

# *NANOMATERIALS*

*DR. SANJAY S. ANKUSHRAO*

*M.Sc., SET, GATE, PhD*

Assistant Professor

Vivekanand College (Autonomous), Kolhapur

# Syllabus

- *Introduction, Terminology & History*
- *Optical Properties and its Characterization*
- *Interaction of light with matter*
- *Surface plasma resonance,*
- *Characterization methods: Electron microscopy, SEM, TEM.*
- *Top-down, Bottom-up fabrication (Colloidal route, sol-gel method, chemical reduction method, electrochemical method)*
- *Applications of nanomaterials.*

# Introduction

- Terminology: Nano = 1 billionth  
 $1 \text{ nm} = 1 / 1000,000,000^{\text{th}}$  of meter  
i.e.  $1 \text{ nm} = 10^{-9} \text{ m}$

## Nanoparticle.....?????

- How small is it?
- Head of pin is roughly  $2 \text{ mm} = 20,000,00 \text{ nm}$
- Human hair =  $50,000 \text{ nm}$
- DNA strand =  $2 \text{ nm}$  wide
- Atom =  $0.1\text{-}0.2 \text{ nm}$
- 10 'H' atoms in line =  $1 \text{ nm}$

# Defination

## • Nanotechnology / Nanoscience

- Term defined by **Prof. Norio Taniguchi** (1974, Tokyo Science Univ. Japan)

- Processing, **Separarion**, **Consolidation** & **deformation** of materials by one atom or by one molecule.

**OR**

- Branch of science which study the fundamental principles of molecules & structures and applications of particles have at least dimensions in between 1 -100 nm.
- The structures are called Nanostructures or nanoparticles.
- And such materials are called Nanomaterials.



According to **U.S. National Science Foundation**

*The study that deals with materials and systems having following key operators*

- **Dimensions: 1- 100 nm**
- **Process: Methodology that shows fundamental control over physical and chemical properties of molecular scale structure.**
- **Building block property: They can be combined to form larger structures.**

# History

- *Too long*
- *Prepared and used in 19<sup>th</sup> century*
- *Decorative coloured glass windows of old churches and palaces. (Fe, Ni, Co, Ag, Au, etc)*
- *Michael Faraday (1857): Prepared colloidal solution of Au NPs*
- *Photographic plates covered by Ag NPs*
- *In 19<sup>th</sup> century people were unknown about size of NPs.*

Year	Scientist name & Information	Invention
1959	<i>Richard Feynman (Nobel)</i>	-There is plenty of room at the bottom -NPs have tremendous applications & diff. properties.
1981	<i>Binnig &amp; Rohrer (Nobel 1986)</i>	<i>Scanning Tunneling Microscope (STM)</i> <i>Atomic size images</i>
1990	<i>Don Eigler &amp; Erhard Shucizer</i>	<b>Atomic manipulation is possible</b> (Milestone advancement of science)
1985	<i>Curl, Kroto &amp; Smalley (Nobel 1996)</i>	<b>Fullerene NP (C<sub>60</sub>)</b>
1991	<i>Iijima</i>	<b>Carbon nanotubes</b>
2004	<i>Gem &amp; Nevoselva (Nobel 2010)</i>	<b>Graphene (Allotope of 'C')</b>

All properties of NPs are differing than its bulk materials. (Mechanical, thermal, optical, magnetic, etc.)

Very Smaller size and larger surface area changes properties

e.g. Graphene good conductor of electricity, thin , strong, transparent, elastic than Cu

# Optical Properties of Nanomaterials

*Interaction of light with matter*

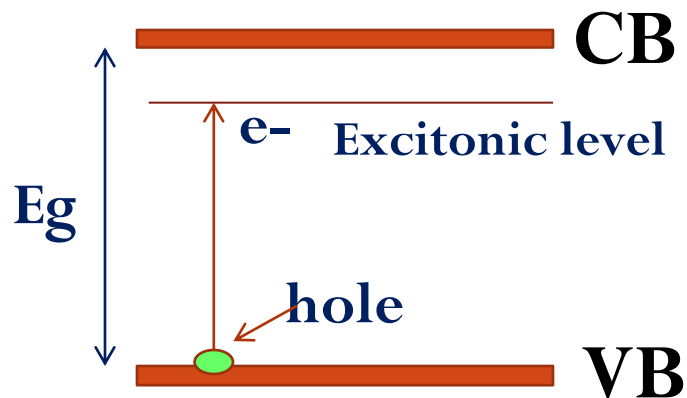
*Various changes in properties of matter when exposed to EMR.*

## 1. Optical properties of Semiconducting NPs

Conductor: **VB & CB overlaps.**

Insulator: **VB & CB separated by large distance.**

Semi-conductor: **VB & CB separated by finite distance.**



**Exciton:** When  $e^-$  passes from VB to CB, a hole is left behind and  $e^-$  hole pair formed in the particle called **exciton**.

*i.e. bound state of an  $e^-$  & hole*

*- this binding is due to electrostatic attraction*

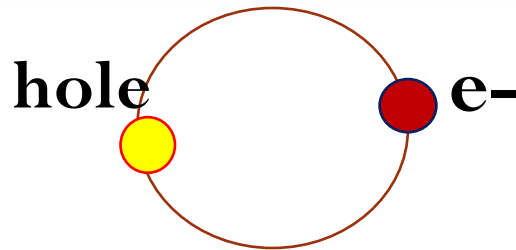
*- Exciton has lower energy than unbound  $e^-$ .*



## Two types of Exciton

a) **Frankel Exciton:** *Distance between e- & hole is comparable to lattice constant.*

(Lattice constant: A parameter measures length or angle of the unit cell of a crystal lattice, which defines size & shape of it.)



## b) **Mott-Wannier Exciton:**

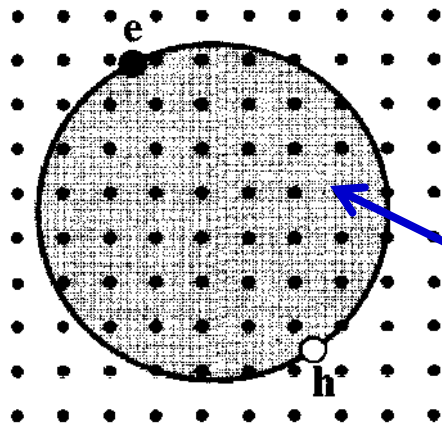
*Distance between e- & hole is larger than lattice constant.*

*This free exciton can move in crystal.*

*Energy of such exciton is slightly less than energy gap ( $E_g$ ) bet<sup>n</sup> VB & CB.*

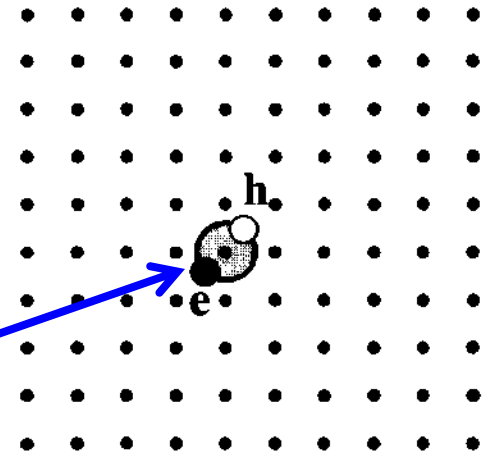
$E_g$  is energy necessary to create free hole and free e-

## There are two types of excitons



(a) Free exciton

Wannier-Mott excitons



Frankel exciton

(b) Tightly bound exciton

The *Hamiltonian for Mott-Wannier exciton* is given as,  
(Hamiltonian: Sum of K.E & P.E. of particles)

$$\hat{H} = (P_e^2/2m_e) + (P_h^2/2m_h) - (e^2 / \epsilon |r_e - r_h|) \text{-----}[1]$$

K.E. of e-

K.E. of hole

Coulomb ener. of e- & hole attraction

Where,

$m_e$  &  $m_h$  = Effective mass of e- & hole

$P_e$  &  $P_h$  = Momentum ( $p=mv$ ) of e- & hole respt.

$\epsilon$  = dielectric const. of semiconductor material.

$|r_e - r_h|$  = Dist. between e- & hole

*Then, Bohr's radius of exciton is,*

$$r_B = h^2 \epsilon / e^2 [1/m_e - 1/m_h] \text{-----} [2]$$

*$r_B$  = Bohr's radius of exciton*

*$h$  = Planck's const (= energy of quantum of EMR / freq).  
( $6.626 * 10^{-34}$  m<sup>2</sup> Kg / s)*

*$e$  = Charge*

*$\epsilon$  = Dielectric const. of medium*

*(Ability of sub. to store electrical energy) or*

*(Permittivity of sub. / Permittivity of free space)*

*Permittivity: Measure of resistance when electrical field forms in medium*



**Wave Function:** *A function satisfies wave equation & describes properties of wave. (describes position & state of an e-)*

**Wave Equation:** *Differential eqn expressing the properties of motion in waves*

Using eqn[1] & considering certain wave functions & potentials, **exciton energy ( $\Delta E$ )** or **effective band gap ( $E_g$ )** of particle having radius ( $R$ ) can be given by eqn.

$$\Delta E = E_g^{\text{eff.}} = h^2\pi^2 / 2R^2 [1/m_e + 1/m_h] - (1.8 e^2 / 4\pi \epsilon_0 \epsilon R) + \text{P.E.} \text{ ---- [3]}$$

Localization energy  
of e- & hole

Coulomb energy  
betn e- & hole

Polarization  
of crystal  
(neglected)

$\Delta E = E_g^{\text{eff.}}$  = Effective band gap of particles of radius  
(Exciton energy)

$R$  = Radius of cluster in which exciton can be created

$\epsilon_0$  = dielectric const. of free space. (State of motion in which an e- found anywhere in material.)

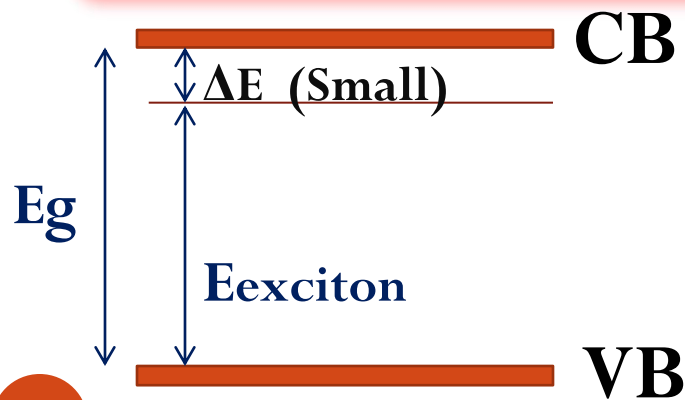
$\epsilon$  = dielectric const. of medium.

From eqn [3]; *as particle size (R) decreases, first term becomes dominates &  $\Delta E$  increases.*

*i.e. energy gap in semiconductor is a characteristics of the material*

*hence, here as energy gap increases in semiconductor material with decreasing particle size, is given by,*

$$\text{Total energy gap } (\Delta E) = h\nu = E_{g \text{ (bulk)}} - E_{\text{exciton}}$$

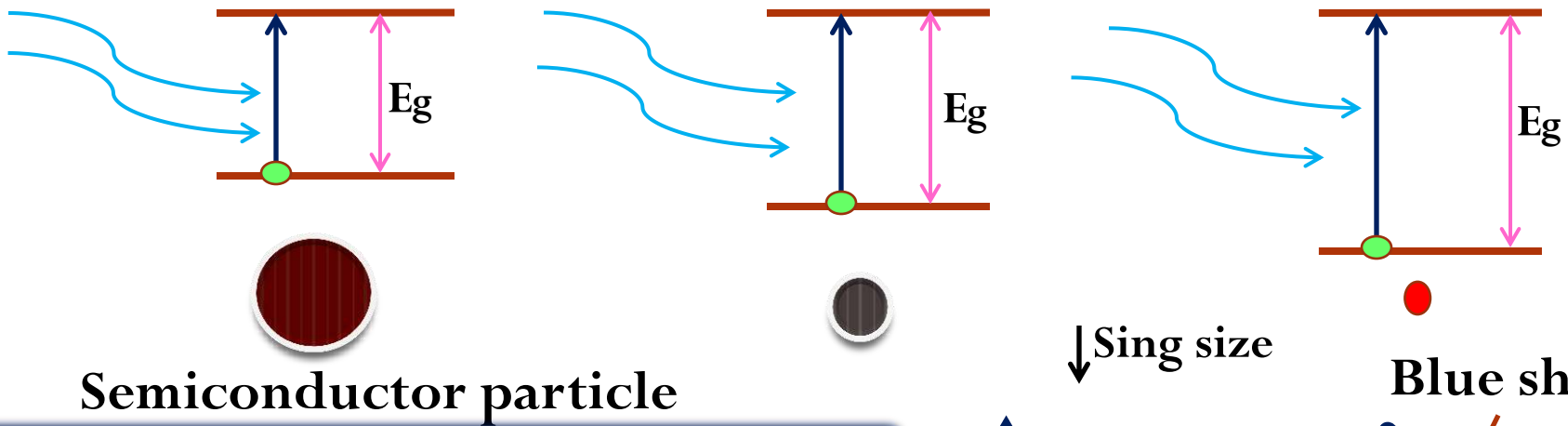


*This can be shown in eqn [3]*

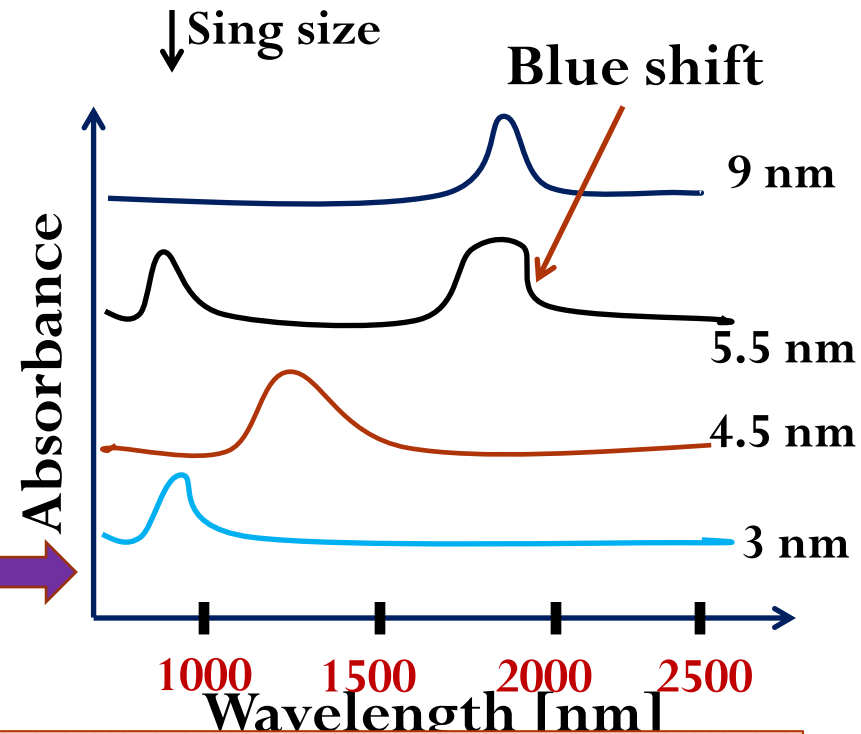




# Characterization of semiconductor nanoparticle



*If proton have sufficient energy to excite  $e^-$ , then only it is absorbed i.e. Particle size decreases,  $E_g$  increases, absorption wavelength decreases (freq. increases) e.g. Absorption spectra of PbSe nanoparticles for diff. size.*



*As particle size increases absorption shifts to longer wavelength, hence shows diff. colour*

# Optical properties of metallic NPs

When light is incident on metallic NP solution, it may be absorbed, transmitted or scattered.

According to *Mie theory* phenomenon can be explained as, When an EMR is incident on **spherical particle** of uniform size which **distributed uniformly in medium**, then a part of light may be absorbed, a part may be transmitted & scattered.

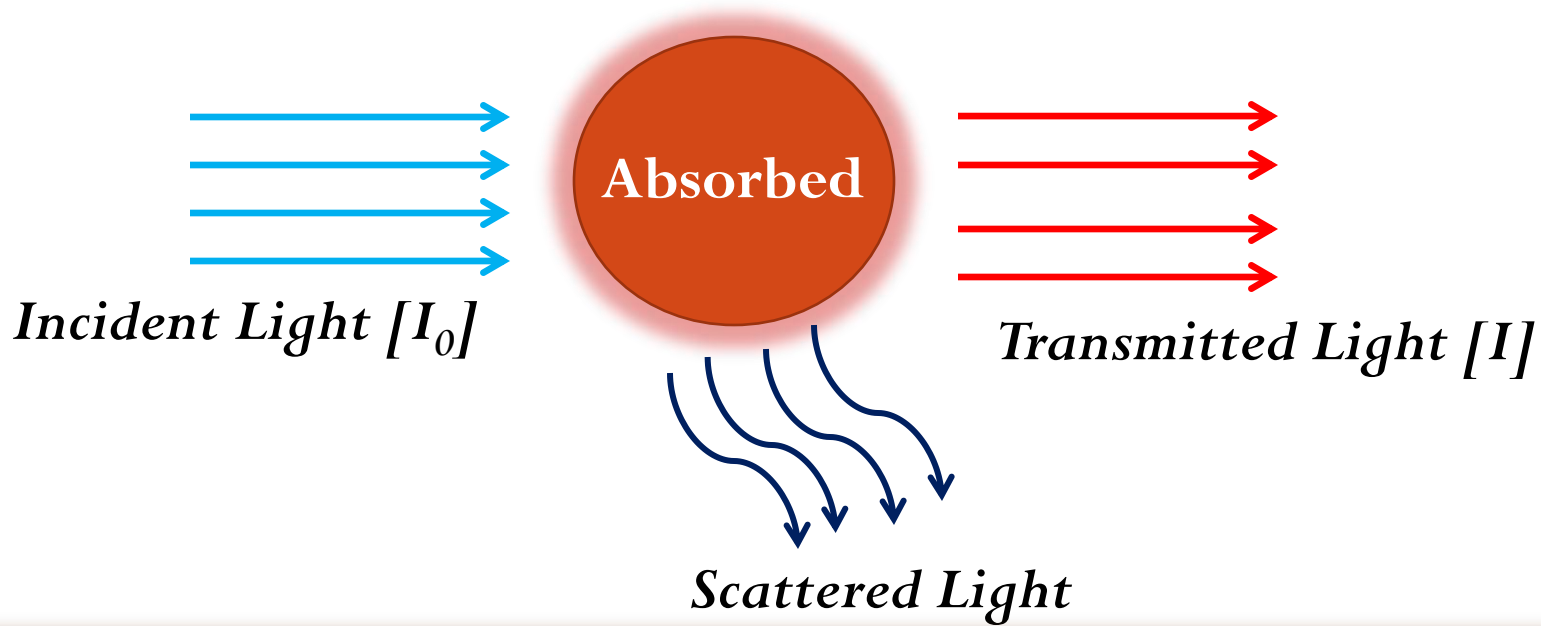
It is observed that, when **light is incident on solution of NP**, **decrease** of intensity takeplace, due to extinction of light. Therefore, amount of **light extinguished is given by**,

$$[Q_{\text{ext}} = C_{\text{ext}} / \pi R^2]$$

Where,  $Q_{\text{ext}}$  = extinction coefficient (**how strongly sub. absorbs light**)

$C_{\text{ext}}$  = Cross section of particle (**Probability that two particle colloid & react in certain way.**)

*i.e.* No. of particles scattered per unit time / No. of particles passing.



If  $I_0$  is intensity of radiation of wavelength  $\lambda$ , passing thro' medium having dielectric constant  $\epsilon_m$  and thickness 'X',  
Then intensity of transmitted light is

$$I = I_0 * e^{-\mu X} \text{-----} [1]$$

$$\mu = \text{Extinction coefficient} = (N/V) \cdot C_{ext}$$

$C_{ext}$  = Cross section of particle

$N$  = No. of particle in medium

$V$  = Volume of colloidal particle

*According to Mie theory,*

$$C_{ext} = C_{obs} + C_{scatt.}$$

*In Mie Theory,*

$$C_{ext} = [24 \pi^2 R^2 \epsilon_m^{3/2} / \lambda] * [\epsilon_2 / (\epsilon_1 + 2\epsilon_m)^2 + \epsilon_2^2] \text{----}[2]$$

$\epsilon_1$  &  $\epsilon_2$  = Real & imaginary parts of complex dielectric functions

*i.e*  $\epsilon = \epsilon_1 + i\epsilon_2$  of the constituent material of NP.

**Real:** Polarization & anomalous dispersion of particle

**Imaginary:** Dissipation of energy into medium by which energy becomes not available

$\epsilon_m$  = dielectric const. of surrounding medium (real number)

(for air  $\epsilon_m = 1$  & blood  $\epsilon_m = 1.4$ )

These dielectric const. for particle obtained from literature.



From eqn [2] indicates that maximum extinction is possible when,

$$\epsilon_1 + 2\epsilon_m = 0 \text{ i.e } \epsilon_1 = -2\epsilon_m$$

(This depends only on material, not size of material)

Therefore wavelength of strong SPR peak doesn't change with particle size

But for particle size  $R > 0.1$  (50 nm), eqn [2] becomes invalid & wavelength of SPR becomes size dependant.

# Surface Plasma resonance

**Plasmon:** Quantum of plasma oscillation or quasi-particle (weakly interacting particles of free space)

**Plasma:** Form of matter where many  $e^-$  wander freely among the nuclei of atom or electrically neutral medium of unbound positive & negative particles.

**Plasma oscillation or Langmuir waves:**

Rapid oscillation of  $e^-$  density (measure of probability) in conducting media such as plasmas or metal

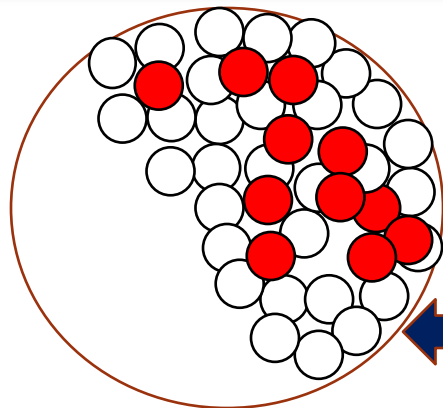
**Resonance:** Freq. of incident photon matches with natural frequency of surface  $e^-$ .

*AuNPs are very strong absorbers of visible light because of high resonance condition is achieved.*

***SPR:** When light incident on the surface of particle, e-cloud of NPs oscillate due to electric field of light. This condition of resonance known as SPR.*

*Or*

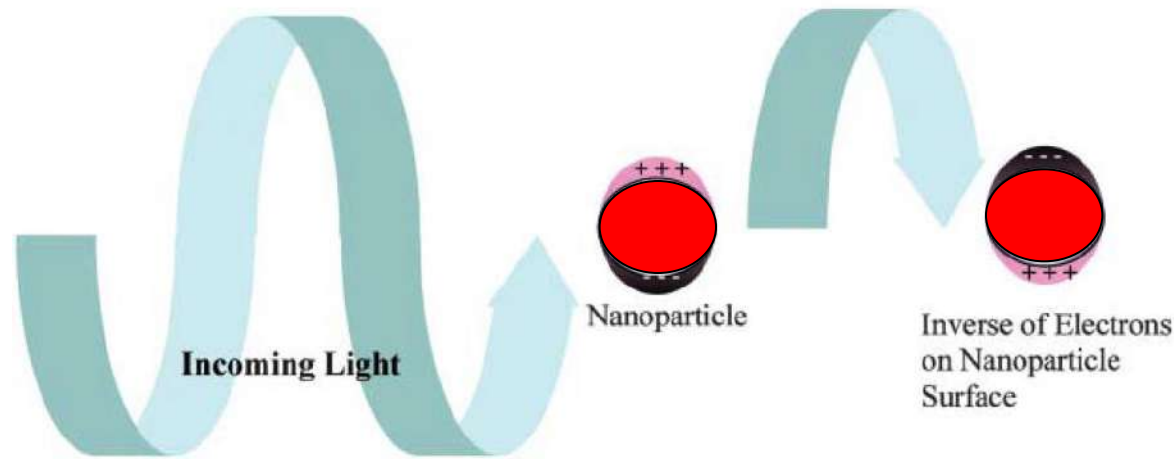
*When NPs is much smaller than wavelength of light, oscillations induced in **conduction band e-** by interaction with EMR.*



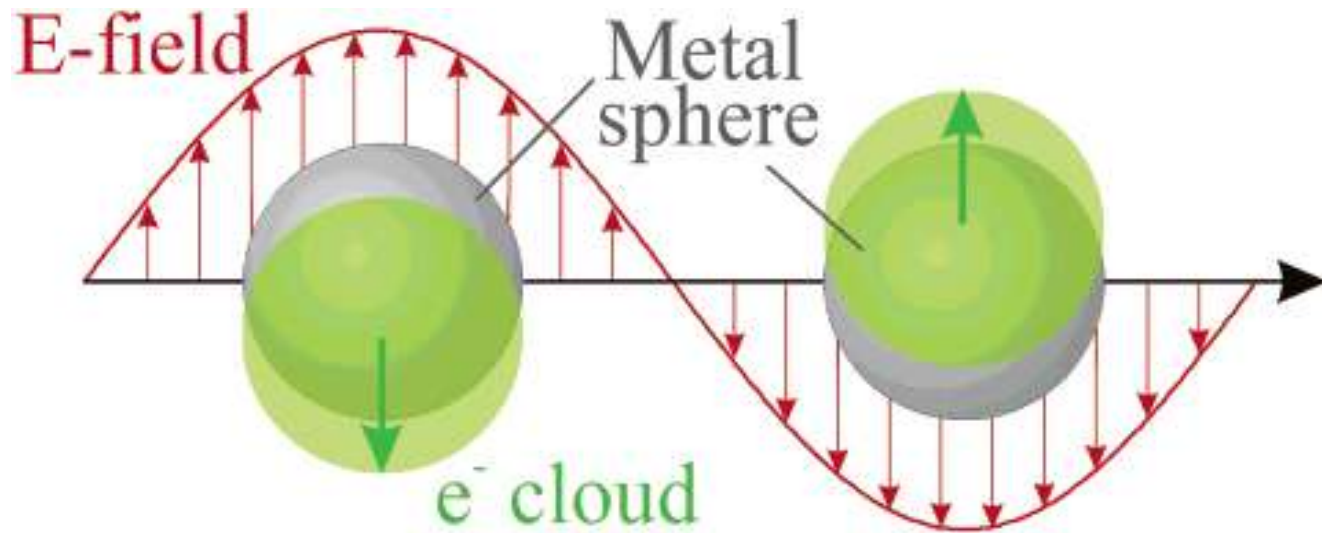
● e- of particle

○ Oscillations about Au atom.

← SPR in AuNPs.



*Light resonance with the surface Plasmon oscillation causes the free electrons in the metal to oscillate.*





Generally interaction of light & particle can be characterized in terms of its extinction (light removed from incident light)

Light is extinguished either by absorption or scattering.

Beam of light excites the loosely bound surface  $e^-$  to form SPR.

**SPR** can generate heat by absorption of light or acts as dipole shaking at the freq. of light & becomes source of light. (Scattering of light)

### **Applications:**

**Scattering of light:** To detect cancer position for treatment by optical microscope.

**Absorption:** Heat generated is used to treat hyperthermia.

Extinction of particle depends on **optical properties** of material & **medium** in which it is distributed.

As per eq<sup>n</sup> [2] in **Mie Theory** & above discussion, we can say that For larger NP, the wavelength of SPR peak is size dependant.

**Now,**

$$Q_{ext} \text{ (Extinction coefficient)} = C_{ext} / \pi R^2$$

By putting value of  $C_{ext}$ , we have

$$Q_{ext} = [24 \pi^2 R^3 \epsilon_m^{3/2} / \lambda \pi R^2] * [\epsilon_2 / (\epsilon_1 + 2\epsilon_m)^2 + \epsilon_2^2]$$
$$= [24 \pi R \epsilon_m^{3/2} / \lambda] * [\epsilon_2 / (\epsilon_1 + 2\epsilon_m)^2 + \epsilon_2^2]$$

i.e  $Q_{ext}$  depends upon  $R$  & dielectric const. medium.



*Relative amount of extinction & absorption depends on the particle size.*

***In Small NPs: Extinction due to absorption***

***In large NPs: Extinction due to absorption & scattering.***

*Relative proportion of scattered & absorbed light varies as a function of particle size.*

*Freq. of SPR oscillation is given by,*

$$\omega_p = \sqrt{4\pi N_e e^2 / m^*}$$

*N = No. of e- in plasma*

*e = Charge on e-*

*m\* = effective mass of e-*

*It is observed that wavelength for resonance of pure Au NP remains in visible region.*

*- We also know that this wavelength decides wavelength of scattered or absorbed light which is dependent on particle size of material.*

*- Again we know that wavelength of scattered light decides **color** of solution*

*- Hence gold solution shows different color depending upon size.*

# Characterization Methods

To know about size, structure, types of atoms, arrangement of atoms, etc. of NPs

Sr. No.	Techniques	Use
1	XRD, e- diffraction, neutron diffraction	Particle Size & type of crystal structure.
2	UV, IR, FTIR, ESR, AAS, NMR, etc.	Information about <b>electronic structure</b> , chemical state analysis & other properties.
3	Optical Microscope, SEM, TEM, STM, Atomic force Microscope (AFM), etc.	<b>Morphology, Size, Structure</b> , image of atomic level, etc.

# *Electron Microscopy*

*(Similar to Optical Microscopy: EMR of proper wavelength, glass lenses used to focus radiations.)*

*In electron spectroscopy e- beam & electrostatic or magnetic lenses used.*

- *Wavelength of e- is given by de-Broglie eqn.  
 $\lambda = h / mv$*
- *Wavelength of e- is very small (0.001-0.02)*
- *Due to smaller wavelength e- microscope can be used to image tiny particles.*

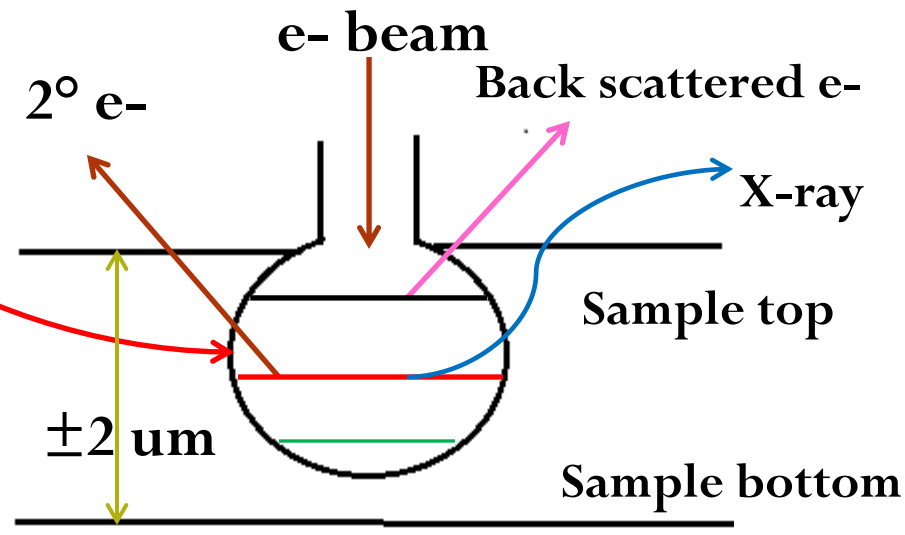
# Principle

Interaction of  $e^-$  with solid is complicated due to i) charge on  $e^-$  ii) Interaction of  $e^-$  with ions in solids.

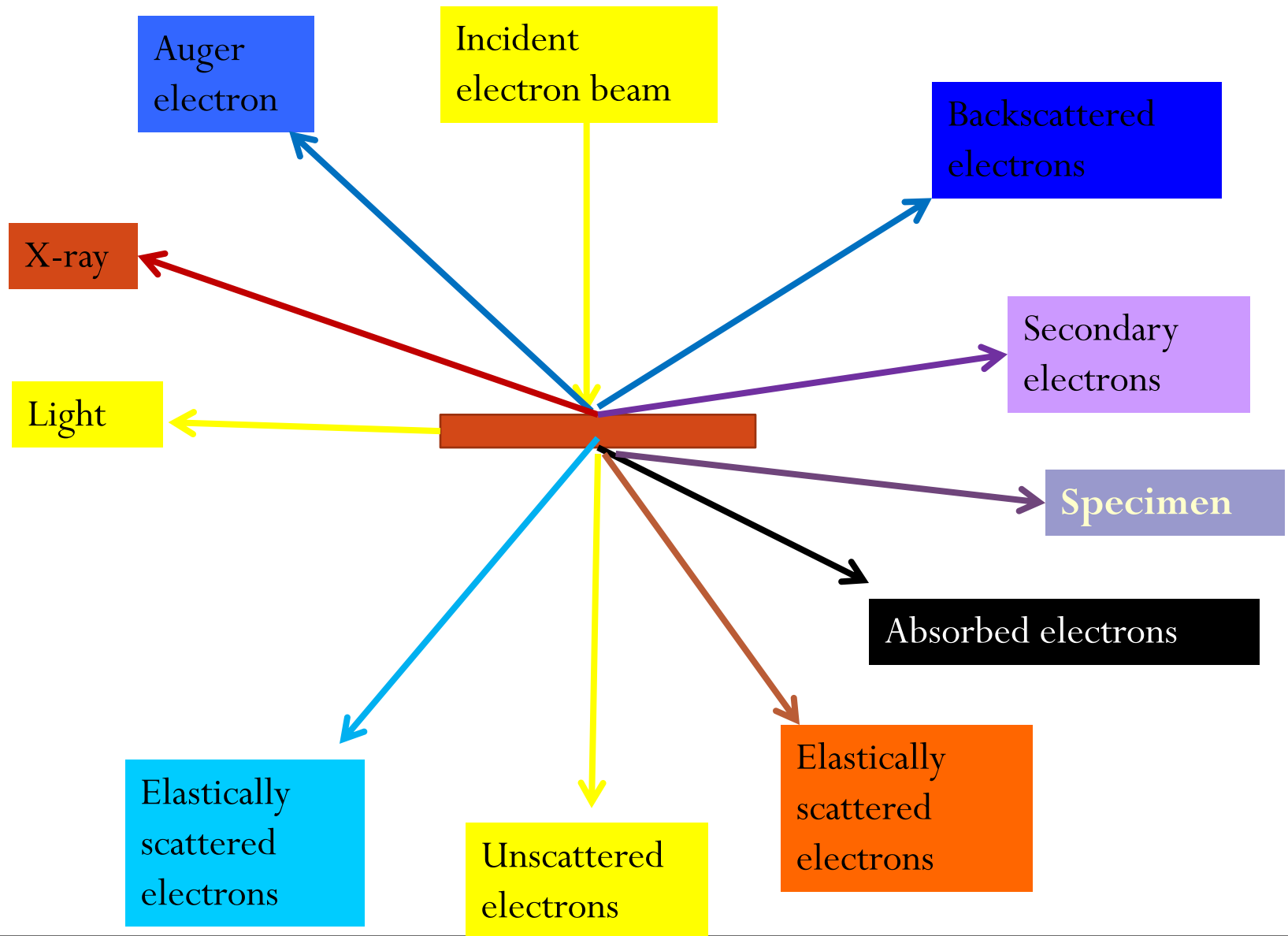
Due to interaction of  $e^-$  with sample, a tear shaped volume of interaction is formed.

When  $e^-$  interacted with surface of solid material, many phenomenon takes place such as **scattering of  $e^-$** , **production of  $2^\circ e^-$** , Production of **X-ray** etc.

$e^-$  beam should focused on sample without getting scattered or deflected by air, therefore  $e^-$  microscopy requires **vaccum**.



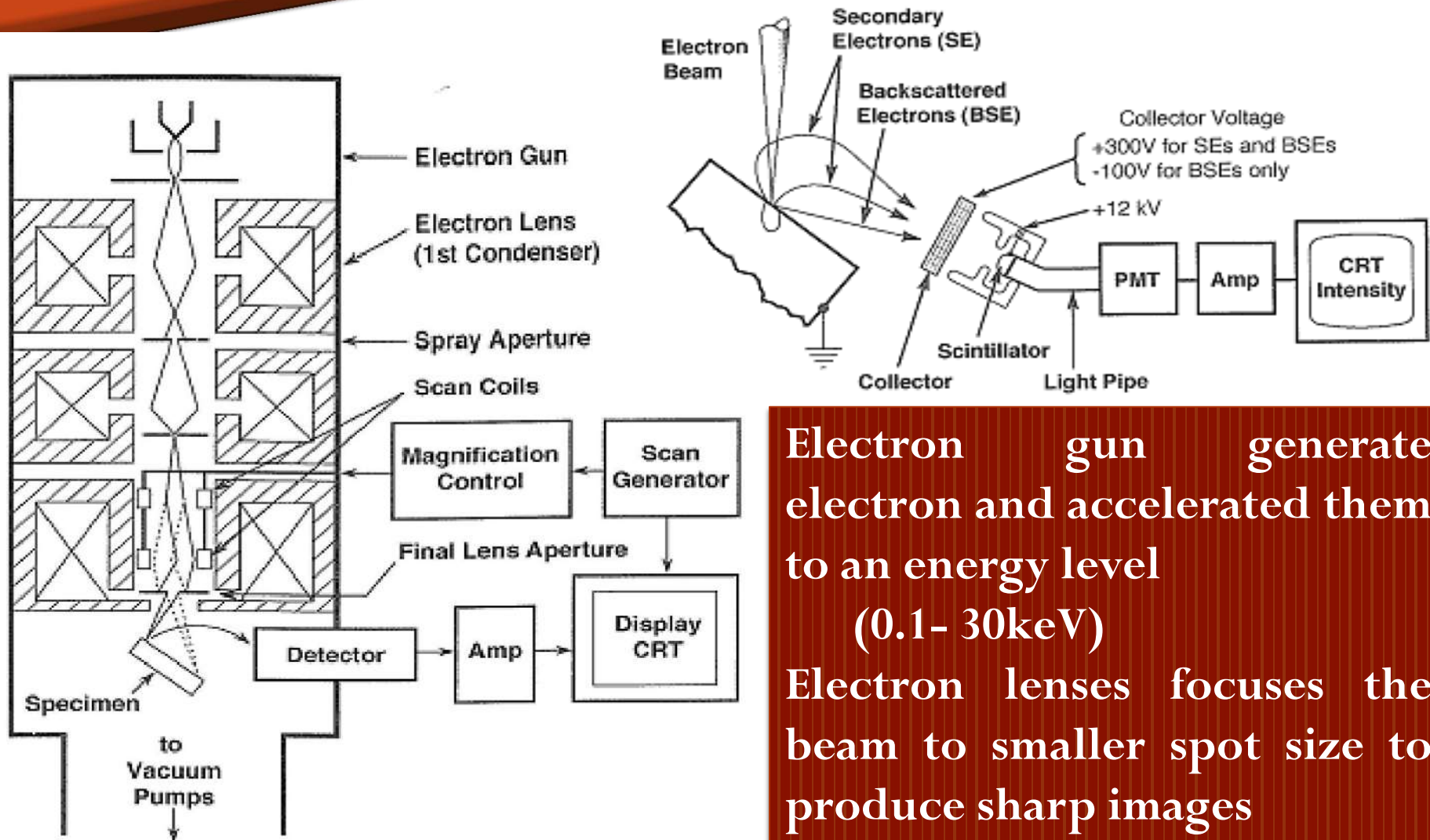
# Specimen-Beam Interaction



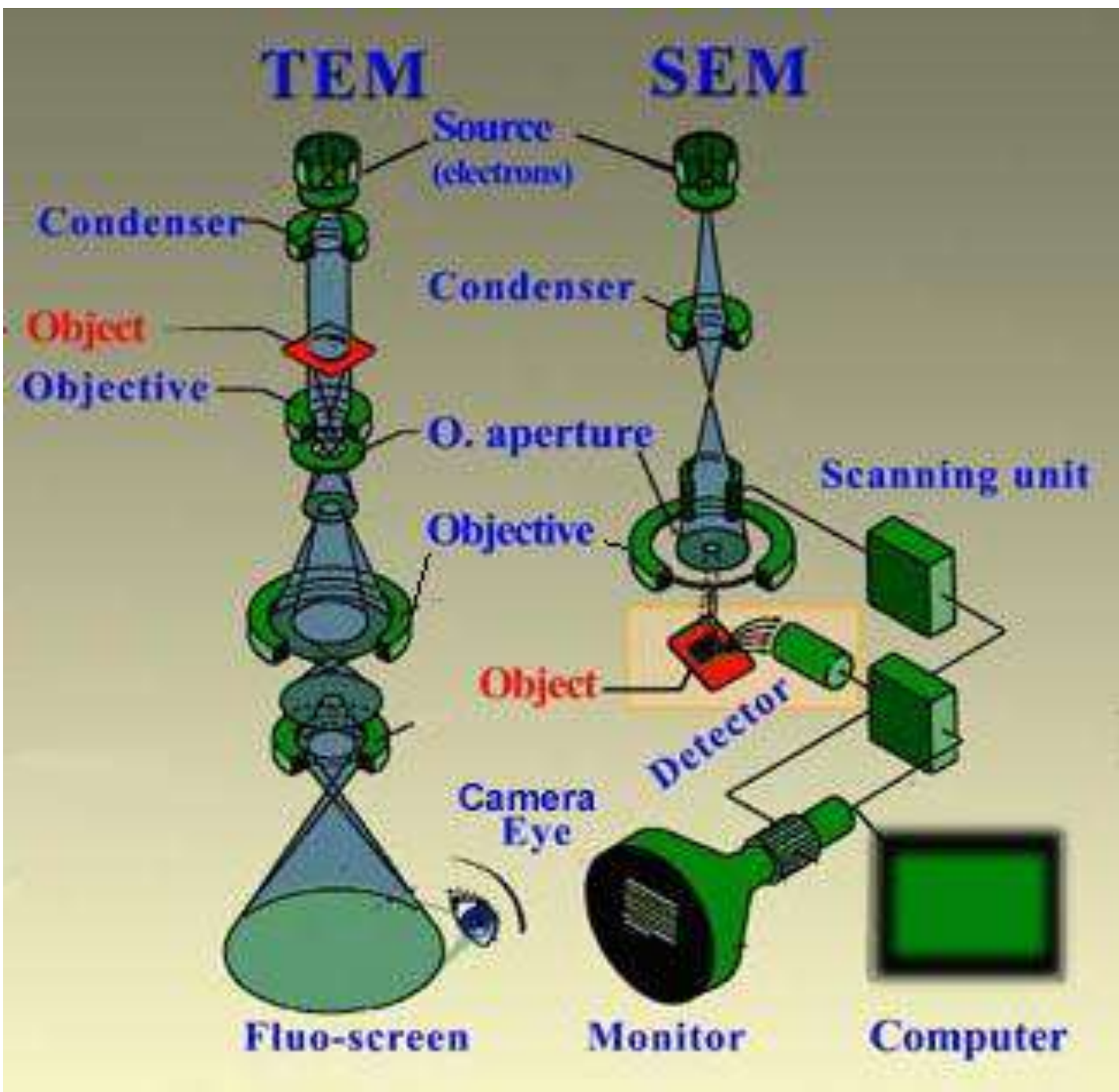


# Scanning Electron Microscope (SEM)

German Scientist  
Ernst Ruska(1933),  
Nobel prize in  
physics (1986)



**Electron gun generate electron and accelerated them to an energy level (0.1- 30keV)**  
**Electron lenses focuses the beam to smaller spot size to produce sharp images**





# Construction & Working

**Electron Source:** Tungsten (highest M.P. & Lowest V.P.) filament or Lanthanum hexaboride cathode.

$e^-$  beam energy = 1000-50000 eV

- This beam is focused by two successive condenser lenses in a very fine spot (5 nm).
- Then the beam of  $e^-$  passes through pairs of scanning coils which deflect the beam linearly through the objective lens over the sample surface.
- Deflection is done magnetically through m.f. generated by electric current flowing through coils.

- $1^\circ$   $e^-$  strikes surface inelastically & scattered from atoms of sample
- Due to this scattering  $1^\circ$  beam spreads & fills the tear-drop shaped volume into surface.
- Now, due to interaction in the tear-drop, emission of  $2^\circ$   $e^-$  takeplace.
- These  $2^\circ$   $e^-$  are detected to produce an image.
- X-ray are also produced & can detected by dispersive X-ray spectroscopy (composition analysis of sample).

# Sample Preparation

- ✓ *Appropriate size to fit specimen chamber*
- ✓ *Sample should be dry*
- ✓ *Hard dry materials eg. Wood, feather, dried insects can be examined with little further treatment.*
- ✓ *For living cells, tissues & soft bodied organisms require **chemical fixation** to preserve & stabilize their structure.*
- ✓ *Dry specimen is mounted on specimen tube using adhesive.*

## ■ **Amplification:**

*e- amplifiers of various types used to amplify signals*

## ■ **Detectors:**

*Back scattered e-s &  $2^\circ$  e-s can be detected by specialized detectors.*

*Resulting image will be **distribution map of intensity of signal emitted from scanned scanned area of specimen.***

*In older microscopes image was captured.*

*In modern machines image is saved to computer data storage.*



## *Affecting factors*

- Spatial resolution of SEM depends on size of e- spot (depends upon magnetic e- optical system, which produces scanning beam of e-)*
- Resolution also depends upon interaction volume or extent of material interacts with e- beam.*
- Resolution of SEM is not high to produce atomic image.*

***Applications: Morphology & distribution of NPs***

### ***Precautions:***

*Placed whole system in vaccum (To avoid oxidation & contamination & to prohibit collisions between e- & air)*



## *Advantages*

- ✓ *First method to obtain image of tiny particles.*
- ✓ *Biological samples can be analyzed with little treatment.*
- ✓ *Non-destructive method.*

## *Disadvantages*

- ✓ *Non conducting material requires coating of thin metal film (Au/pt) [ $< 10\text{nm}$ ] & it becomes conducting*  
*(Insulating material get charged due to incident e-s & images may become faulty & blurred.)*

## Transmission Electron Microscopy (TEM)

**Principle:** Transmitted  $e^-$  hit fluorescent screen gives shadow image.

- Sample should be very thin
- Sample is powdered & made thin film
- Energy of  $e^-$  should very high (greater than 50000 eV)
- Single particle of very small dimension can be analyzed.

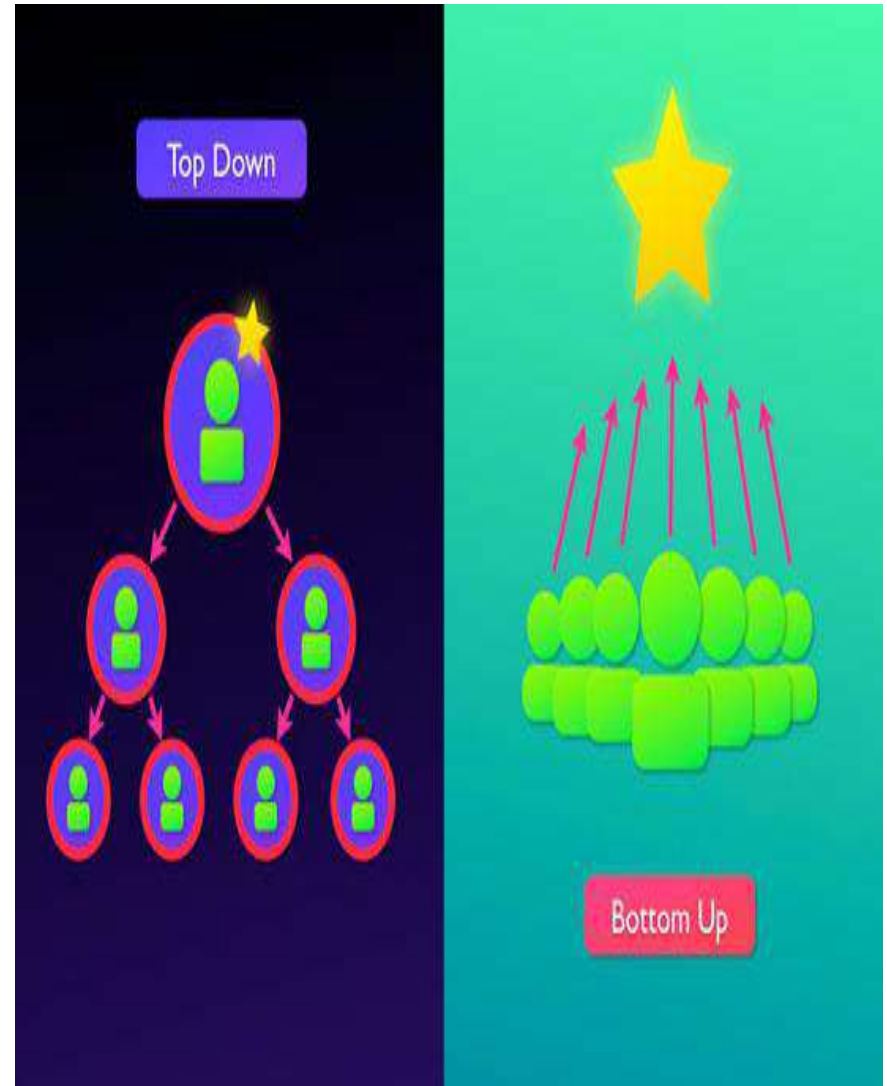
## *Diff. between SEM & TEM*

<b>Sr. No.</b>	<b>SEM</b>	<b>TEM</b>
1	<i>e- beam scans over surface of sample</i>	<i>e- beam passes thro' thin film</i>
2	<i>Sample can be of any thickness &amp; mounted on stub</i>	<i>Thin sample supported on grid</i>
3	<i>Specimen stage is at bottom</i>	<i>Specimen stage is at halfway down</i>
4	<i>Image is of surface of sample</i>	<i>Image is two dimensional projection of sample</i>
5	<i>Image shown on TV monitor</i>	<i>Image shown on fluorescent screen</i>

# Top-Down, Bottom-up Fabrication

**Top-Down:** Larger  $\longrightarrow$  Smaller  
High mfg. capability, low spatial resolution

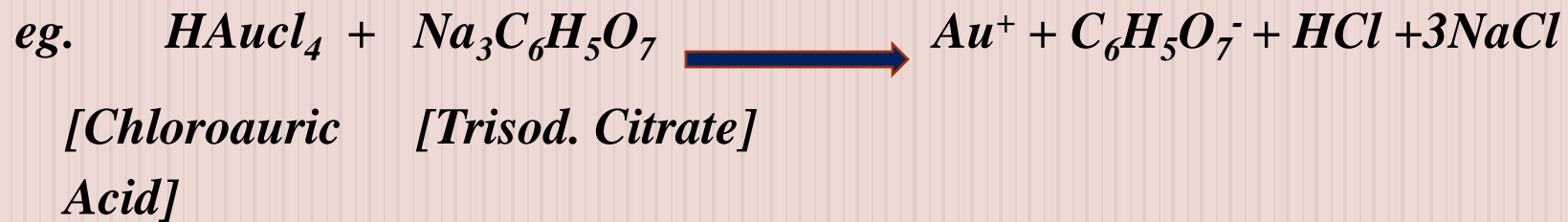
**Bottom up:** Molecule or atom come together in proper way to form required nanostructure.  
High spatial resolution, limited mfg. capability  
But, now combination of both is most famous & effective



# Methods of Synthesis of NPs

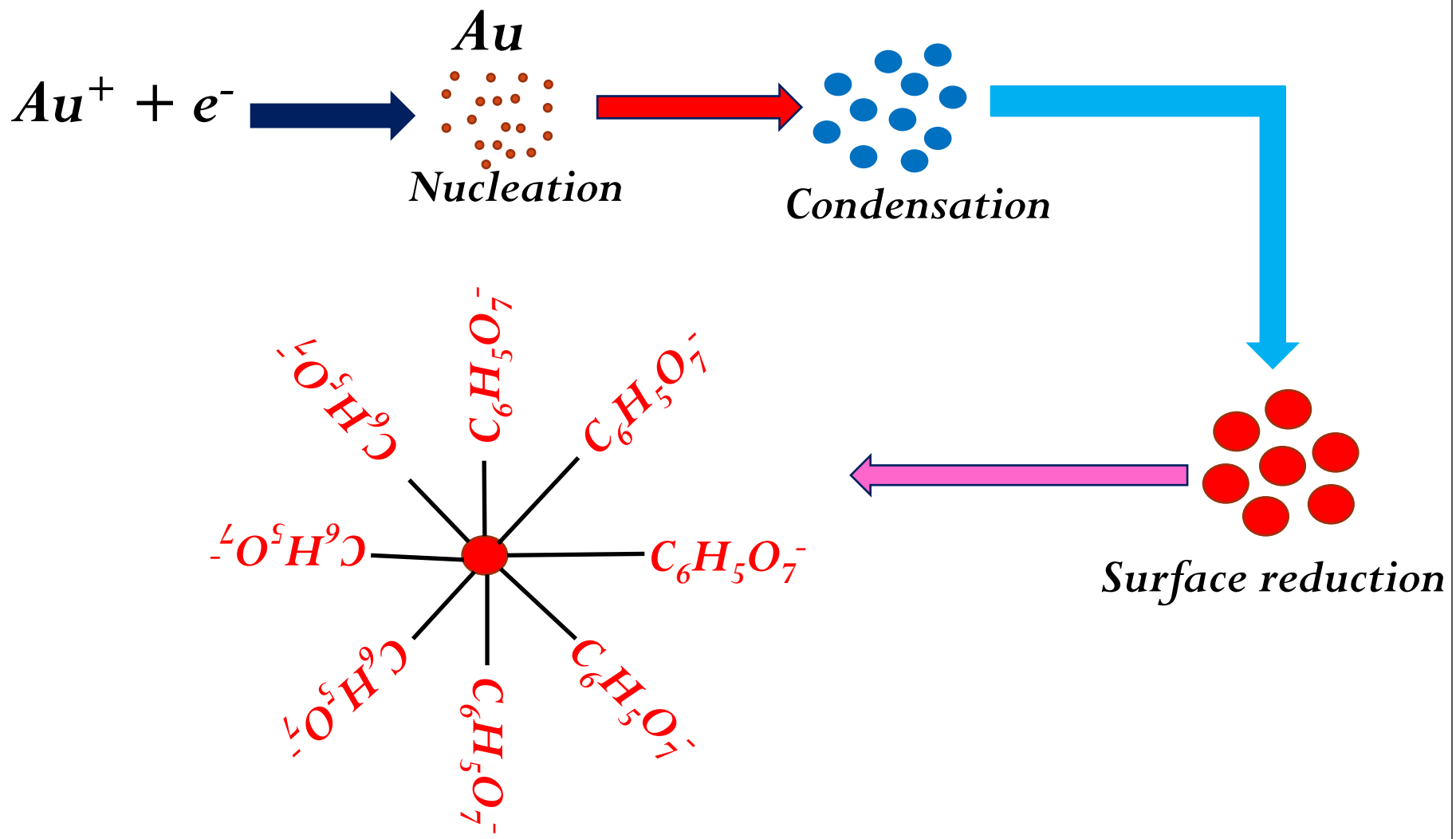
## A) Colloidal Route: ( $10^{-9}$ to $10^{-6}$ m)

To synthesize metal NPs Reduction of metal salt by proper reducing agent



- ✓ Au Nps are stabilized by **repulsive coulomb interaction** (due to formation of double layer at particle)
- ✓ Also stabilized by **thiol** or **other capping molecule**
- ✓ AuNPs exhibit intense **red, magenta, blue-violet** colour depending upon size.

# Process for synthesis of AuNPs





## *Semiconductor NPs by Colloidal route*

*e.g. ZnS NPs*

- *ZnCl<sub>2</sub> or Zn(NO<sub>3</sub>)<sub>2</sub> or ZnSO<sub>4</sub> dissolved in aq. or non-aq. Solvents*
- *Added Na<sub>2</sub>S or H<sub>2</sub>S gas passed*
- *ZnS particles formed*

i.e.



*Colloids formed in the solution have a tendency to coagulate due to attractive forces existing between them.*

# Chemical Capping

- Capping used in synthesis of NPs.
- Some chemicals are used in colloidal synthesis **to inhibit NP overgrowth** & **aggregation** & **to control structural characteristics**.
- Thro' colloidal route NPs also obtained by drying off the liquid.
- Spin coating or dipping coating also used to obtain thin film of capped particles.
- Coating should be stable & non interactive with the particle except at surface.

**Disadvantages:** Chemicals used for capping may be toxic & difficult to handle.

# Sol-gel Method

Used to  
prepare  
silica  
gel

Performed  
in liquid  
phase

- ✓ Useful for self-assembly process for **fabrication of NPs** & three dimensional materials as **aerogels**

**Sol:** Type of colloid, in which dispersed solid phase mixed in homogeneous liquid medium.

**Process:** Formation of colloidal suspension (sol) & gelation of sol (gel) to form network in liquid phase

# Four Steps of synthesis of Silica-gel

1) **Hydrolysis reaction:**  $-OR$  group substituted by  $-OH$  group

Occur without catalyst

If catalyst used increases rate of reaction

Catalyst:  $NaOH$ ,  $NH_3$ ,  $HF$ ,  $CH_3COOH$ , etc.



2) **Condensation:** Complex reaction, many intermediate products formed



**3) Polymerization:** Step growth of particle takes place

- Growth depends upon  $P^H$ , tempt, etc.
- Complex reaction



**4) Agglomeration:** Network particles start to form thro' liquid medium due to which gel is formed.

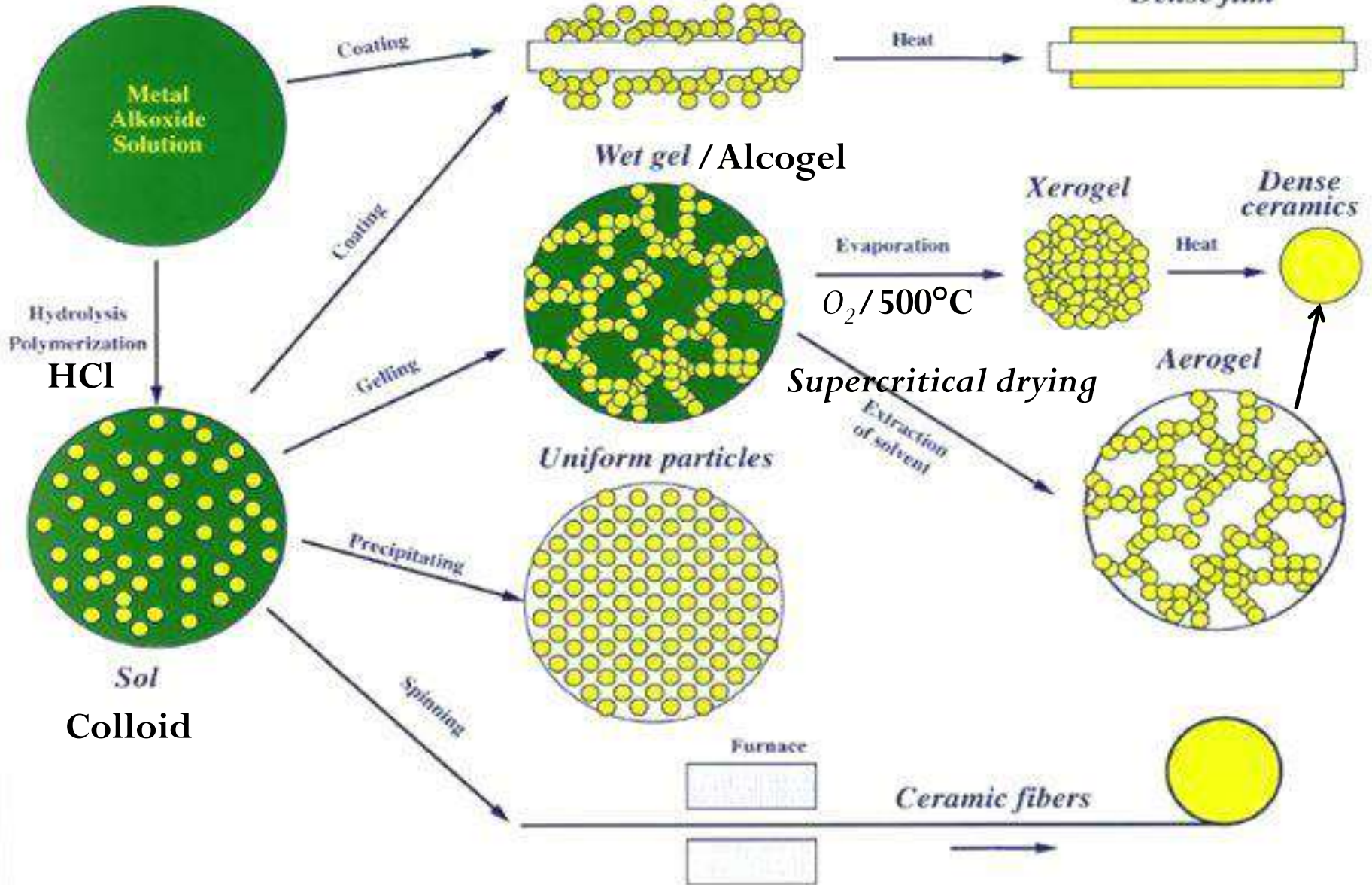
All 4 steps are affected by  $P^H$ , tempt., time of reaction, catalyst.

**Application:** Inorganic coating, Reactive oxides, Ceramic materials, Ceramic coating, Glasses, Mfg. of silica gel catalyst, Special types of alumino-silicates gels (e.g. Imgolite: ext. dia. = 2.5 nm, int. dia = 1.5 nm).



# Sol-Gel process overview

Soln of Metals + Alkoxysilanes  
Alkoxides + Alcohol



# Chemical reduction Method

- *Metal salt solution treated with suitable reducing agent.*
- *Added appropriate stabilizing agent.*
- *Further treatment Dried & get NPs. **Eg. AgNPs***

*AgNO<sub>3</sub> Sol<sup>n</sup> + Hydrazine hydrate + Sod. Doacyl sulfate & Sod. Citrate (stabilizing agent)*



*Pale yellow or Pale red colour (due to form<sup>n</sup> of AgNPs)*



*Purified by centrifugation*



*AgNPs washed with deionized water under N<sub>2</sub> gas to remove excess Ag ions*



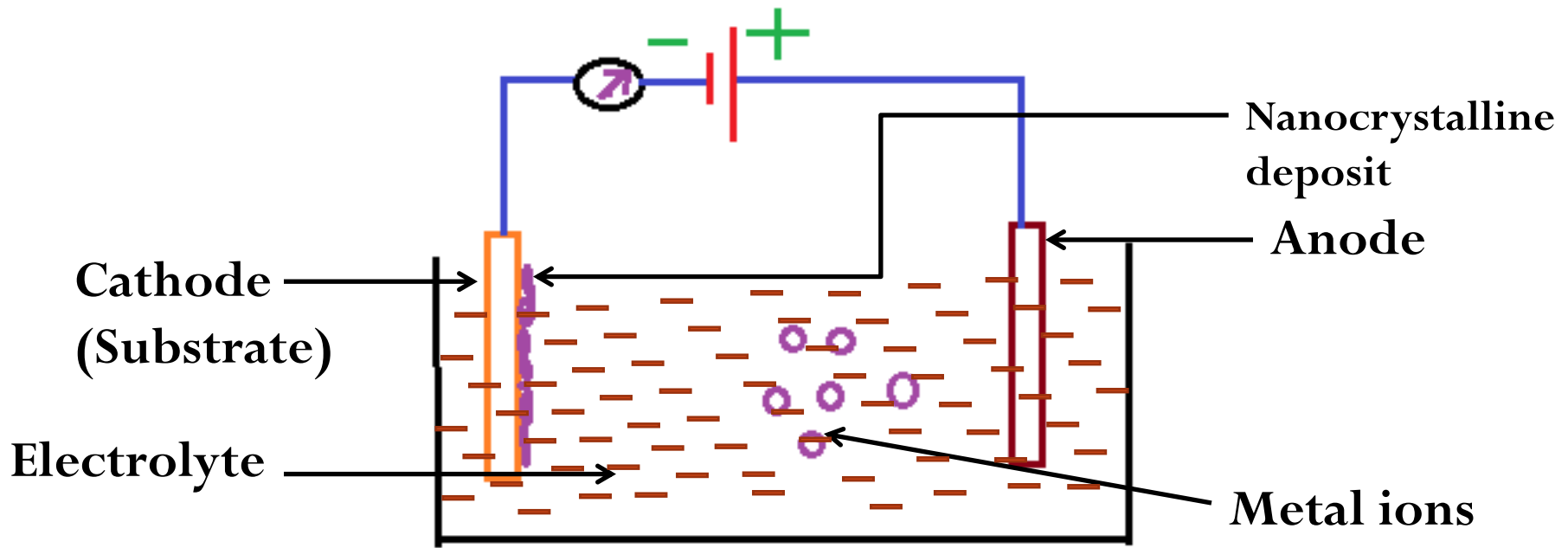
*Dried powder of nanosize silver can be obtained by freeze drying*



*Particle size 15 to 48 nm*

# Electrochemical method

- Process of using electric current to coat on electrically conductive object with thin layer of metal.
- As a result of electrical current, electrolysis of electrolytic solution occurs & deposition of metal in the form NP takes place on cathode, so called as **electrodeposition**.
- As result of reduction reaction metal ions in a solution deposits on negatively charged cathode metal atoms.  
*e.g.* Ag, Cu, Au Nps can be synthesized.



➤ *e.g. preparation of AgNP*

### **Advantages:**

- *Cheap & fast Method.*
- *Thickness of layer depends on current density & time of current flow.*
- *The deposit can be detached by suitable method*
- *Recent Mostly used process by many researchers.*

# Applications of NMs

**Electronics:** NPs of ZnSe, ZnS, CdS improves resolution of TV screen. So used in HD TV & computer monitors.

**Energy (Fuel cells):** NM as catalyst to produce hydrogen ions from fuel.

**High Storage capacity batteries:** Aerogel & Ni-MH

**Industry:** Tougher & harder cutting tools. e.g. WC, TaC, TiC NPs, etc.

**Automobile with greater efficiency:** engine cylinders (liner) with zirconia & alumina NPs which retain heat & increases efficiency.



## **Health Care:**

-Heart valves from **ZrO** ceramics, **SiC** (low wt., extreme hardness, high strength, corrosion resistance, etc.)

-NM used in cancer therapy, drug release, etc.

**Food- Agriculture:** Food packaging, food processing catalyst, food quality analysis sensor, etc.

**Textile:** NM used to produce medical textile, technical textile, antistain textile, self-cleaning textile, etc.

**Environment:** Pollution scavengers, pollution monitoring sensors, etc.

**Cosmetics:** Various creams & gels e.g. ZnO, TiO<sub>2</sub>

**Domestic Appliances:** NMs used in various domestic appliances such as air purifiers, air conditioners, water purifiers, refrigerators, window material, etc.

**High sensitive sensors:** NM of ZrO is used in CO sensor. NM also used in smoke detectors, ice detectors on aircraft wings, automobile engine performance sensors.

NM used in aerospace components, longer lasting satellites, self-cleaning glasses, etc.

**Future Applications:** Quantum computers, microelectro-mechanical systems, optoelectronic devices, environmental devices, nano-electronic & magnetic devices, etc.

Questions ...???

Thank you

