Engineering Physics

(PHY1701)

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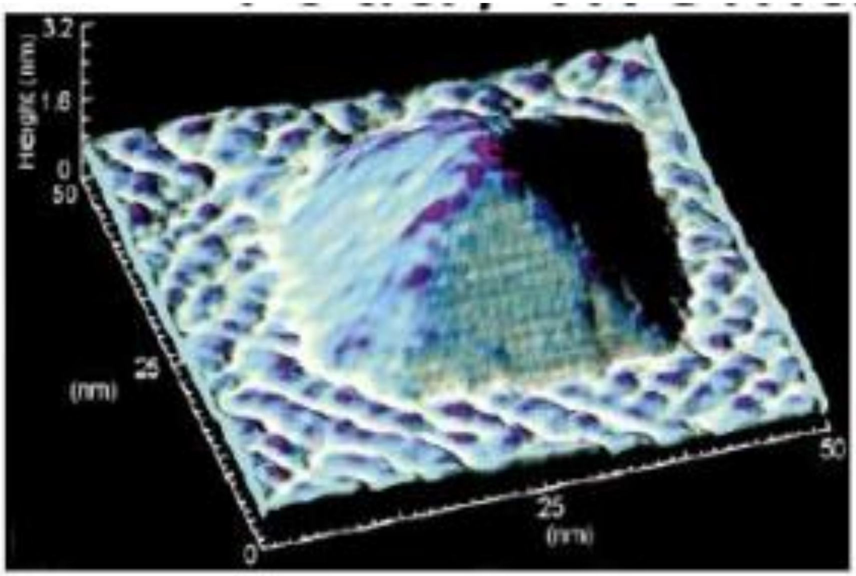
Contents

- Introduction to Nano-materials,
- Moore's law,
- Properties of Nano-materials*,
- Quantum confinement, Quantum well, wire & dot (CF 226-236),
- Carbon Nano-tubes (CNT) (CF 115-125), &
- Applications of nanotechnology in industry

❖ Introduction to Nano Technology, Charles P Poole Jr., Frank J Owens, Willey Publication. (CF)

Once upon a time …….Big is good

Today…… smaller is better

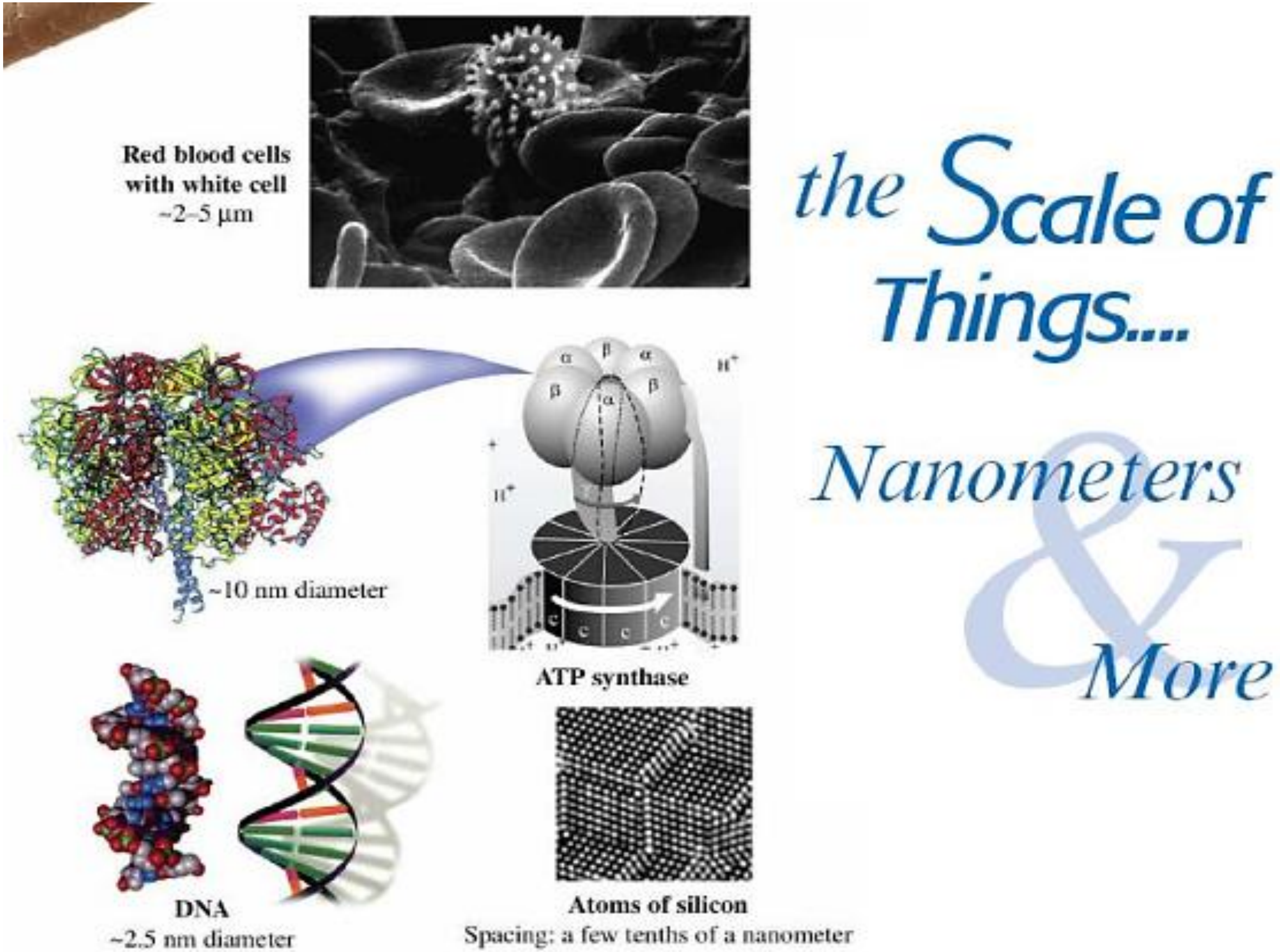


Modern Pyramids. This nanoscale pyramid of Ge atoms— one kind of quantum dot—formed spontaneously on Si.

Writing With Atoms. Written literally with atoms, the Chinese characters above—each just a few nanometers across—means "atom."

Scale of nanometers

Scale of nanometers



Richard Feynman ("Father of Nanotechnology")

December 29th 1959 at the annual meeting of the American Physical Society at the California Institute of Technology (Caltech)

'There's plenty of room at the bottom'

Feynman explored the possibility of manipulating material at the scale of individual atoms and molecules, imagining the whole of the Encyclopaedia Britannica written on the head of a pin and foreseeing the increasing ability to examine and control matter at the nanoscale.

Feynman: 1965, Nobel Physics
"for their fundamental work in quantum electrodynamics, with deep-ploughing consequences for the physics of elementary particles"

Ancient History of Nanotechnology

Lycurgus cup :
currently located in British Museum, London
Made in Rome period at BC 4th century

This extraordinary cup is the only complete example of a very special type of glass, known as dichroic, which changes colour when held up to the light. The opaque green cup turns to a glowing translucent red when light is shone through it. The glass contains tiny amounts of colloidal gold and silver, which give it these unusual optical properties.

Stained glasses in middle age churches

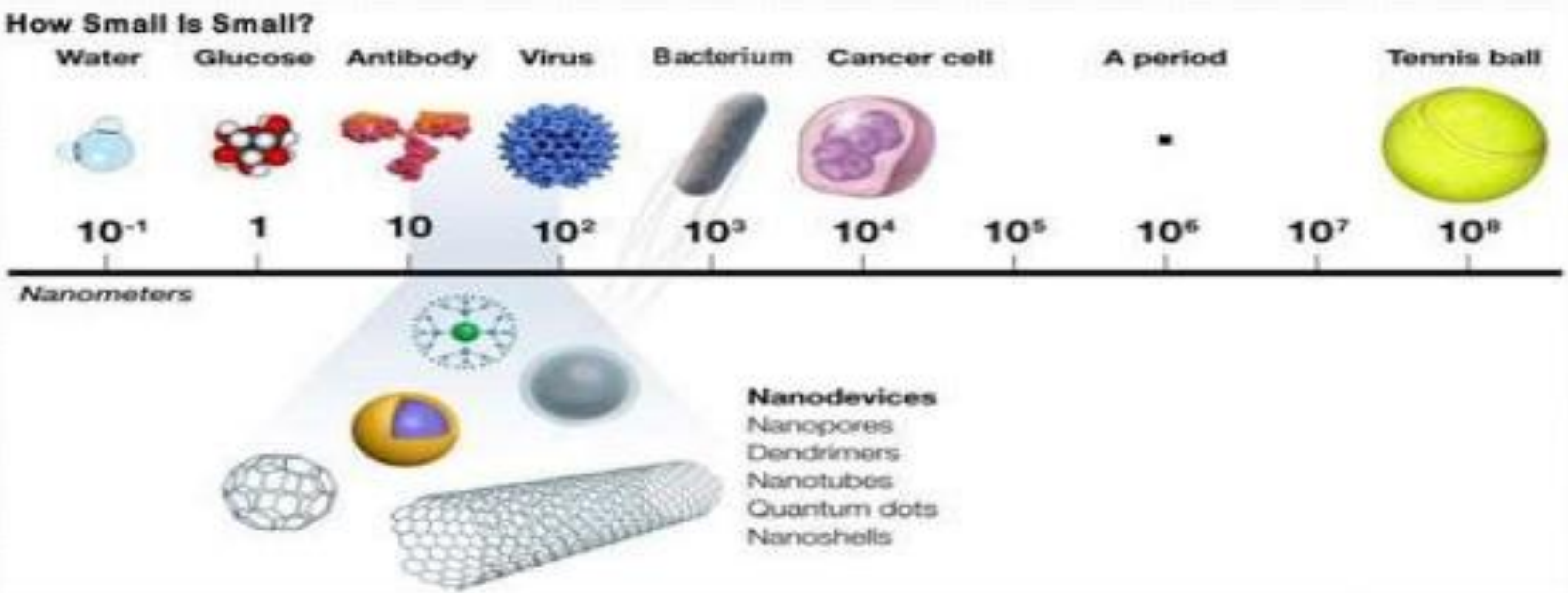
Color of glass changed, due to nanoparticles contained in the glass

INTRODUCTION

- A nanometer in one thousand millionth of a mater (i.e. 10^{-9} m). Single atom can vary from 0.1 nm to 0.5 nm depending on the type of the element.
- ***Nano particles*** are the particles with in size ranging from 1 – 50nm.
- ***Nano materials*** are the materials having components with in size 1nm to 100nm in one dimension.
- ***Nano technology*** is the manipulation of mater on molecular and atomic scale and study the use of structures between 1nm to 100nm
- Nanotechnology takes advantage of different material properties at the nanoscale to make new materials and tiny devices.
- Nanotechnology allows scientists and engineers to make other things like smaller, faster computer chips and new medicines to treat diseases like cancer.
- Nanotechnology may be able to create many new materials and devices with a vast range of applications.

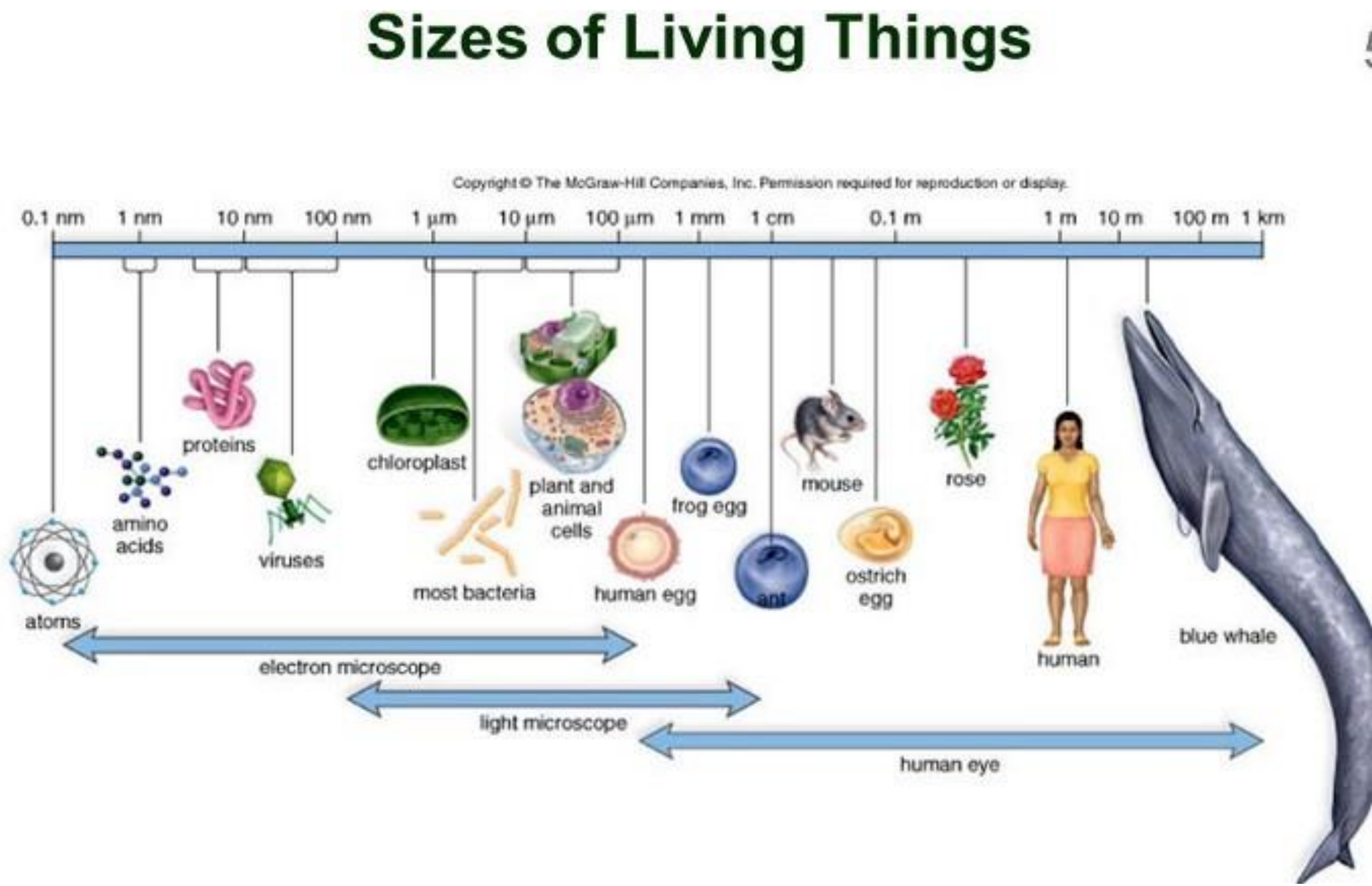
SO WHAT IS NANO?

- NANO is a *GREEK* word meaning *EXTREMELY SMALL*.
- Nanotechnology deals with sizes from 1-100nm range
- A nanometer is very very small its 10^{-9} m.

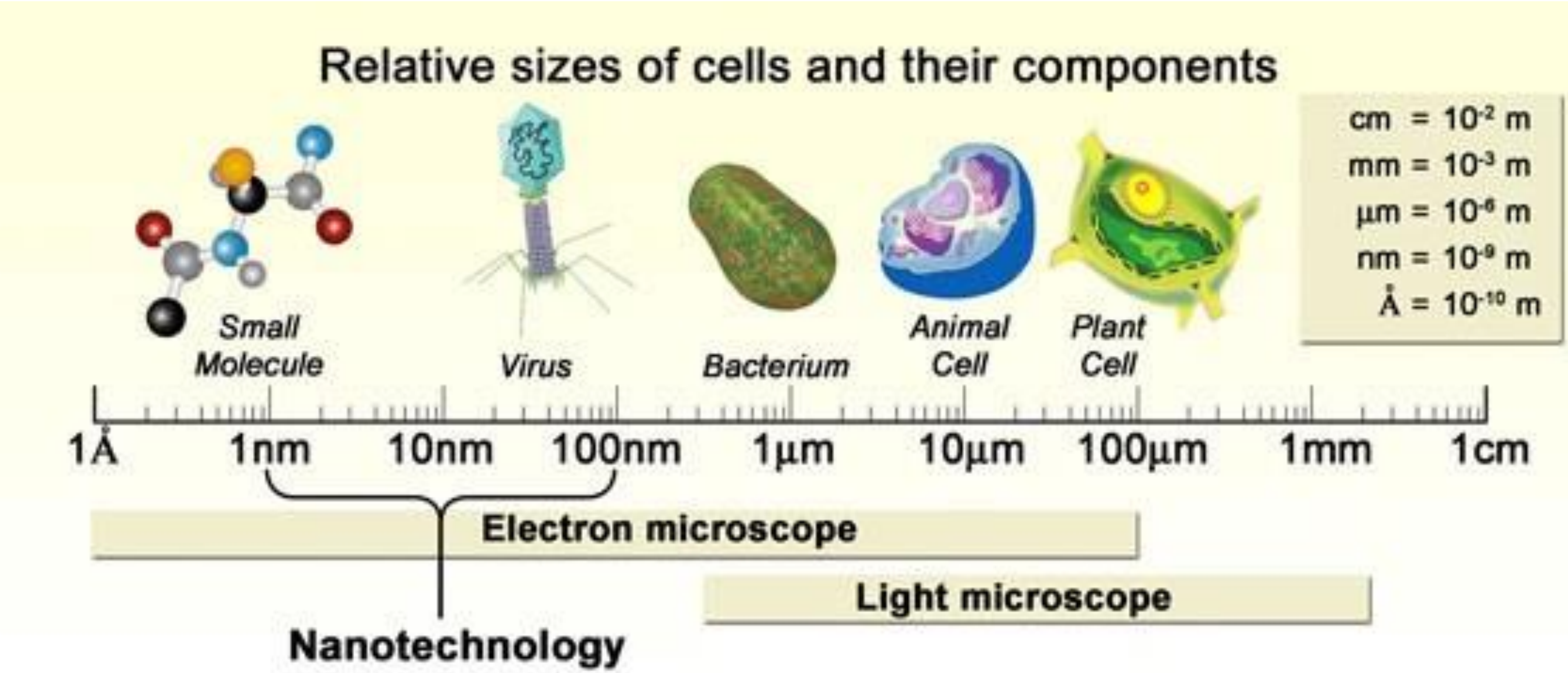


- 1 carbon atom $\approx 0.15\ nm$
- H_2O molecule $\approx 0.3\ nm$
- 1 RBC $\approx 7000\ nm$
- Human hair $\approx 80{,}000\ nm$

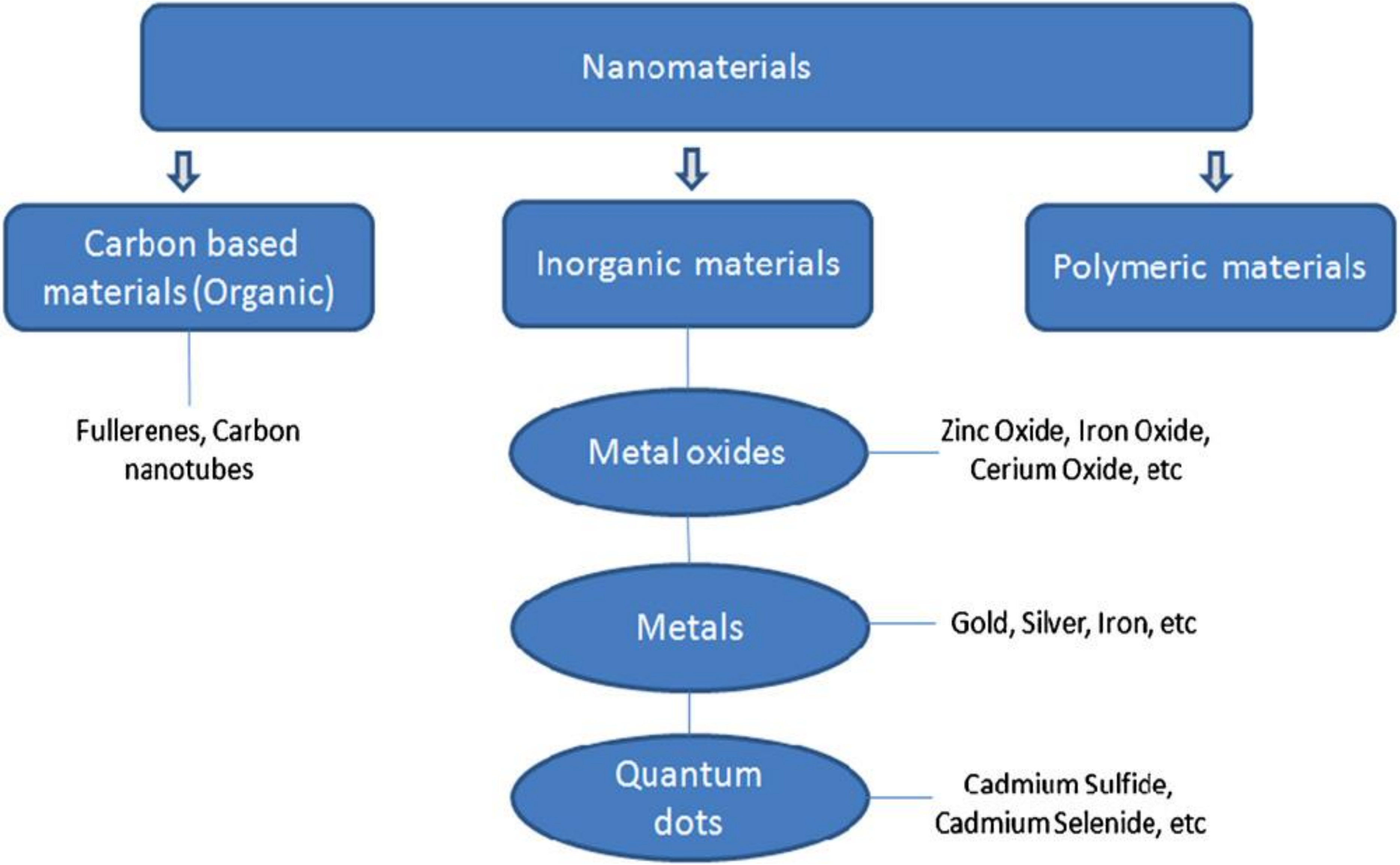
Comparison of sizes of Living things



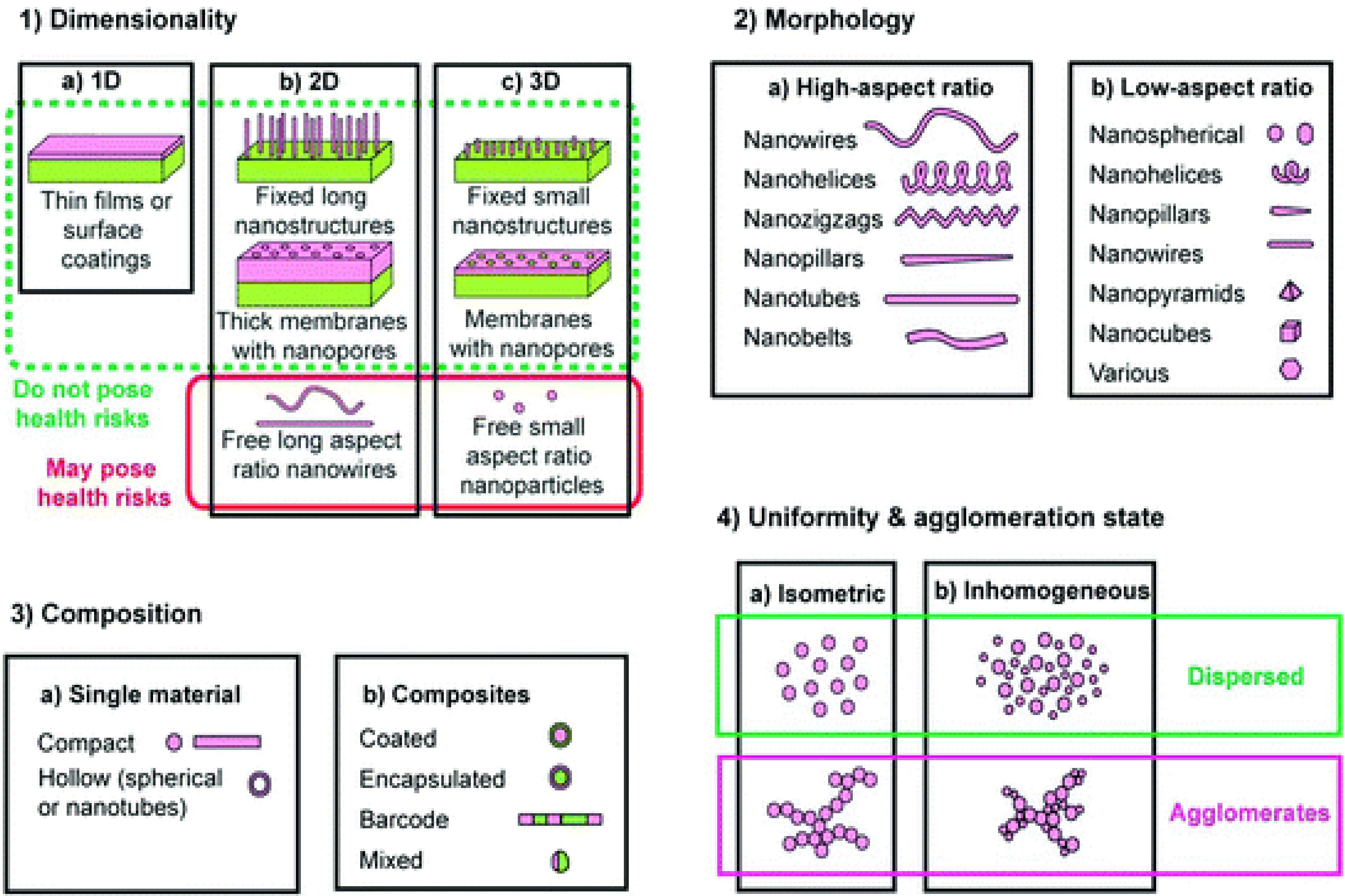
Comparison of different sizes of cells



Broad Classification



General classification



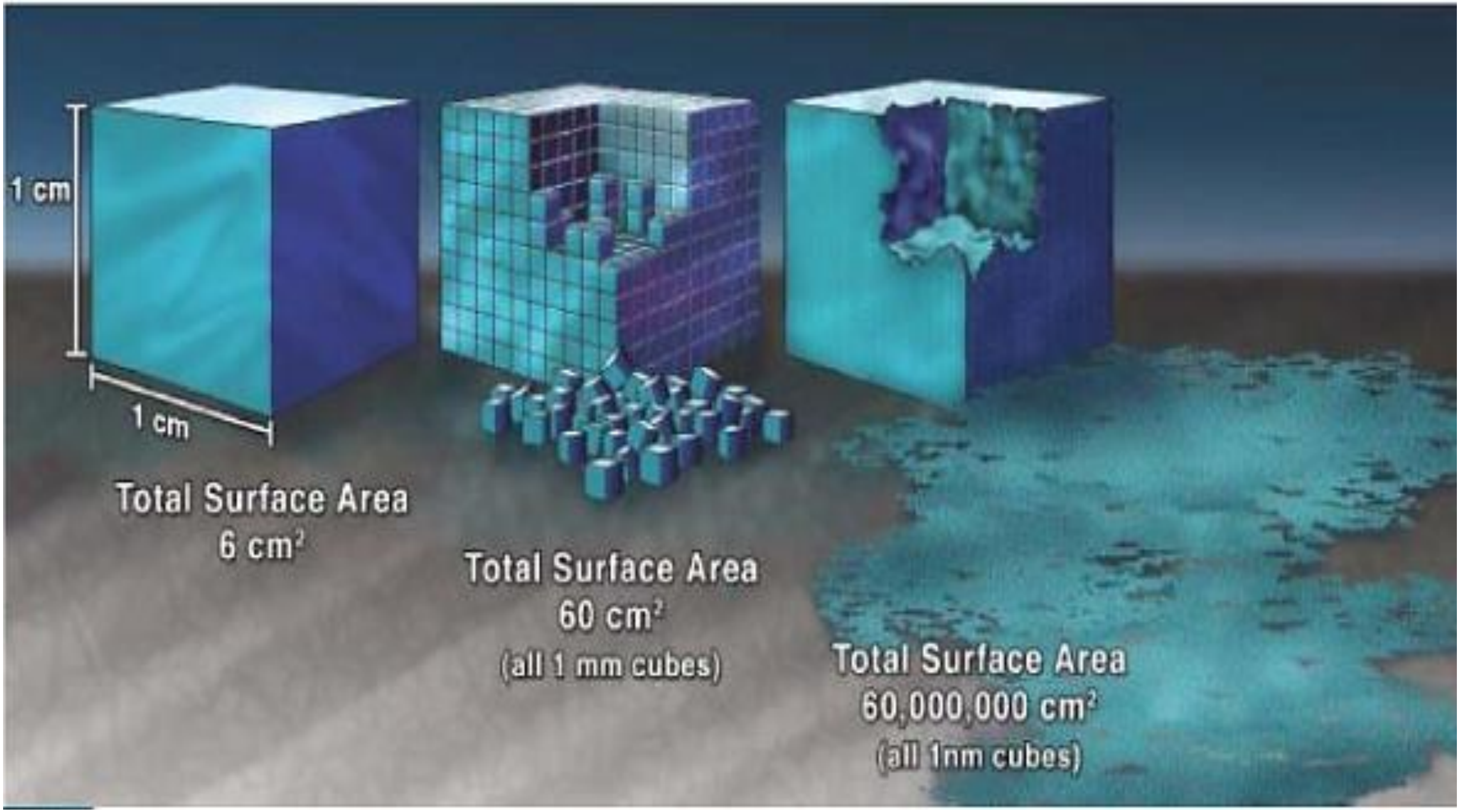
Unique Properties

Two principal factors cause the properties of nanomaterials to differ significantly from Bulk materials :

- ❑Increased relative surface area
- ❑Quantum effects

These factors can change or enhance properties such as reactivity, strength and electrical characteristics.

Surface to Volume ratio



Surface Effects

- The surface to volume ratio follows an inverse power law
- The fraction of atoms on the surface increases with decreasing the size
- Large surface is favorable for applications such as catalysis.
- As a particle decreases in size, a greater proportion of atoms are found at the surface compared to those inside.
- For example, a particle of
  - Size-30 nm-> 5% of its atoms on its surface
  - Size-10 nm->20% of its atoms on its surface
  - Size-3 nm-> 50% of its atoms on its surface

Nanoparticles are more reactive than large particles (Catalyst)

Surface to Volume ratio

Cubic:

Surface area $S = 6a^2$

Volume $V = a^3$

Surface area to volume ratio

$$\frac{S}{V} = \frac{6a^2}{a^3} = \frac{6}{a}$$

Sphere

Surface area $S = 4\pi R^2$

Volume of sphere $V = \frac{4}{3}\pi R^3$

Surface to volume ratio $\frac{S}{V} = \frac{4\pi R^2}{\frac{4}{3}\pi R^3} = \frac{3}{a}$

Increase in surface area

Imagine a sphere of radius R=1cm. How many no. of tiny spheres of radius r=1nm is possible from the material?

$$\frac{4}{3}\pi R^3 = \frac{4}{3}\pi r^3$$

$$\text{i.e. } R^3 = N\, r^3$$

$$N = \frac{R^3}{r^3} = \frac{1cm^3}{1nm^3} = \frac{10^{-6}m^3}{10^{-27}m^3} = 10^{21}$$

10^{21} tiny 1 nm spheres are formed.

Increase in surface area

Total surface area available on these particles:

Surface area of the big sphere

$$S = 4\pi R^2 = 4\pi(10^{-2}\ m)^2 = 4\pi(10^{-4})\ m$$

Surface area of the tiny sphere

$$S = 4\pi r^2 = 4\pi(10^{-9}\ m)^2 = 4\pi(10^{-18})\ m$$

There are 10^{21} numbers of tiny spheres,

so their total surface area

$$s_t = 10^{21} \times 4\pi(10^{-18})\ m = 4\pi 10^3\ m^2$$

So, $\frac{s_t}{S} = \frac{4\pi \times 10^3\, m^2}{4\pi \times 10^{-4}\, m^2} = 1 \times 10^7$

The surface area has increased by a factor of 10 million times.

Increase in surface area

- Nanoparticles exhibit unique properties due to their high surface area to volume ratio.
- A spherical particle has a diameter (D) of 100nm.
  - Calculate the volume (V) and surface area (SA)

$$V = \frac{4}{3}\pi r^3 = \frac{\pi D^3}{6}$$

$$V = \frac{\pi(100 \times 10^{-9})^3}{6}$$

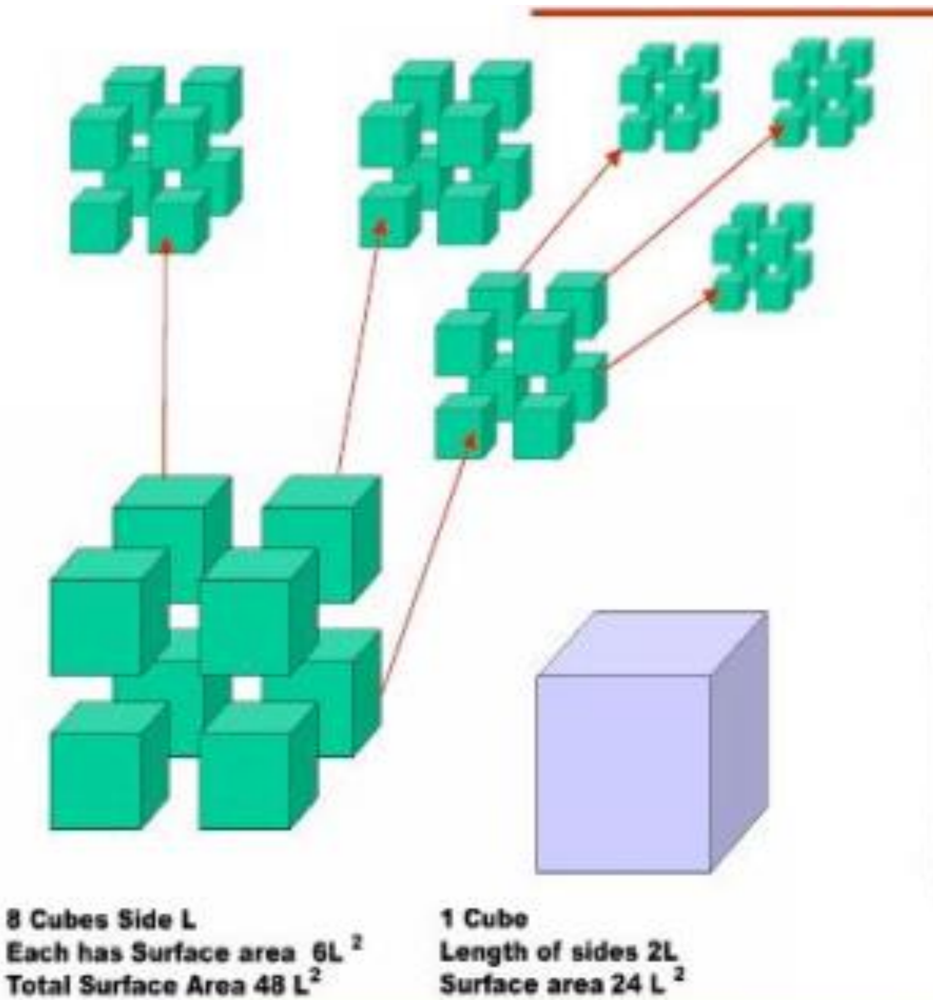
$$V = 5.24x10^{-22} m^3$$

$$SA = 4\pi r^2 = \pi D^2$$

$$SA = \pi(100 \times 10^{-9})^2$$

$$SA = 3.141 \times 10^{-14} m^2$$

Increase in surface area



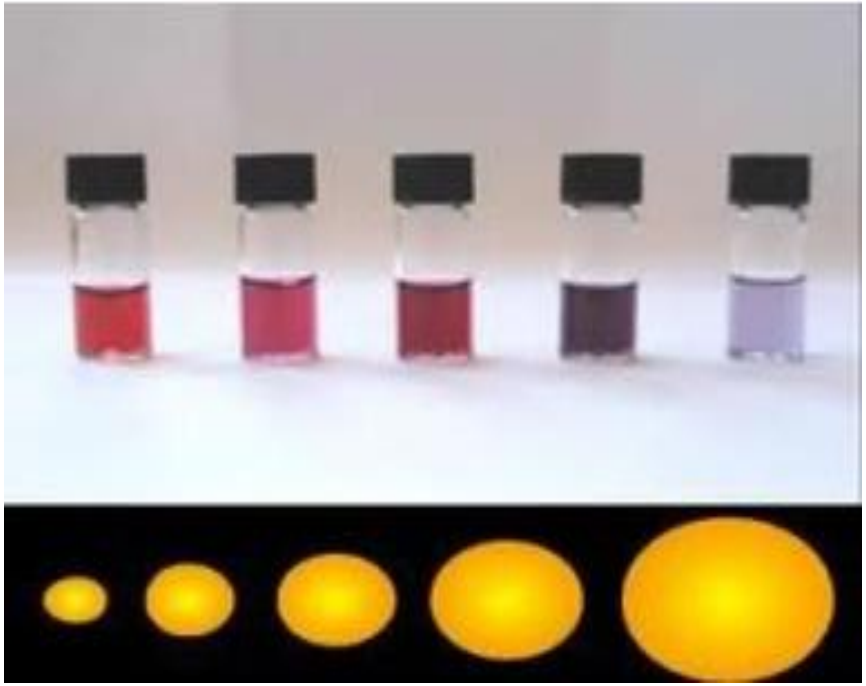
For example, 5 cubic centimeters - about 1.7 cm per side - of material divided 24 times will produce 1 nanometer cubes and spread in a single layer could cover a football field

Quantum confinement

- Quantum effects can begin to dominate the behaviour of matter at the nanoscale – particularly at the lower end - affecting the optical, electrical and magnetic behaviour of materials.
- When the particle size is comparable to the debroglie wavelength of electrons or mean free path of electrons, the energy levels of electron changes leading to an effect – quantum confinement characteristics.
- The quantum confinement effect can be observed once the diameter of the particle is of the same magnitude as then wavelength of the electron Wave function.
- Quantum confinement is responsible for the increase of energy difference between energy states and band gap.

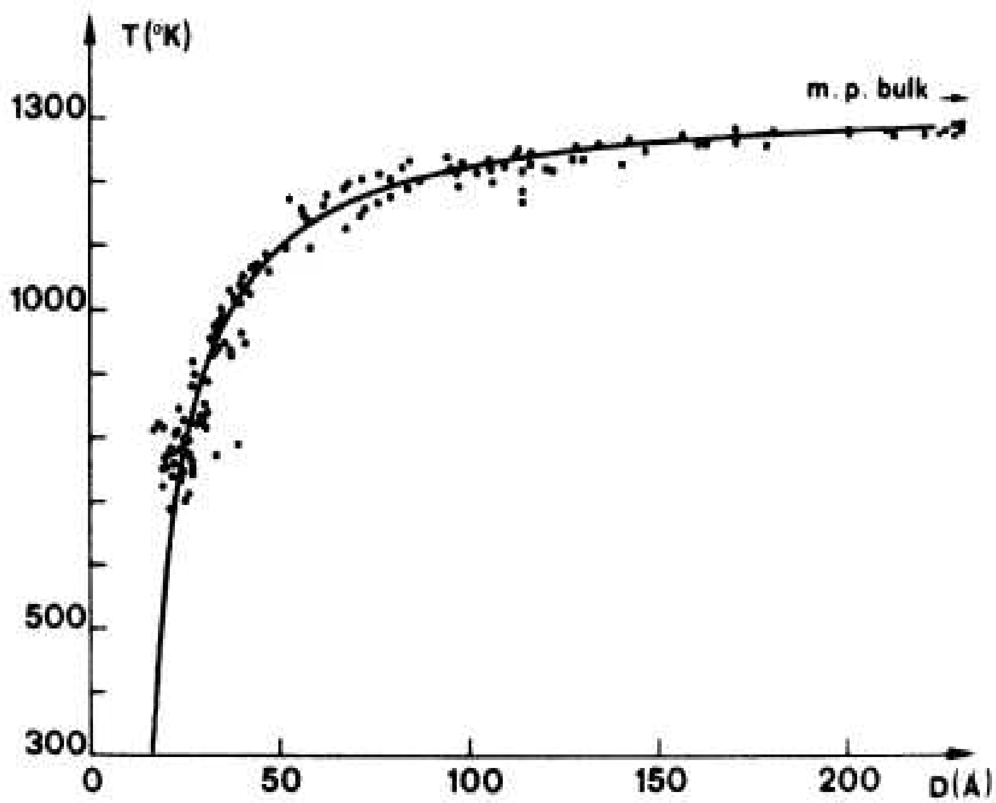
Quantum confinement

- A phenomenon tightly related with the optical and electronic properties of the materials.
- When materials are this small, their electronic and optical properties deviate substantially from those of bulk materials.(GOLD)



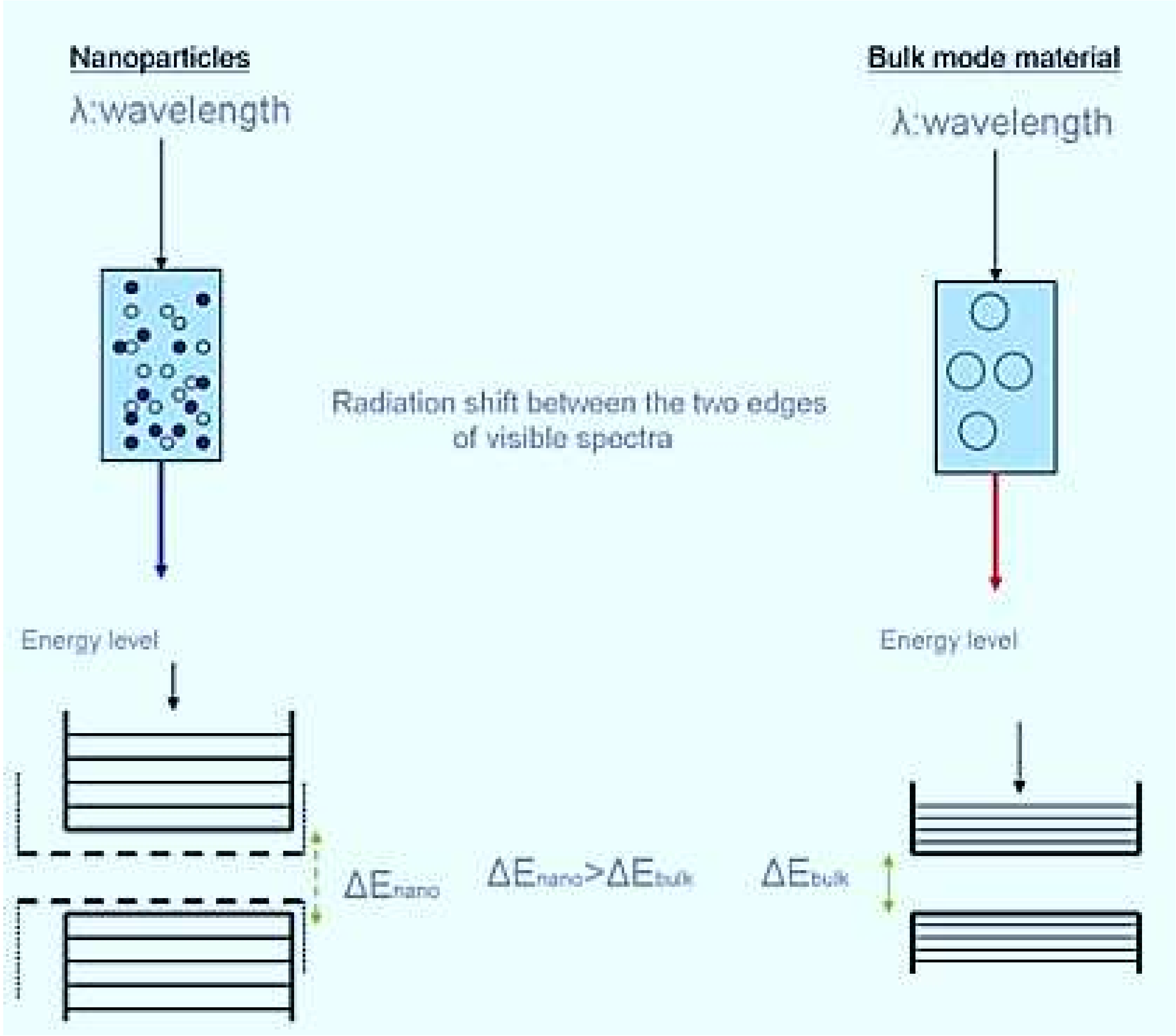
Melting point as a function of particle size

- Nanoparticles have a lower melting point than their bulk counterparts



Melting point of gold nanoparticles as a function of size.

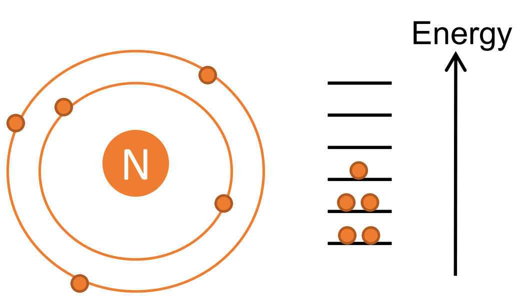
Quantum confinement



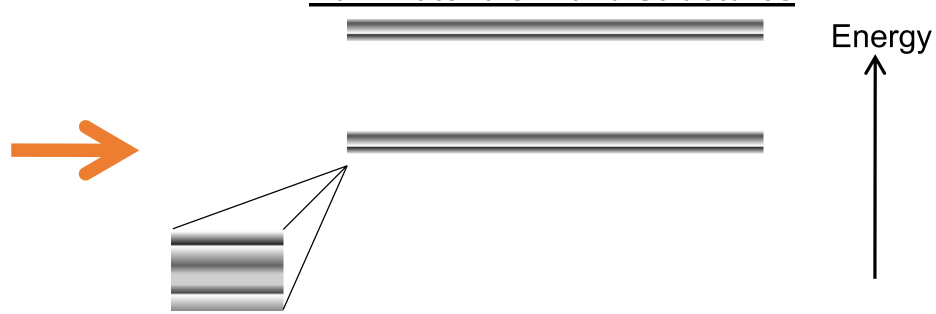
Quantum confinement

- Energy levels: from atoms to bulk materials…
  - The Pauli Exclusion Principle states that electrons can only exist in unique, discrete energy states.
  - In an atom the energy states couple together through spin-orbit interactions to form the energy levels commonly discussed in an introductory chemistry course.
  - When atoms are brought together in a bulk material, the energy states form nearly continuous bands of states, or in semiconductors and insulators, nearly continuous bands separated by an energy gap.

Atoms: Discrete Energy Levels



Bulk Materials: Band Structures



Quantum confinement

- Energy level spacing and quantum confinement
  - The reduction in the number of atoms in a material results in the confinement of normally delocalized energy states.
  - Electron-hole pairs become spatially confined when the dimensions of a nanoparticle approach the de Broglie wavelength of electrons in the conduction band.
  - As a result the spacing between energy bands of semiconductor or insulator is **increased** (Similar to the *particle in a box* scenario, of introductory quantum mechanics.)