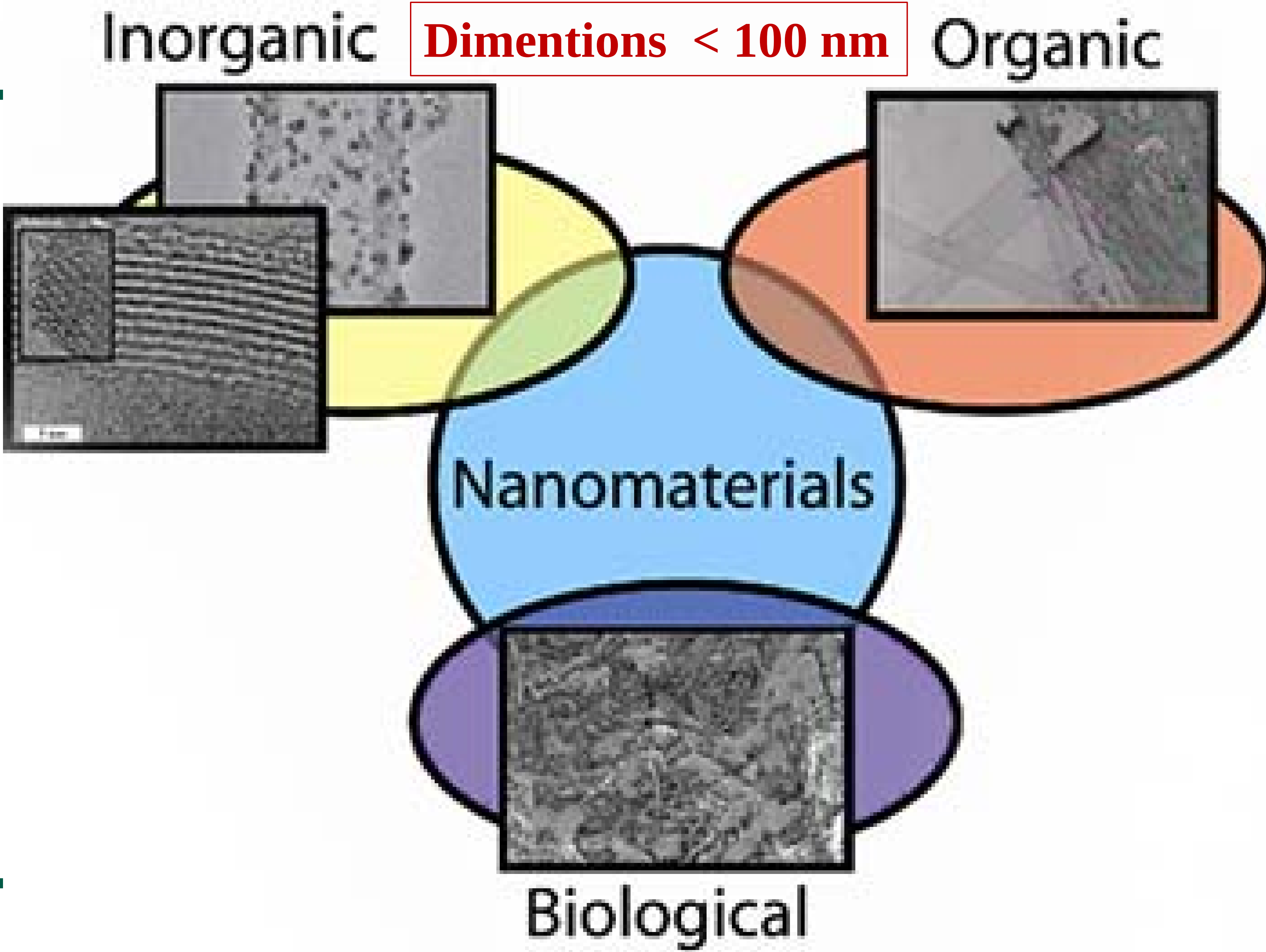
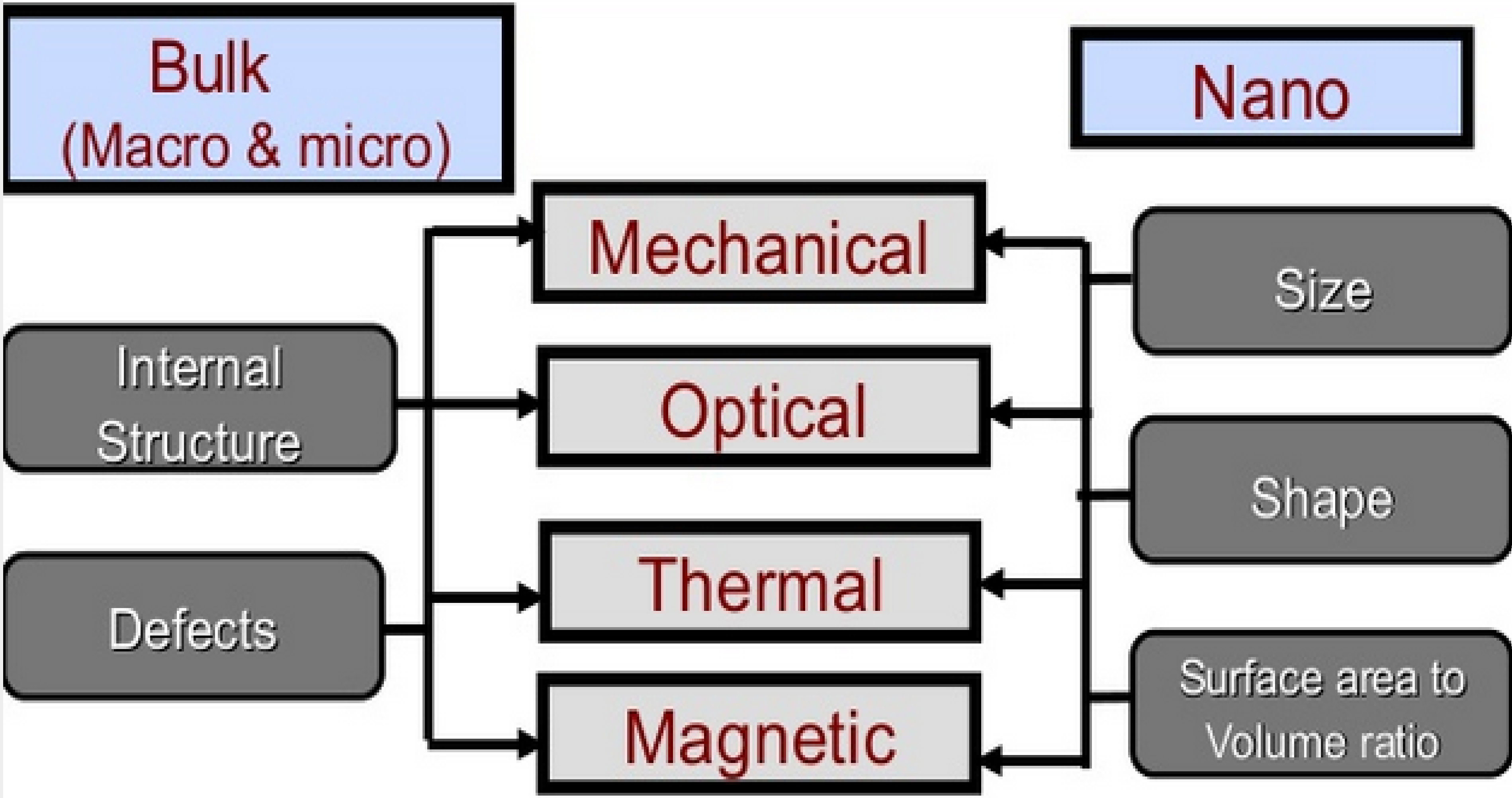
THE NANO WORLD!

From Micro to Nanomaterials

From Micro to Nanospectroscopy

Dimentions < 100 nm





- **At the nanoscale, interactions with heat ,light, stress, electrical field & magnetic field give rise to interesting & novel properties**
- **A thorough understanding of the nature of interactions at the bulk & nano levels are essential for designing nanomaterials**

What changes when going from macro or micro to NANO scale?

What are the greatest challenges?

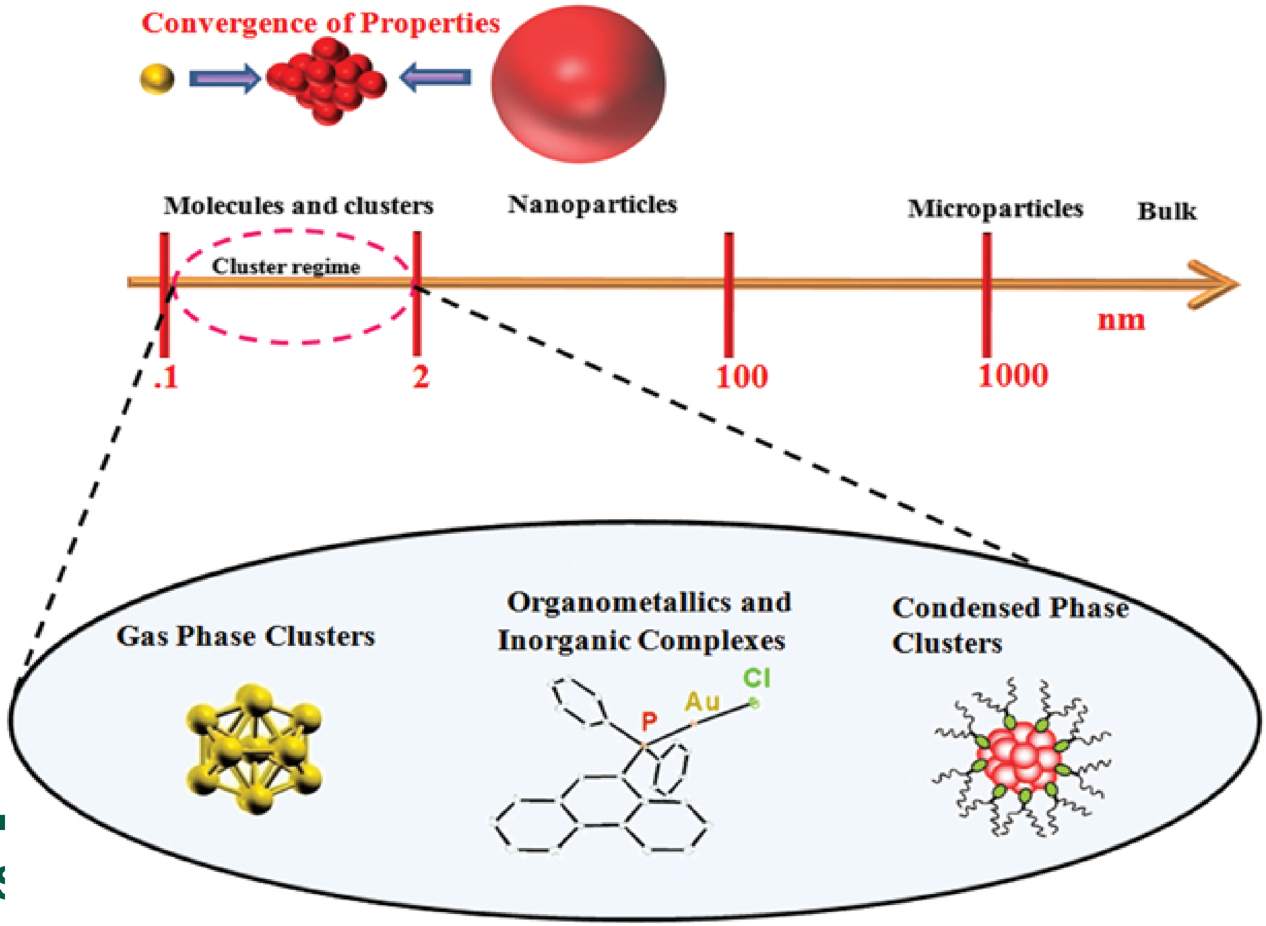
Probing of such materials is not an easy task; when going from macro, even micro to nano spectroscopy instead of a bulk of atoms or molecules we are interested in **sets particles** or even **single atoms or molecules**, thus making it difficult to realise by traditional spectroscopy probing because element concentration gets lower, spatial resolution gets higher resulting in very weak signals, some of them can even be confused with noise level of electronics!

N**anomaterials have different properties from bulk materials**:

increased relative surface area and quantum effects

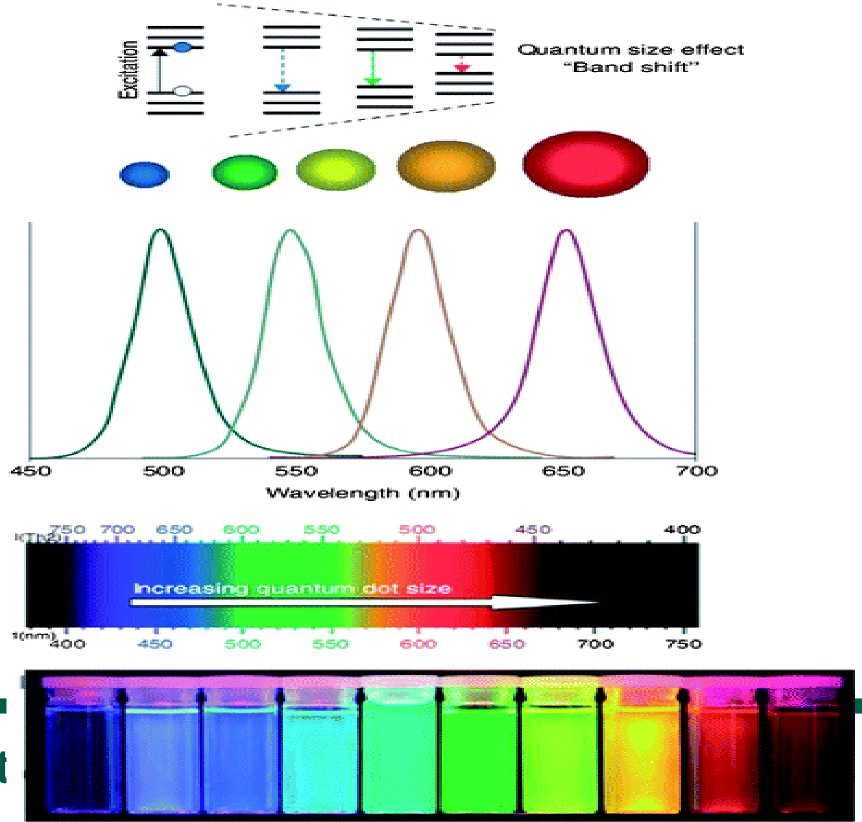
These factors can change or enhance strength, reactivity, electrical and thermal properties, and other physical properties such as **transition rates**, **width of electronic levels** and **energy band gaps**.

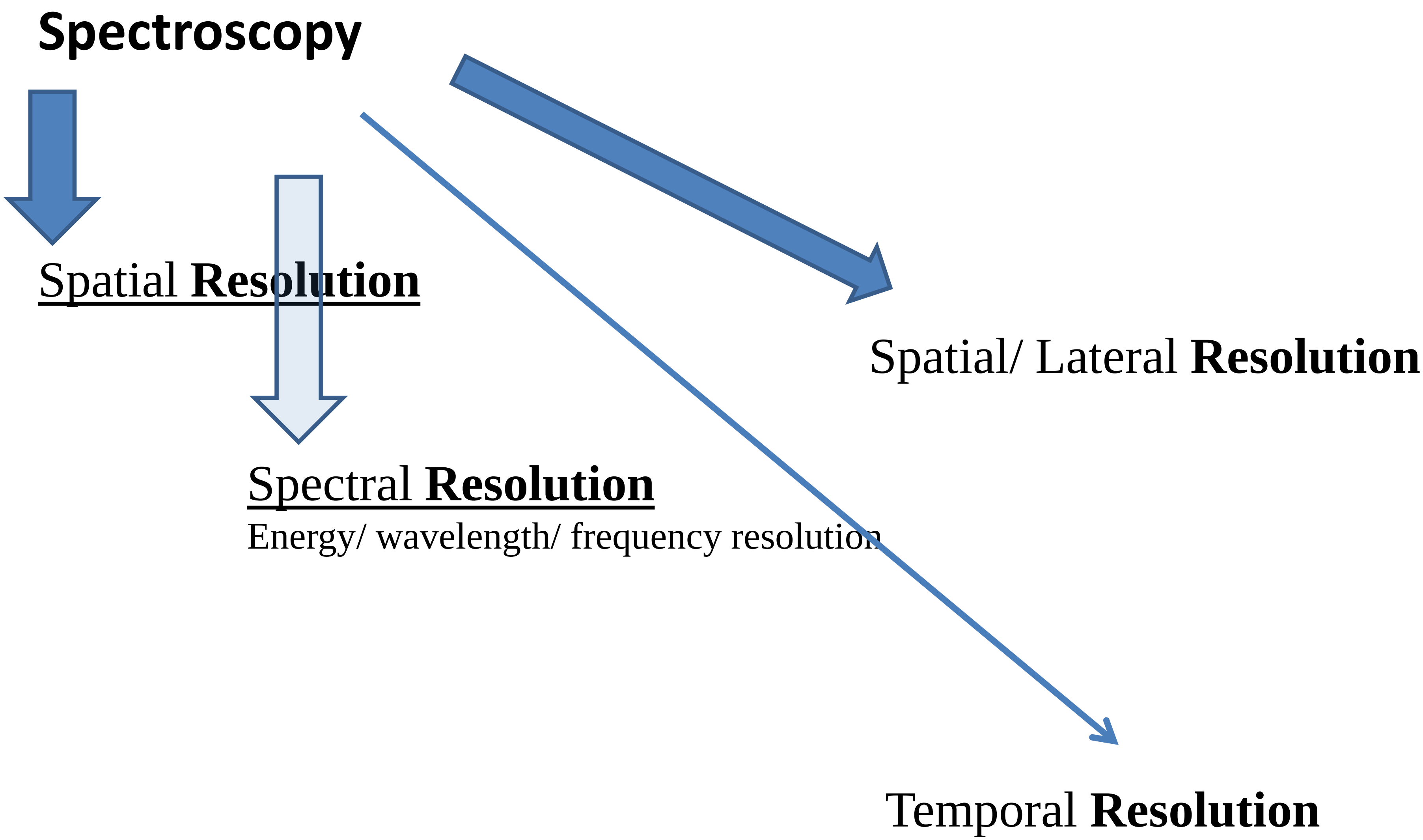
Surface effects: as particles decrease in size, a greater proportion of atoms are found at the surface compared to those inside, and this is what makes nanoparticles more reactive than larger particles.



<u>Quantum effects:</u> The quantum confinement is observed when the diameter of the particle is of the same magnitude as the wavelength of the electron (wave function).

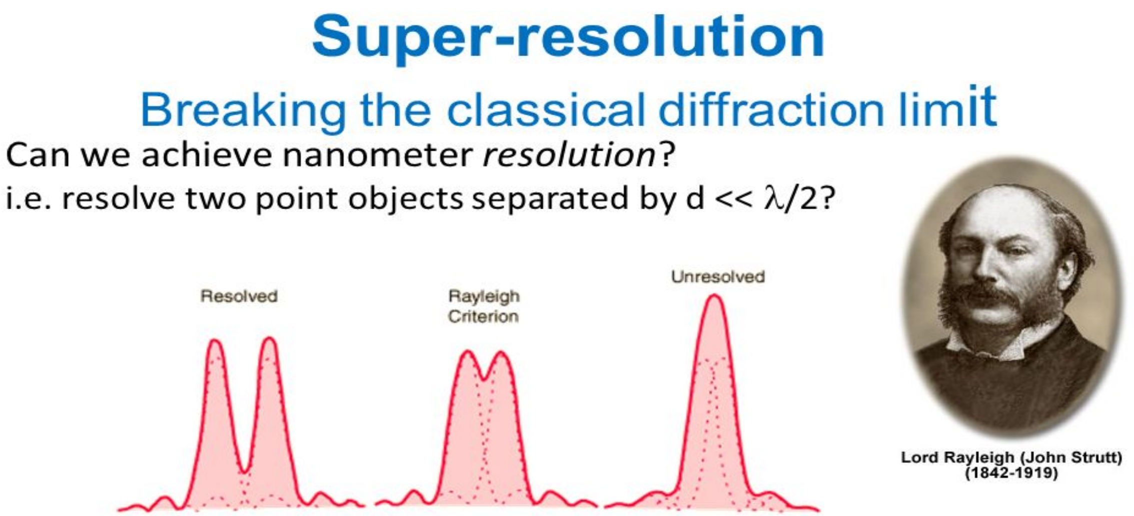
Quantum confinement is responsible for the increase of energy difference between energy states and band gaps, which relates to the optical and electronic properties of the materials. Therefore, when materials are these small, their electronic and optical properties deviate substantially from those of bulk materials (example is gold).




Spectroscopy
Spatial Resolution
Spatial/ Lateral Resolution
Spectral Resolution
Energy/ wavelength/ frequency resolution
Temporal Resolution

The first greatest challenge is breaking through the **spatial resolution** by **overcoming the 'diffraction limit'**, that is to say the inability of light microscopy to **distinguish between structures smaller than half the wavelength of visible light** (~200 nm).

This advance allowed nanoscale structures – including individual molecules – to be visualised within cells while they are still alive, something that is not possible with techniques such as electron microscopy.

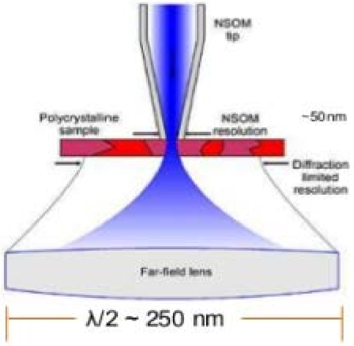


How ?

Shorter wavelengths: X-rays, electrons

HOW ?

NEAR FIELD TECHNIQUES

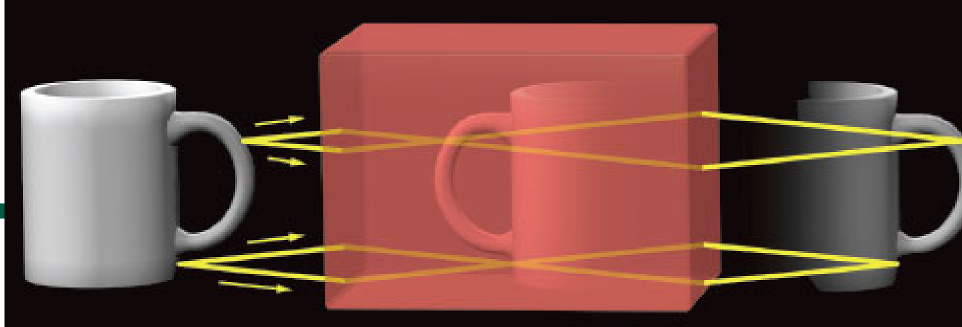


d=0.61*λ/NA

For high spatial resolution, the probe must be close to the sample

THE SUPERLENS

A rectangular slab of negative-index material forms a superlens. Light (*yellow lines*) from an object (*at left*) is refracted at the surface of the lens and comes together again to form a reversed image inside the slab. The light is refracted again on leaving the slab, producing a second image (*at right*). For some metamaterials, the image even includes details finer than the wavelength of light used, which is impossible with positive-index lenses.



Near Field Techniques

https://science.sciencemag.org/content/sci/257/5067/189.full.pdf

Superlenses

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

The second challenge is **temporal resolution** to understand chemical processes in real time. Most of the processes in chemistry and biochemistry take place at length scales that are much smaller [than the wavelength of light].

Example: Graphene Growth

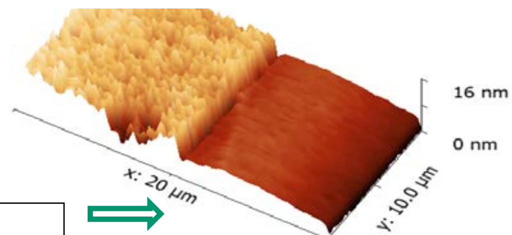
(click link for animation)

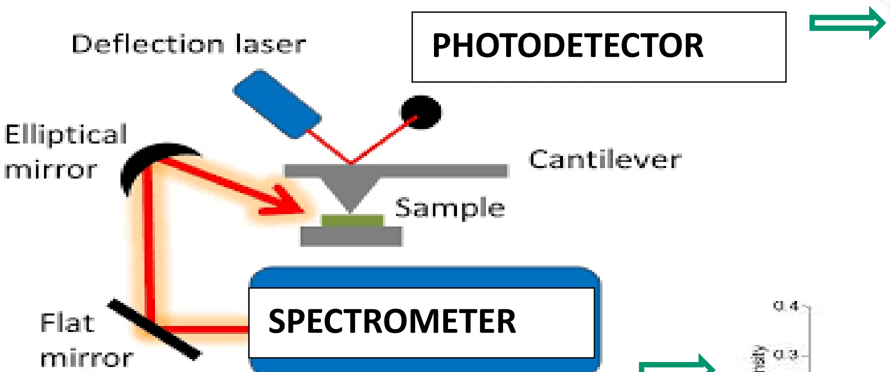
Breaking through the diffraction limit

What about spectral resolution ?

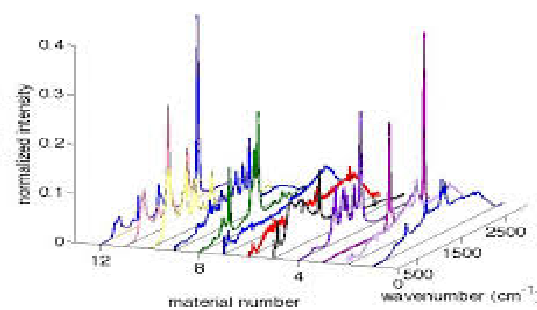
Properties of the Nanomaterials

Nanospectroscopy addresses these challenges by combining micro spectroscopy with some sort of **nano-microscopy**, in which near field optics or super-resolution optics is implemented associated to the spectroscopic ability to distinguish different chemical species. There are numerous combinations possible as well techniques specifically under development for each combination.





Example: TERS on CNTs



Finally there is the challenge of **separating, enhancing and amplifying the electronic signal** generated during detection process which requires faster and more sophisticated electronic devices for signal processing.

Lock-in Amplification/ Lock-in Techniques

Surfaces

Next Lecture (s)

Super Lattices

Heterostructures

Quantum Confined Structures

Quantum Wells

Quantum Dots

Quantum Wires

…and Applications ☺