DSE CLASS

CONDENSED MATTER PHYSICS

Lecture-10

24/12/2020

Nanoscience and Nanotechnology?

- ***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.

Key ideas:

1. The nanometer is extremely small.
2. At the nanometer scale, materials may behave differently.
3. We can harness this new behavior to make new technologies.

What is Nano?

Prefixes for SI Units			
Prefix	**Symbol**	**Meaning**	**Notation**
exa-	E	1,000,000,000,000,000,000.	1.E+18
peta-	P	1,000,000,000,000,000.	1.E+15
tera-	T	1,000,000,000,000.	1.E+12
giga-	G	1,000,000,000.	1.E+09
mega-	M	1,000,000.	1.E+06
kilo-	k	1,000.	1.E+03
hecto-	h	100.	1.E+02
deka-	da	10.	1.E+01
		1.	1.E+00
deci-	d	.1	1.E-01
centi-	c	.01	1.E-02
milli-	m	.001	1.E-03
micro-	μ	.000001	1.E-06
nano-	n	.000000001	1.E-09
pico-	p	.000000000001	1.E-12
femto-	f	.000000000000001	1.E-15
atto-	a	.000000000000000001	1.E-18

UNDERSTANDING SIZE

1 meter

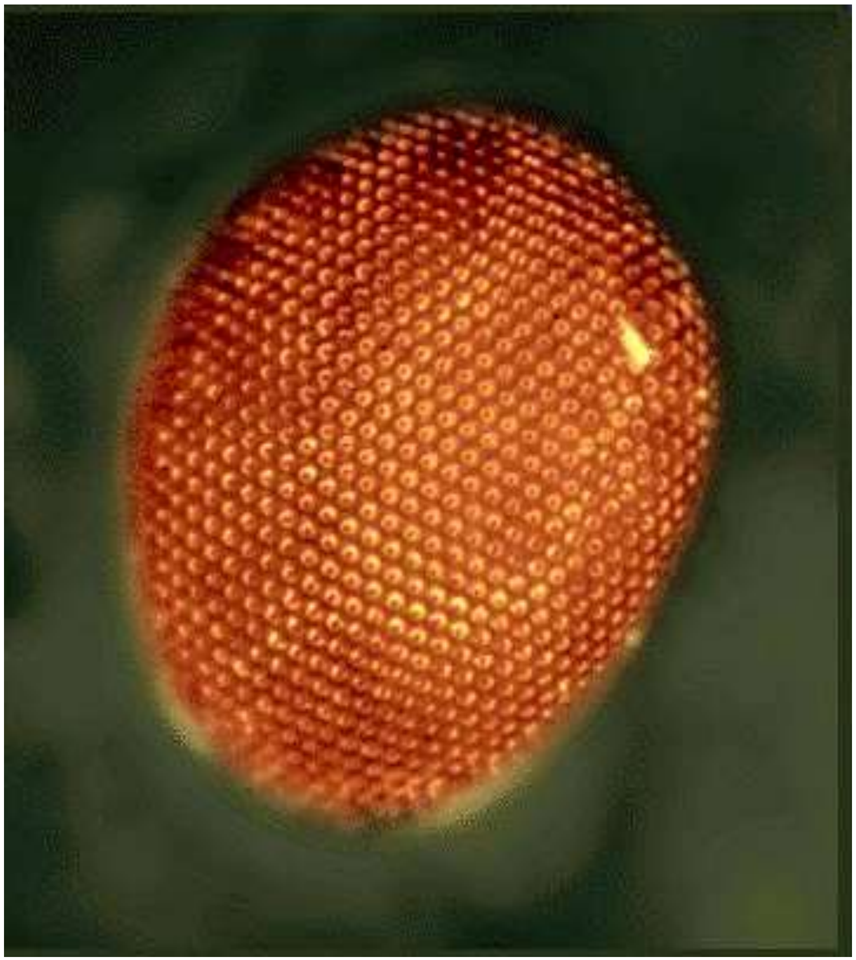
UNDERSTANDING SIZE

10 centimeters

UNDERSTANDING SIZE

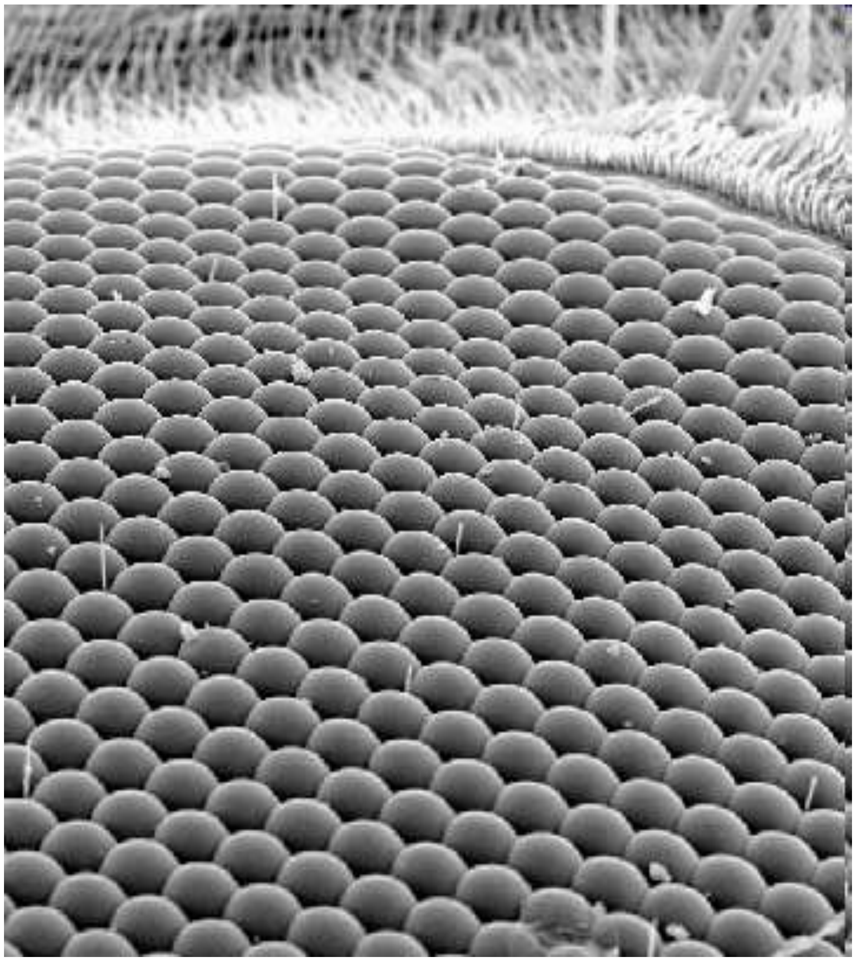
1 centimeter

UNDERSTANDING SIZE



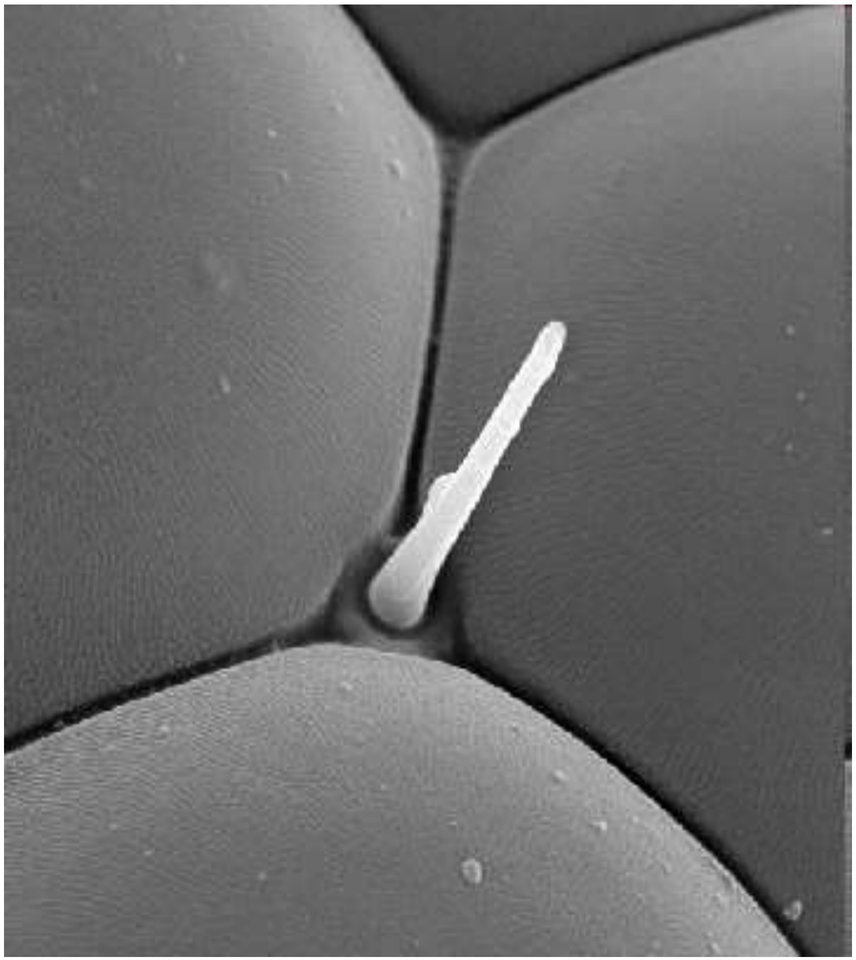
100 micrometers

UNDERSTANDING SIZE



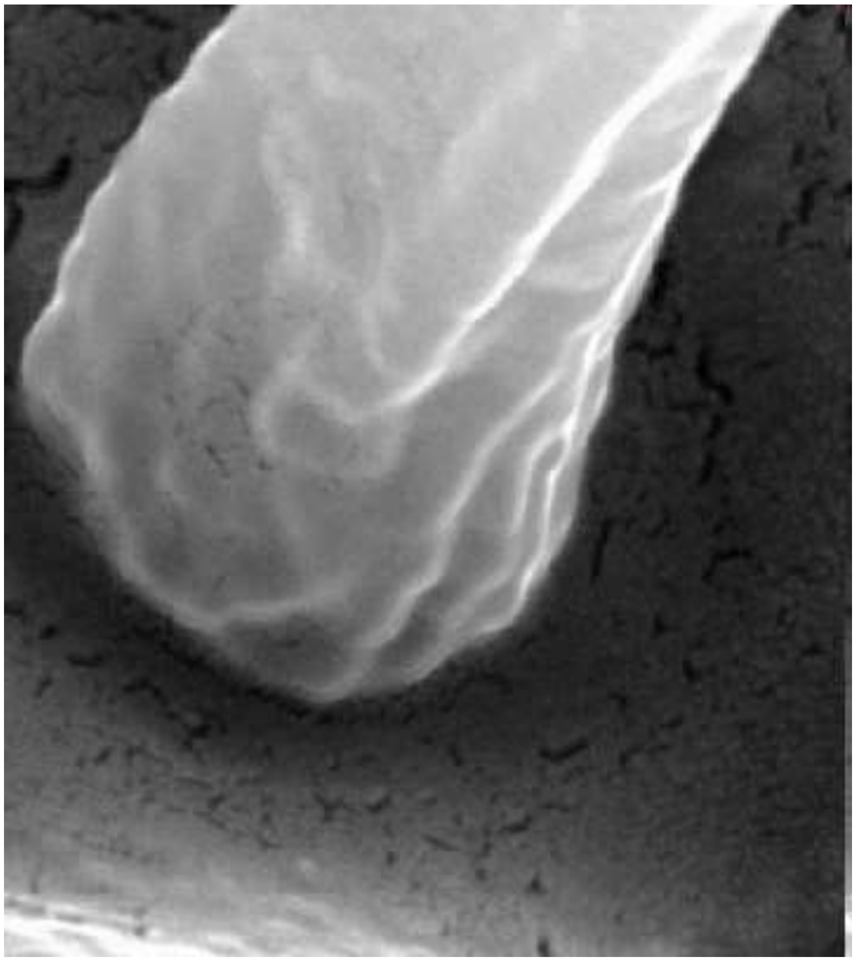
10 micrometers

UNDERSTANDING SIZE



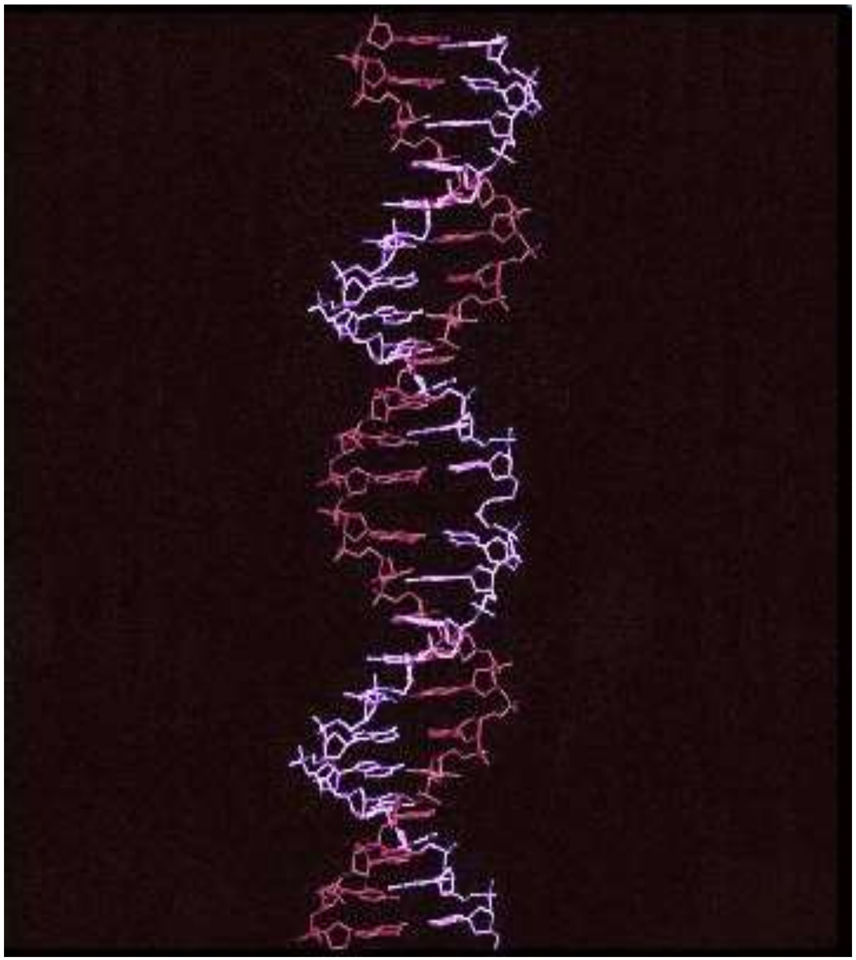
1 micrometer

UNDERSTANDING SIZE



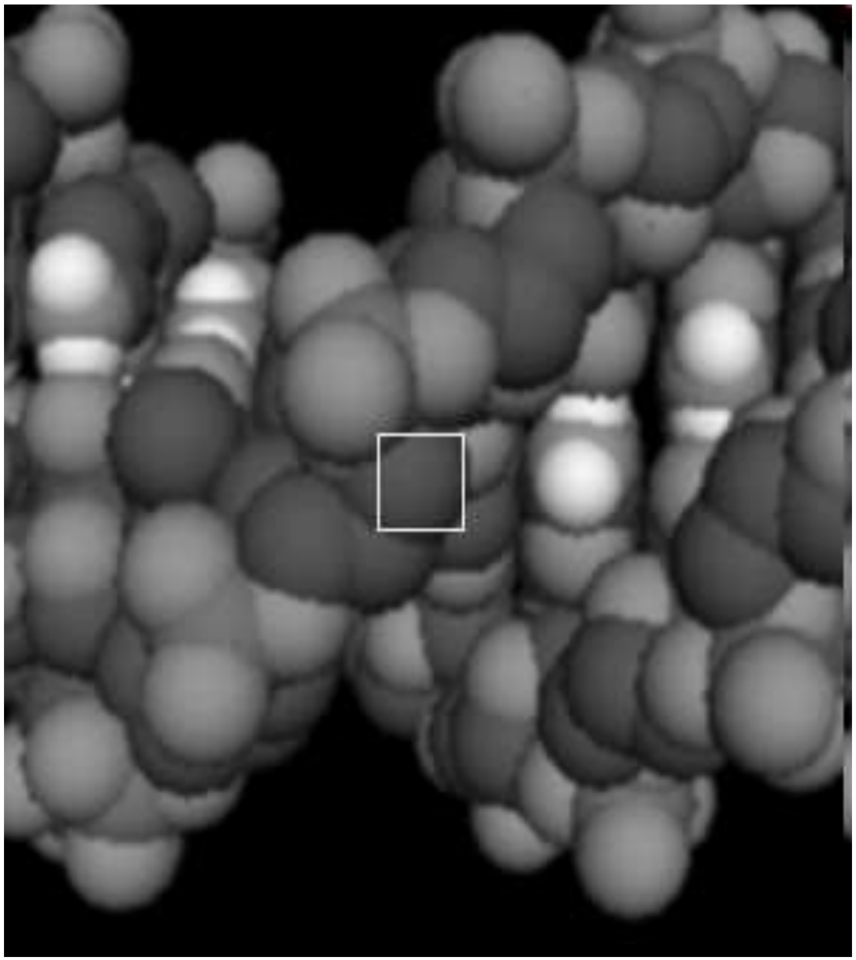
100 nanometers

UNDERSTANDING SIZE



10 nanometers

UNDERSTANDING SIZE



1 nanometer

How Big is a Nanometer?

Sugar cubes

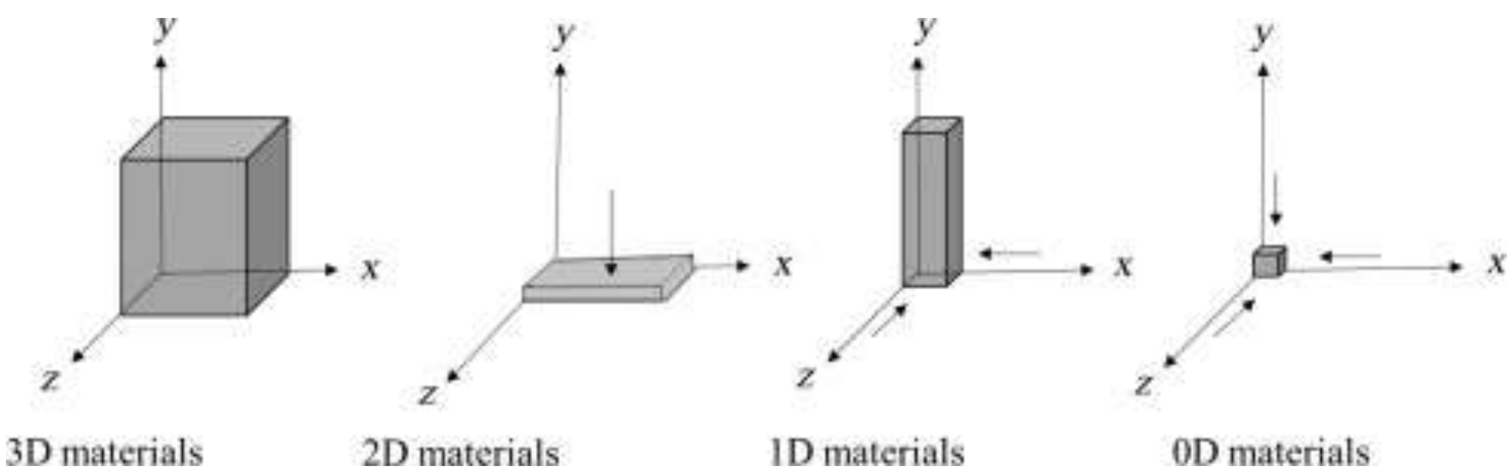
- **How many sugar molecules in a sugar cube?**
- **What do we need to know (estimate)?**
  - Sugar cube = $(1\ \text{cm})^3$
  - 1 sugar molecule = $(1\ \text{nm})^3$

- $\therefore$ 10^{21} sugar molecules in a sugar cube

Dimensions of nanomaterials

This classification is based on the number of dimensions of a material, which are outside the nanoscale (<100 nm) range

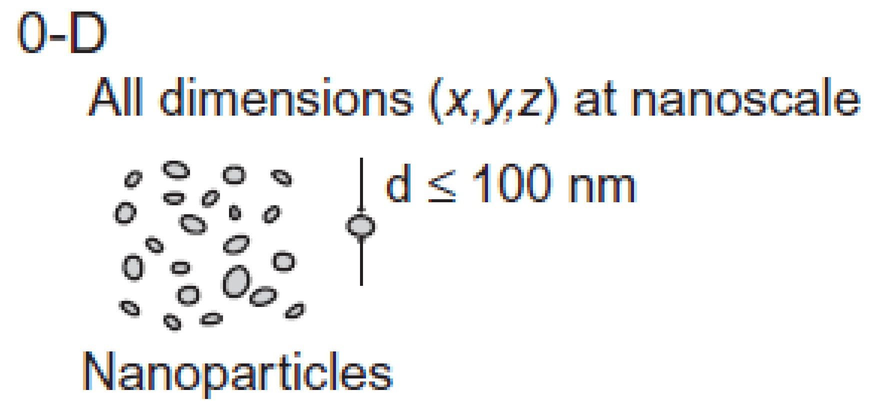
- (1) zero-dimensional (0-D),
- (2) one-dimensional (1-D),
- (3) two-dimensional (2-D), and
- (4) three-dimensional (3-D).



***zero-dimensional* (*0D*)**

all the dimensions are measured within the nanoscale (no dimensions are larger than 100 nm).

Most commonly, 0D nanomaterials are nanopar

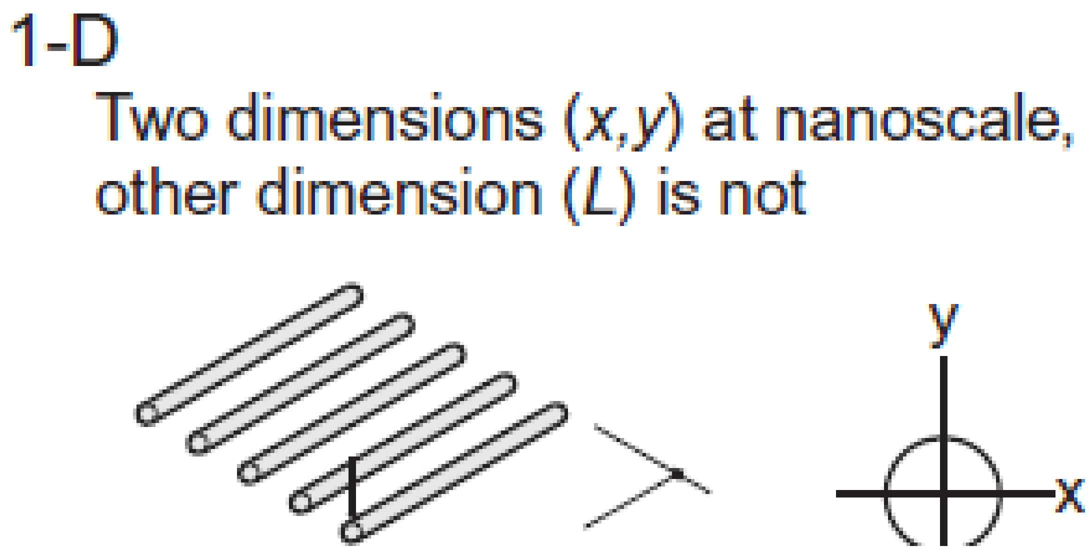


***one-dimensional* (*1D*):**

one dimension is outside the nanoscale.

This class includes nanotubes,

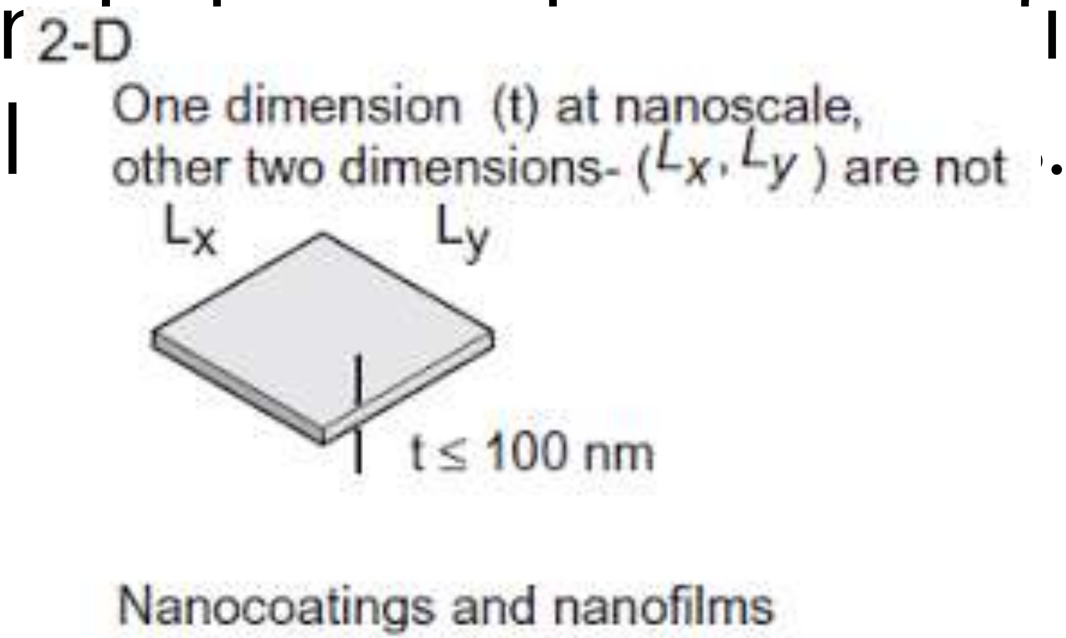
n



***Two-dimensional* (*2D*):**

two dimensions are outside the nanoscale.

This class exhibits plate-like shapes and ir ... ilms, nanol ... .



***Three-dimensional* nanomaterials (*3D*) :**

materials that are not confined to the nanoscale in any dimension. This class can contain bulk powders, dispersions of nanoparticles, bundles of nanowires, and nanotubes as well as multi-nanolayers.

Nanotechnology

What make technology at the nanoscale different from technology at the macroscale?

Physical Properties of Nanoparticles

Physical properties of nanoparticles are dependent on:

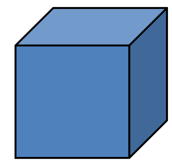
- Size
- Shape (spheres, rods, platelets, etc.)
- Composition
- Crystal Structure (FCC, BCC, etc.)
- Surface ligands or capping agents
- The medium in which they are dispersed

Unique Characteristics of Nanoparticles

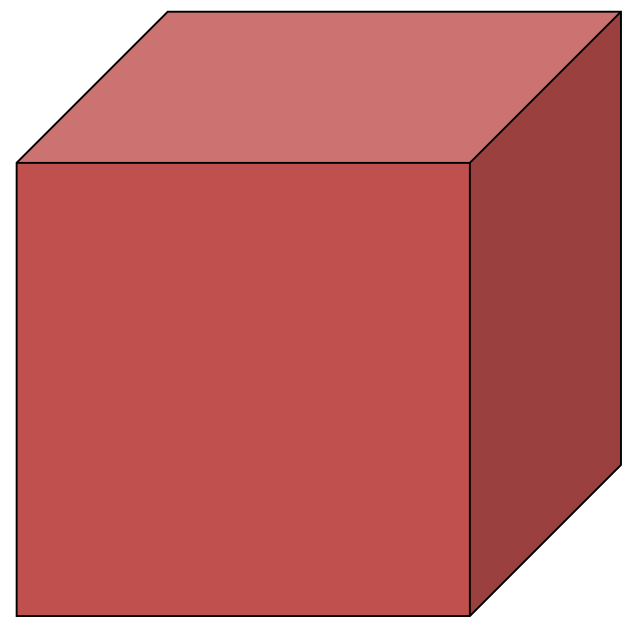
- Large surface to volume ratio
- High percentage of atoms/molecules on the surface
- Surface forces are very important, while bulk forces are not as important.
- Metal nanoparticles have unique light scattering properties and exhibit plasmon resonance.
- Semiconductor nanoparticles may exhibit confined energy states in their electronic band structure (e.g., quantum dots)
- Can have unique chemical and physical properties

Surface to Volume ratio

As objects get smaller they have a much greater surface area to volume ratio

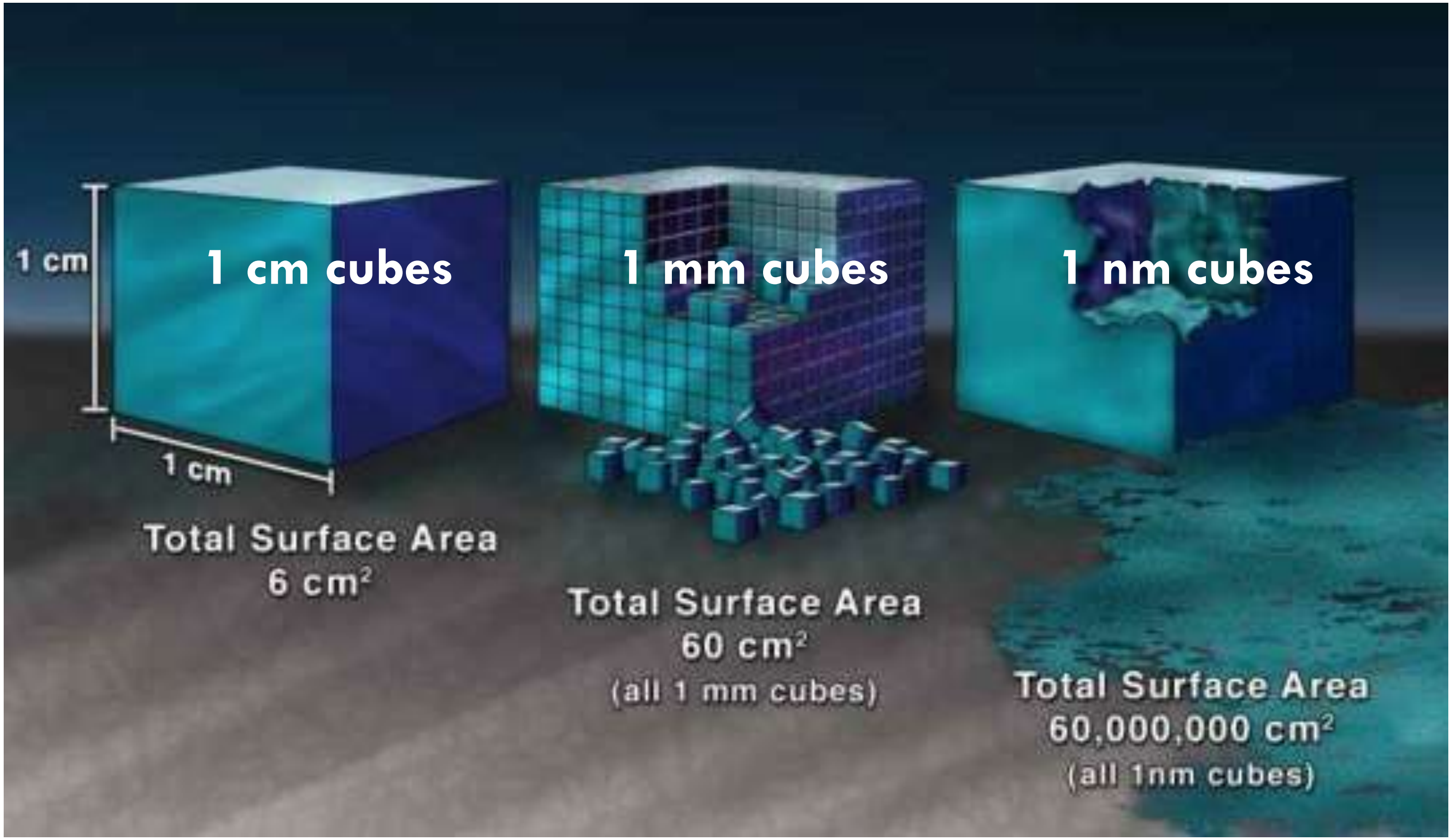


2 cm cube has a surface area of 24 cm^2 and a volume of 8 cm^3 (ratio = 3:1)



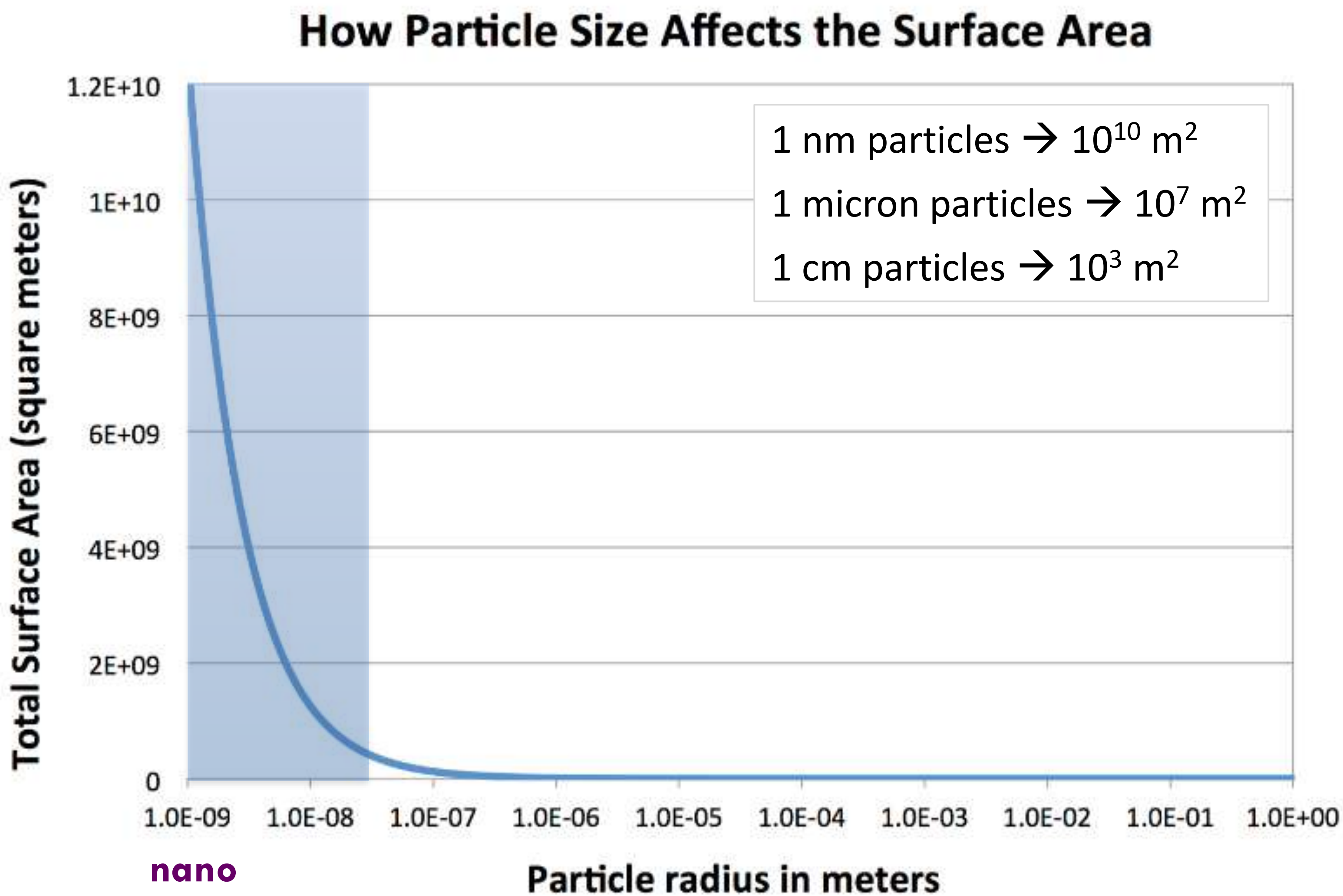
10 cm cube has a surface area of 600 cm^2 and a volume of 1000 cm^3 (ratio = 0.6:1)

Surface Areas at the Nanoscale



Crushing a 1cm particle into nano particles increases the surface area thousands of times!

How Surface Area Scales (Changes)



Smallness Leads to New Properties

At very small sizes physical properties of materials can change dramatically.

Reactivity

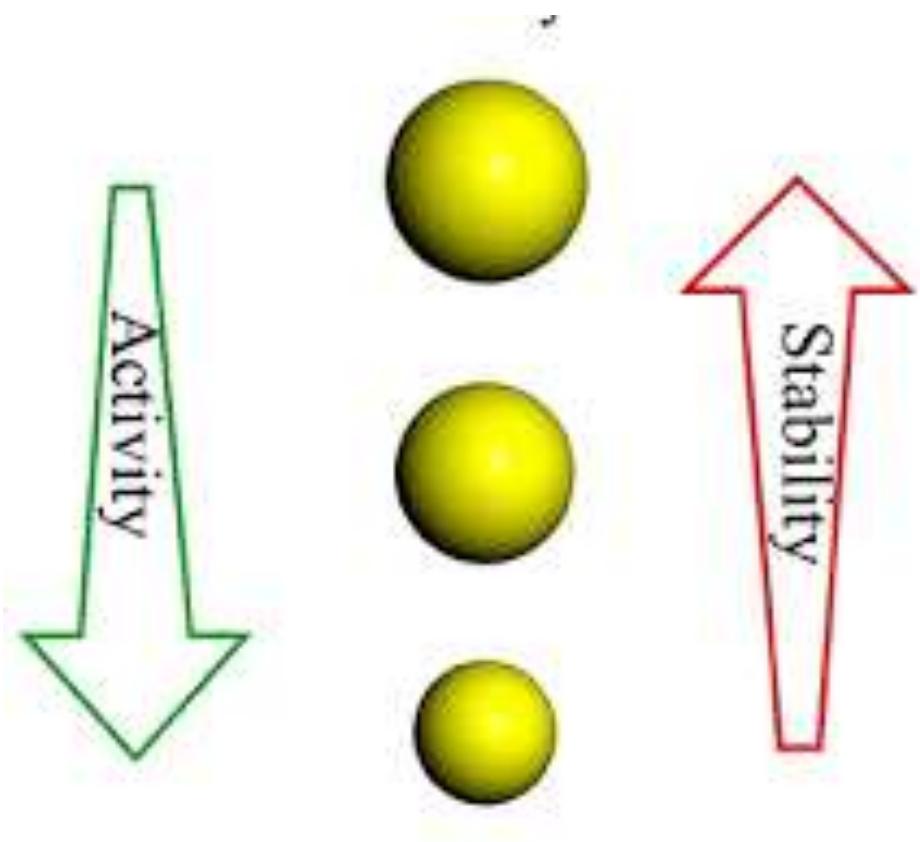
Melting point

Strength

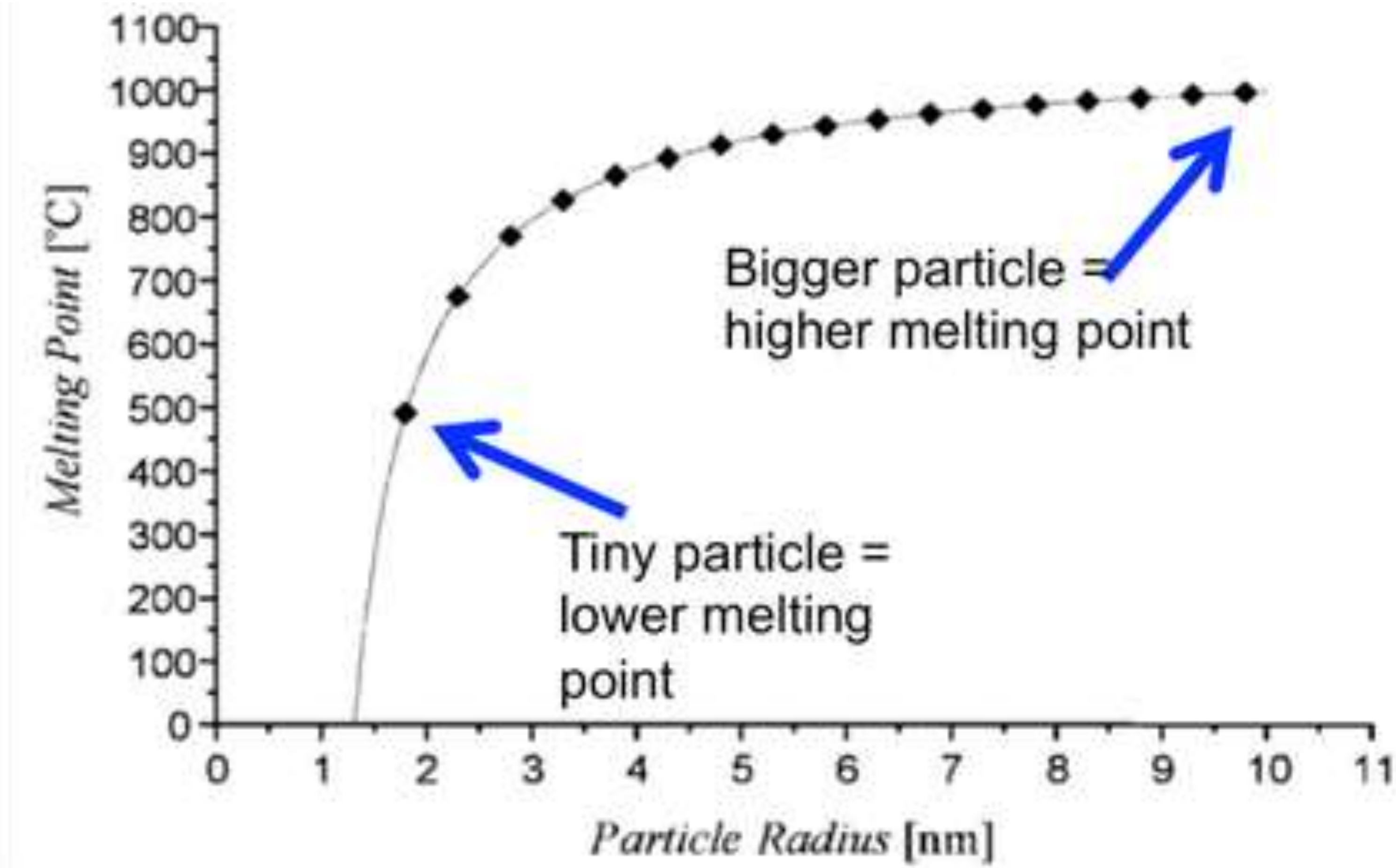
Conductivity

Color

- ✓ Nanoparticles has a large surface area than the bulk one. It enhances the number of reaction site.
- ✓ More surface area means more surface energy.
- ✓ Material with high energy will always unstable so it wants to share the energy with other sources.



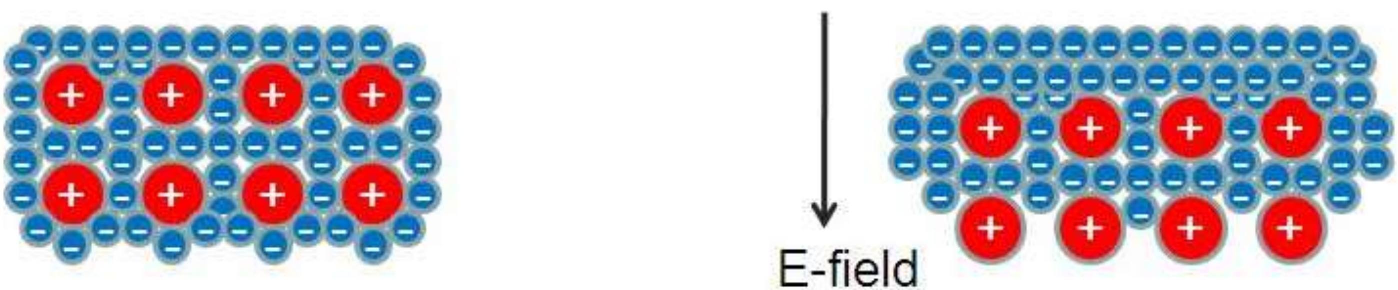
MELTING POINT



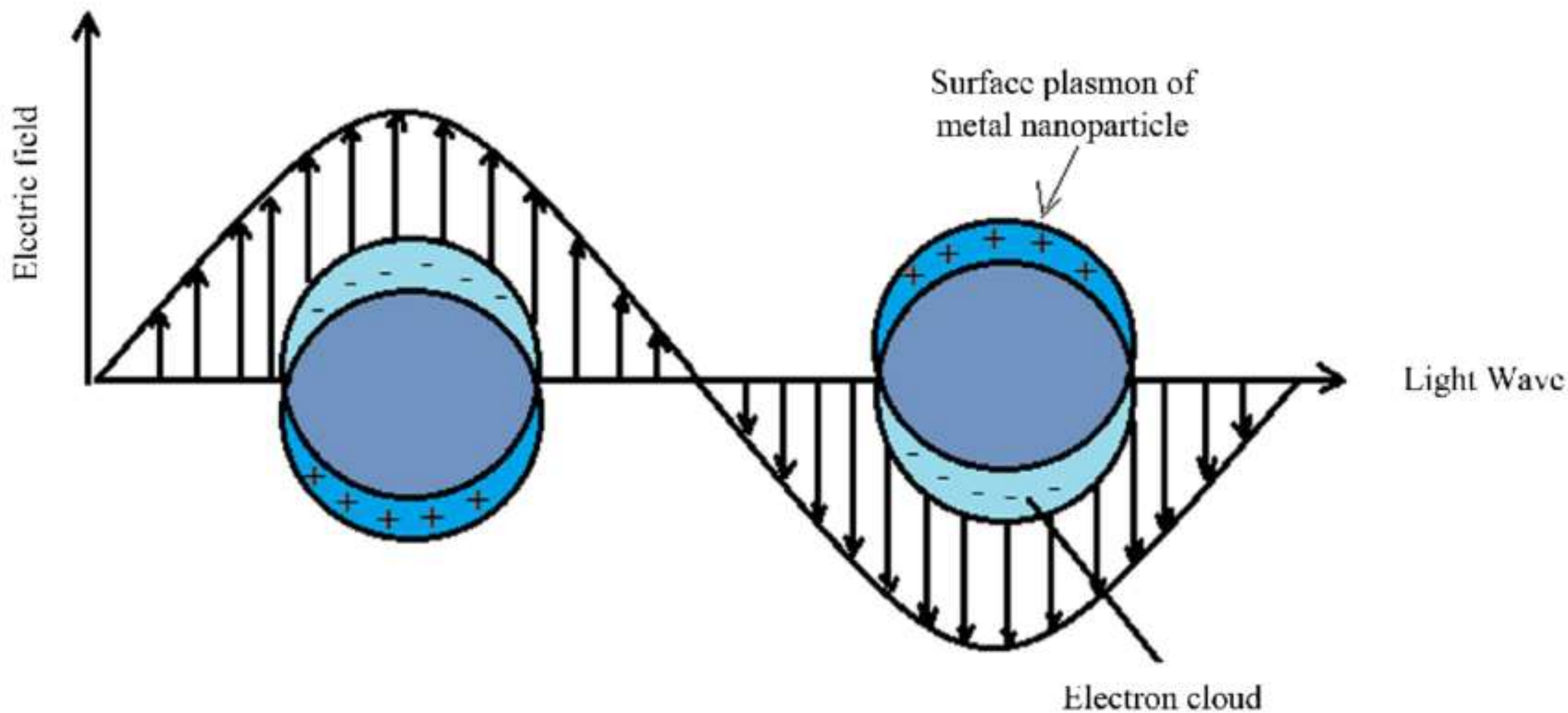
Optical properties

- The reduction of materials' dimension has pronounced effects on the optical properties
  - One is due to the increased energy level spacing →quantum size effect
  - the other is related to surface plasmon resonance.

- Surface Plasmons
  - Recall that metals can be modeled as an arrangement of positive ions surrounded by a sea of *free electrons.*
  - The sea of electrons behaves like a fluid and will move under the influence of an electric field

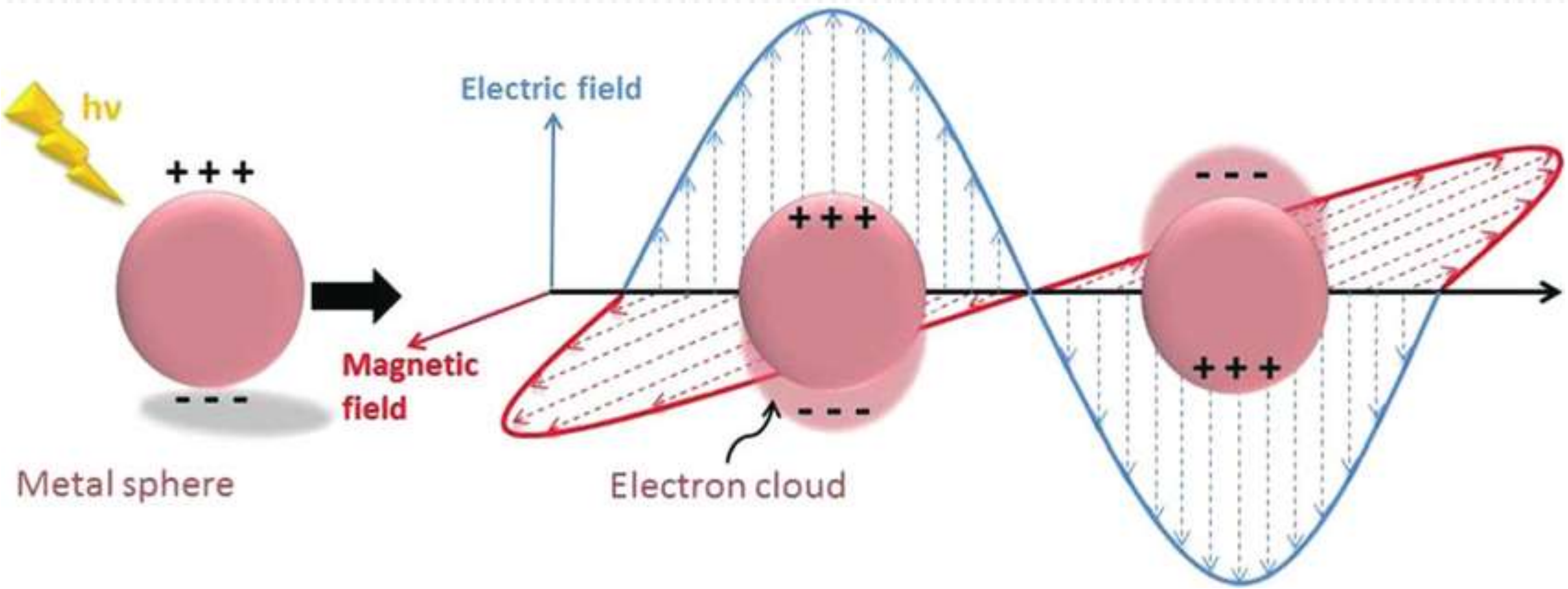


Plasmons are collective oscillations of the electrons which are present at the bulk and surface of conducting materials.



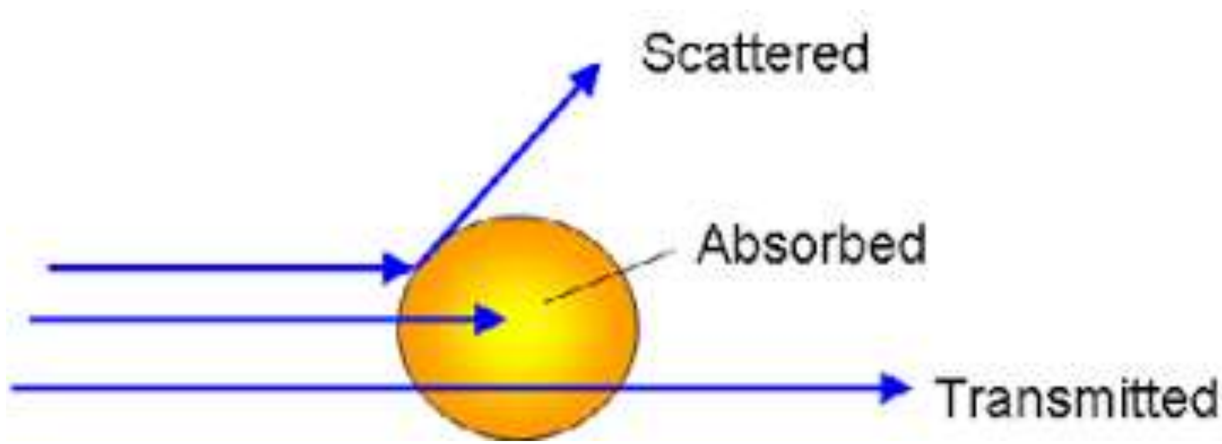
Surface plasmon resonance

When a nanoparticle is much smaller than the wave length of light, coherent oscillation of the conduction band electrons induced by interaction with an electromagnetic field. This resonance is called Surface Plasmon Resonance (SPR).

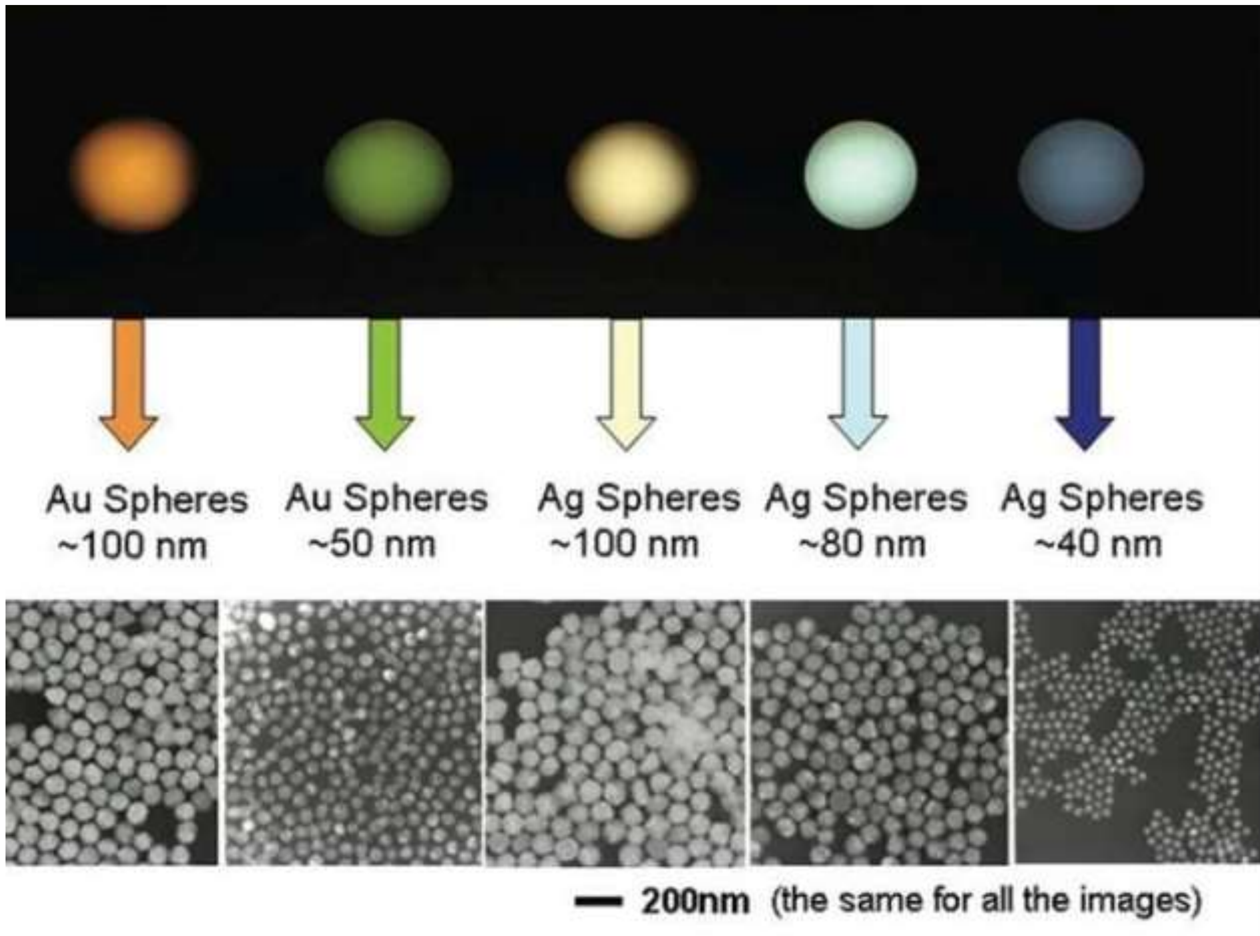


Surface plasmon resonance (SPR), results in the unusually strong scattering and absorption of light.

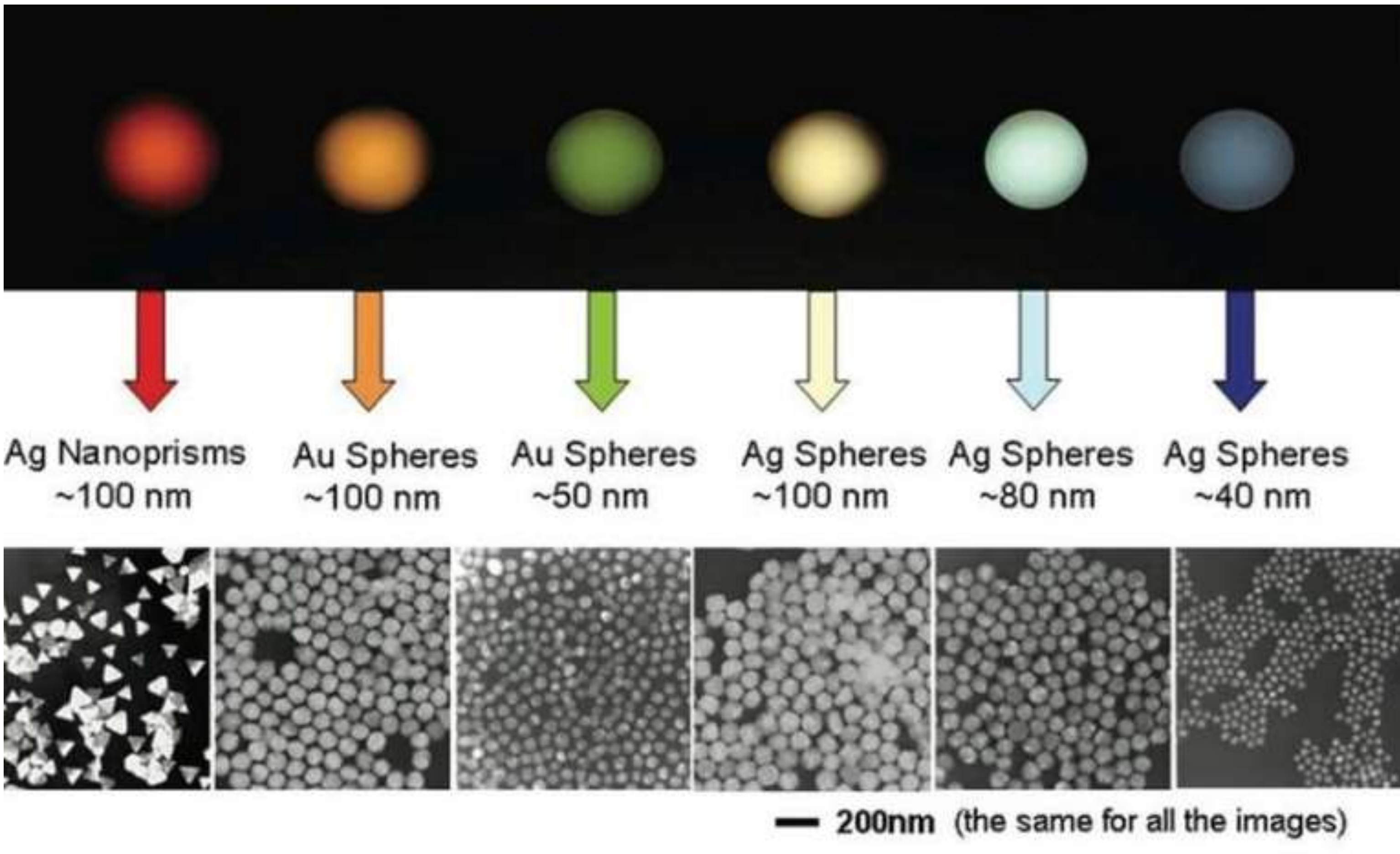
The nanoparticle optical properties are highly dependent on material composition, size, and the medium in which the particles are embedded.



Stained Glass: Size and Shape Matter

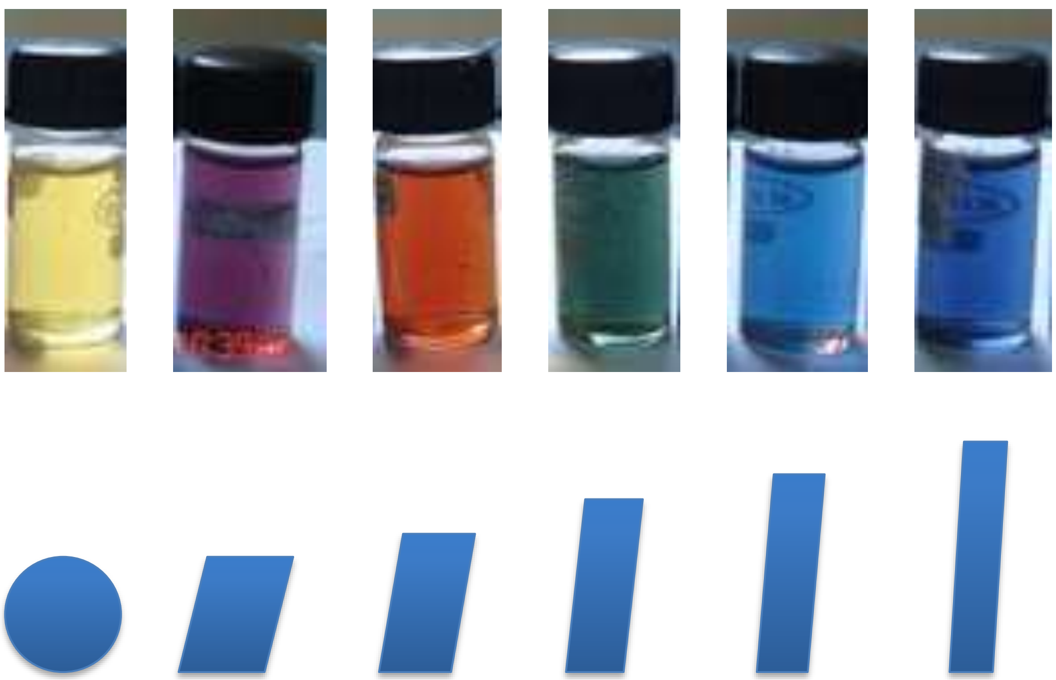


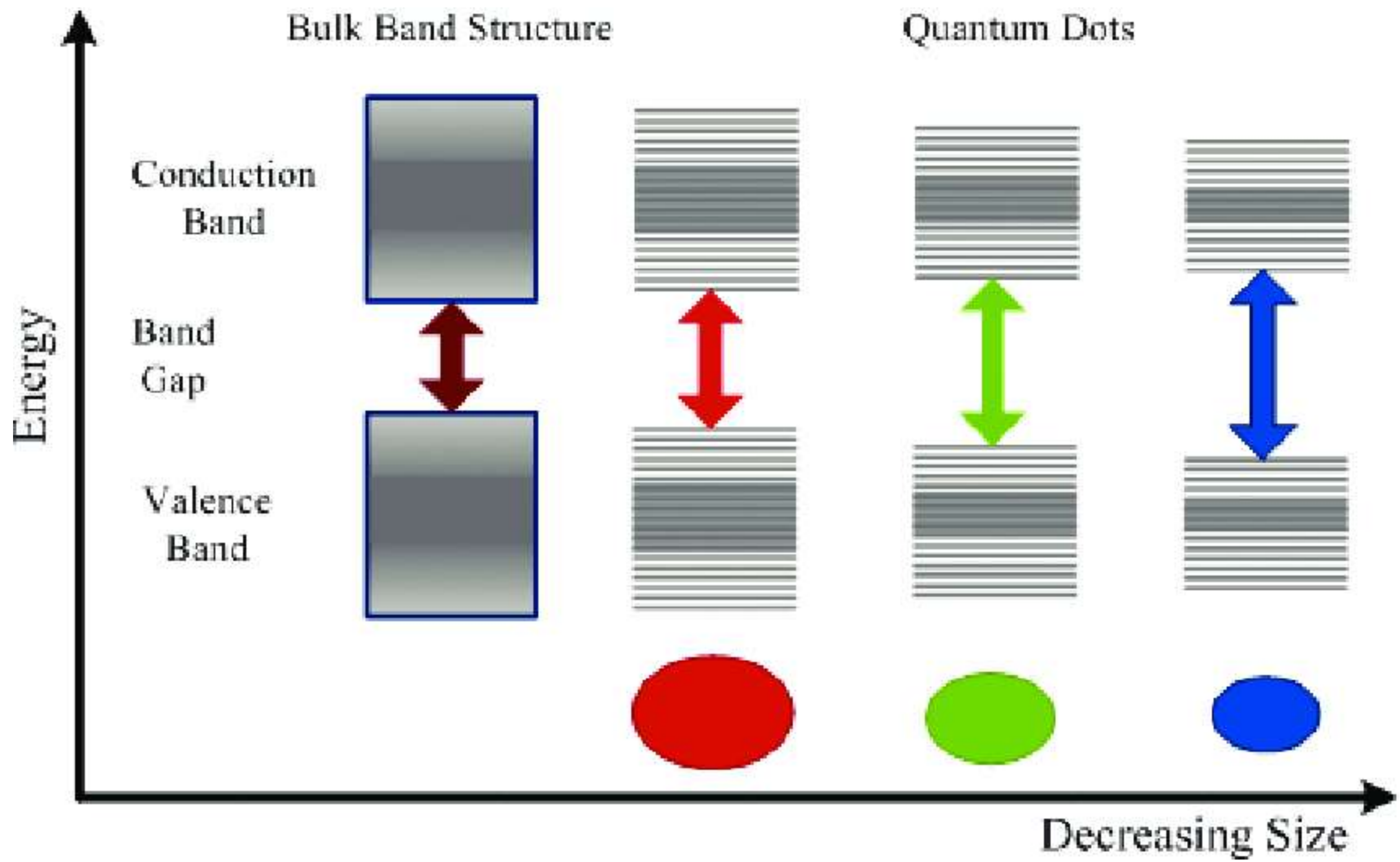
Stained Glass: Size and Shape Matter



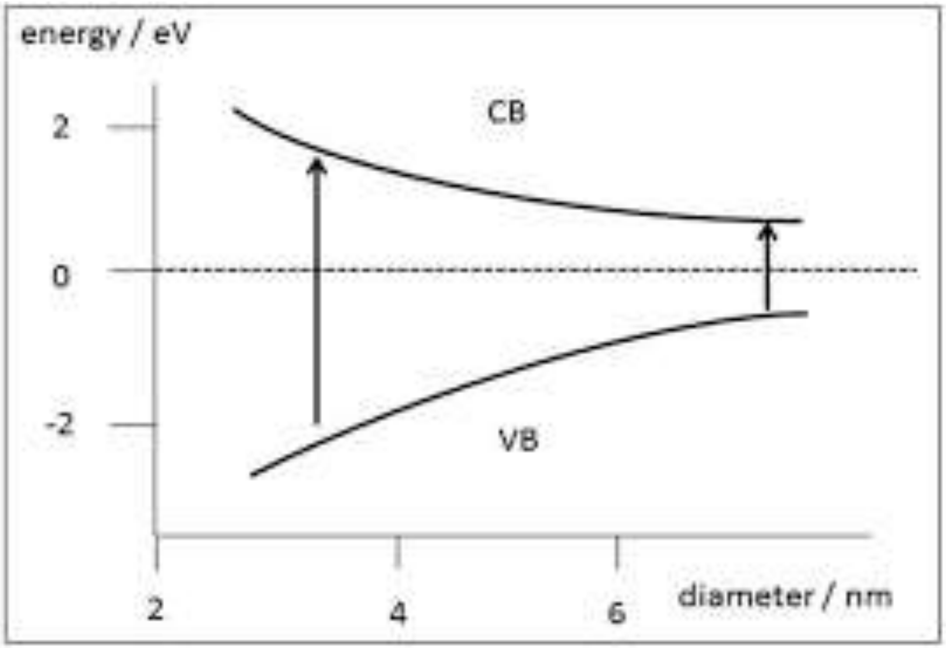
Stained Glass: Size and Shape Matter

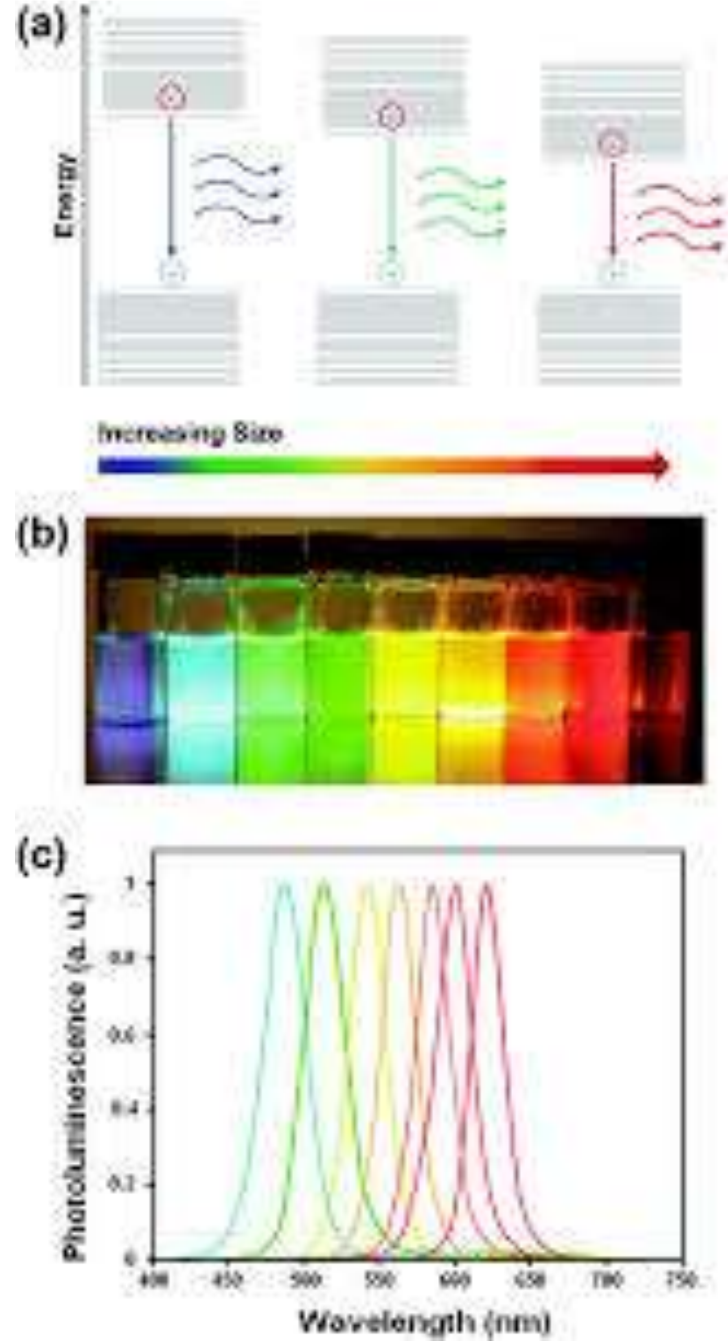
Particle shape also affects the color!





Bulk Band Structure
Quantum Dots
Conduction Band
Band Gap
Valence Band
Energy
Decreasing Size

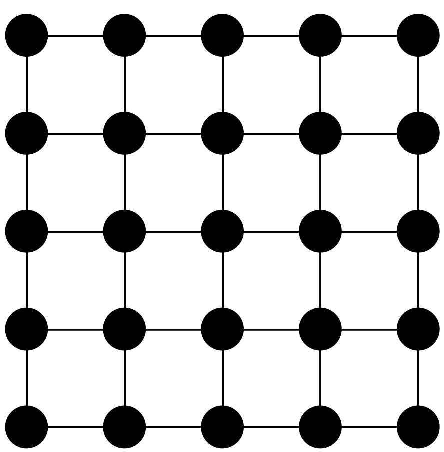

energy / eV
2
0
-2
CB
VB
2
4
6
diameter / nm


(a)
Energy
Increasing Size
(b)
(c)
Photoluminescence (a. u.)
Wavelength (nm)

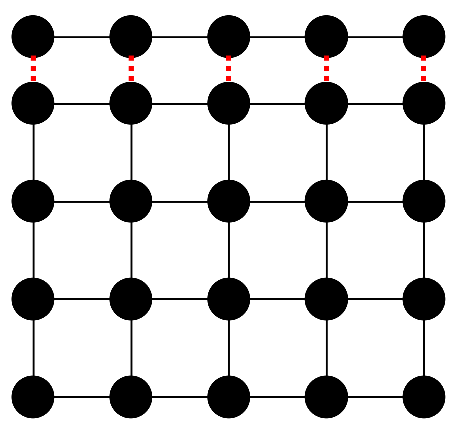
Altered Lattice Constants

- Compare lattice structure of nano and bulk materials
- Shortening of bonds near the surface
- Surface reconstruction

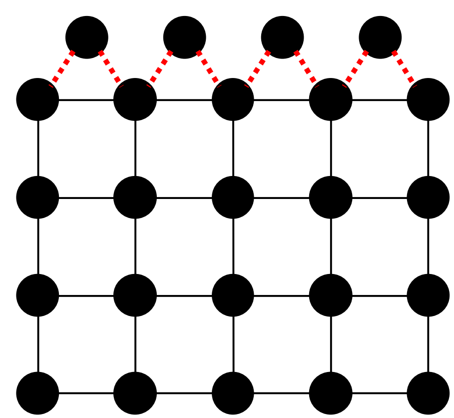
Original Structure



Shortened Surface Bonds

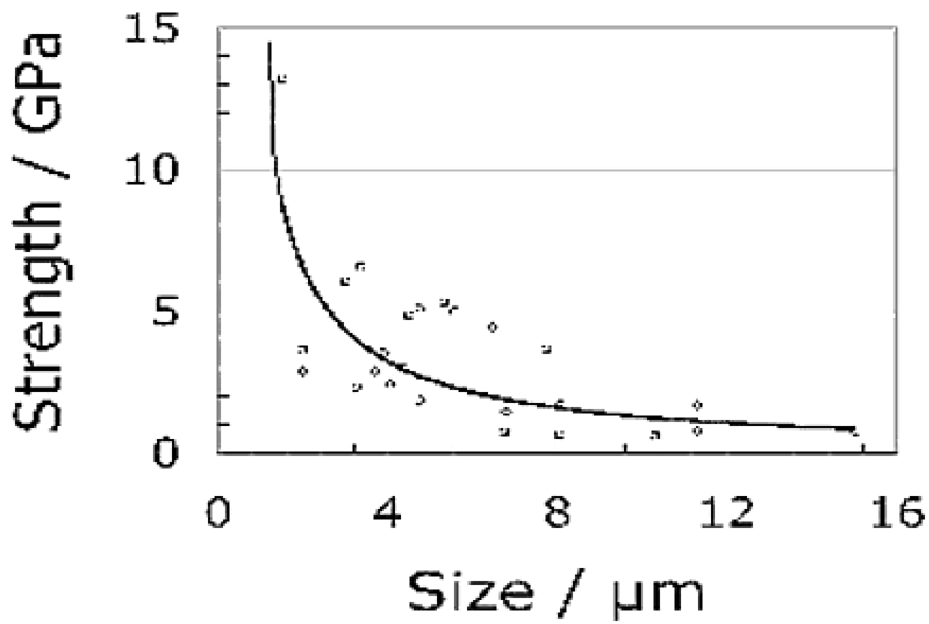


Shifted Surface Bonds



Influence on mechanical properties:

- Increased Hardness,
- Higher Young modulus and tensile strength (to 4 times higher)
- Lower plastic deformation



The tensile strength of whiskers of Iron
H.K.D.H. Bhadeshia Ironmaking and Steelmaking, 32 (2005) 405-410