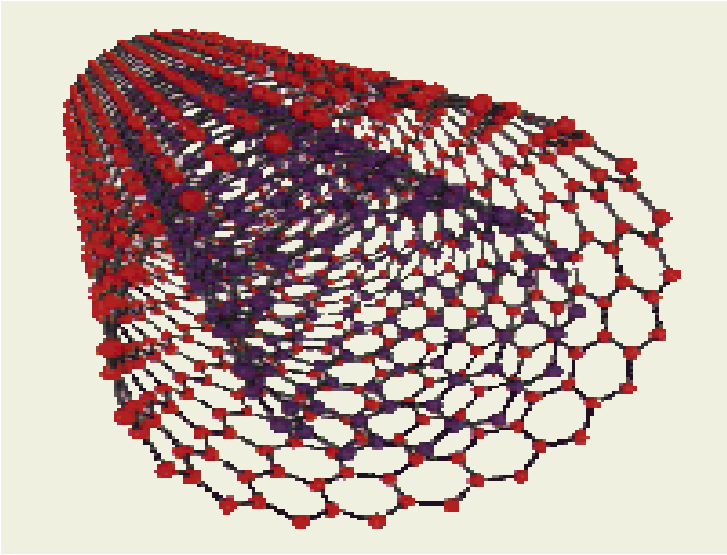
	At the macro scale	*At the Nanoscale*
The majority of the atoms are…	***…almost all on the inside of the object*** 	***…split between the inside and the surface of the object*** 
Changing an object's size…	***…has a very small effect on the percentage of atoms on the surface***	***…has a big effect on the percentage of atoms on the surface***
The melting point…	***…doesn't depend on size***	***… is lower for smaller particles***

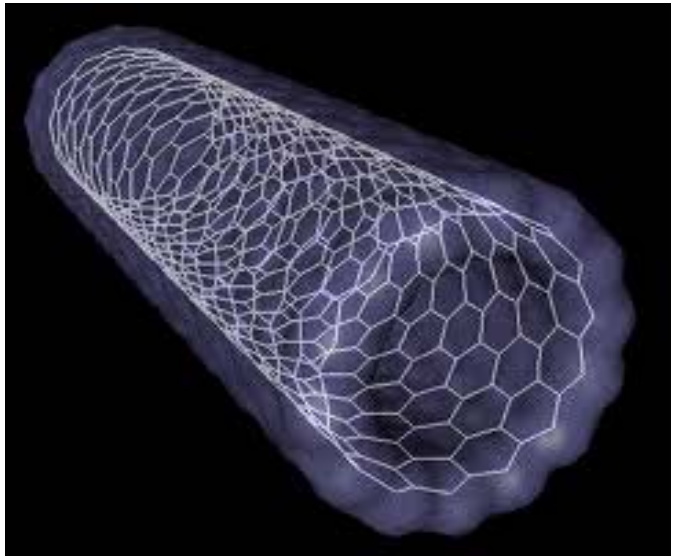
Electrical Properties :Conductivity of Nanotubes

- **Nanotubes are long, thin cylinders of carbon:**

Their electrical properties change with diameter, “twist”, and number of walls

They can be either conducting or semi-conduc their electrical behavior.





Chemical Property: Reaction Rate

- Nano particles are very small in size.
- Very high surface area to volume ratio.
- Reactions are very quick.

Length Scale - Changes Everything

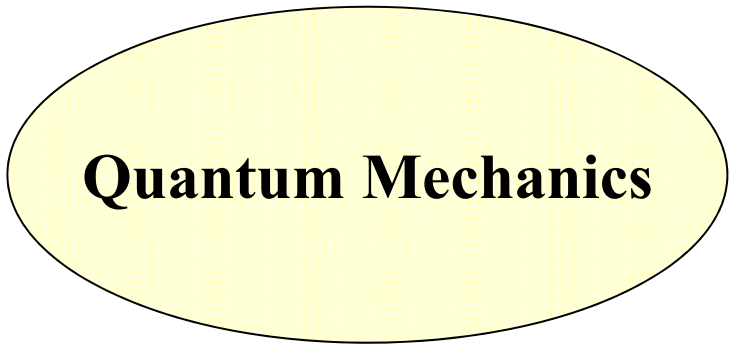
Three important ways in which Nanoscale materials may differ from macro scale materials

Gravitational forces become negligible and electromagnetic forces dominate.

1.Quantum mechanics is the model used to describe motion and energy instead of the classical mechanics model.

2.Greater surface to volume ratios.

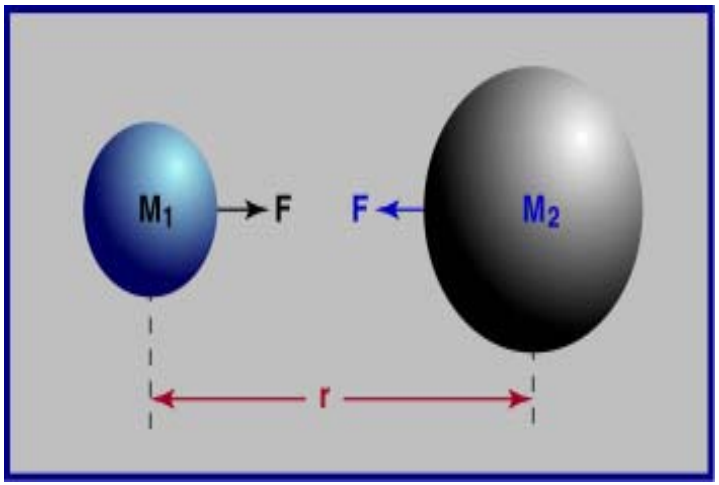
3.Quantum Mechanics dominates the world of atoms. ***Nanoscience is where atomic physics converges with the physics and chemistry of complex systems***



Dominance of Electromagnetic Forces

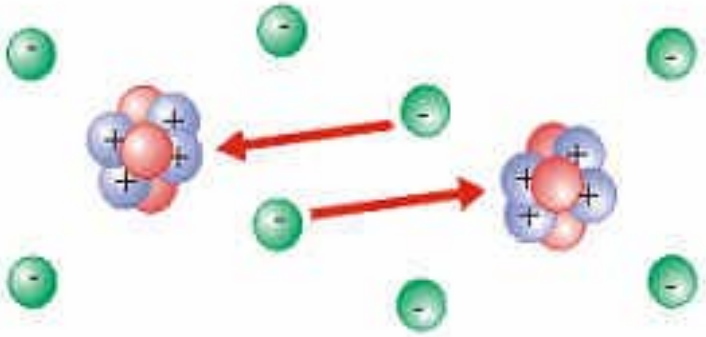
- Gravitational force

is a function of **mass** and distance and is ***weak*** between (low-mass) Nano sized particles.



- Electromagnetic force

is a function of **charge** and distance is not affected by mass, so it can be very ***strong*** even when we have Nano sized particles.



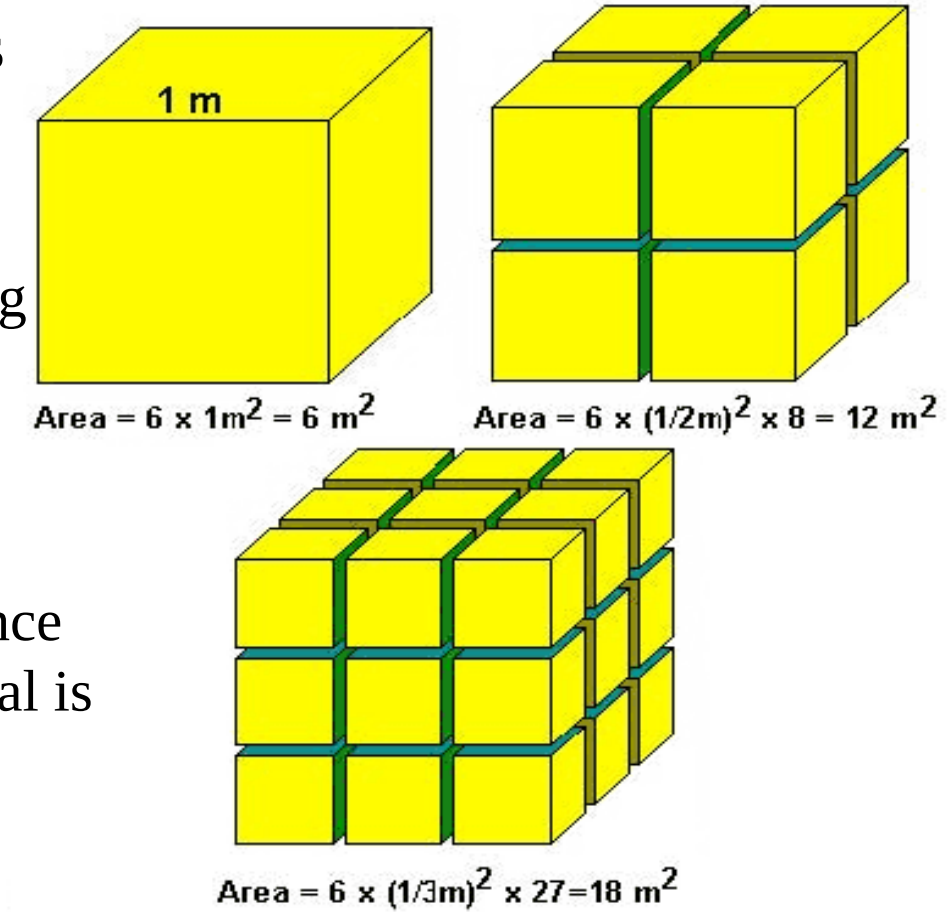
Sources:
http://www.physics.hku.hk/~nature/CD/regular_e/lectures/images/chap04/newtonlaw.jpg
http://www.antonine-education.co.uk/Physics_AS/Module_1/Topic_5/em_force.jpg

Surface to Volume Ratio Increases

As surface to volume ratio increases

- A greater amount of a substance comes in contact with surrounding material.

- This results in better catalysts, since a greater proportion of the material is exposed for potential reaction.

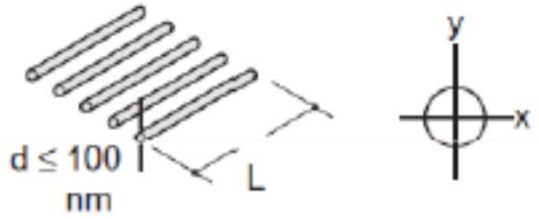


Classification

- Classification is based on the number of dimensions, which are not confined to the nanoscale range (<100 nm).
- (1) zero-dimensional (0-D),
- (2) one-dimensional (1-D),
- (3) two-dimensional (2-D), and
- (4) three-dimensional (3-D).

1-D

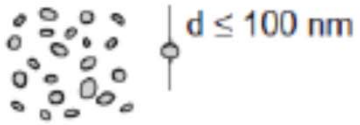
Two dimensions (*x*,*y*) at nanoscale, other dimension (*L*) is not



Nanowires, nanorods, and nanotubes

0-D

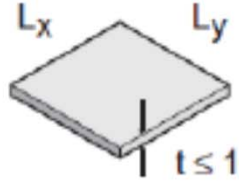
All dimensions (*x*,*y*,*z*) at nanoscale



Nanoparticles

2-D

One dimension (t) at nanoscale, other two dimensions- (L_x, L_y) are not



Nanocoatings and nanofilms

Applications of Nanotechnology

Carbon Nanotube Composites

- Nano Ridge Materials has developed a carbon nanotube strengthened composite that is 70% stronger than metal and 40% the weight.

- This very strong composite has potential for aircraft replacement parts.

Insulation

- Nanoscale materials hold great promise as insulators because of their extremely high surface-to-volume ratio. This gives them the ability to trap still air within a material layer of minimal thickness. Insulating nanomaterials may be sandwiched between rigid panels, applied as thin films, or painted on as coatings.

Nano Cable

- **Nano Ridge Material** and **Boeing** (Long beach) are partners on a $5.75 million Advanced Technology Program to develop **Nano Cable** by 2010. Nano Cable is a lightweight, highly conductive, electrical wire and cable that could bring significant gains in fuel savings, energy efficiency and operating costs.
- The technology is based on carbon nanotubes which conduct greater amounts of electric current than copper while having only 1/6th the weight.
- By 2010, the market for conductive polymer cable is expected to be 465 million lbs per year, worth **$1.4 billion annually**.

Nano Coatings

- Self-cleaning
- Scratch-resistant
- Anti-icing and anti-fogging
- Antimicrobial
- UV protection
- Corrosion-resistant
- Waterproofing

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Anti Stain Coatings

- In 2002, **Eddie Bauer** apparel became the first brand to employ **Nano-Tex** stain resistance technology in its designs. Nano-Tex has now expanded to bring resistance to fabrics and other interior finishes. Nano-Tex uses a process that bonds to each fiber, making textiles last longer, retain their natural feel and breathe normally.

Behr Paints Offers NanoGuard

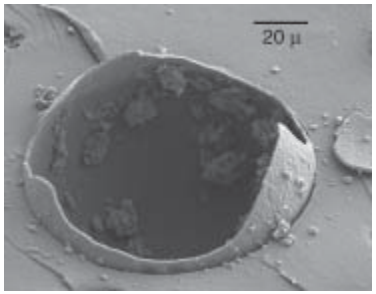
- Behr's best line of paint uses nanoparticles to provide a long lasting, anti-fade, more durable house paint that also prevents mildew.

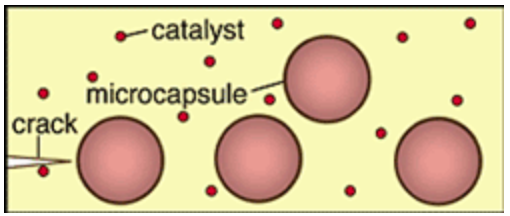
Automotive Paint – Mercedes-Benz

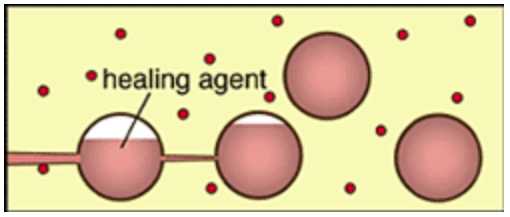
- The 2007 Mercedes-Benz SL series cars sport a protective coating of nanoparticles that provides a three-fold improvement in the scratch resistance of the paintwork.

Self Healing Composites

- Polymeric and composite materials are subject to weakening due to fatigue cracking. A self-healing composite has the potential to defend against material failure due to fatigue and to greatly improve product safety and reliability. Patent 6858659 - Office of Technology Management – University of Illinois Urbana Champian







Nanomedicine

- **NanoBioMagnetics** is an Edmond, Oklahoma company that has demonstrated the ability to move nanoparticles through the body to specific cells. In the future, companies like NanoBioMagnetics anticipate being able to attach a drug to the nanoparticle and then deliver it reliably to the site of a cancerous cell and kill it.