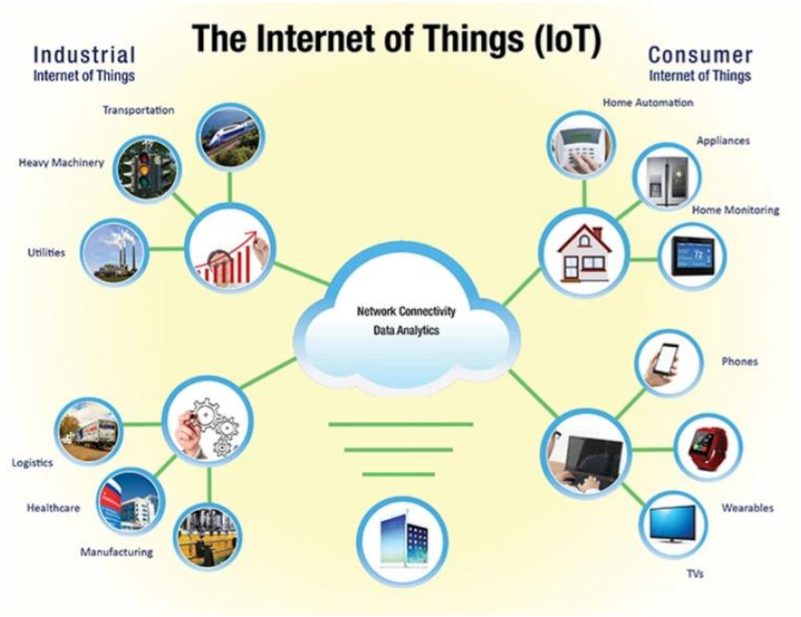
UNIT-V

Smart sensors and devices:
RFID and IoNT materials: Synthesis, properties and applications in logistic information, intelligent packaging systems (Graphene oxide, carbon nanotubes (CNTs) and polyaniline). **Sensors:** Introduction, types of sensors (Piezoelectric and electrochemical), nanomaterials for sensing applications (Strain sensors, gas sensor, biomolecules and volatile organic compounds).

Internet of Things (IoT)

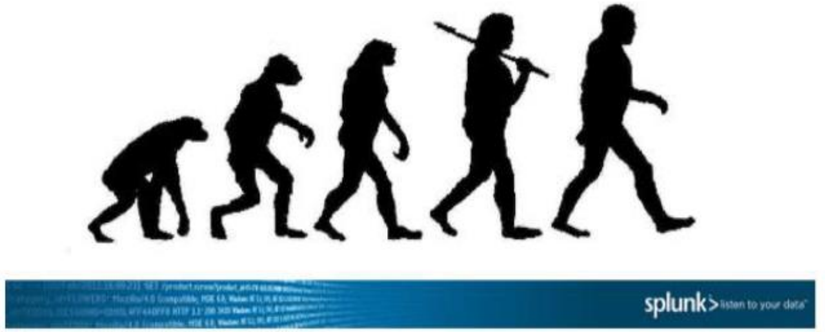
The purpose of this technology is to

- Connect
- Communicate
- Control through internet



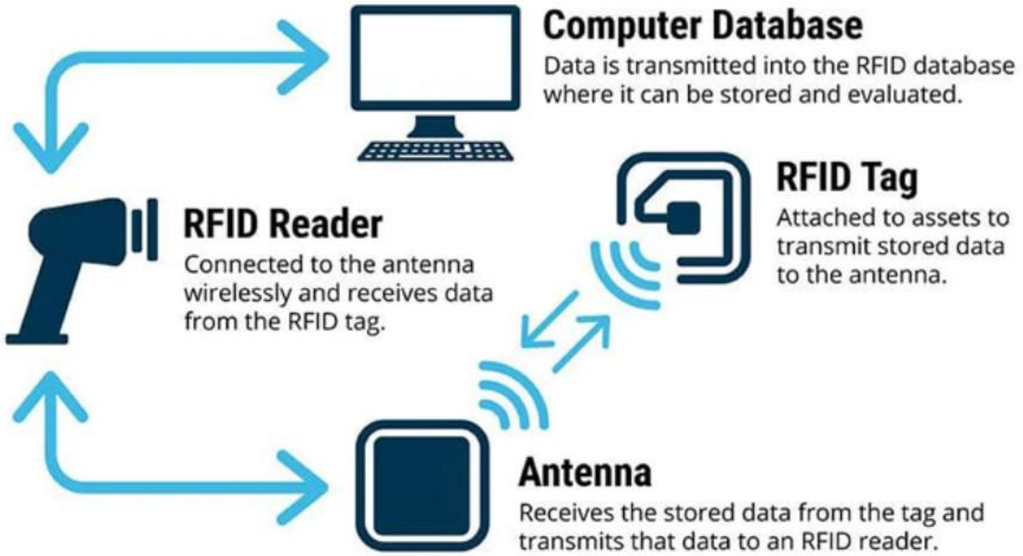
- This technology is an integration of internet and sensor network, via (Radio Frequency Identification) RFIDs devices

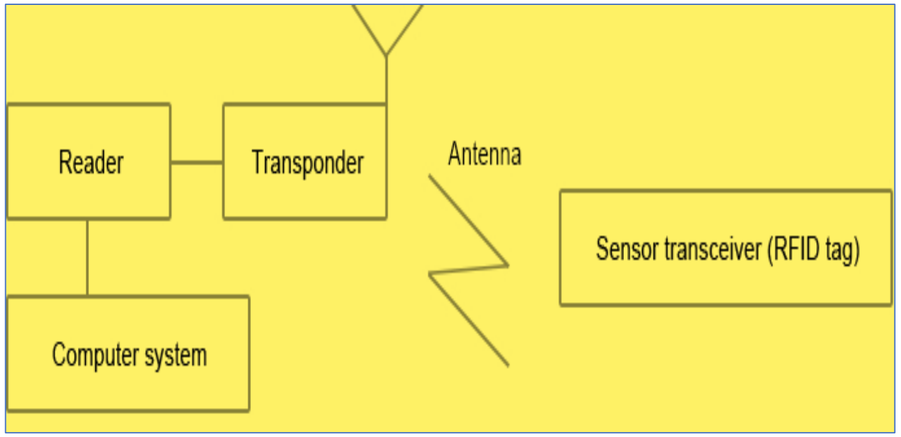
- If this technology involve the smart devices made-up of nanomaterials, it is called Internet of nanothings (IONTs)



Radio Frequency Identification (RFID)

It is a wireless, an electronic device/tag, which uses electromagnetic field to identify, track and connect with the objects attached with tags.





Classification of RFID tags (Based on power source)

1) **Passive RFID Tag:** It is a RFID tag with no inbuilt power source (Battery) designed to use in small range (up to 10 m) tracking systems, operates on low, high or ultra-high frequency.

- It is very thin
- long service life.

2) Active RFID Tag: It has its own power source, such as battery, inbuilt. It is used for long scanning and reading range (up to 100 m), operates only at high frequency.

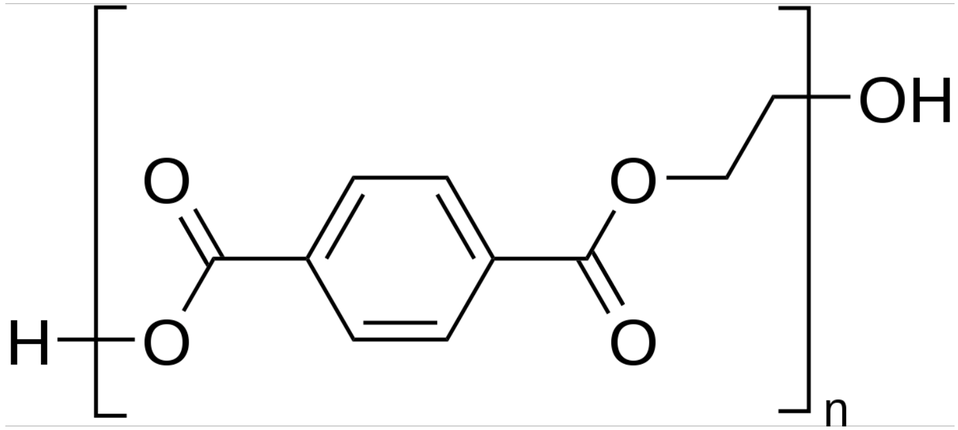
- The price is relatively high,
- Volume is larger than the Passive tag because of the built-in battery.

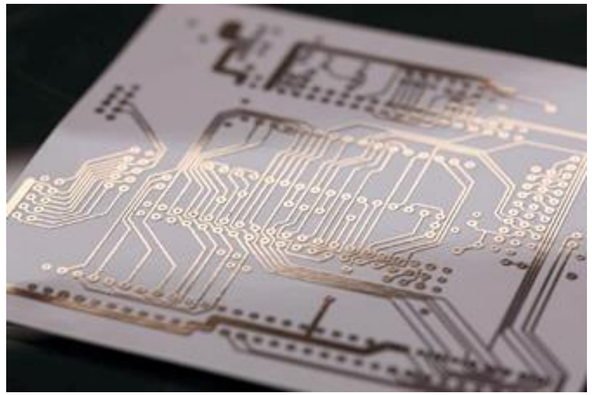
Classification of RFID tags (Based on frequency)

Types	Low-Frequency	High-Frequency	Ultra High-Frequency
Frequency Range	100~500 KHz	10~15 MHz	850~950 MHz~2.45 GHz
inductive distance	shorter	longer	longest
reading speed	slower	relatively high	fastest
penetration ability	good	Avearge	bad

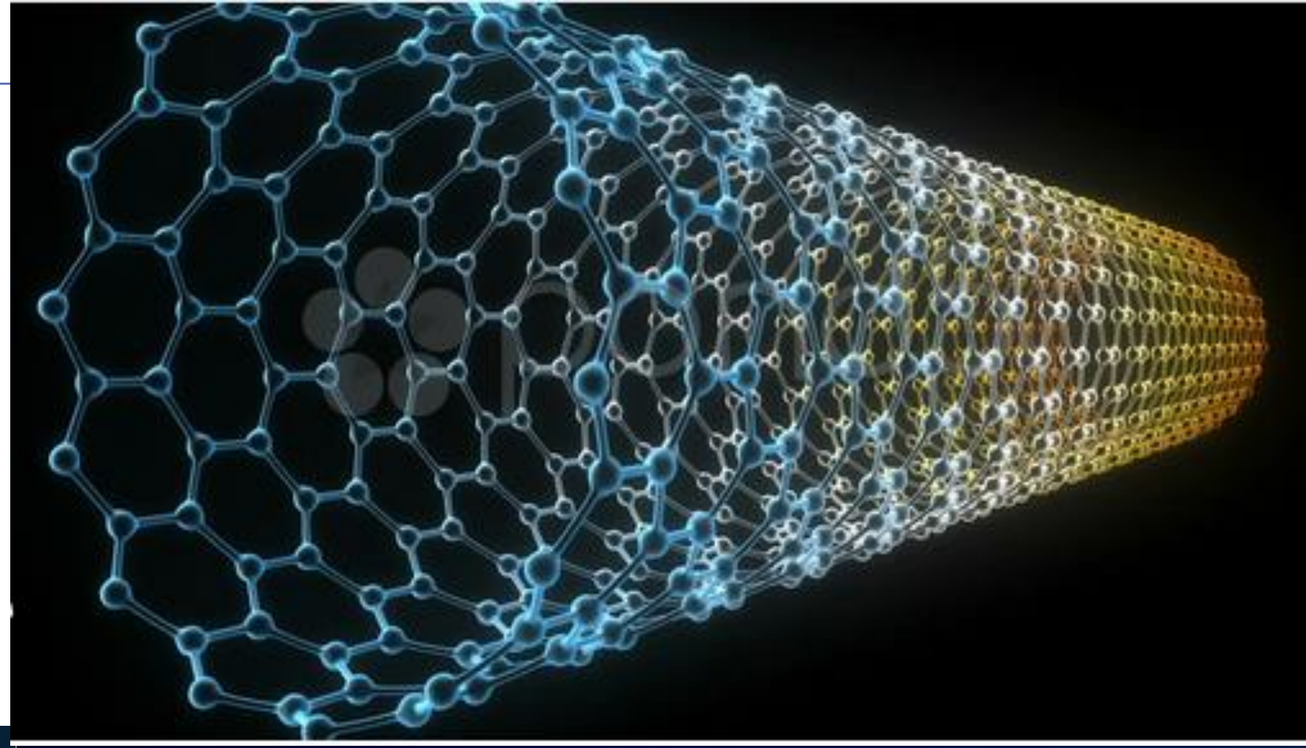
Materials for RFID tag

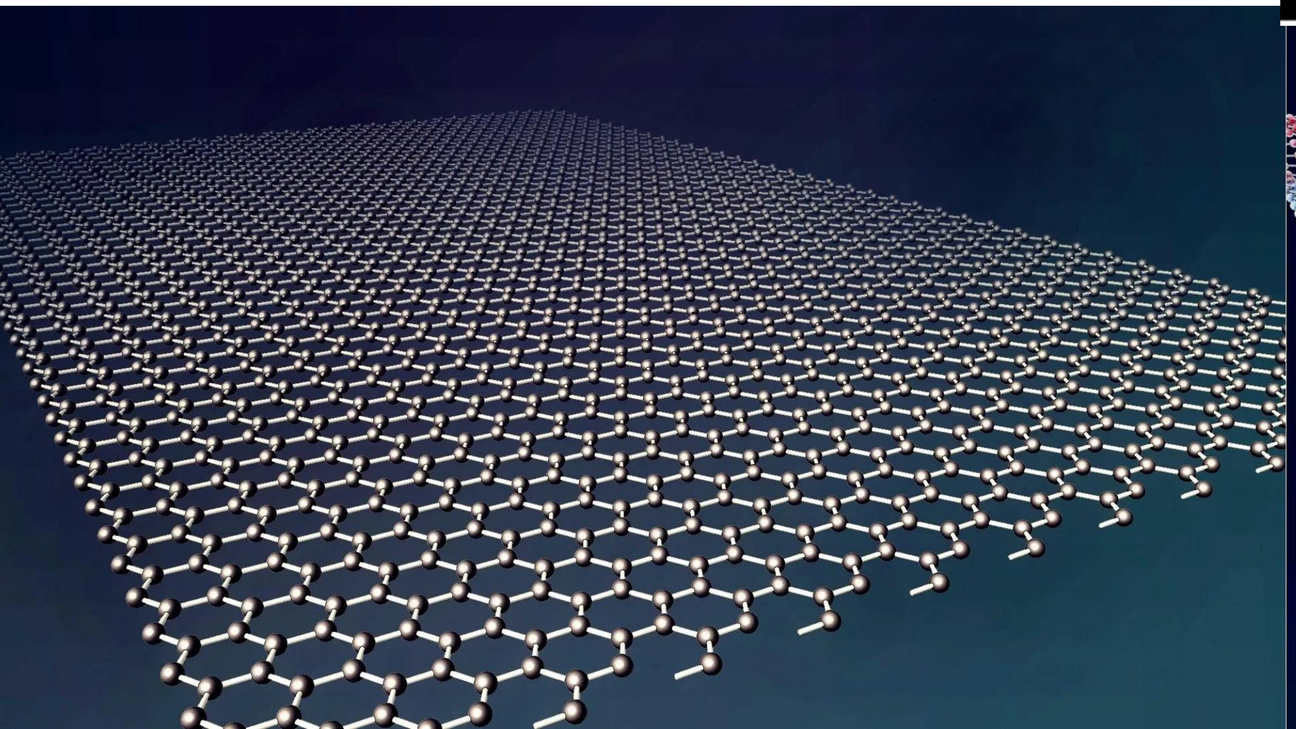
Polyethylene Terephthalate (PET)
as substrate

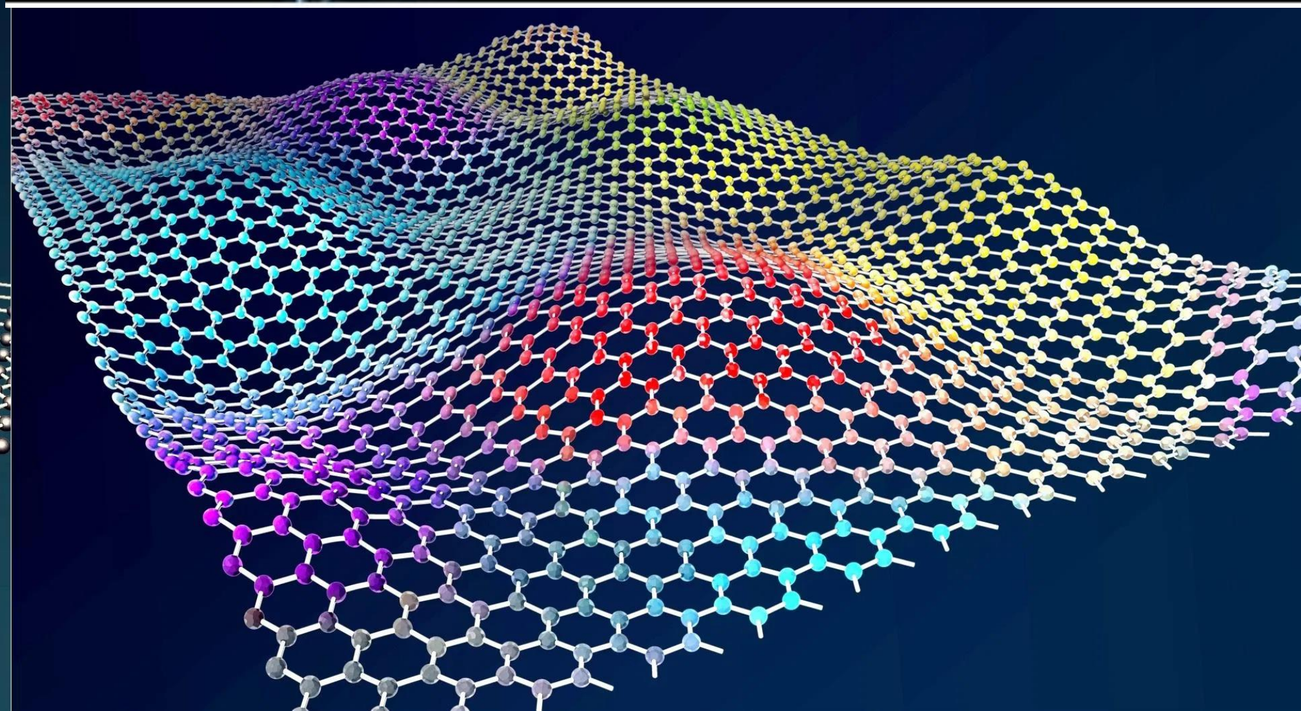




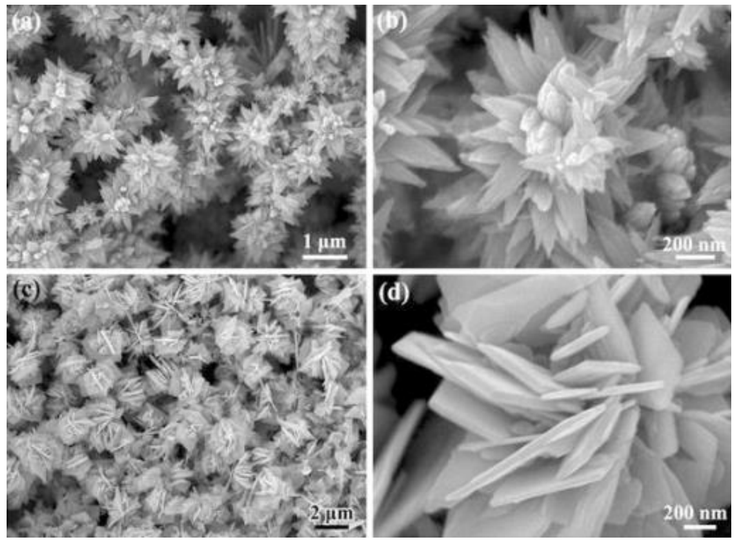
Carbon Nanomaterials for RFID







Introduction to Nanomaterials/Science/Technology



❖ **Nanomaterials** are commonly defined as materials with an average grain size less than 100 nanometers.

❖ The word ***"nano***" originates from the Greek word "nanos" which means "dwarf". However, in scientific language it is a prefix which has a value equal to "one billionth, i.e. 10^{-9}.

❖ Therefore, one nanometer is ***one billionth of a meter (1 nm = 10^{-9} m).***

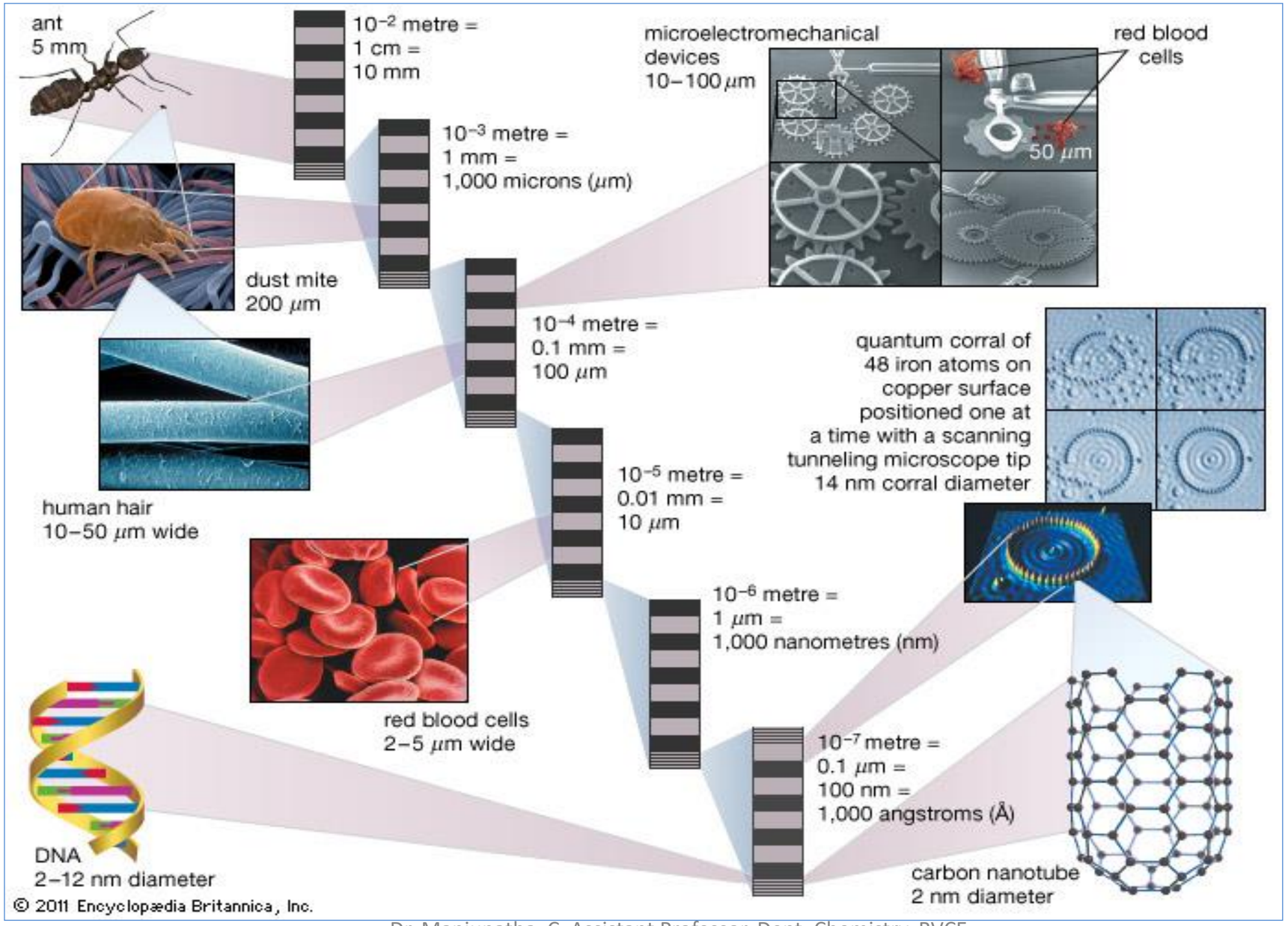
Nano-dimension comparison

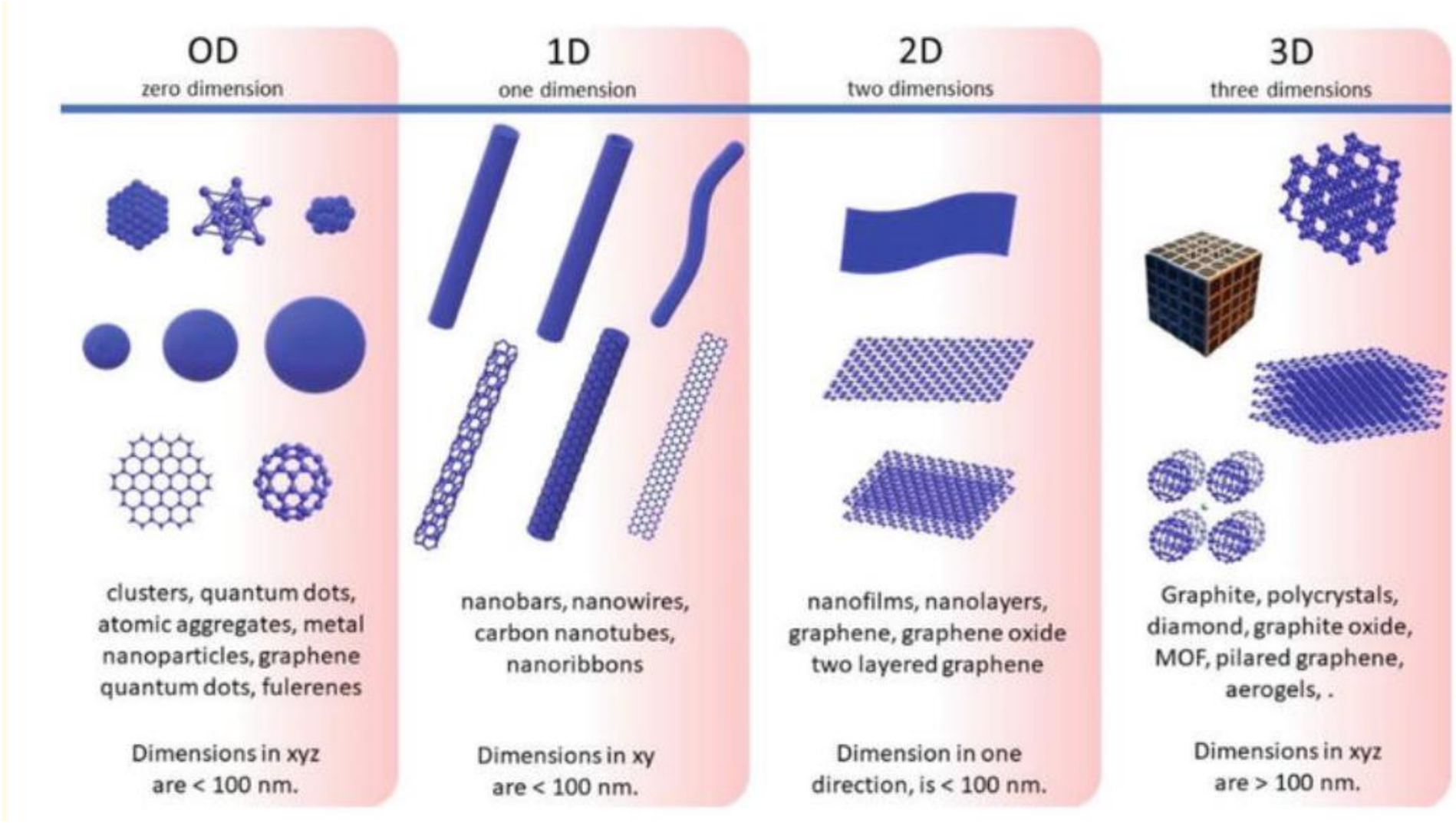
1.Diameter of a hydrogen atom is about 0.1 nm. If ten hydrogen atoms are aligned in a line, then the resulting length would be approximately 1 nm. Similarly, 1 nm is approximately 5 silicon atoms aligned in a line.

2.A single strand of human hair is around 20,000 nm in diameter. A nanometer is one millionth of a millimeter - approximately 100,000 times smaller than the diameter of a human hair.

3.Size of a DNA molecule is about 2.5 nm.

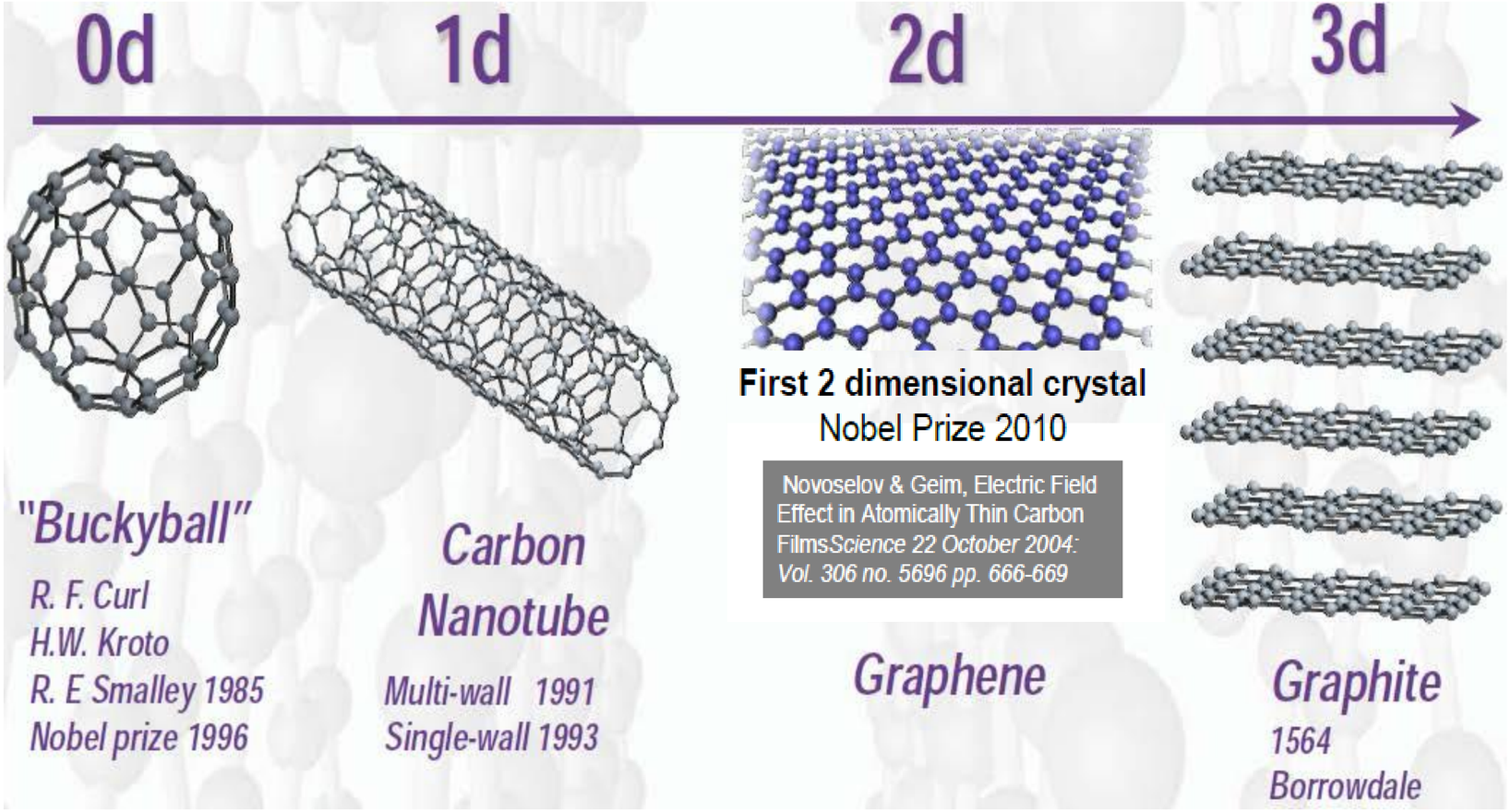
Nano-dimension comparison




0D
zero dimension
clusters, quantum dots, atomic aggregates, metal nanoparticles, graphene quantum dots, fulerenes
Dimensions in xyz are < 100 nm.
1D
one dimension
nanobars, nanowires, carbon nanotubes, nanoribbons
Dimensions in xy are < 100 nm.
2D
two dimensions
nanofilms, nanolayers, graphene, graphene oxide two layered graphene
Dimension in one direction, is < 100 nm.
3D
three dimensions
Graphite, polycrystals, diamond, graphite oxide, MOF, pilared graphene, aerogels, .
Dimensions in xyz are > 100 nm.

Carbon nanotubes

Carbon is an incredibly versatile element. Depending on how atoms are arranged, it can produce hard diamonds or soft graphite. Carbon materials can exist in various dimensions.

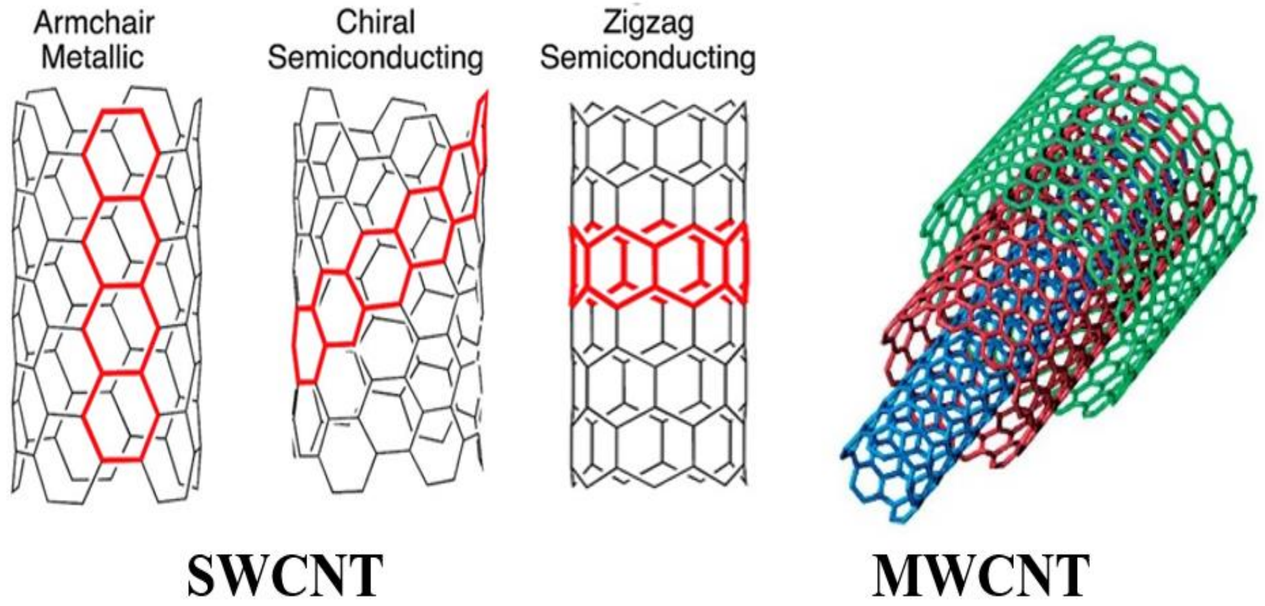


Carbon Nanomaterials

Carbon nanotubes are a new form of a hexagonal network of carbon atoms rolled up in the form of cylindrical shape.

Types of CNTs

1. **Single-Wall Nanotube (SWNT) (Arm Chair, Zig-Zag and Chiral)**
2. **Multi-Walled Nanotubes (MWNT)**



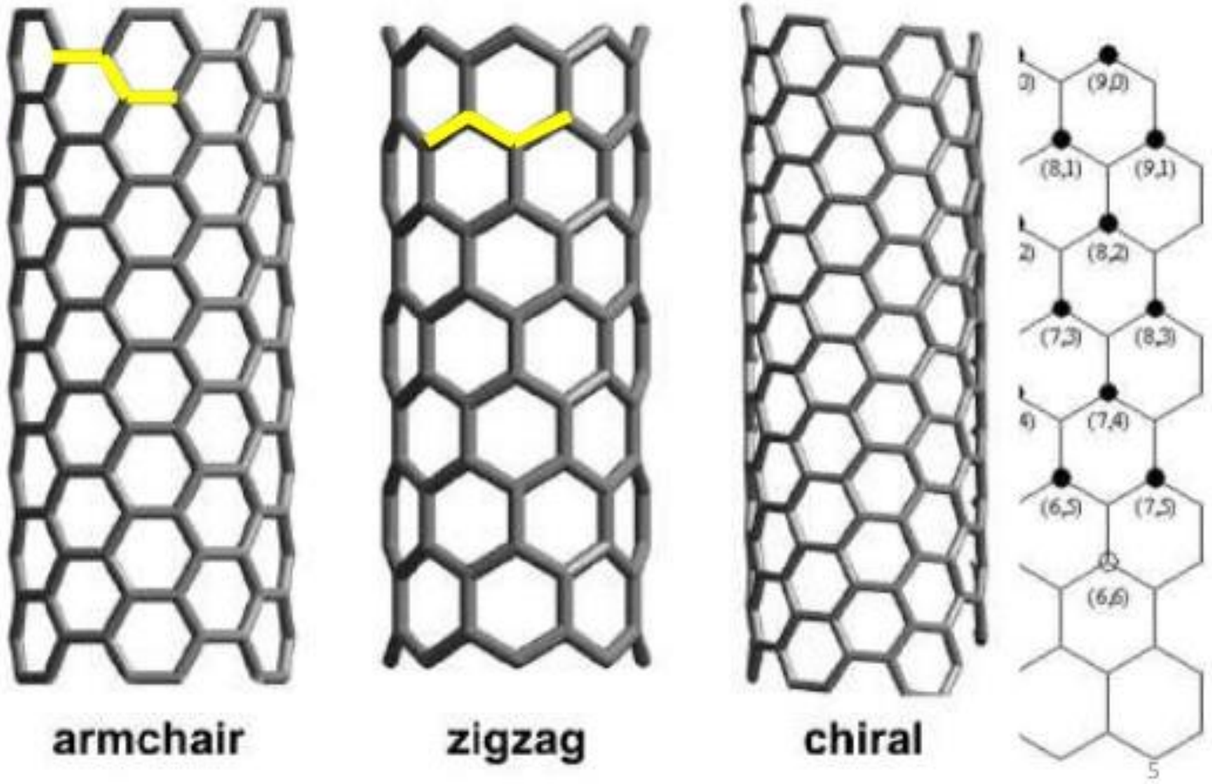
CNT types

Based on symmetry

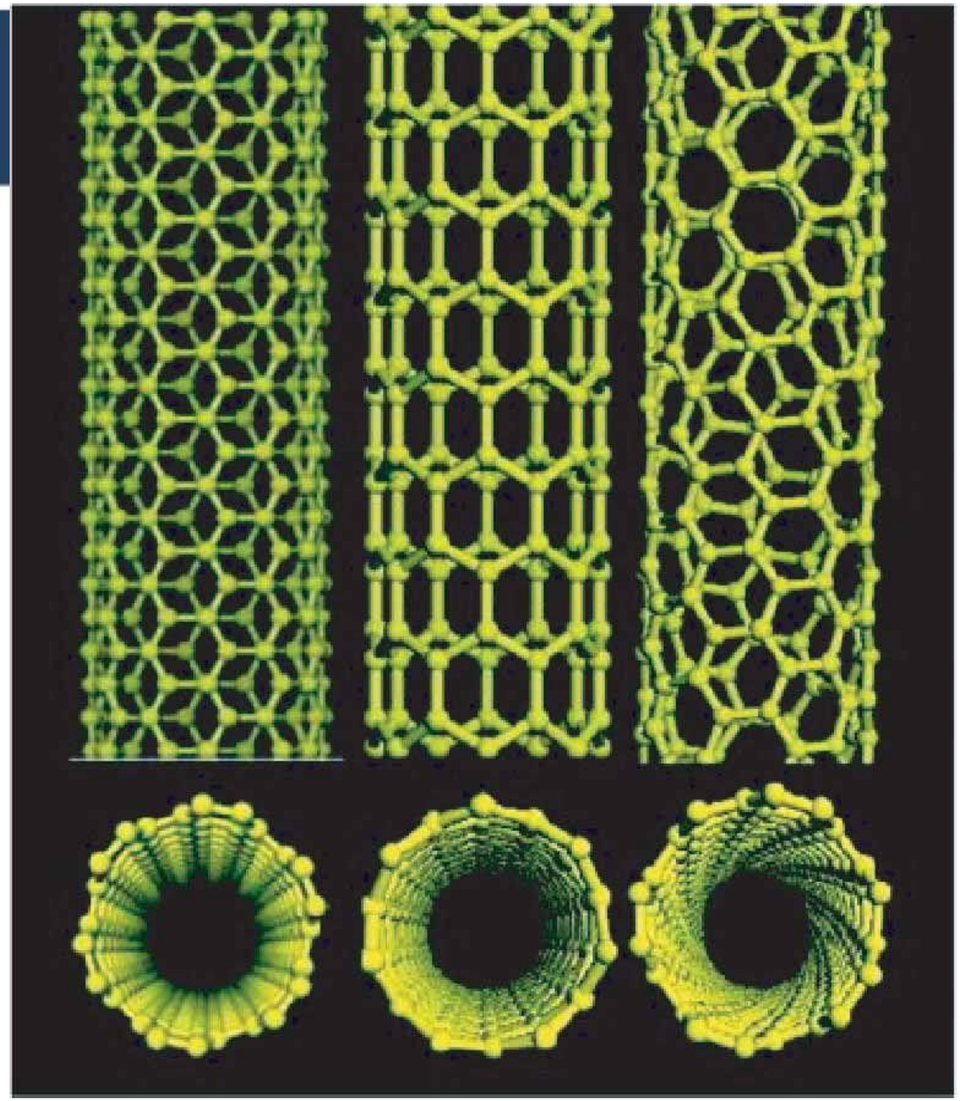
(n,m)

n= colu
m= row

If:
n=m →
n≠m →
(n,0) →



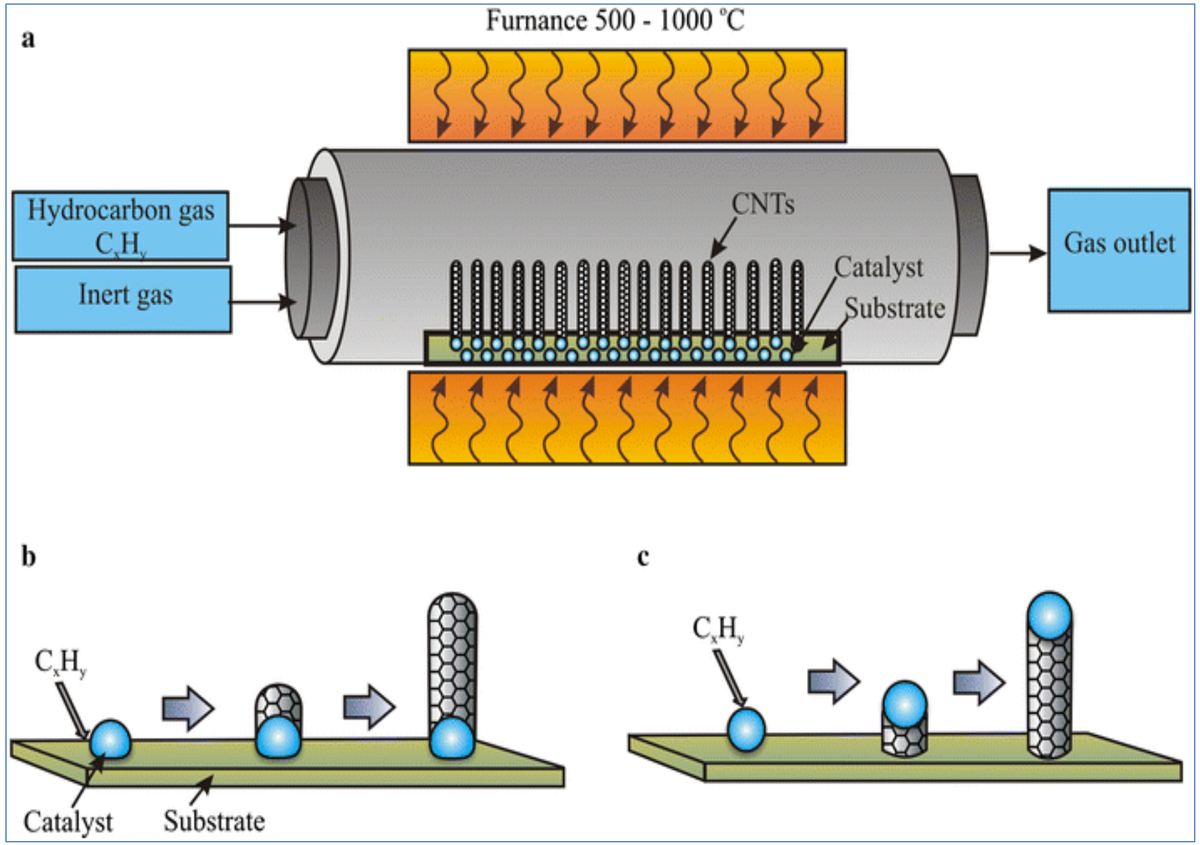
armchair zigzag chiral



Synthesis of CNTs by modified CVD method

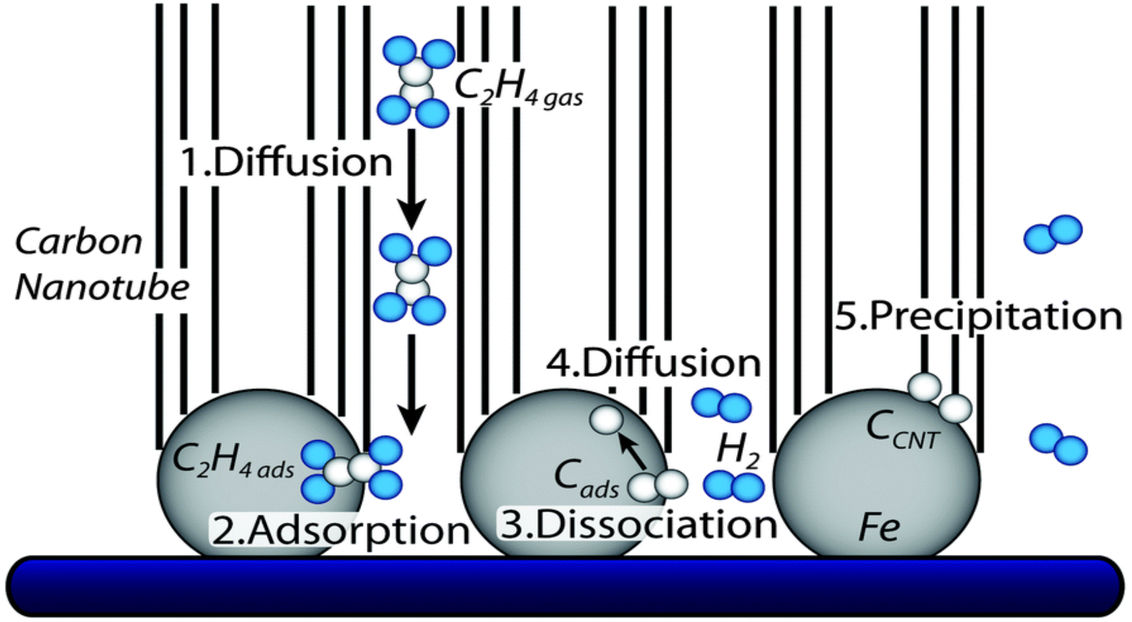
Chemical Vapor Deposition: Requirements**:**

- High Temperature Tubular furnace (500 to 1500 ℃)
- Source of Carbon: Methane, ethylene, hydrocarbon gas, xylene, natural gas
- Substrate: carbon, quartz, silicon
- Inert gas: Argon, Hydrogen, Nitrogen
- Catalyst: Ferrocene, Nickellocene, Cobaltocene

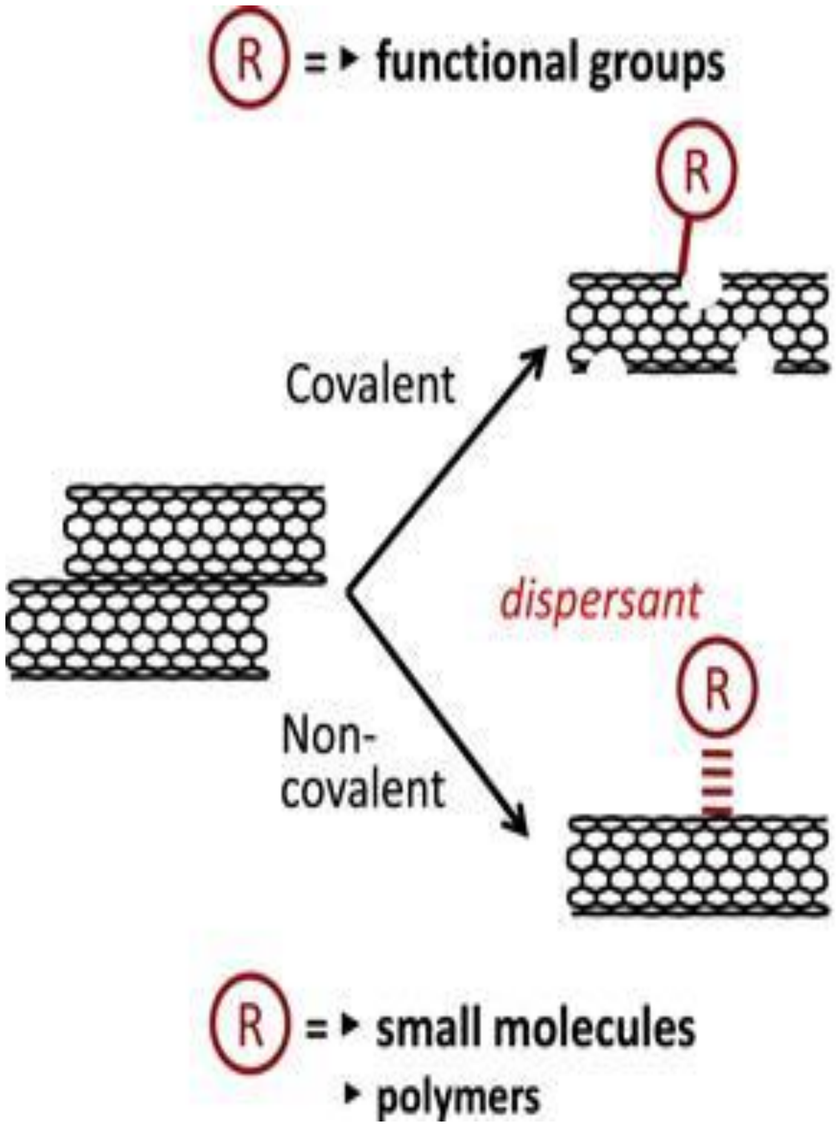


Mechanism of CNTs growth

1. **Diffusion** of Hydrocarbon gas
2. **Adsorption** of Hydrocarbon gas on the surface active site of catalyst particles.
3. **Dissociation** (Homolytic fission) of Hydrocarbon in to highly reactive free radicals of ‘C’ and ‘H’.
4. Repetition of steps 1, 2 and 3 leading to increase in concentration (saturation) of free radicals.
5. **Precipitation** (aggregation) of carbon free radicals results into crystal growth in the form tube on the surface. ‘H’ free radicals escape as H_2 gas.



Functionalization of CNT



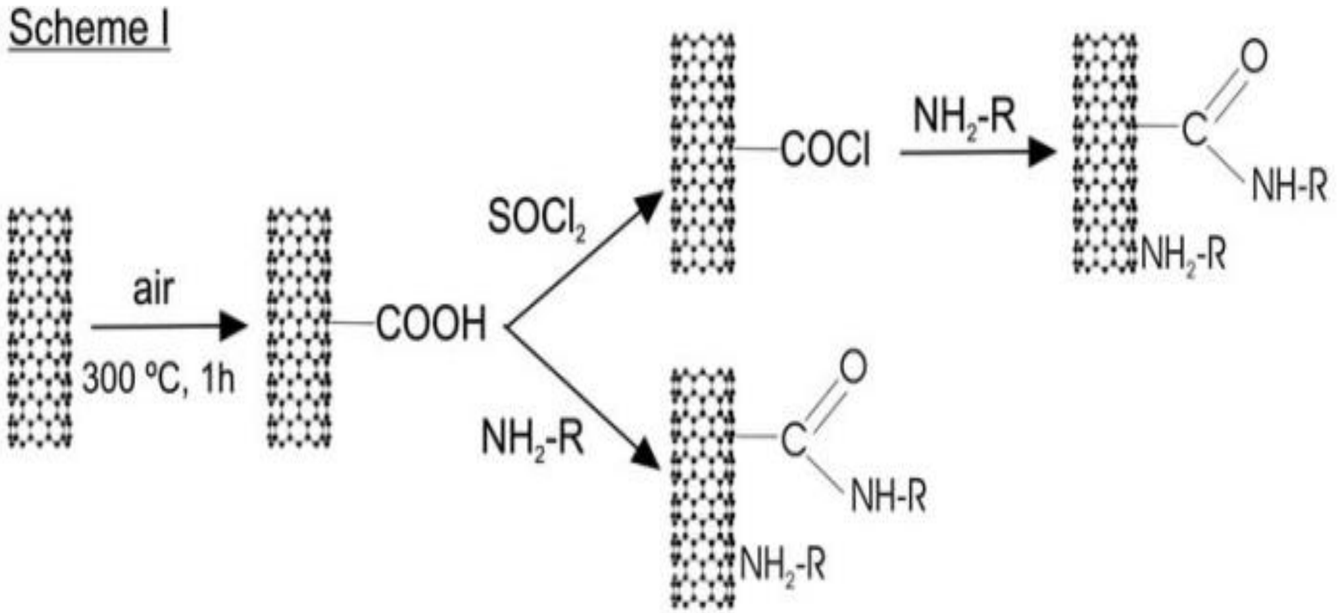
advantage
- high dispersion stability

disadvantage
- loss of inherent properties
- structural damage,
- shortening

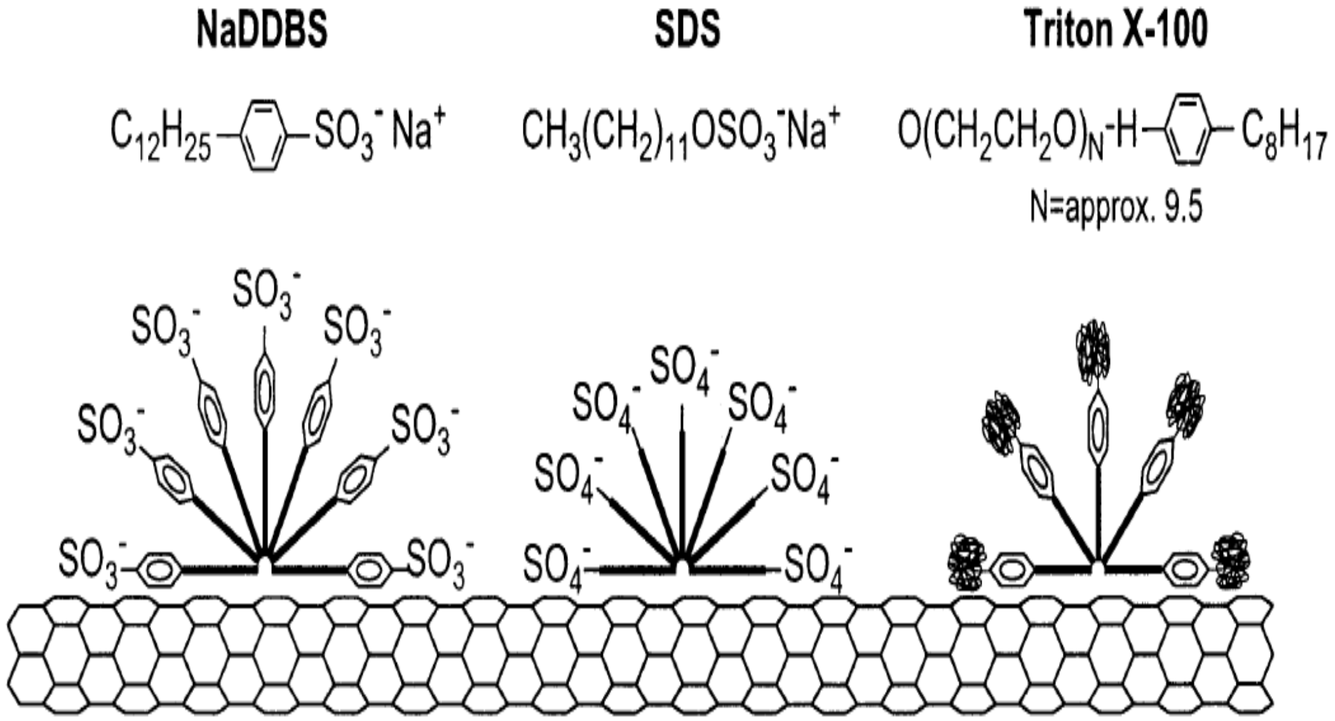
advantage
- easy procedure
- minimum damage

disadvantage
- weak coating stability

Chemical (covalent) functionalization



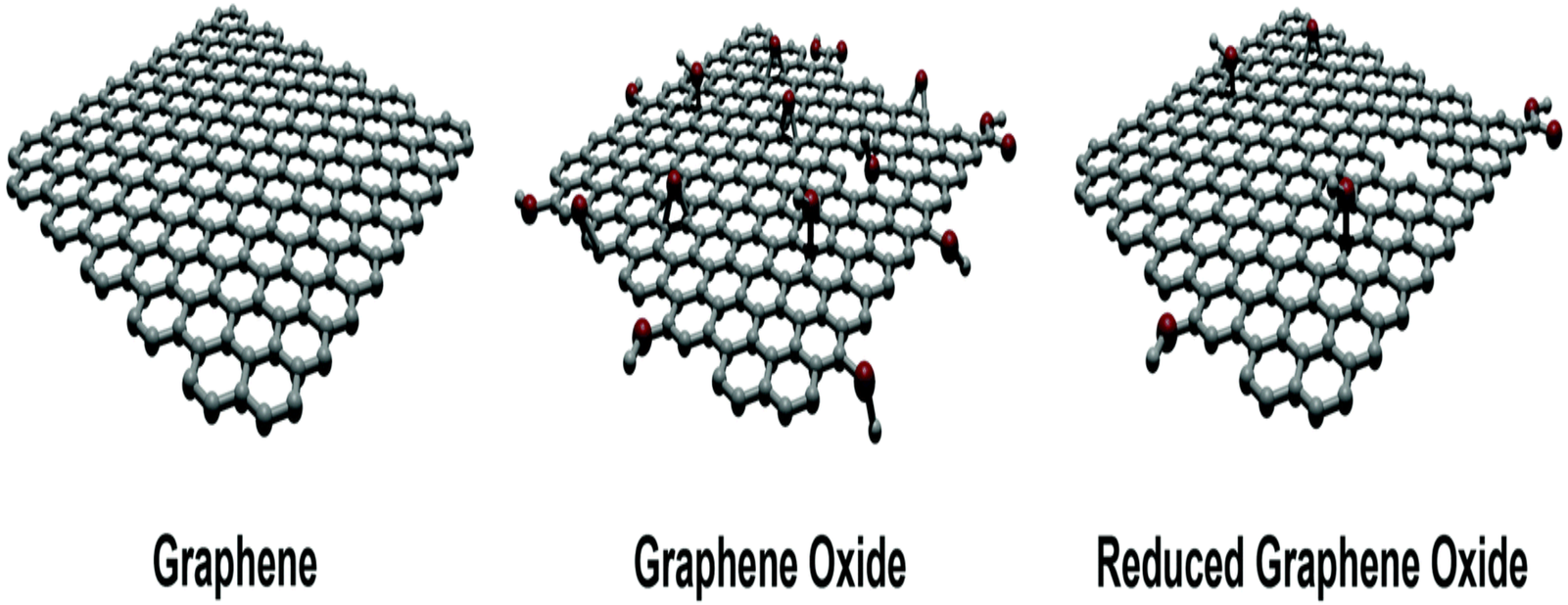
Physical (Non-covalent) functionalization



Applications of CNTs

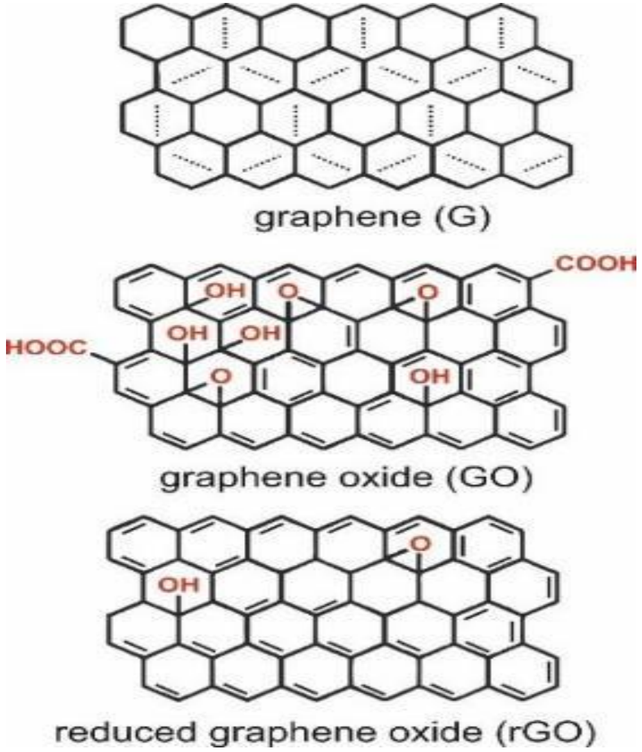
- RFIDs, Sensors, IoNTs sensors
- Optoelectronic devices (Field Emission Display (FED))
- As *electrodes in* batteries*, capacitors and super capacitor electrodes*.
- As *electrode catalyst supports in Polymer Electrolyte Membrane (PEM) fuel cells*
- *Hydrogen* Storage material in hydrogen fuel car.
- As electrically *powered artificial* muscles.
- Electro catalyst for water splitting, H_2 production.
- Adsorbent and photocatalyst for organic pollutants degradation.
- Sensor for heavy metal ion, gases, volatile organic compounds and biomolecules.
- Drug carriers

Graphene

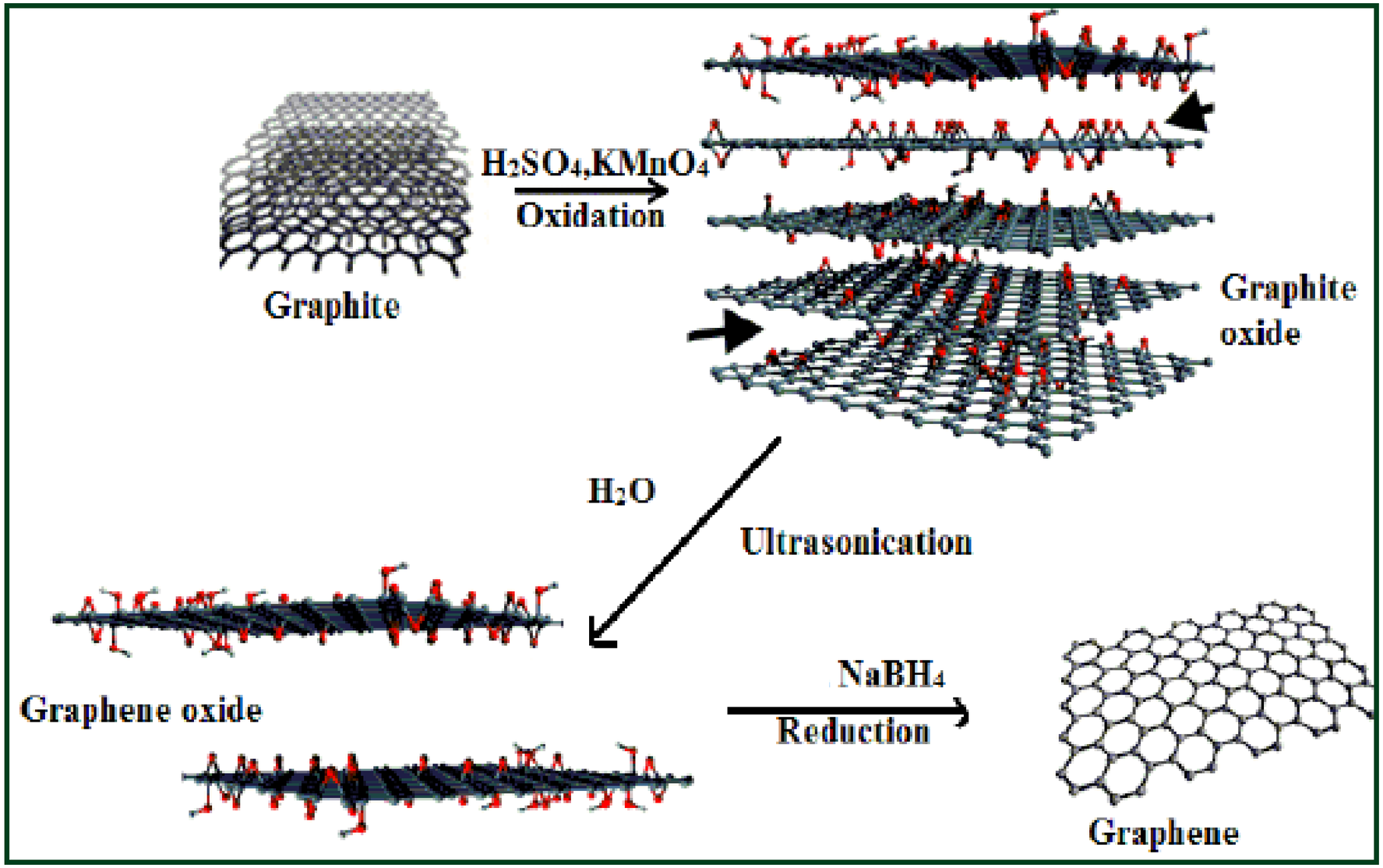


- Graphene is a newly found allotrope of carbon, consisting of single layer atoms in hexagon pattern.
- It is a purely carbon-based, honeycomb-structured, one-atom thick layer of carbon atoms (two dimensional sheet), bonded to one another by sp2 hybridization.

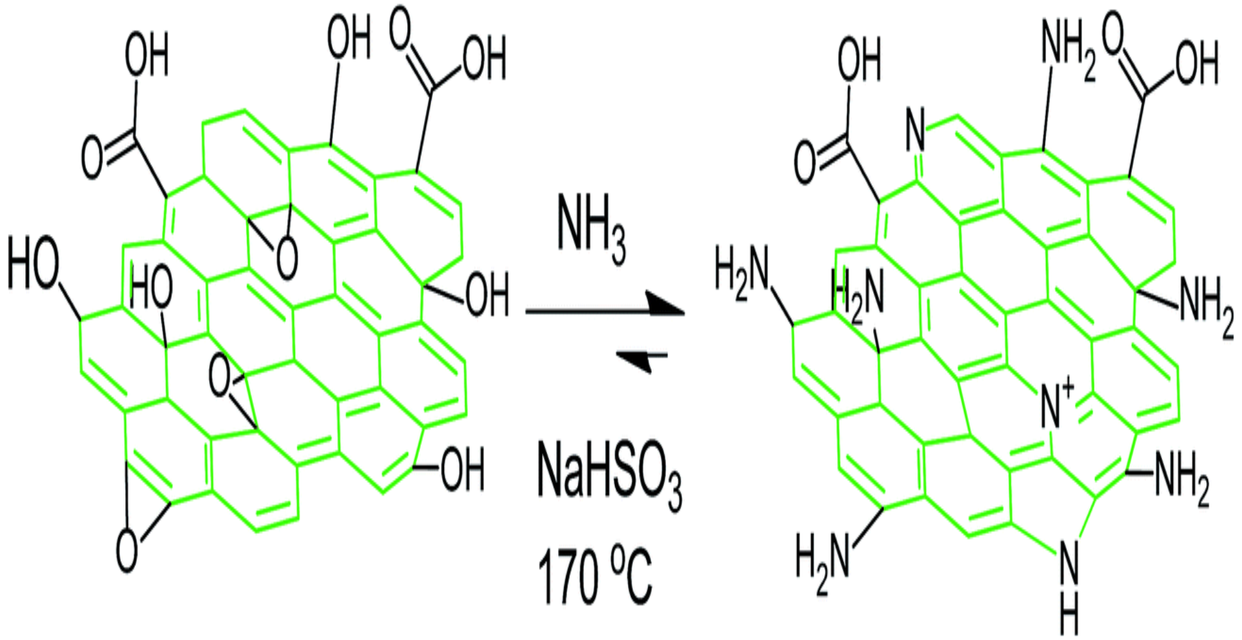
Synthesis of Graphene Oxide and Reduced Graphene Oxide- Modified Hummer's Method

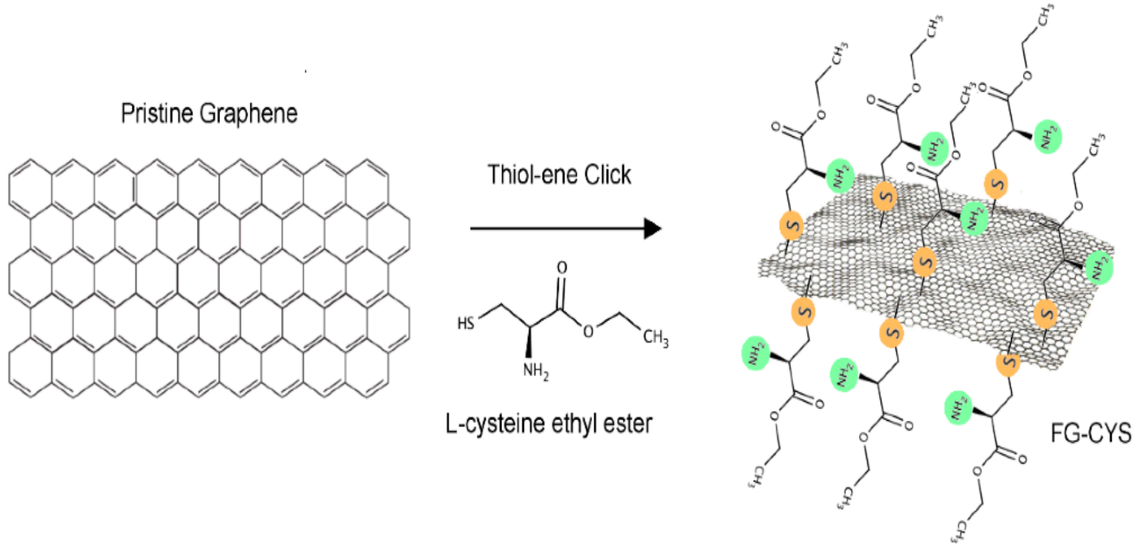


Synthesis of Graphene Oxide and Reduced Graphene Oxide (rGO) Modified Hummer's Method

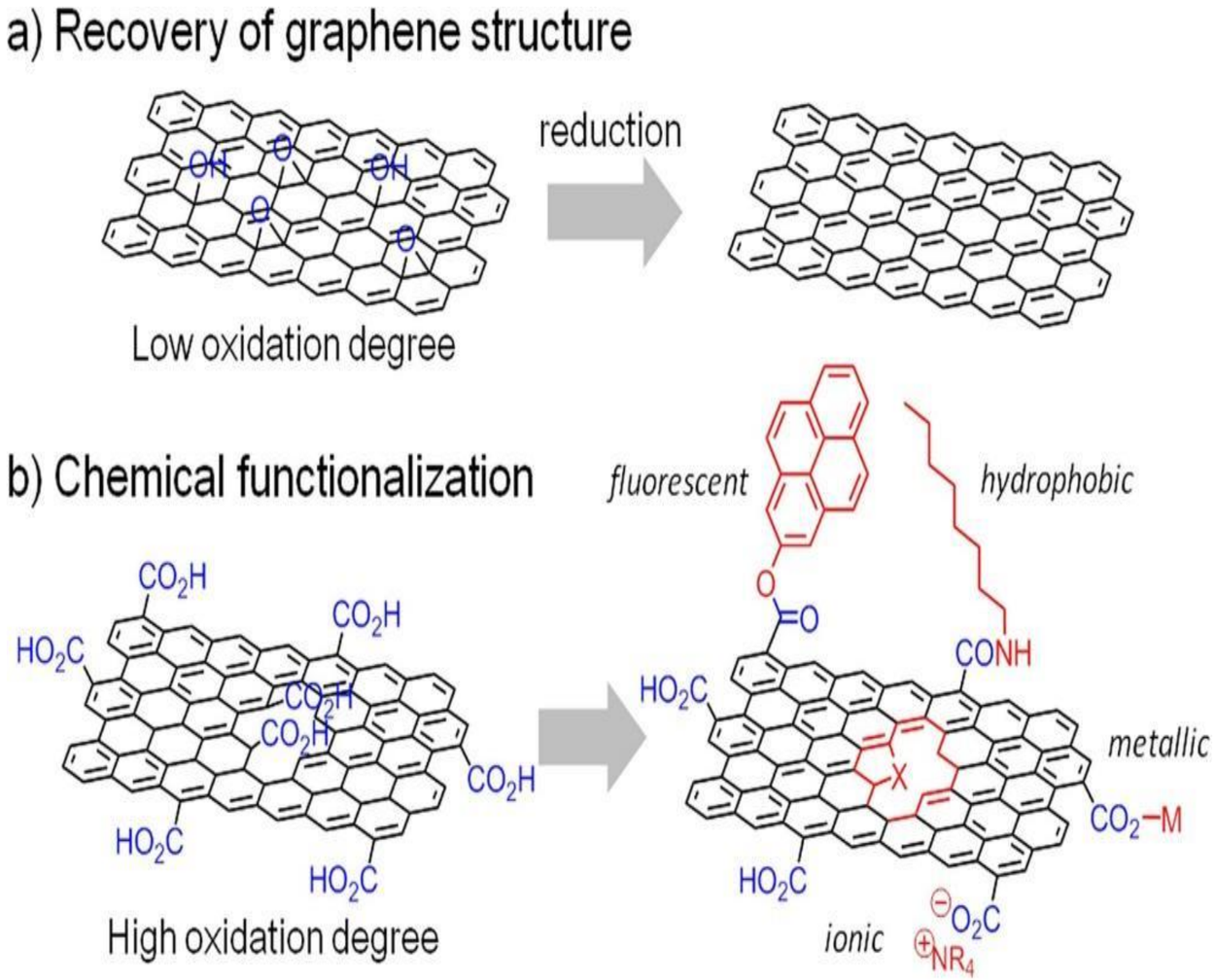


Functionalization of Graphene

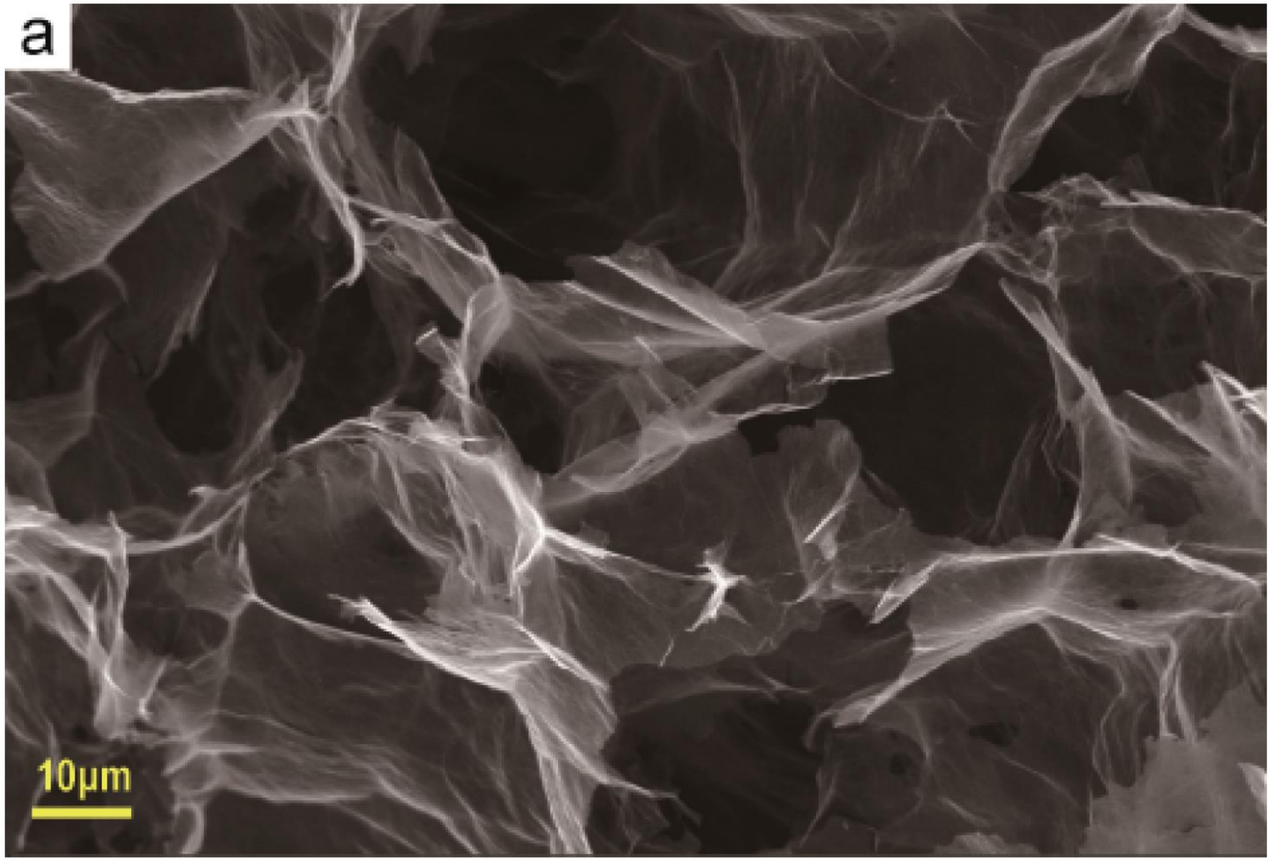


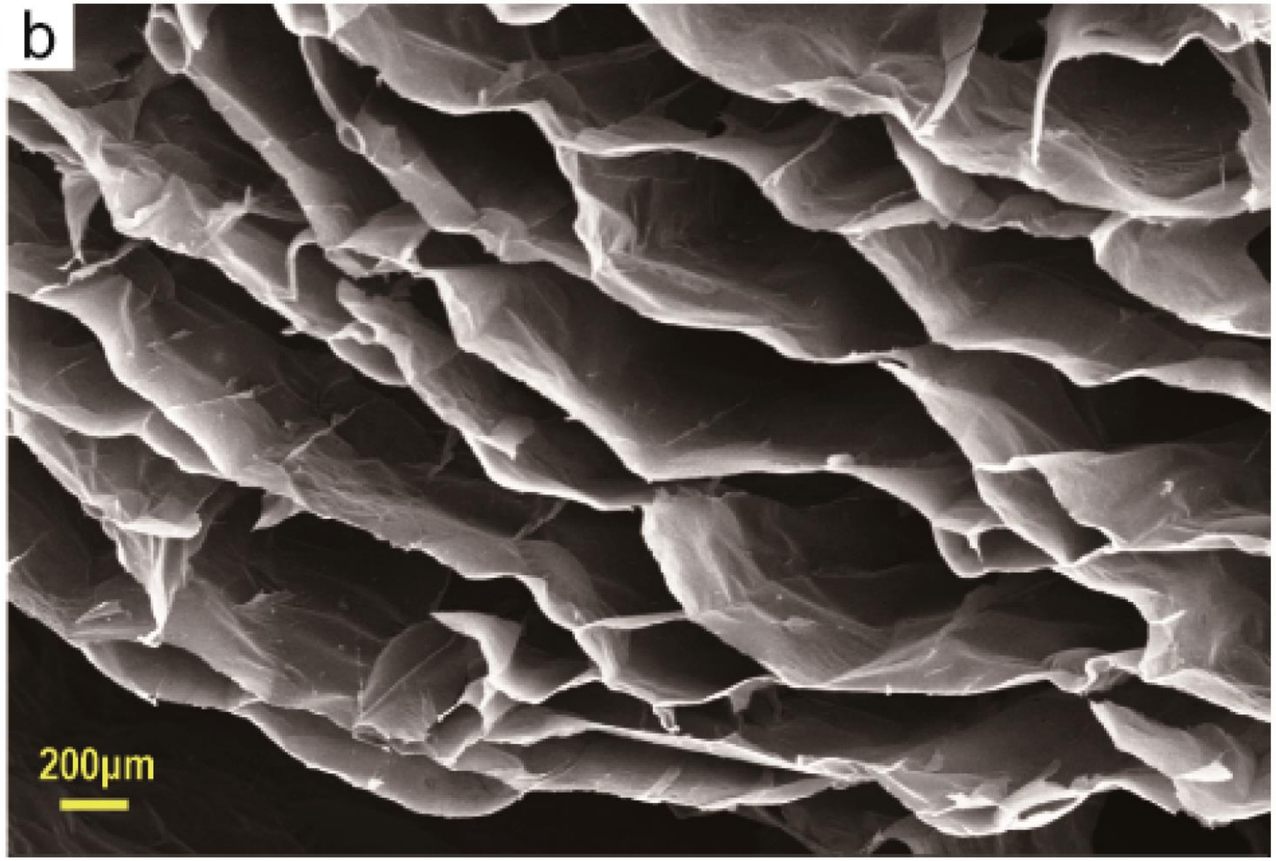


The graphene oxide can be functionalized with cysteine and thiolene


a) Recovery of graphene structure
reduction
Low oxidation degree
b) Chemical functionalization
fluorescent
hydrophobic
metallic
ionic
High oxidation degree

SEM images of Graphene



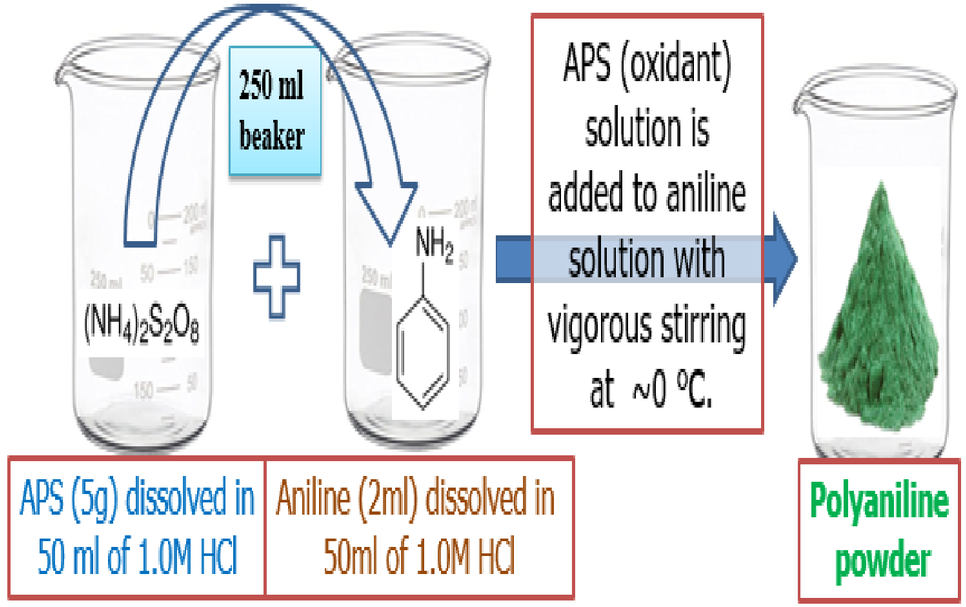


Graphene Applications

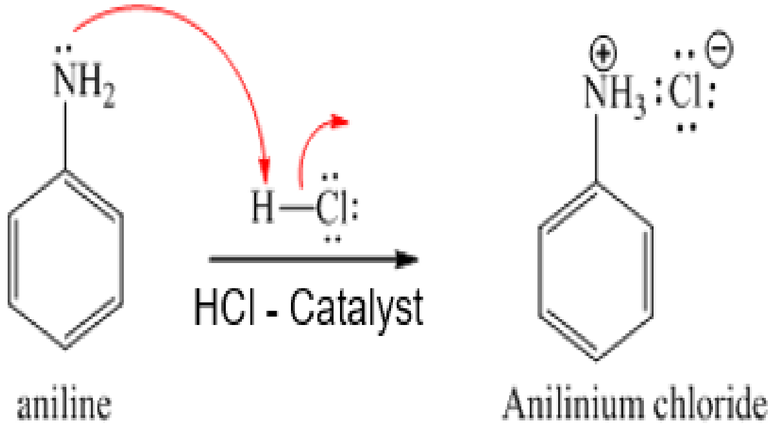
- RFID,
- IoNTs,
- Solar Cells,
- Batteries,
- Fuel cells,
- Medicine (Drug Delivery, Cancer Treatment, Gene Delivery, Photothermal Therapy, Diabetes Monitoring, Dialysis, Bone and Teeth Implantation, Tissue Engineering and Cell Therapy),
- UV Sensors, Biosensors,
- Transistors, Wearable Electronics, Flexible Screens, Optoelectronics, Optical Sensors, Water Purification, Desalination, Lubricants.

Polyaniline

- Polyaniline (PANI) that has been extensively used as conducting polymer.
- Band gaps in the reduced and oxidized form of polyaniline are 4.3 and 2.7 eV respectively.



Polyaniline polymerization reaction

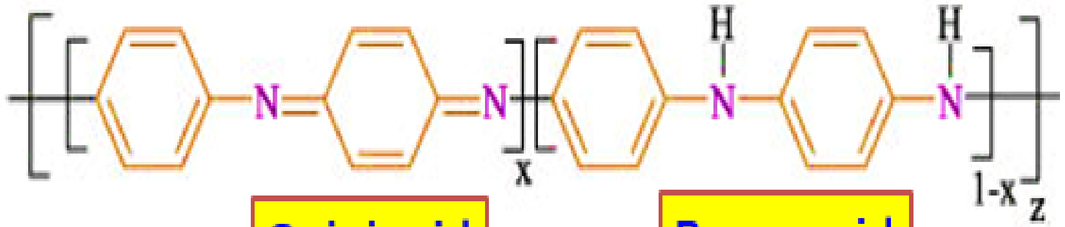


aniline Anilinium chloride

Polyaniline is synthesized by oxidative polymerization of aniline

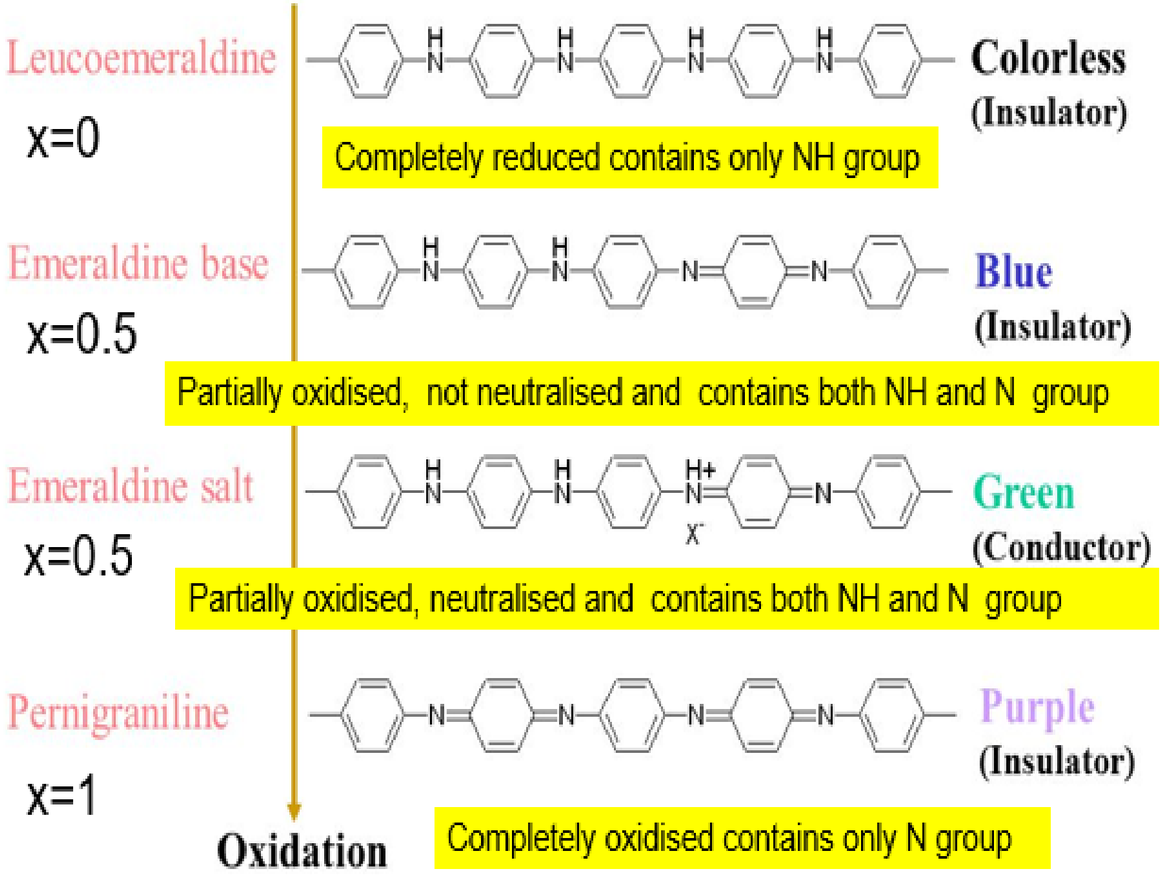
Stirring at ~0 °C

$(NH_4)_2S_2O_8$ Oxidant

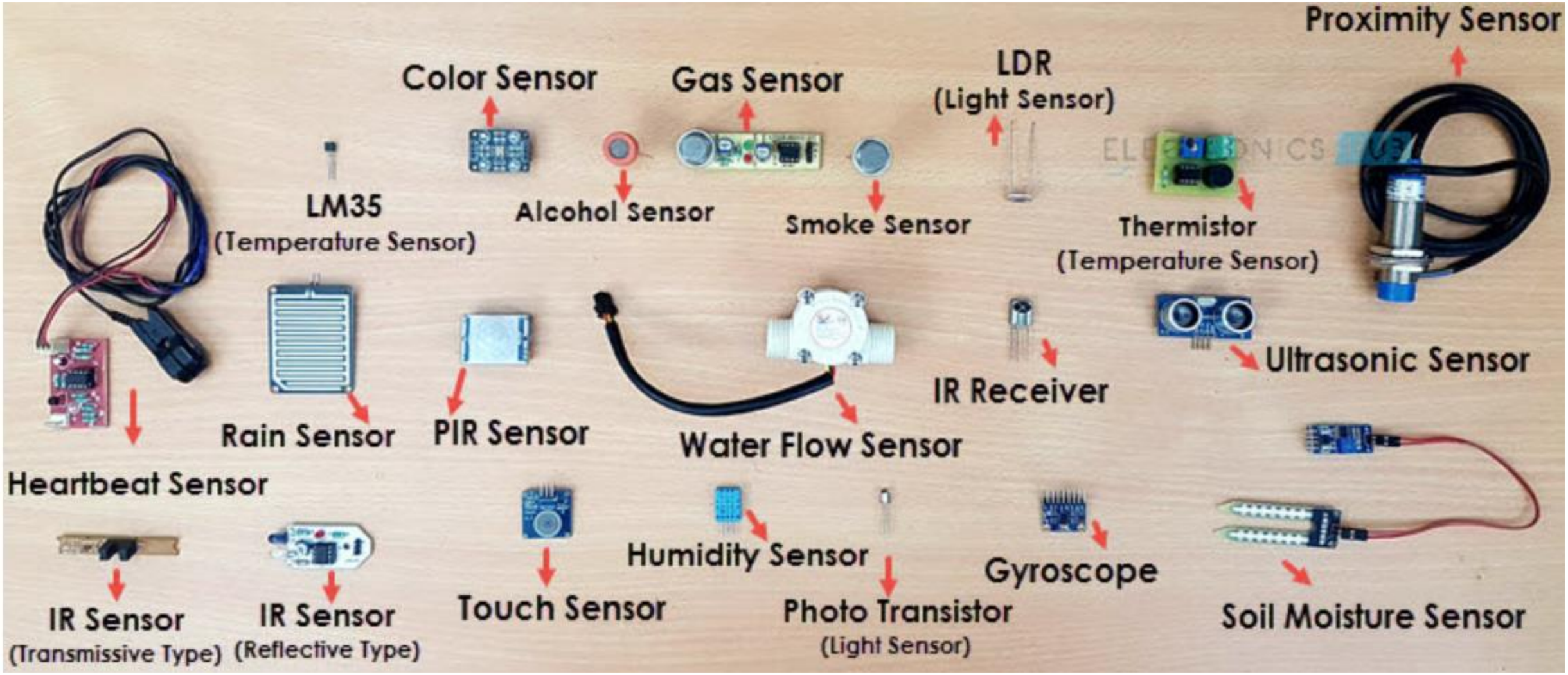


Quininoid Benzenoid

Different forms of POLYANILINE

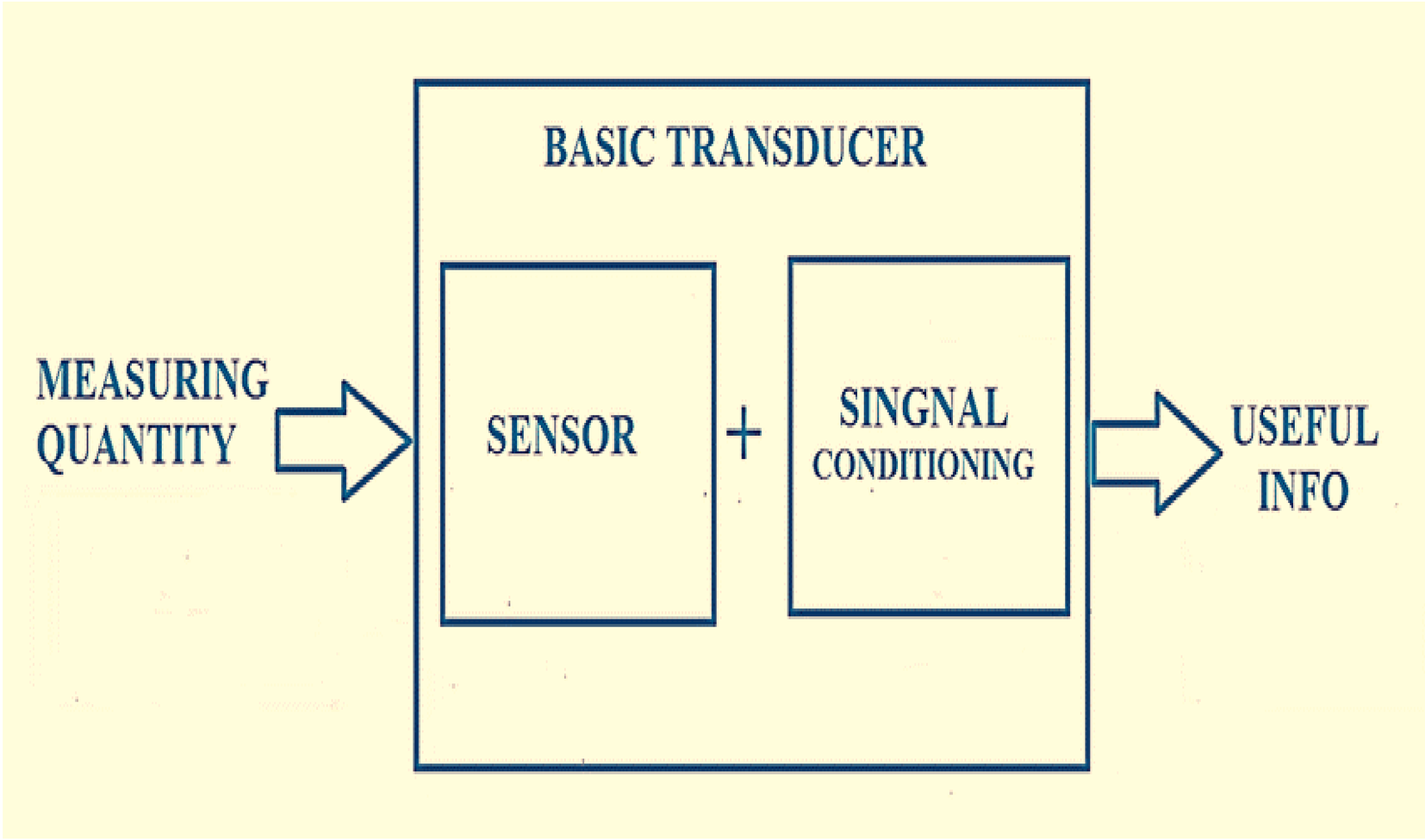


Sensors


Proximity Sensor
Color Sensor
Gas Sensor
LDR
(Light Sensor)
LM35
(Temperature Sensor)
Alcohol Sensor
Smoke Sensor
Thermistor
(Temperature Sensor)
Ultrasonic Sensor
IR Receiver
Rain Sensor
PIR Sensor
Water Flow Sensor
Heartbeat Sensor
IR Sensor
(Transmissive Type)
IR Sensor
(Reflective Type)
Touch Sensor
Humidity Sensor
Photo Transistor
(Light Sensor)
Gyroscope
Soil Moisture Sensor

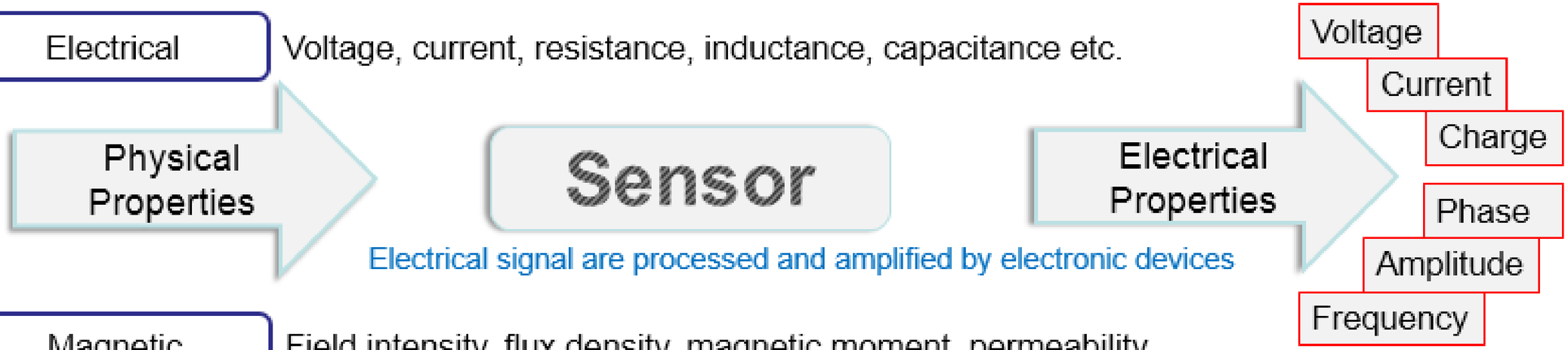
How does sensor work?

It is device that measures change in a physical (heat, light, sound, pressure etc) and/or chemical (pH, smell, taste, concentration, humidity etc) parameters of interest in an environment and transforms it into an electronic signal.

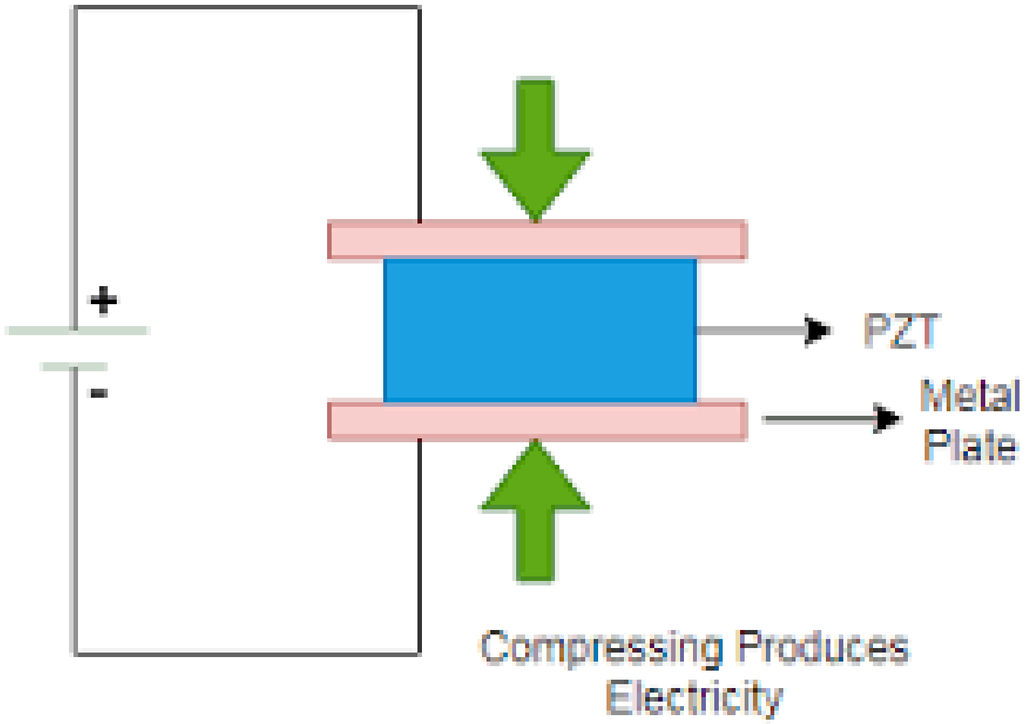


Types of sensors

Form of Energy	*Physical quantity measured: Measurand*
Mechanical	Length, area, volume, displacement, velocity, mass, flow, pressure
Thermal	Temperature, specific heat, entropy, heat flow
Electrical	Voltage, current, resistance, inductance, capacitance etc.
Magnetic	Field intensity, flux density, magnetic moment, permeability
Radiant	Intensity, phase, wavelength, polarization, reflection, transmittance, refractive index
Chemical	Composition, concentration, reaction rate, pH, oxidation etc

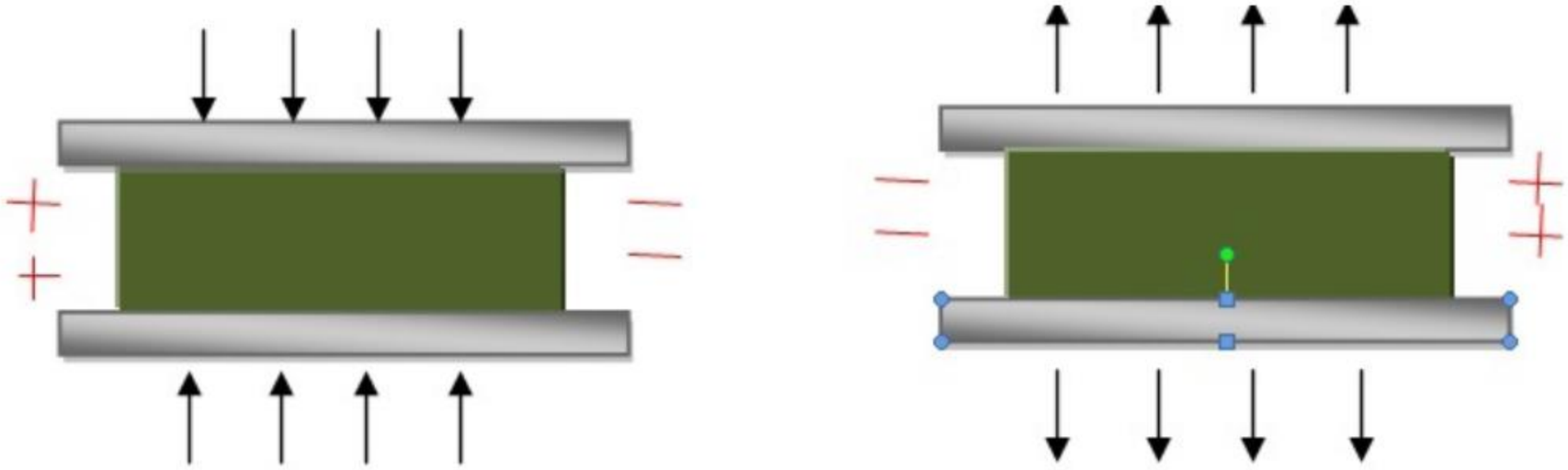


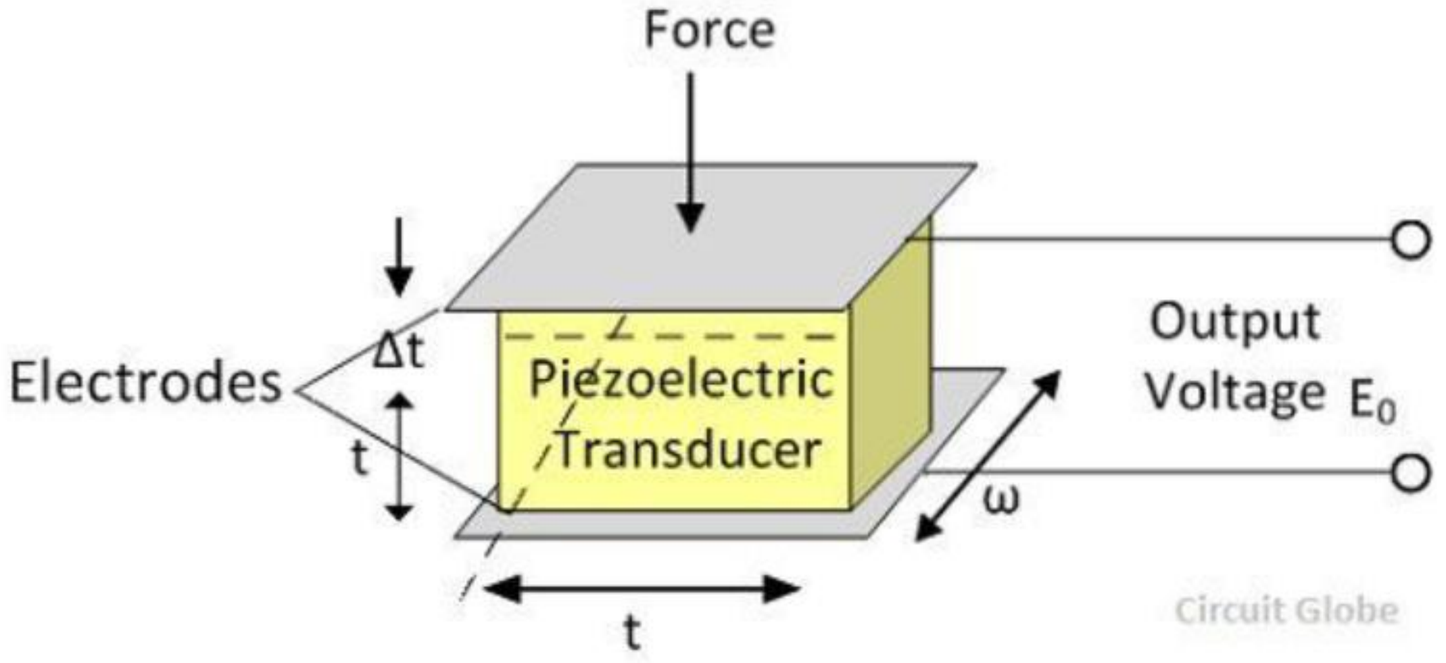
Piezoelectric (PE) Sensors

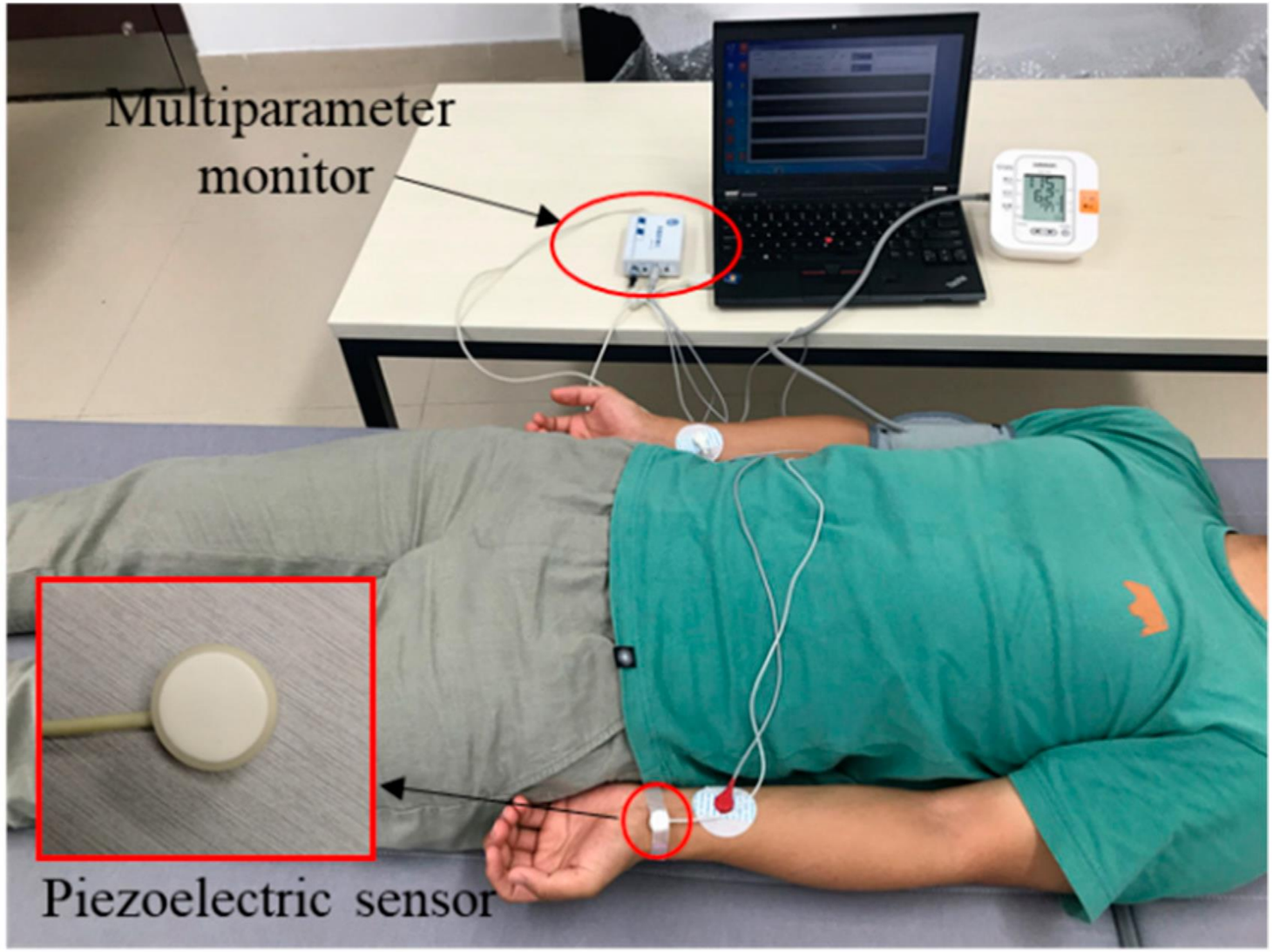


A piezoelectric sensor is a device, which converts physical parameters like acceleration, strain, pressure, vibration, temperature, or force into an electrical charge which can then be measured.

How does piezoelectric (PE) sensor work?






Multiparameter
monitor
Piezoelectric sensor

Characteristics of PE sensors

- High strength
- High stability
- High voltage output
- Highly flexible
- High mechanical strength

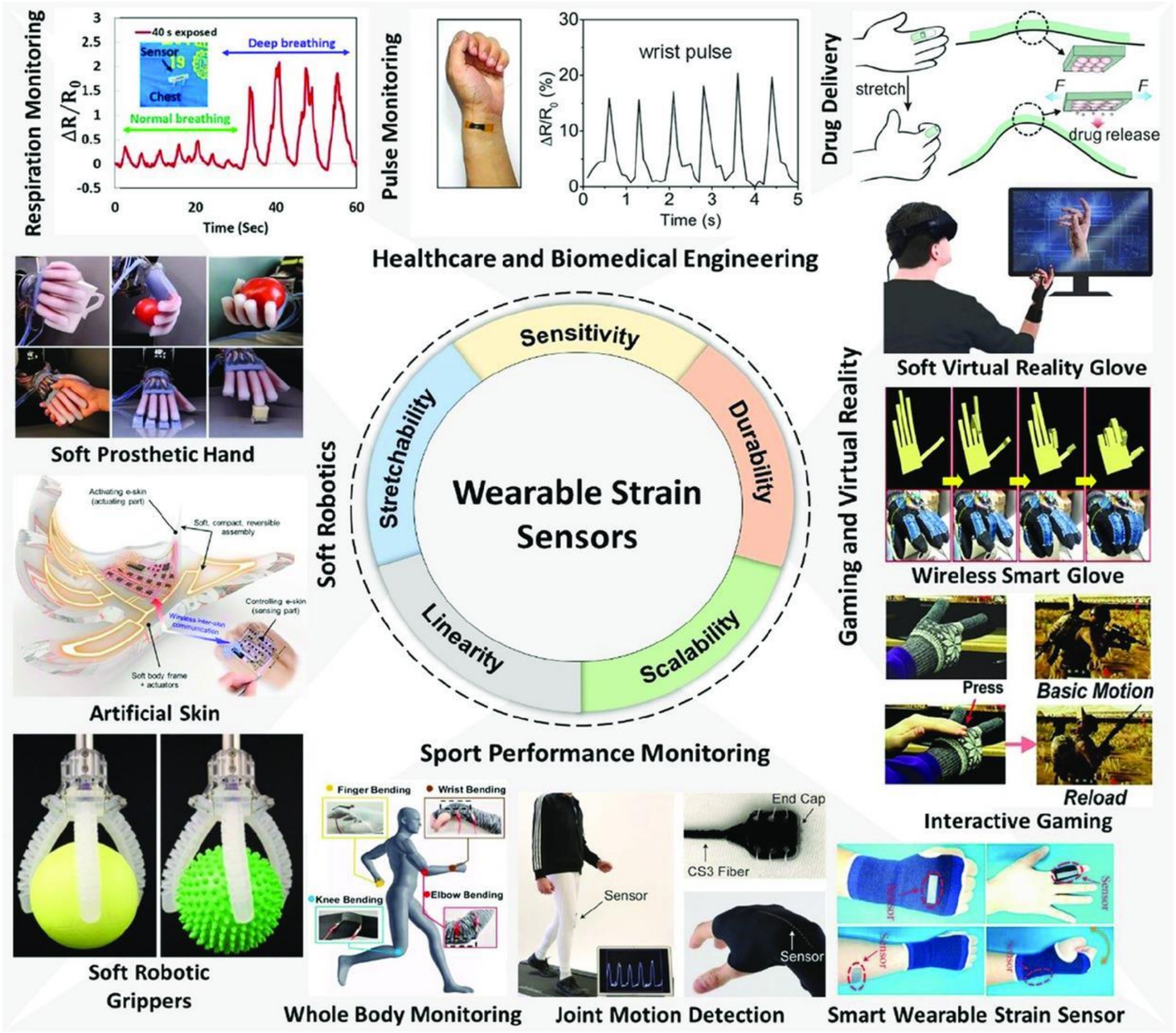
Strain Sensor

Upon applying the external force on an object, the strain (permanent/temporary) is induced in the object due to its structural (internal) deformation, this results in change in internal resistance of the object, which can be measured by using the device called strain sensor.

Various nanomaterials like graphene, CNT, PVDF, and their hybrids are used in these sensors.

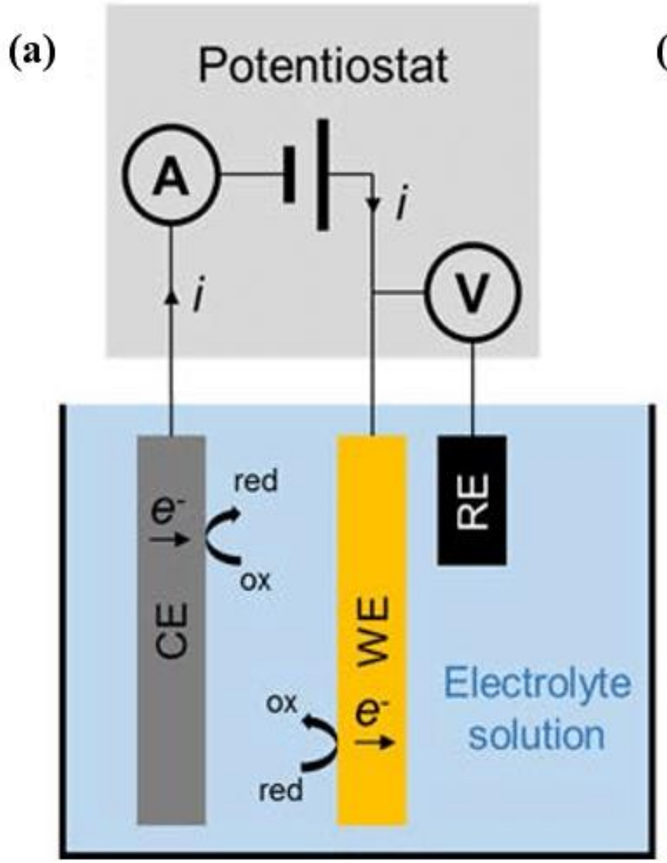
- **Pulse measurement** – PE sensors are very sensitive to record pulse measurements and effective in monitoring the patients' health.
- **Stethoscopes** – Due to high sensitivity and robustness PE sensors, they are often used within stethoscopes.
- **Anaesthesia Effectiveness** - PE sensors are capable of accurately measuring the muscles stimulations, and hence can be helpful in understanding the effectiveness of anaesthesia.

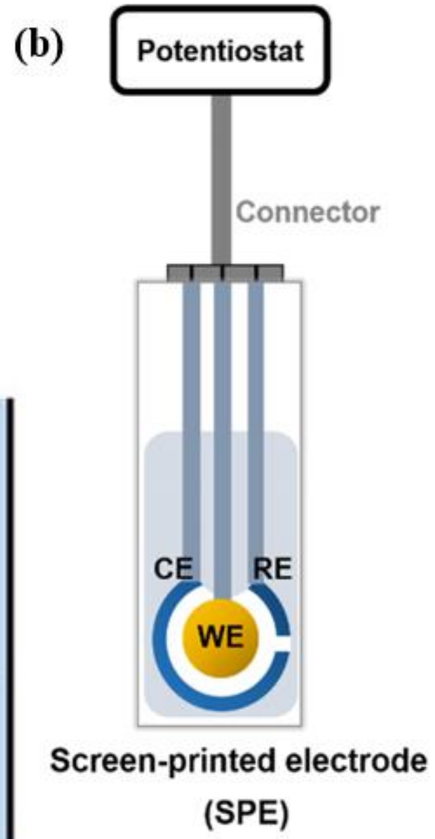
Sleep Studies

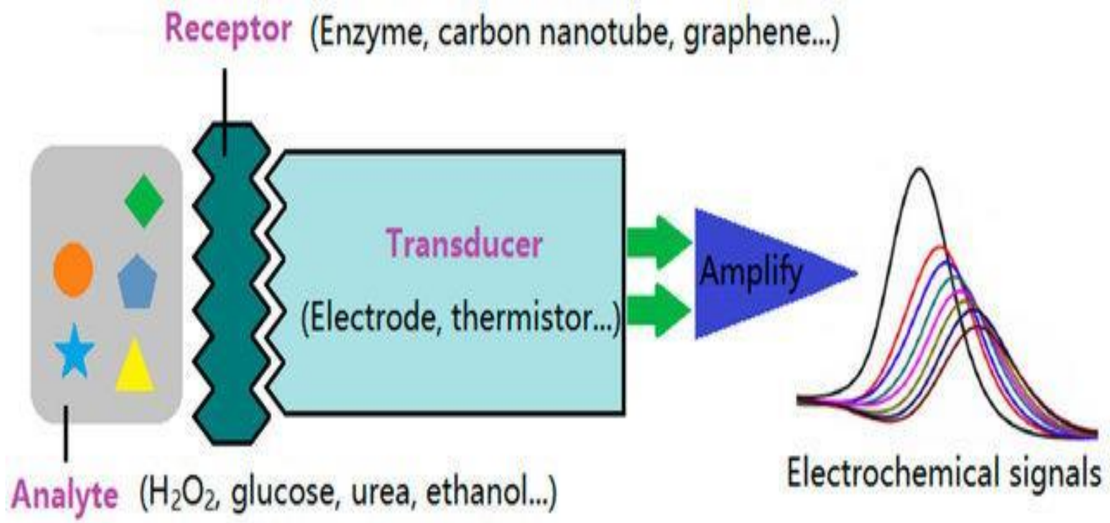

Respiration Monitoring
40 s exposed
Sensor
Chest
Deep breathing
Normal breathing
ΔR/R0
Time (Sec)
Pulse Monitoring
wrist pulse
ΔR/R0 (%)
Time (s)
Drug Delivery
stretch
F
F
drug release
Healthcare and Biomedical Engineering
Soft Prosthetic Hand
Soft Virtual Reality Glove
Gaming and Virtual Reality
Soft Robotics
Sensitivity
Durability
Scalability
Linearity
Stretchability
Wearable Strain Sensors
Activating e-skin (actuating part)
Soft, compact, reversible assembly
Controlling e-skin (sensing part)
Wireless inter-skin communication
Soft body frame + actuators
Artificial Skin
Wireless Smart Glove
Press
Basic Motion
Reload
Interactive Gaming
Sport Performance Monitoring
Soft Robotic Grippers
Finger Bending
Wrist Bending
Knee Bending
Elbow Bending
Whole Body Monitoring
Sensor
Joint Motion Detection
End Cap
CS3 Fiber
Sensor
Smart Wearable Strain Sensor

Electrochemical (EC) Sensors

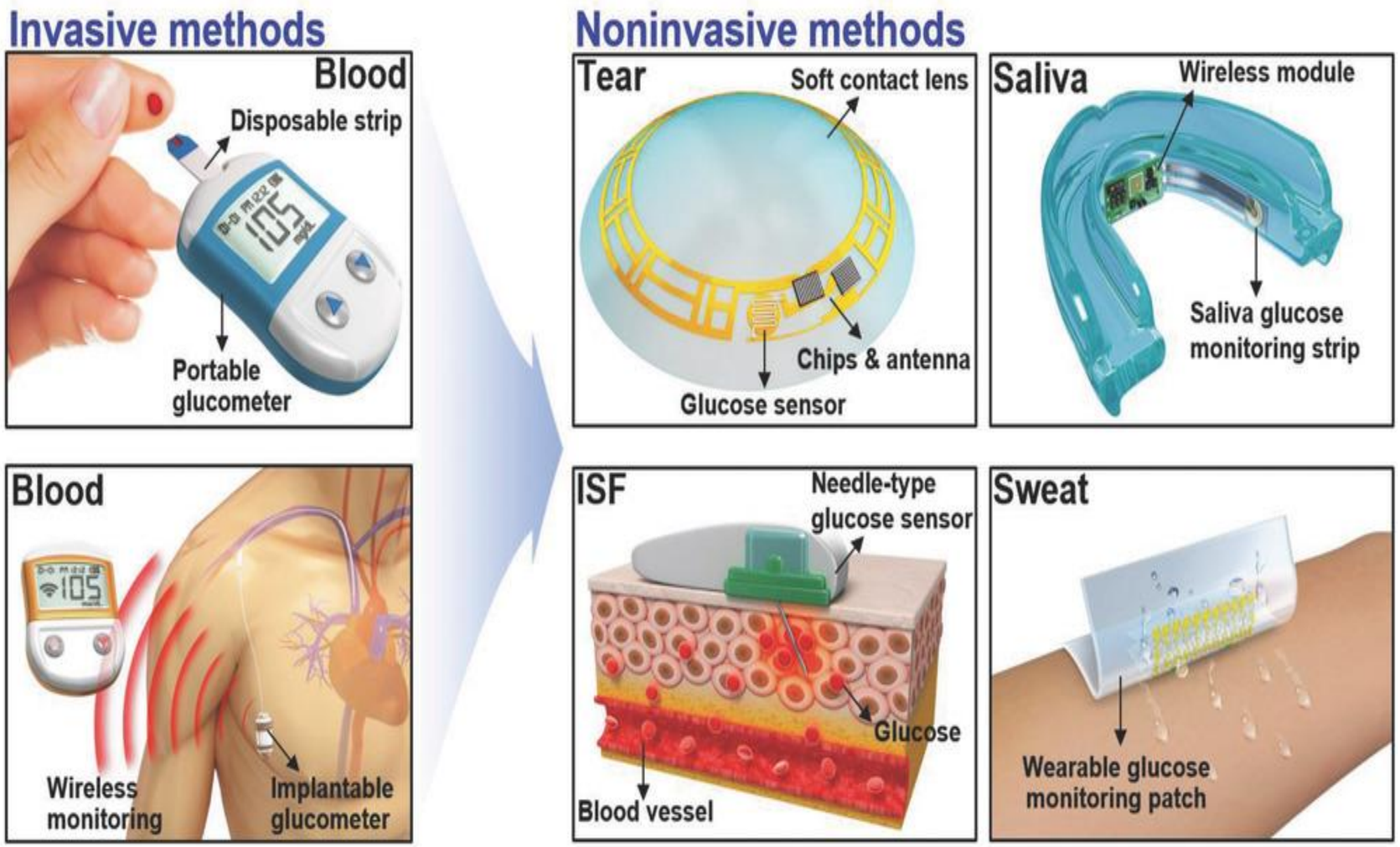
A device that converts chemical composition data of the analyte into an analytically usable signal.







Glucose sensor in diabetes management

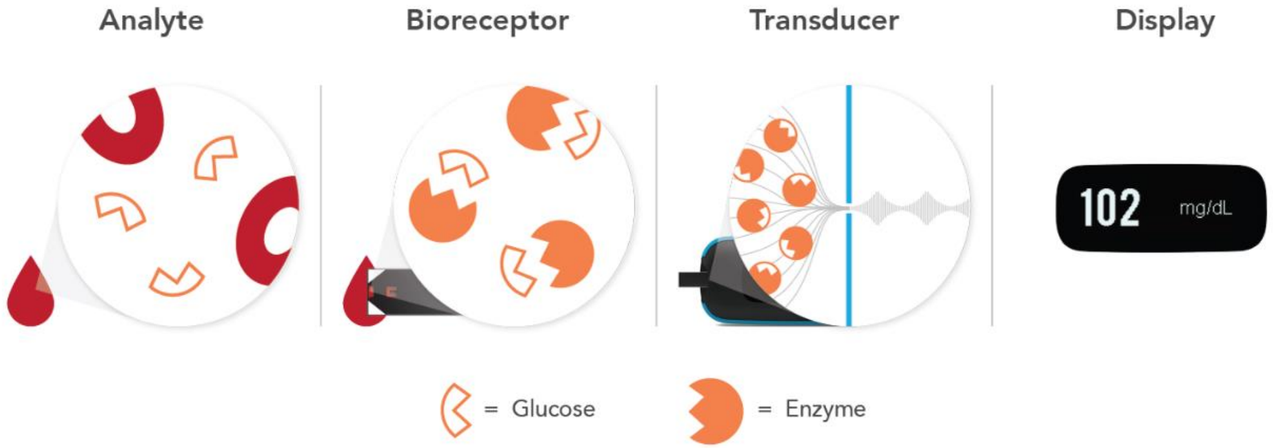


Applications of Electrochemical sensor for biomolecules

Glucose sensor in diabetes management

WE: $Glucose + O_2 + H_2O \longrightarrow Gluconic\ acid + H_2O_2$

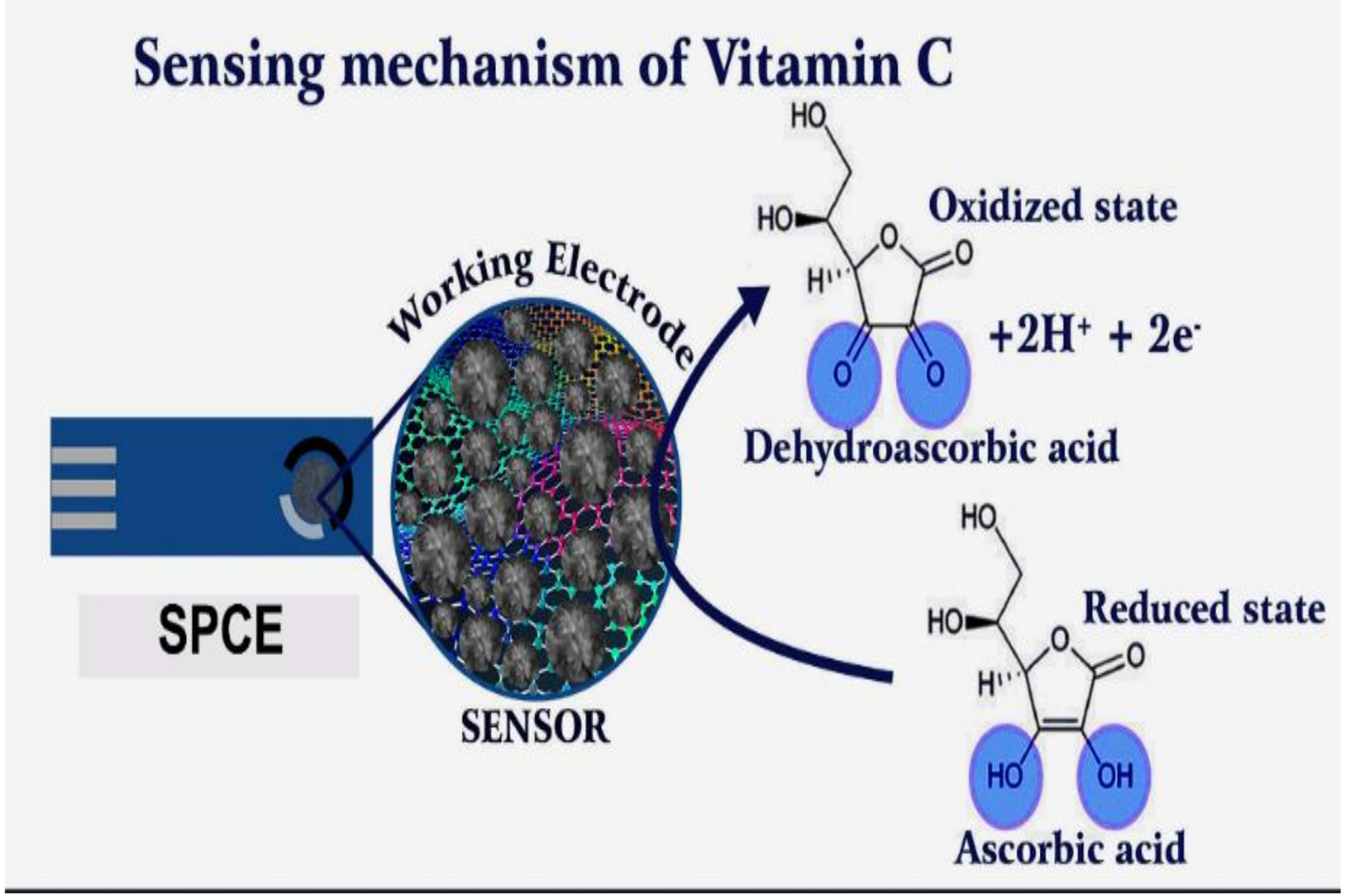
CE: $O_2 + 4H^+ + 4e \longrightarrow 2H_2O$



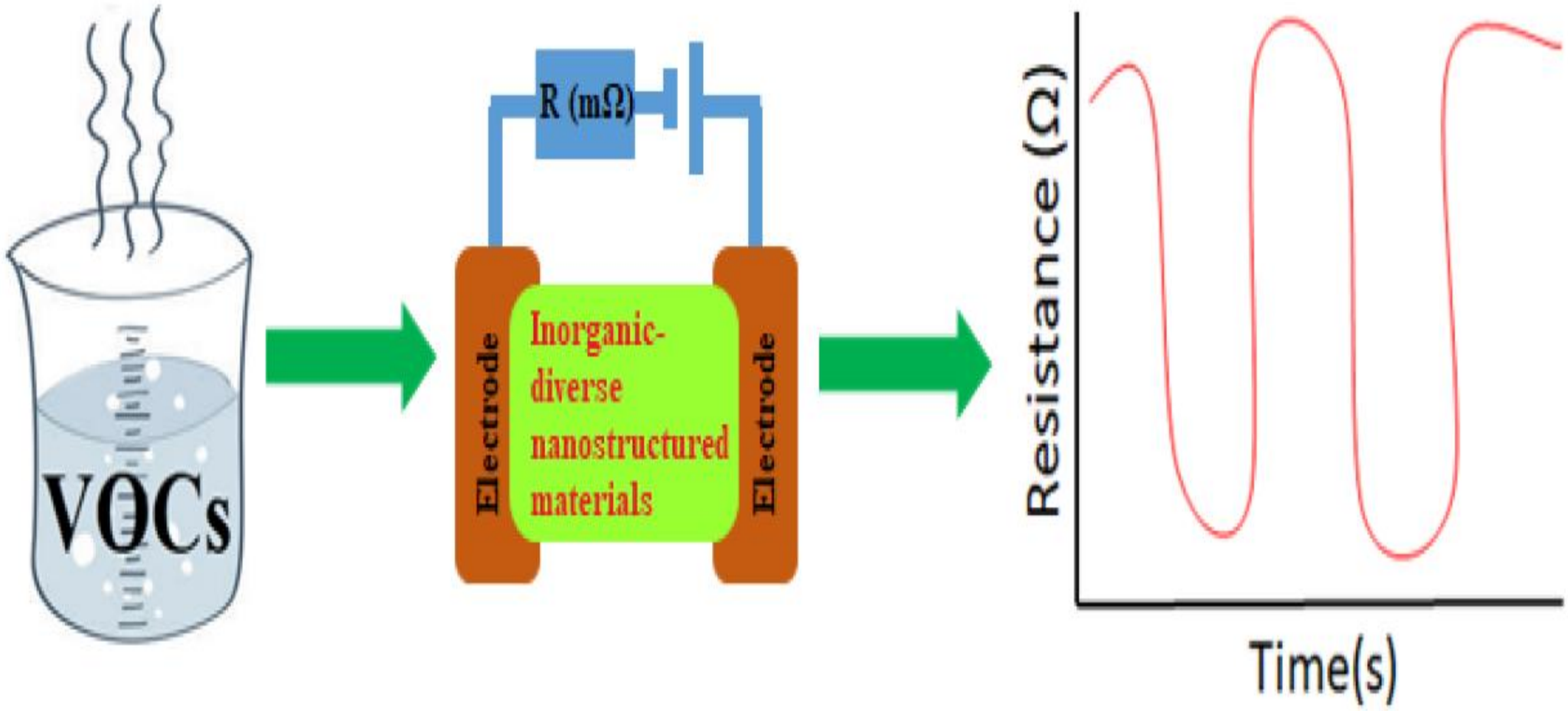
Commonly used bio receptors

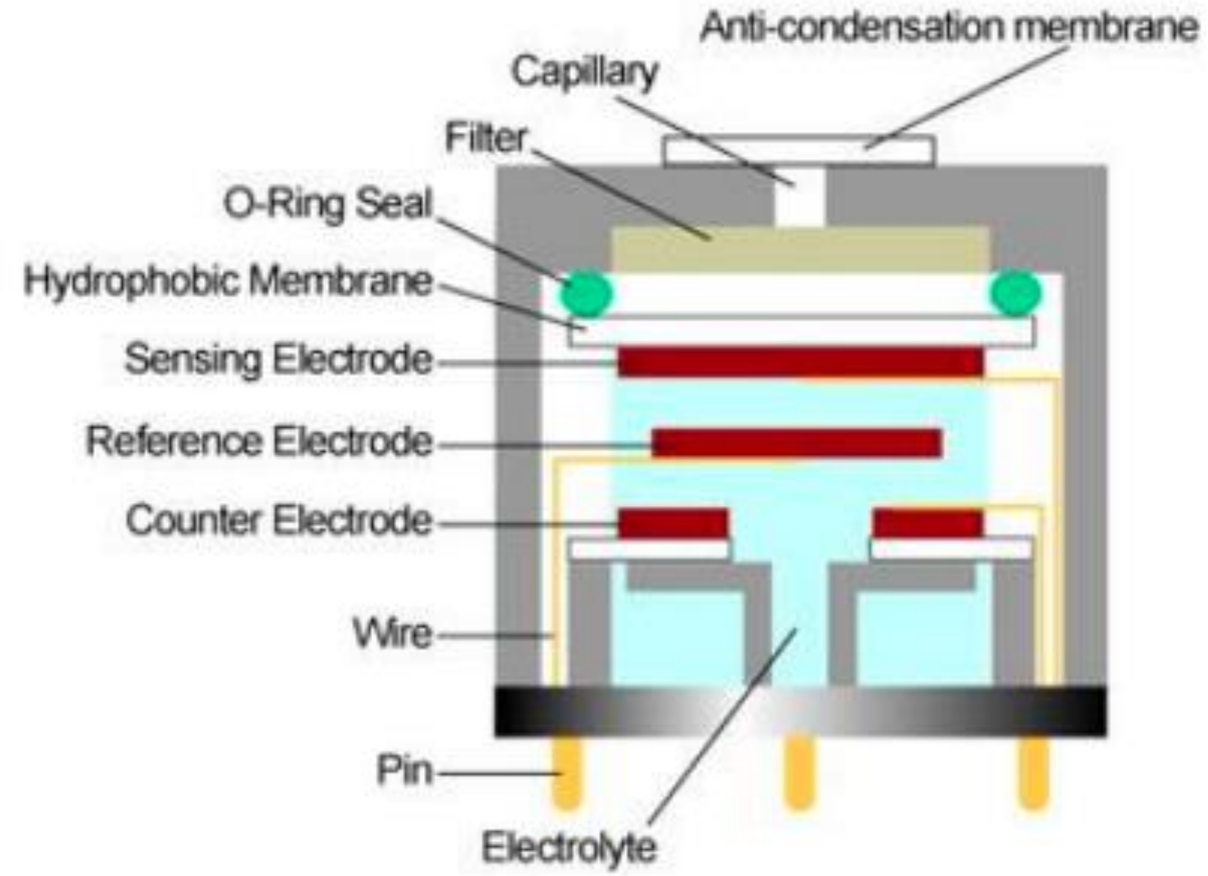
- Glucose oxidase (GOx)
- Glucose dehydrogenase nicotinamide adenine dinucleotide (GDH-NAD)
- Glucose dehydrogenase flavin adenine dinucleotide (GDH-FAD)
- Glucose dehydrogenase pyrroloquinoline quinone (GDH-PQQ)

Ascorbic acid sensor

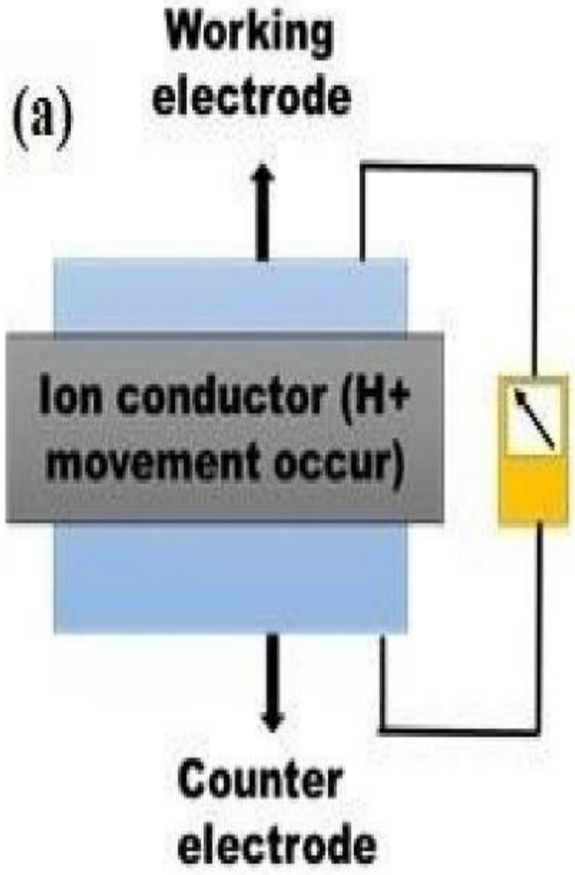


VOCs sensor

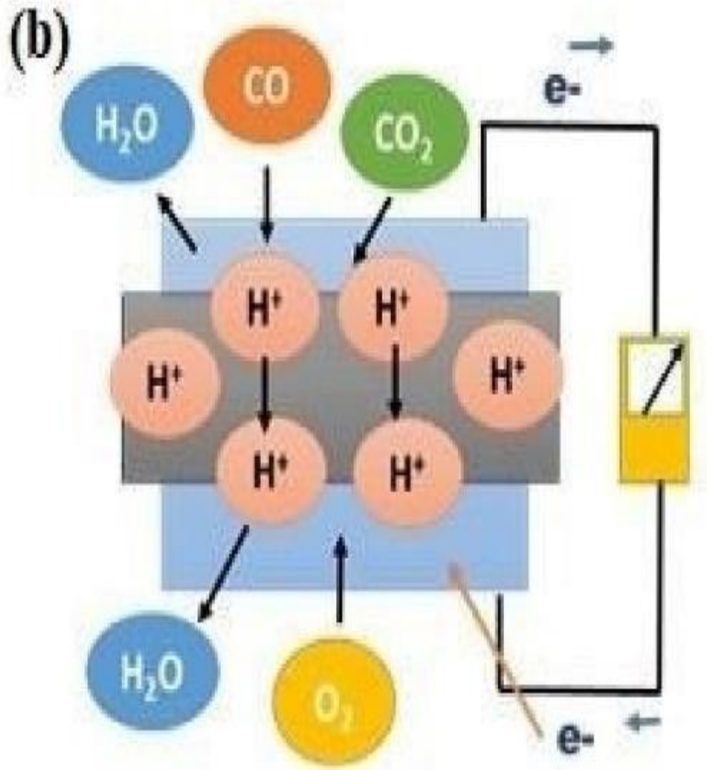

VOCs
R (mΩ)
Electrode
Inorganic-diverse nanostructured materials
Electrode
Resistance (Ω)
Time(s)


Anti-condensation membrane
Capillary
Filter
O-Ring Seal
Hydrophobic Membrane
Sensing Electrode
Reference Electrode
Counter Electrode
Wire
Pin
Electrolyte

Electrochemical gas sensors



Electrochemical cell in presence of air



Electrochemical cell in CO atmosphere

CO_2 sensor

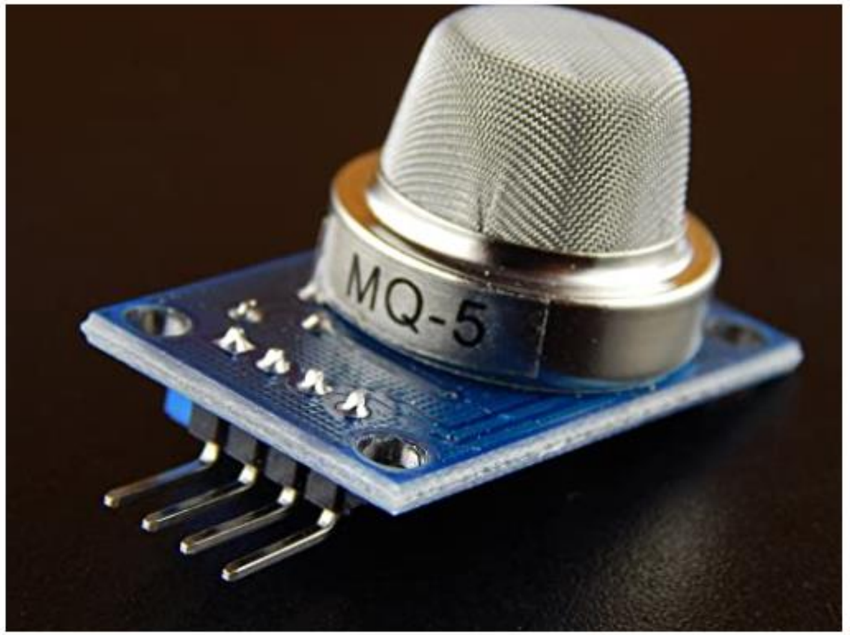
MG811 Air Carbon Dioxide (CO2) Sensor Module

Product Code: EC-5093

Availability: 6

Rs.2799.00

(Excluding 18% GST)



Gas sensor