Joint Institute for Nuclear Research
International Intergovernmental Organization
Agency of Nuclear Energy and Advanced Technologies

NUMAR - 2024. INTERNATIONAL SCHOOL ON NUCLEAR METHODS AND APPLIED RESEARCH IN ENVIRONMENTAL, MATERIALS AND LIFE SCIENCES

FEBRUARY 25 – 28 2024, VARADERO, CUBA

CARBON NANOSTRUCTURES AND THEIR APPLICATIONS

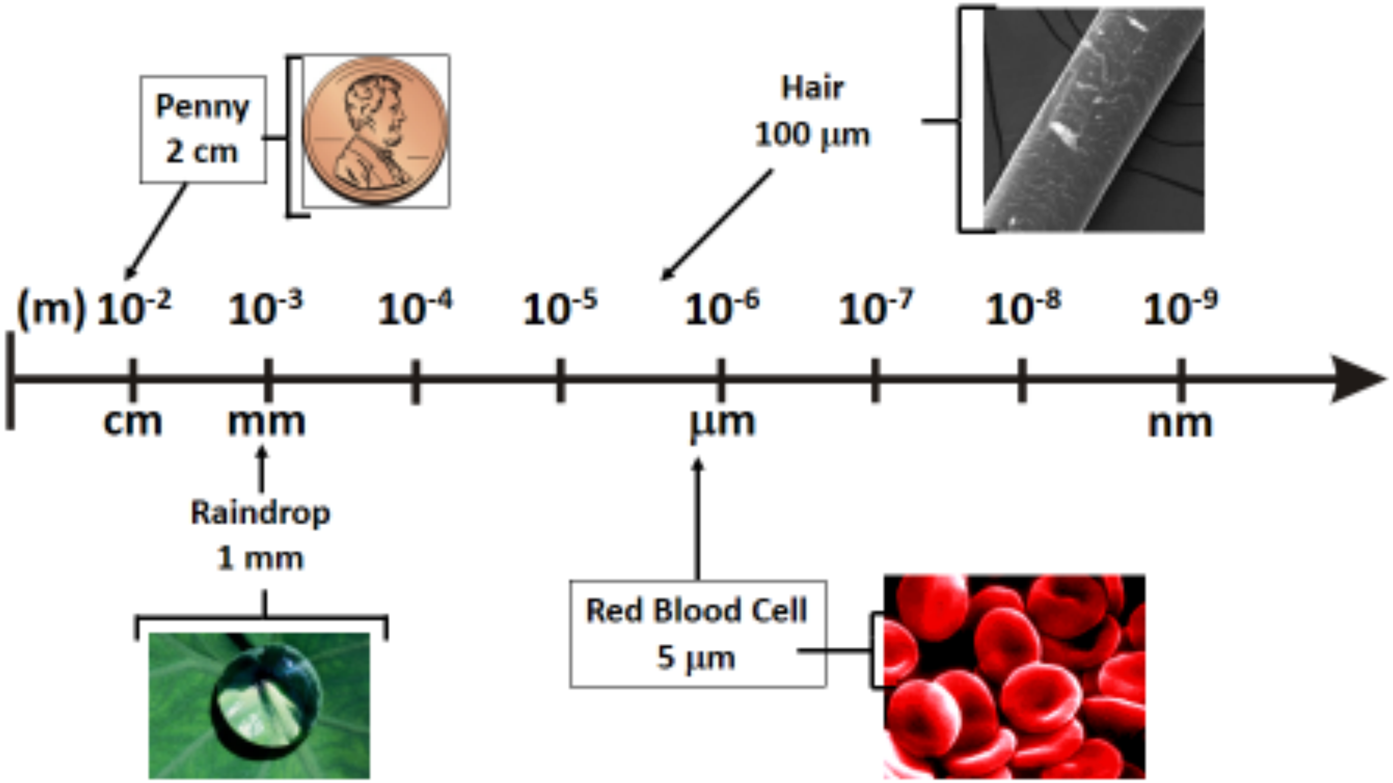
Stone, Bronze, Iron, Steel, Concrete, Polymer, Silicon,...Nano-Carbon???

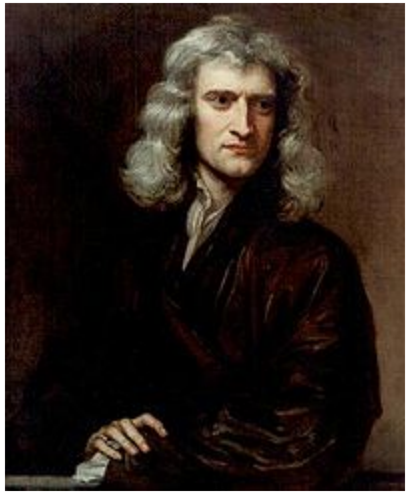
LUIS FELIPE DESDIN-GARCIA
CENTRO DE APLICACIONES TECNOLOGICAS Y DESARROLLO NUCLEAR
HAVANA, CUBA

LECTURE OVERVIEW

- **Nanoscale and Nanostructures**
- **Carbon Nanostructures**
- **Synthesis methods of Carbon Nanostructures**
- **Applications of Carbon Nanostructures in Life Sciences, Environment and Materials**
- **Nuclear Methods and Carbon Nanostructures**

MACRO AND MICRO SCALE

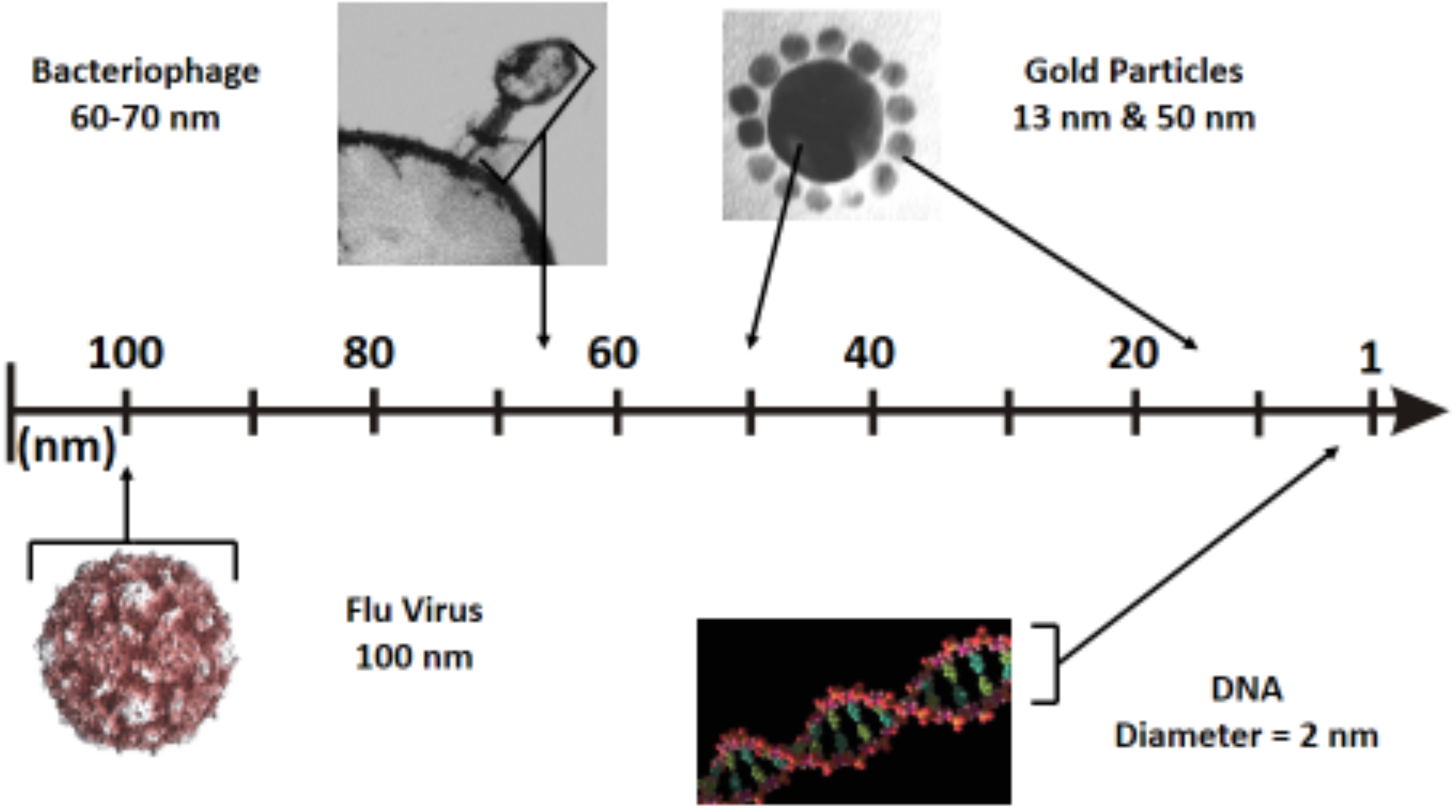




Classical Physics

Dynamic Laws

NANO SCALE

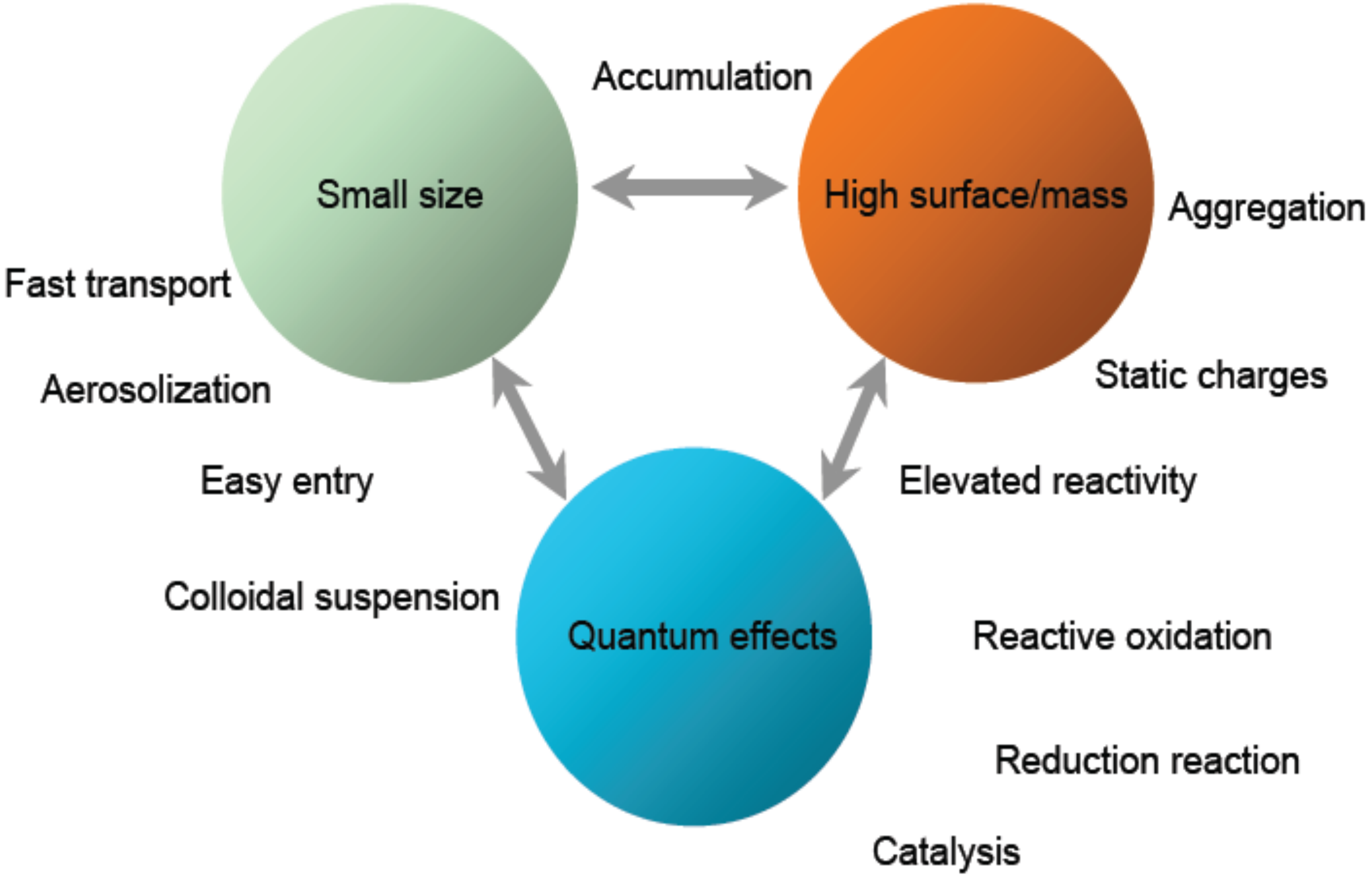


Quantum physics

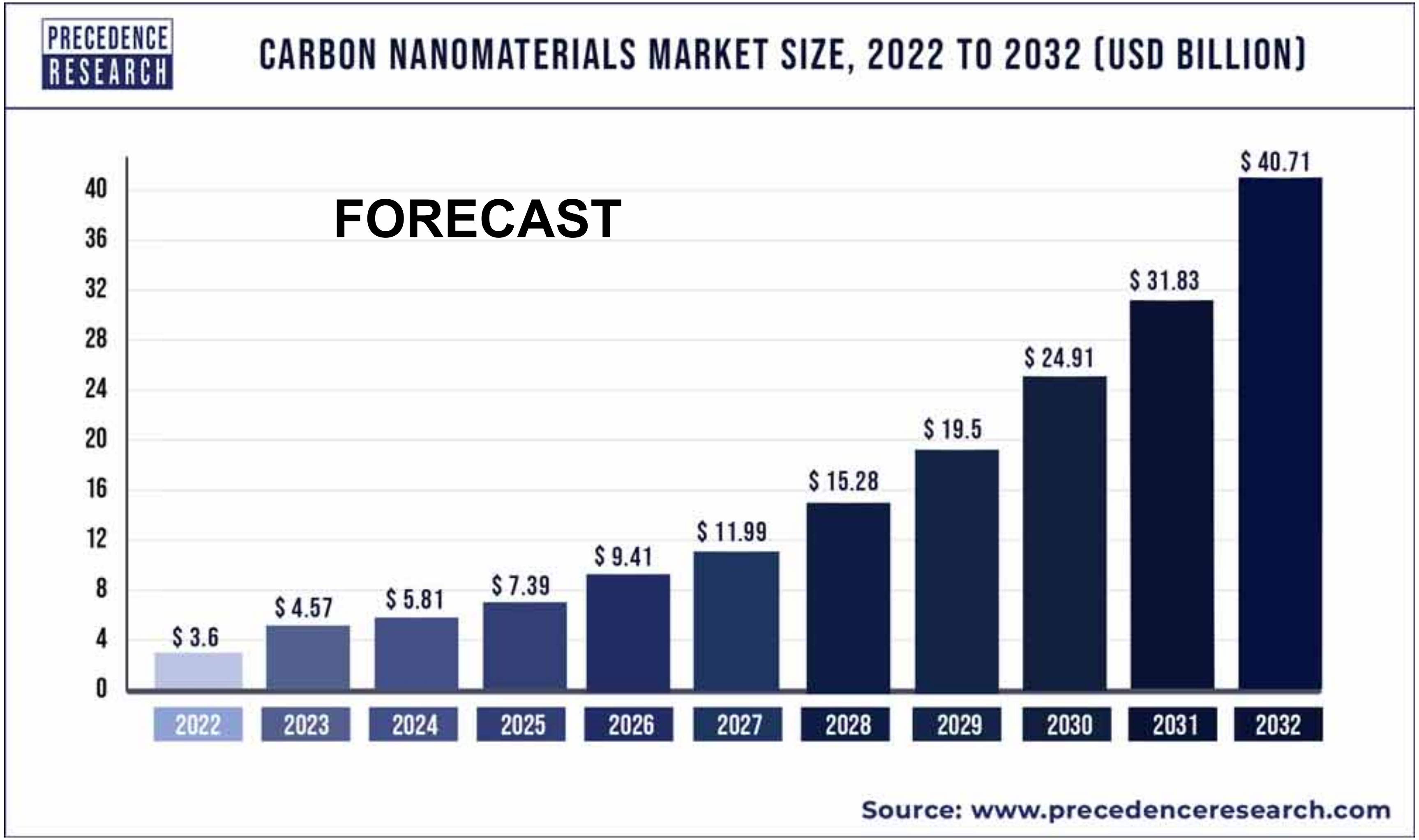
Statistical Laws

Uncertainty principle

Physico-chemical properties of nanomaterial

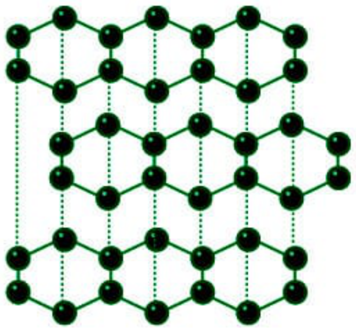


WHY CARBON NANOSTRUCTURES?

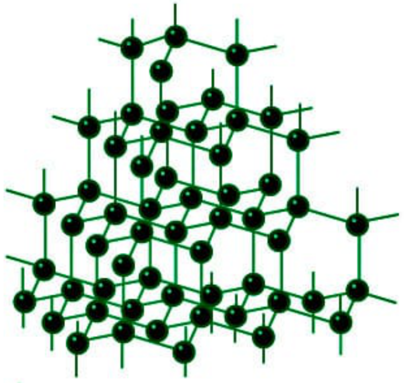


- Paints & Coatings
- Wings
- Fuselages
- Engines
- Fuel component system
- Tires
- Therapeutics
- Drug Delivery
- Photovoltaics
- Li-Ion Batteries
- Transistors
- Sensors
- Tennis Rackets
- Sports Balls
- Racing Equipment
- Others

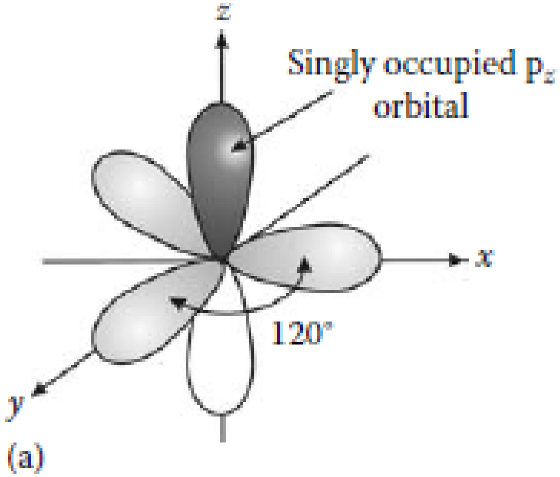
Traditional Allotropic Forms

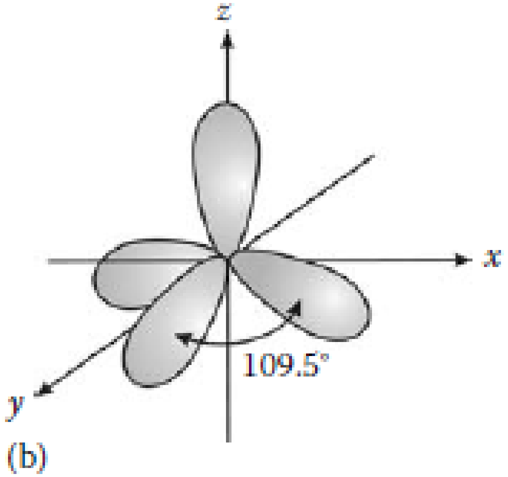


Graphite



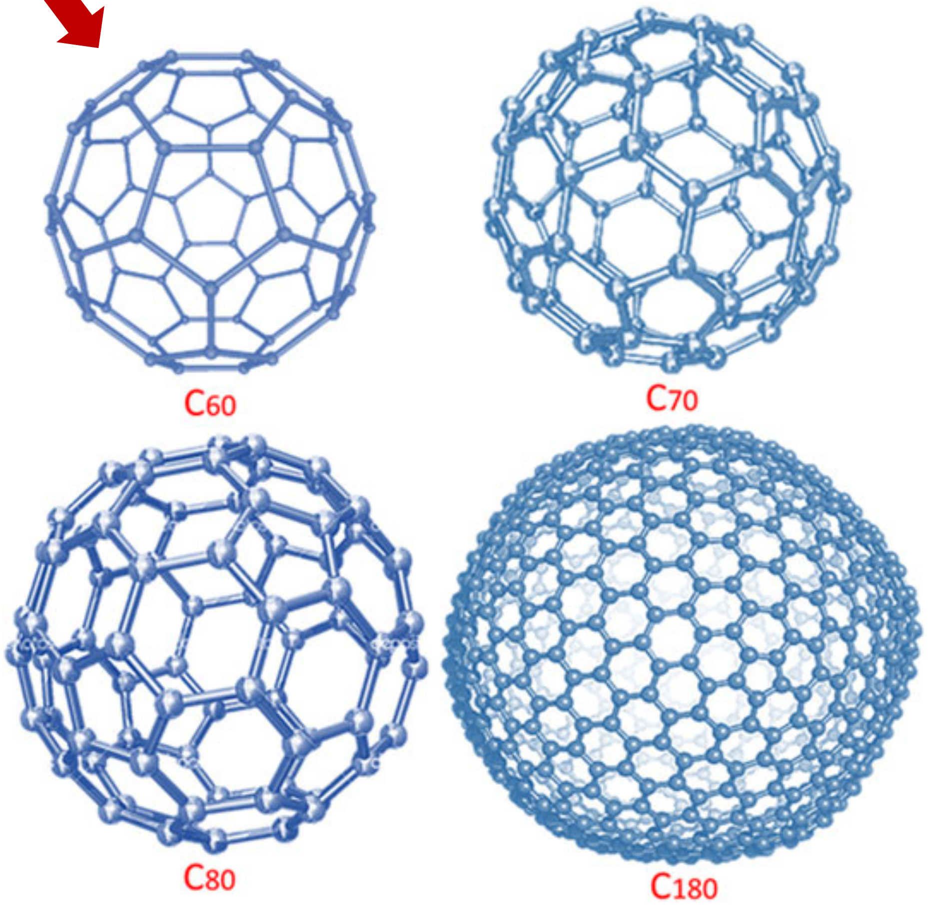
Diamond





Schematic representation of (a) sp2 hybridization and (b) sp3 hybridization

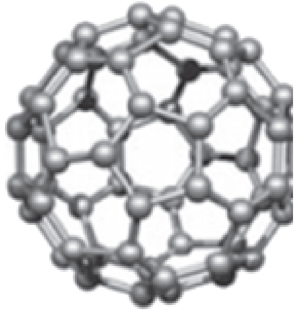
Buckminsterfullerene



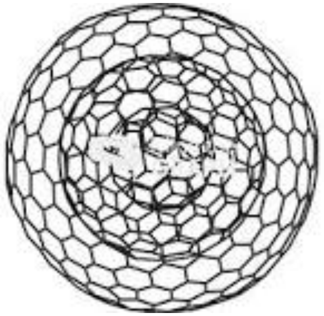
H.W. Kroto, J. Heath, S. O'Brien, R.F. Curl, R.E. Smalley C_{60}: Buckminsterfullerene. *Nature* 318, 162–163 (1985). https://doi.org/10.1038/318162a0

THE VERSATILITY OF CARBON BONDS ALLOWS THE EXISTENCE OF MULTIPLE NANOSTRUCTURES

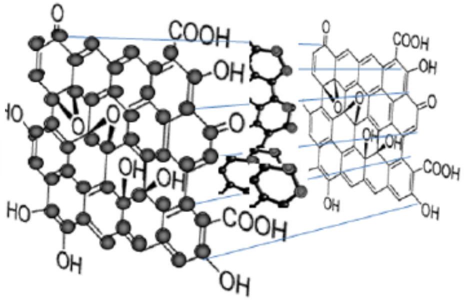
0D



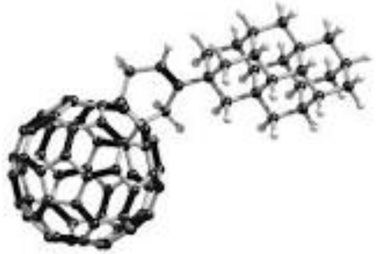
Fullerene



Nanoonions

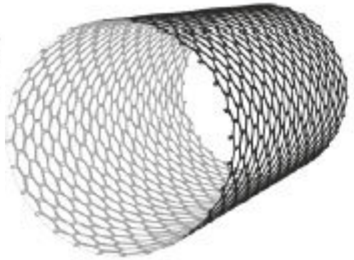


Carbon Dots

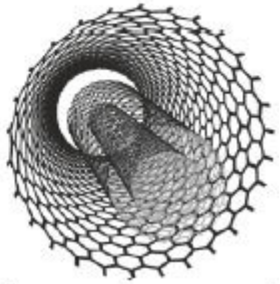


Nanodiamond

1D



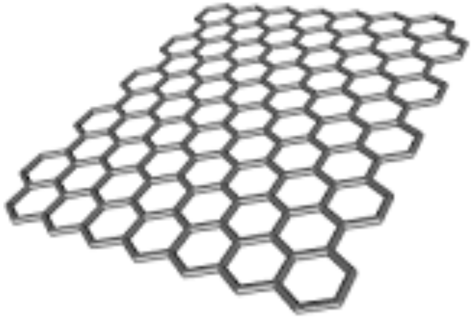
SWCNT



MWCNT

SWCNH

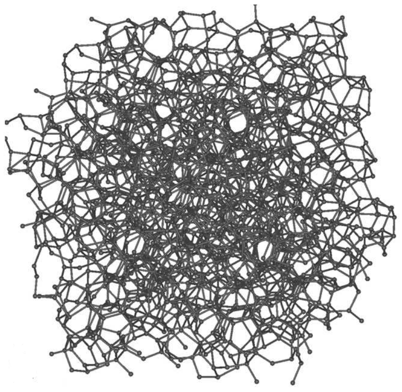
2D



Graphene

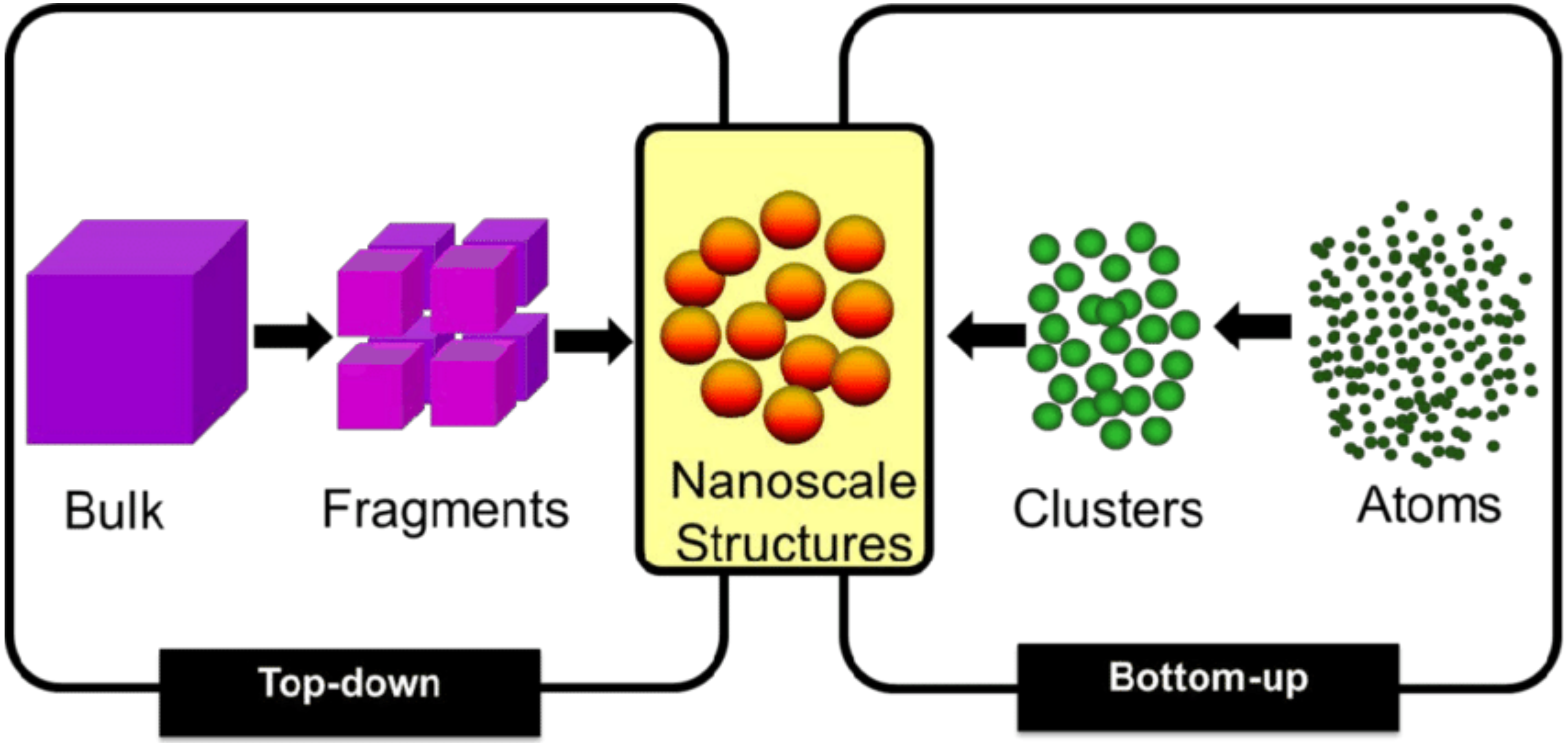
Graphene Oxide

3D

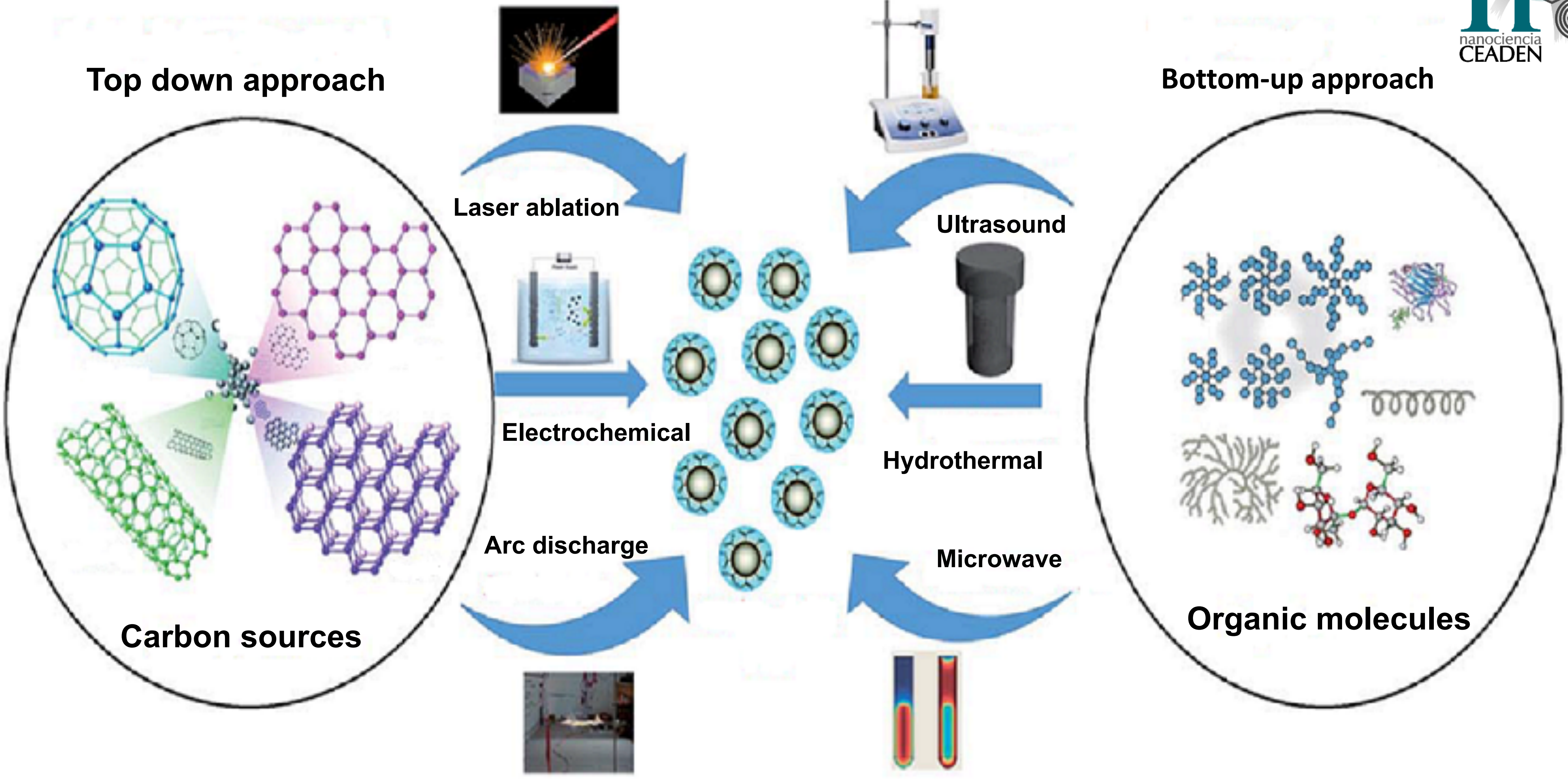


Nanofoam

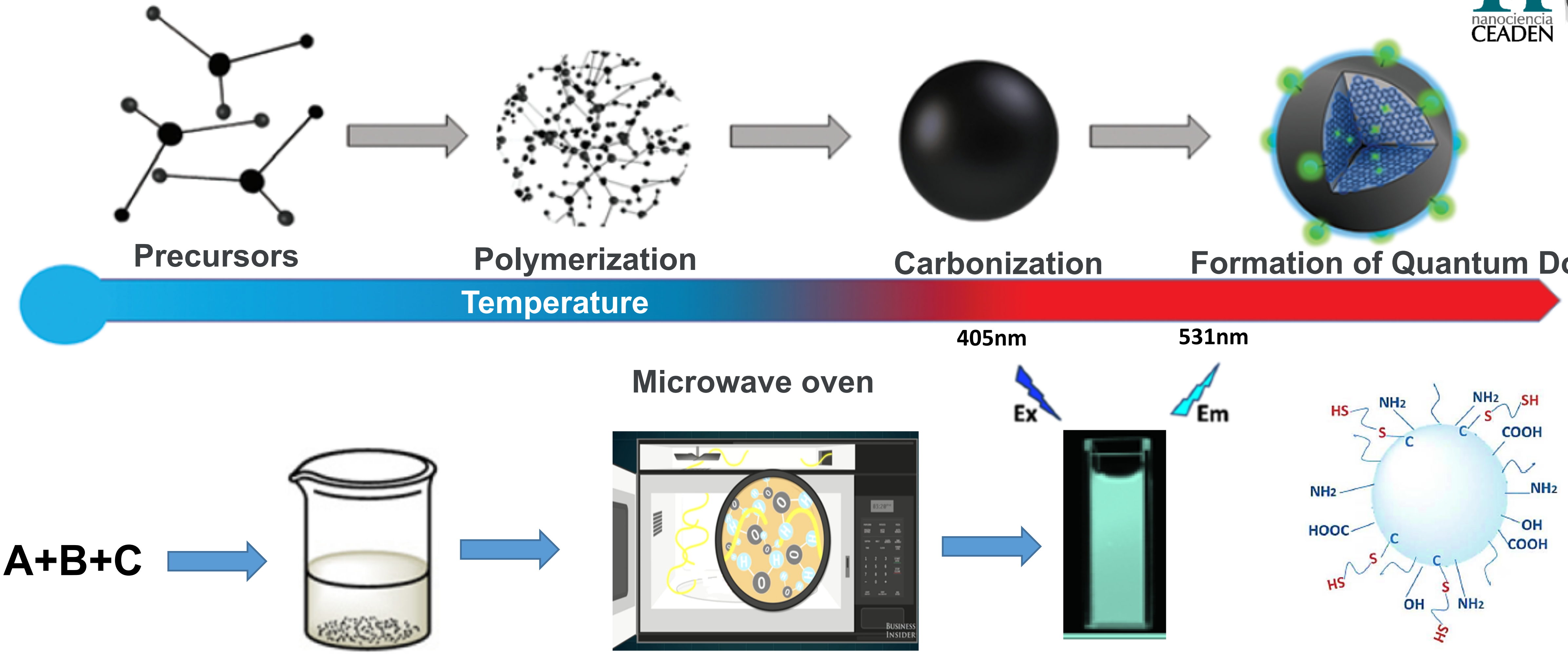
SYNTHESIS METHODS OF CARBON NANOSTRUCTURES



0D - CARBON QUANTUM DOT SYNTHESIS ROUTES

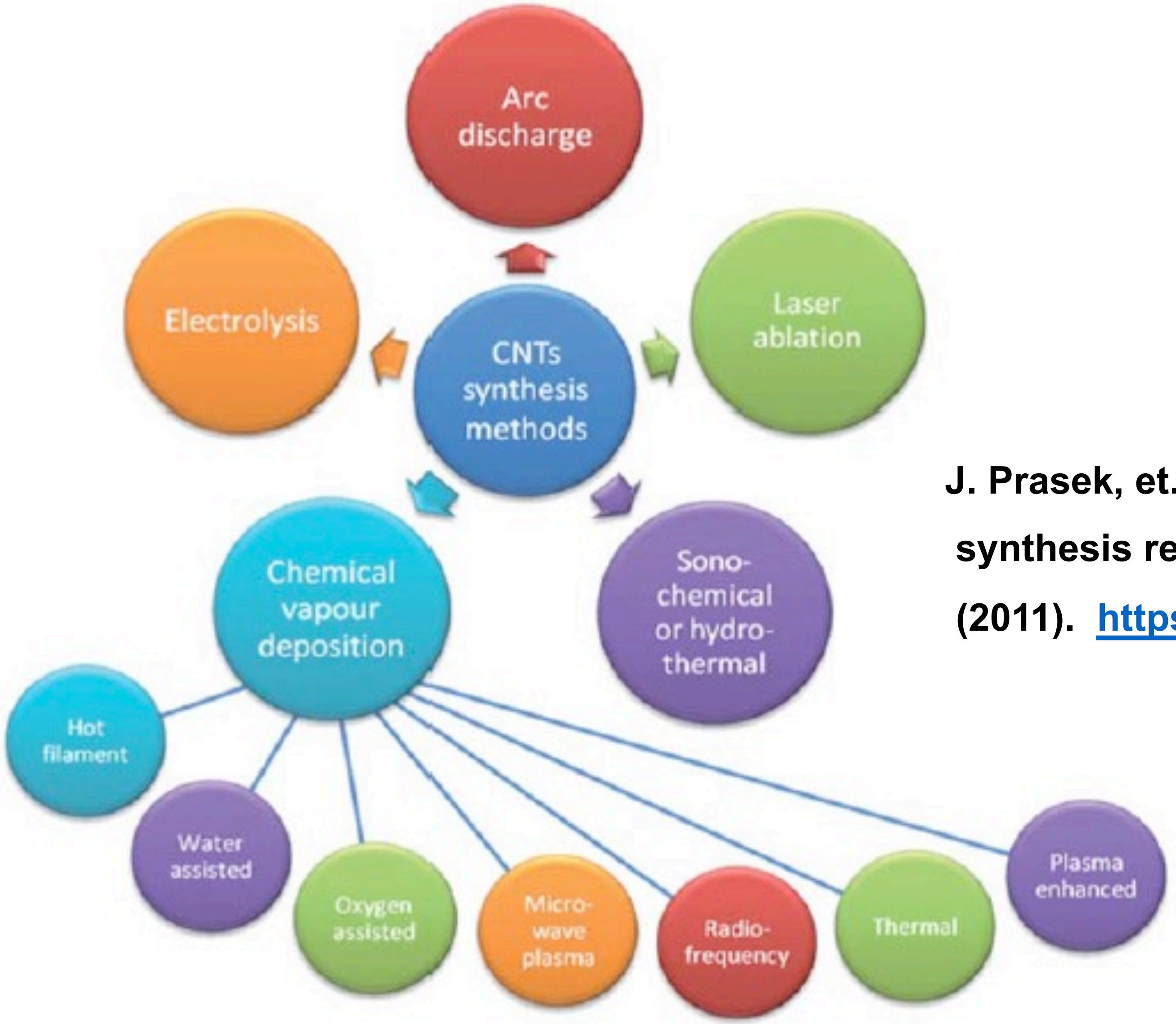


MICROWAVE CARBON QUANTUM DOT SYNTHESIS



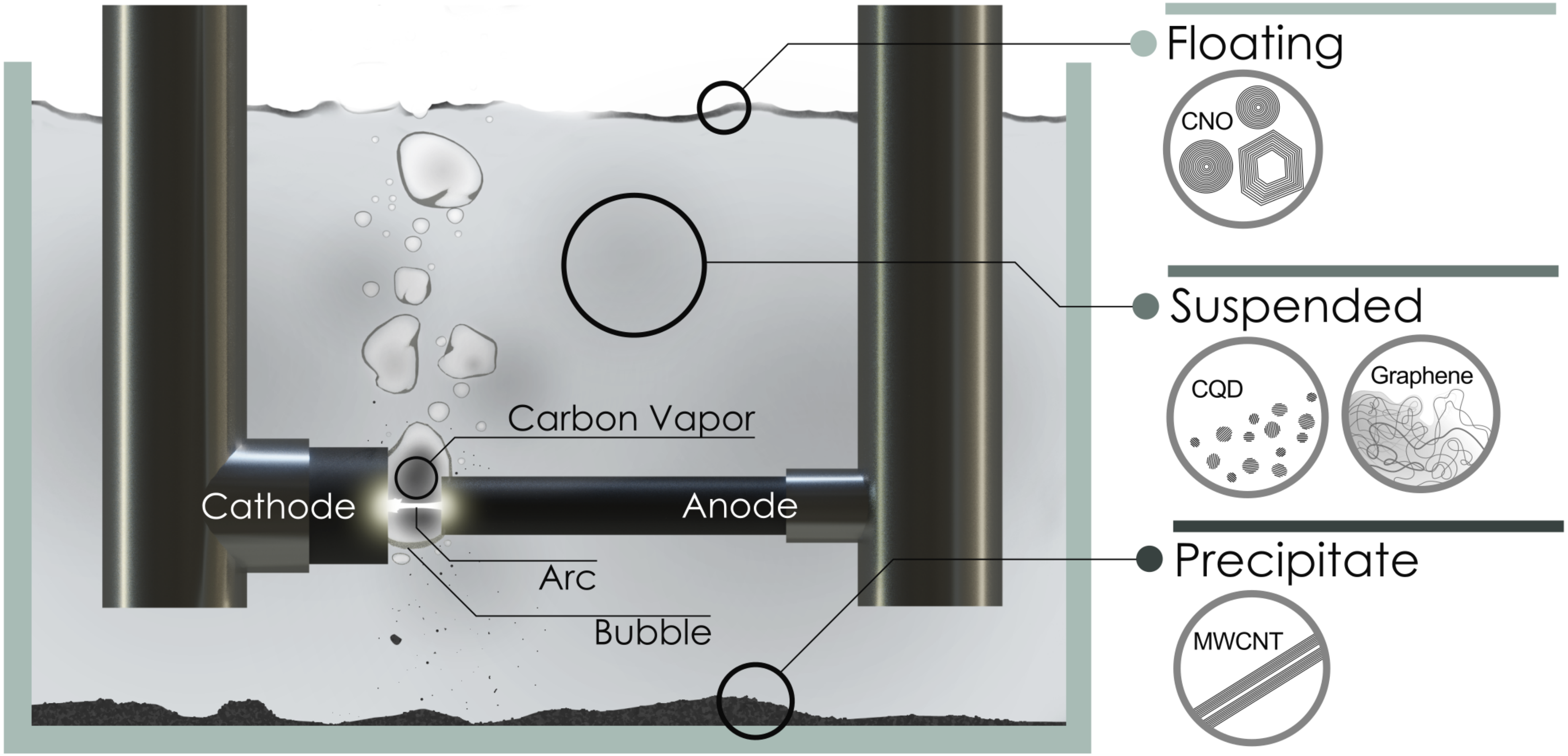
M. Antuch, L. Morales-Alvarez, L.F. Desdin-Garcia et.al. Design of Fluorescent Carbon Dots (CDs) for the Selective detection of Metal-Containing Ions. Chemistry - A European Journal (2023). https://doi.org/10.1002/chem.202300188

1D- METHODS FOR CARBON NANOTUBES SYNTHESIS



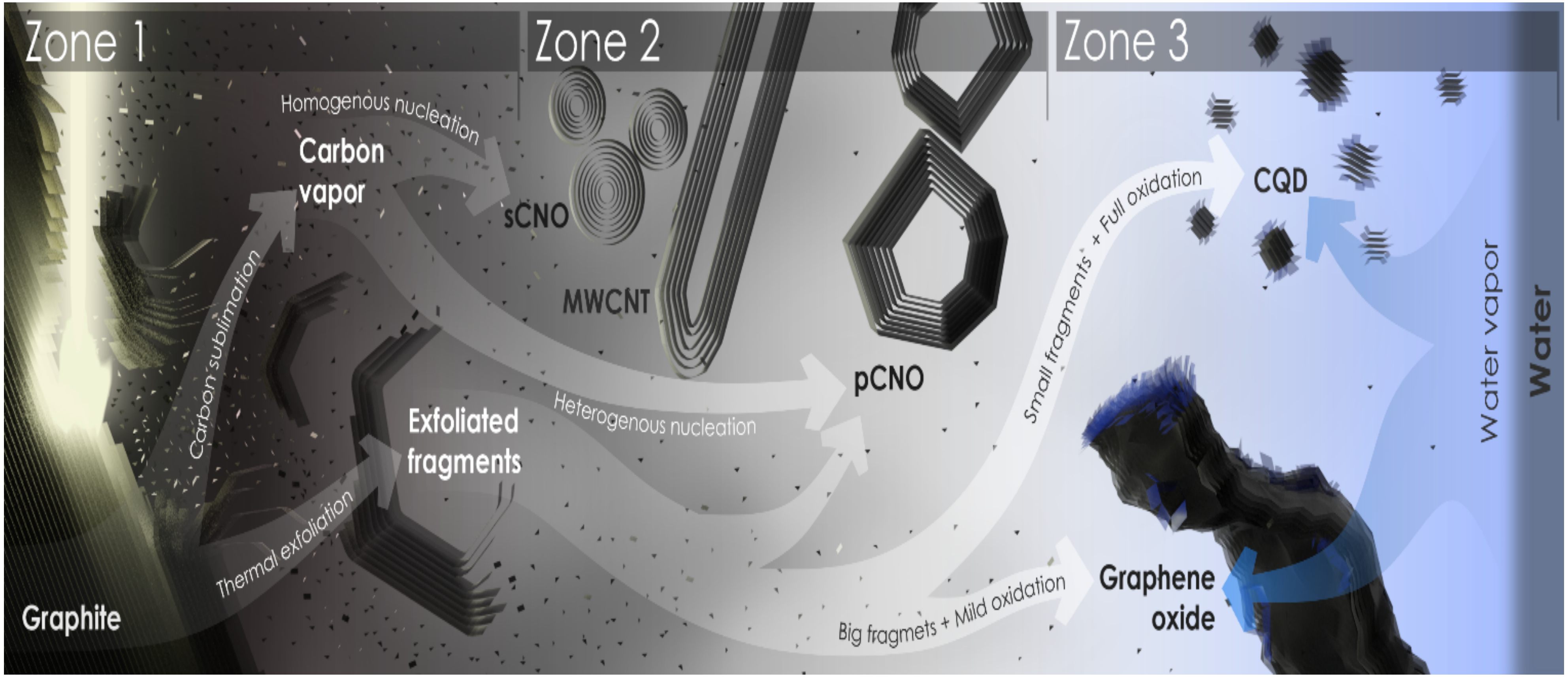
J. Prasek, et. al. Methods of carbon nanotubes synthesis review. J. Mater. Chem. 21, 15, 15872 (2011). https://doi.org/10.1039/cljm12254a

SUBMERGED ARC DISCHARGE



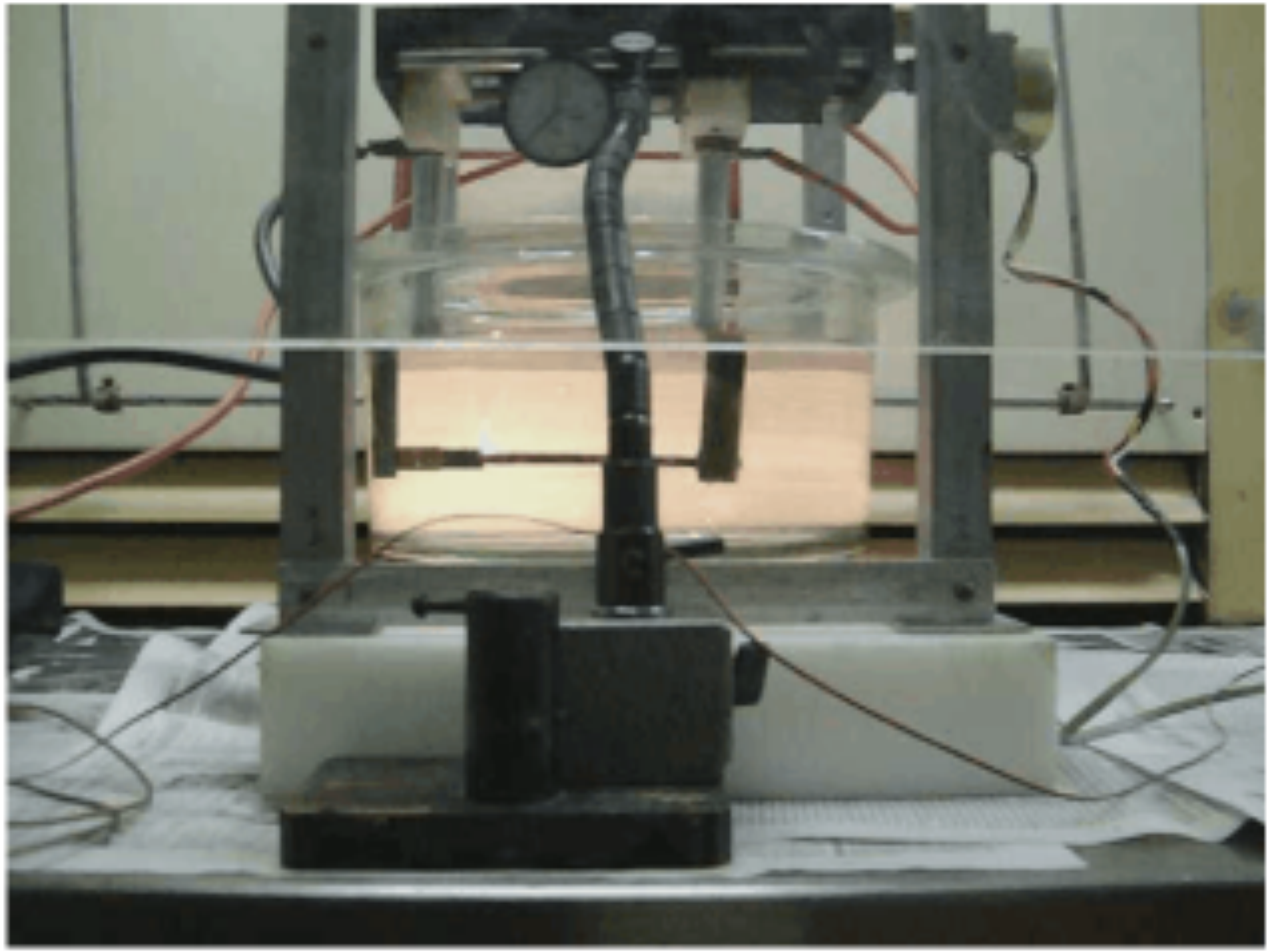
L.F. Desdín-Garcia, et. al. Multiparametric diagnostic in the synthesis of carbon nanostructures via submerged arc discharge: Stability, nucleation and yield. Journal of Applied Physics Vol. 126, p. 183301 (2019) https://doi.org/10.1063/1.5108815

NUMAR- 2024. FEBRUARY 25 – 28 2024, VARADERO, CUBA



L.F. Desdin-García, et. al. Carbon quantum dots by submerged arc discharge in water: Synthesis, characterization, and mechanism of formation”. J. of Applied Physics (AIP)129, 163301 (2021), https://doi.org/10.1063/5.0040322

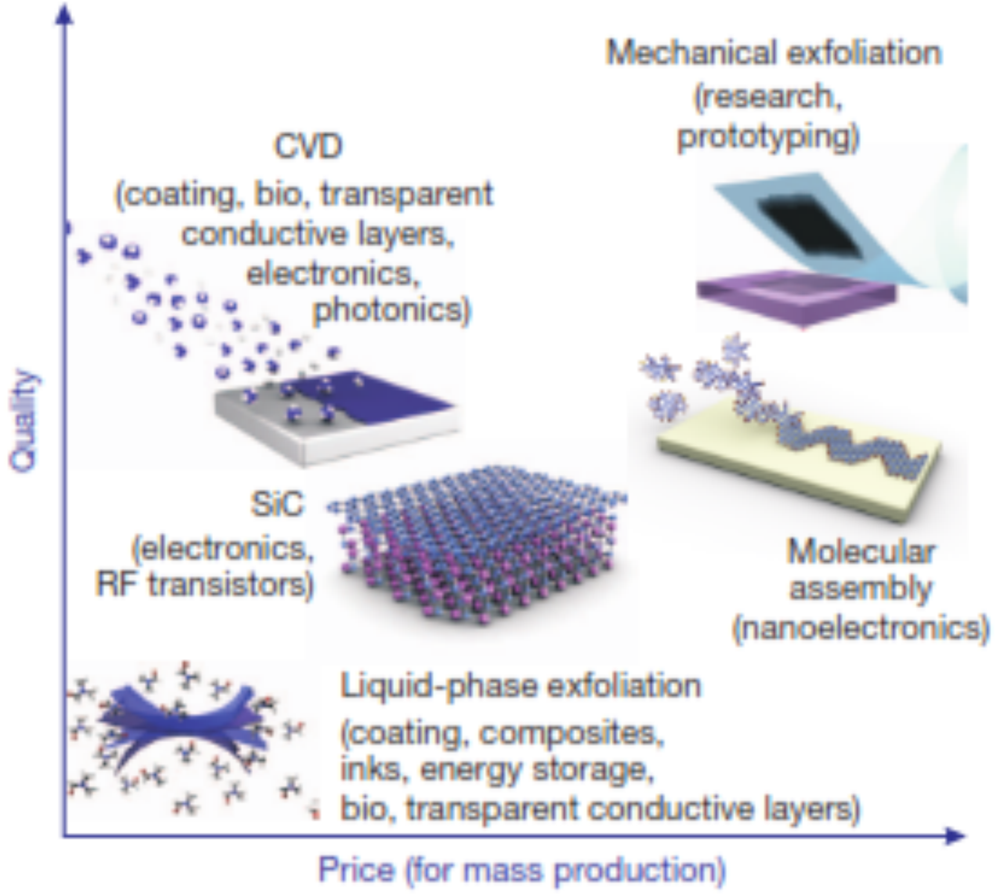
SYNTHESIS OF CARBON NANOSTRUCTURES BY SUBMERGED ARC DISCHARGE

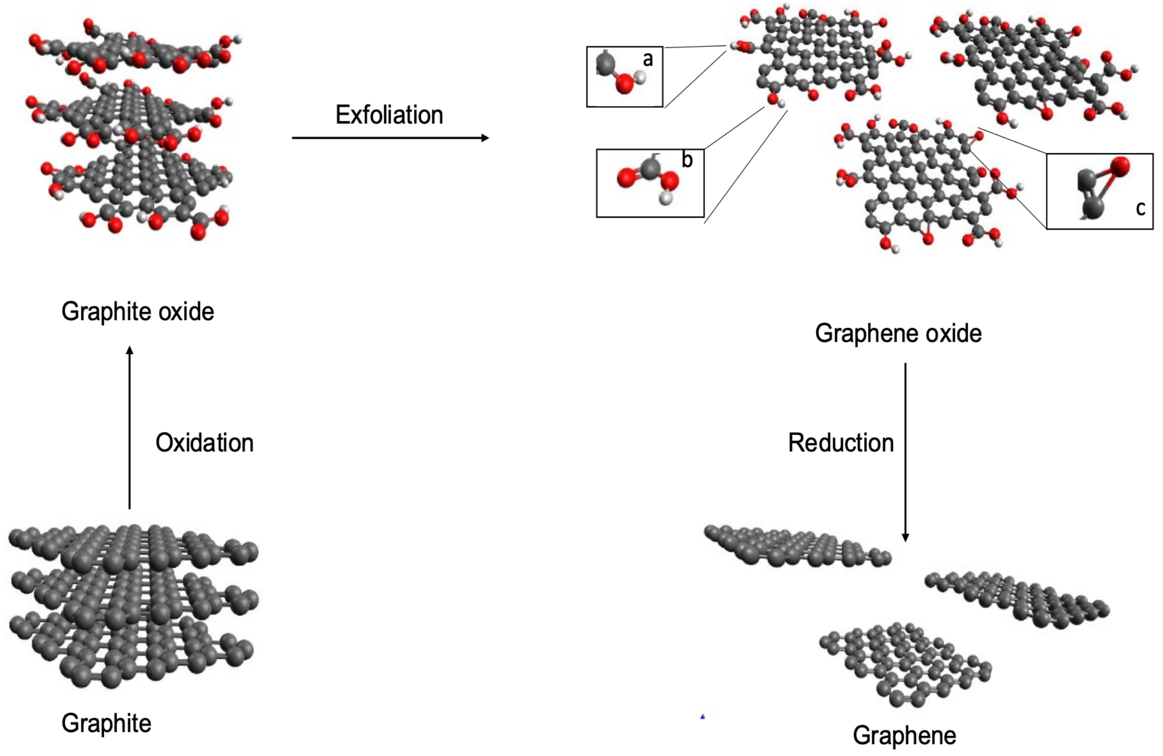


HOMEMADE INSTALLATION

L.F. Desdín – Garcia, et. al. "Automated system for the synthesis of nanostructures via arc-discharge in liquids". Advances in Natural Sciences: Nanoscience and Nanotechnology (IOP) Vol.9, Pág.035002 (2018). https://doi.org/10.1088/2043-6254/aad1a6A

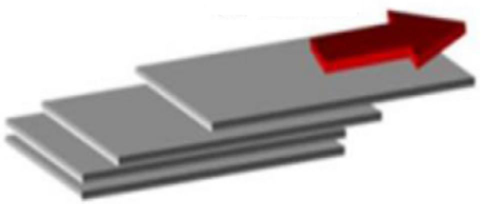
2D - GRAPHENE MANUFACTURING METHODS

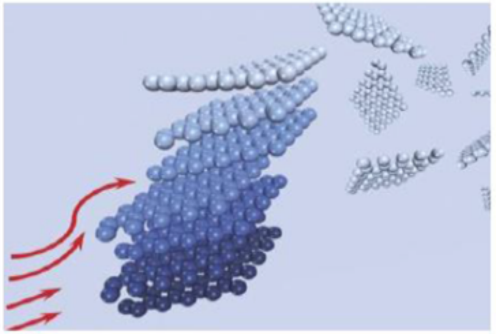




D. Saini. Synthesis and functionalization of graphene and application in electrochemical sensing. Nanotechnology Review. https://doi.org/10.1515/ntrev-2015-0059

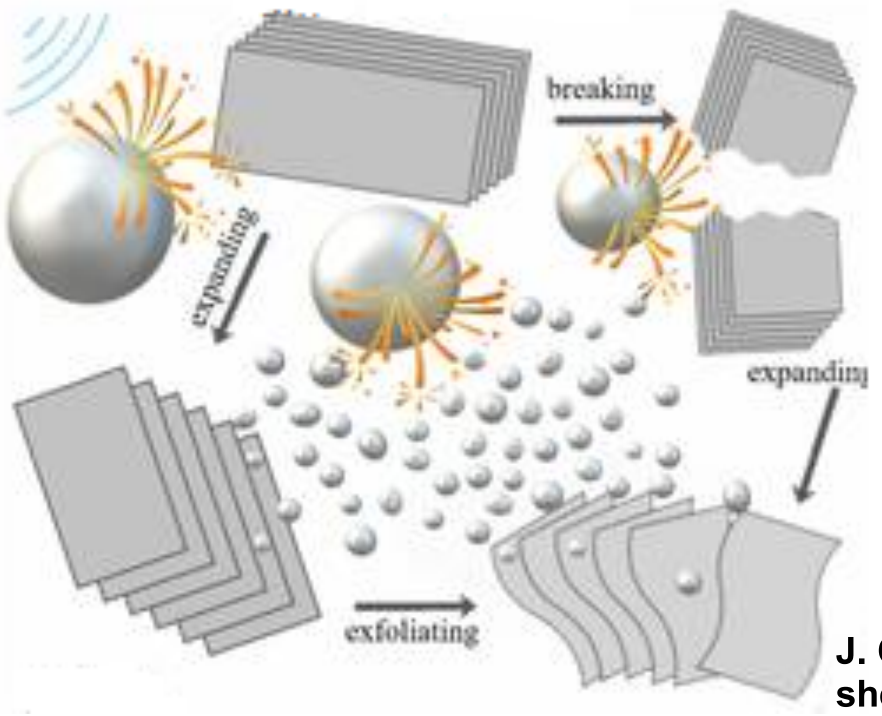
GRAPHENE PRODUCTION METHOD: SHEAR AND ULTRASOUND EXFOLIATION

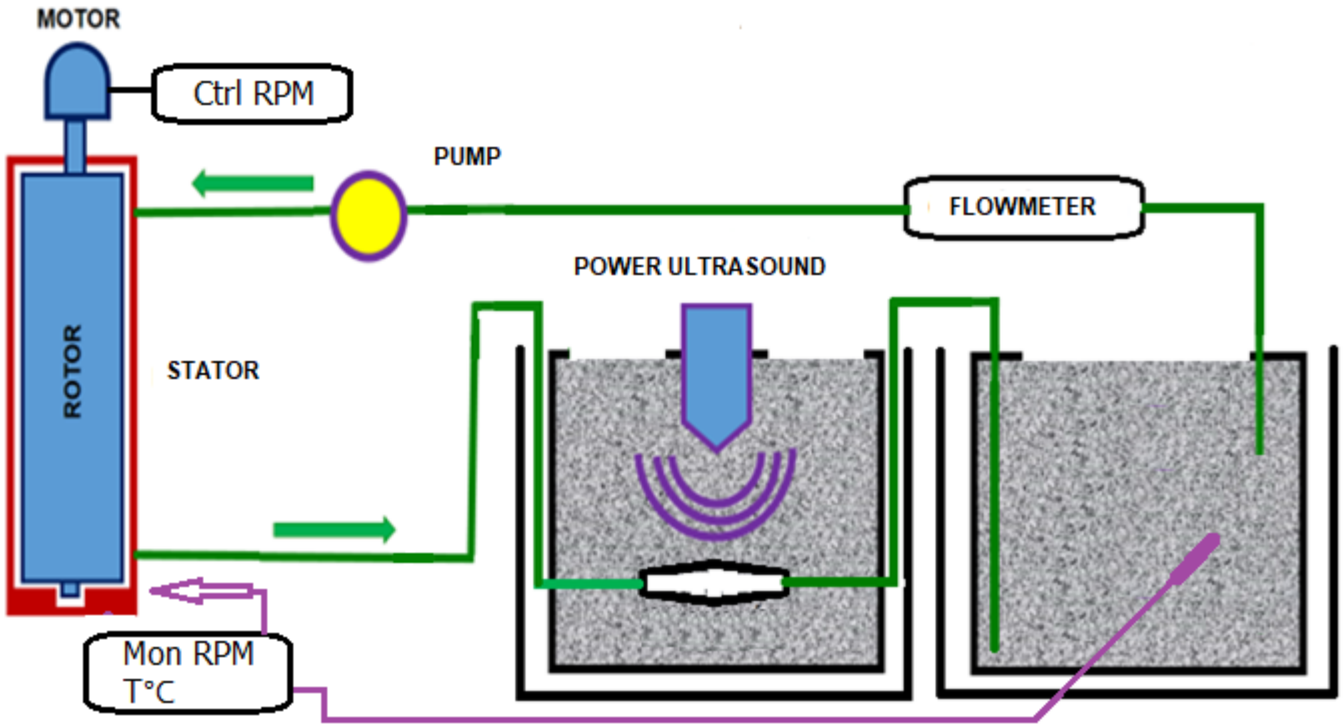




Share Rate = wr/d > 10,000 P > 100 W/L

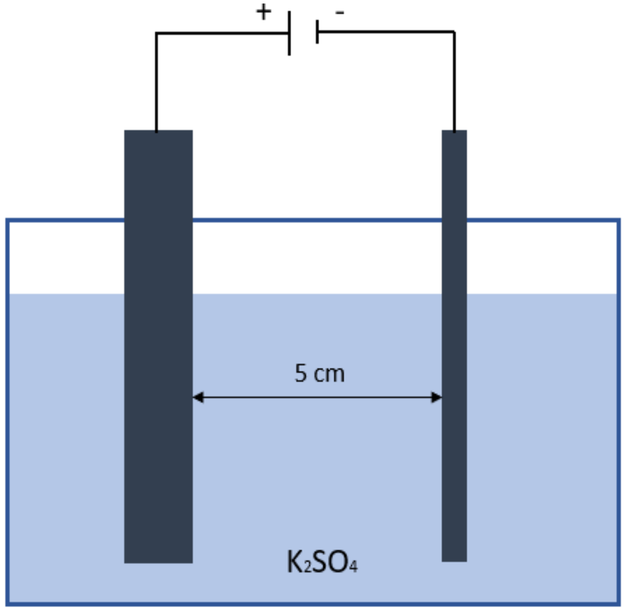
Ultrasound Power ~ 700 – 1000 W



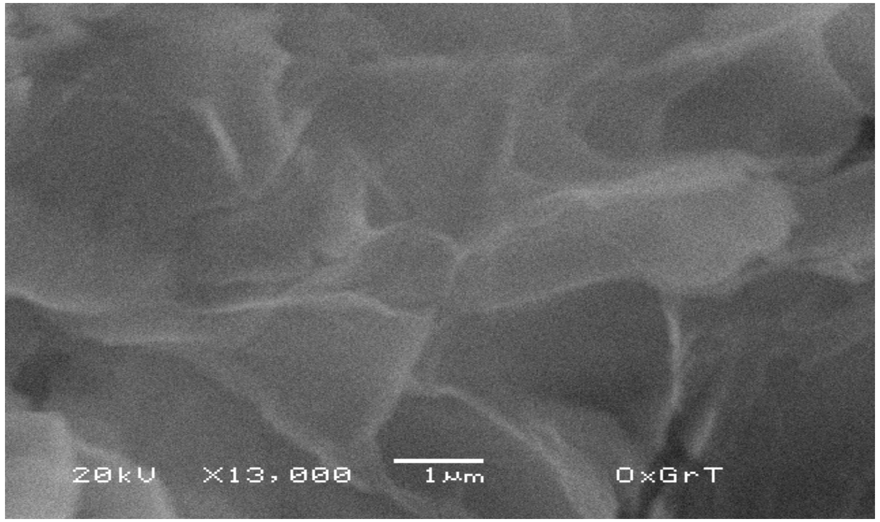


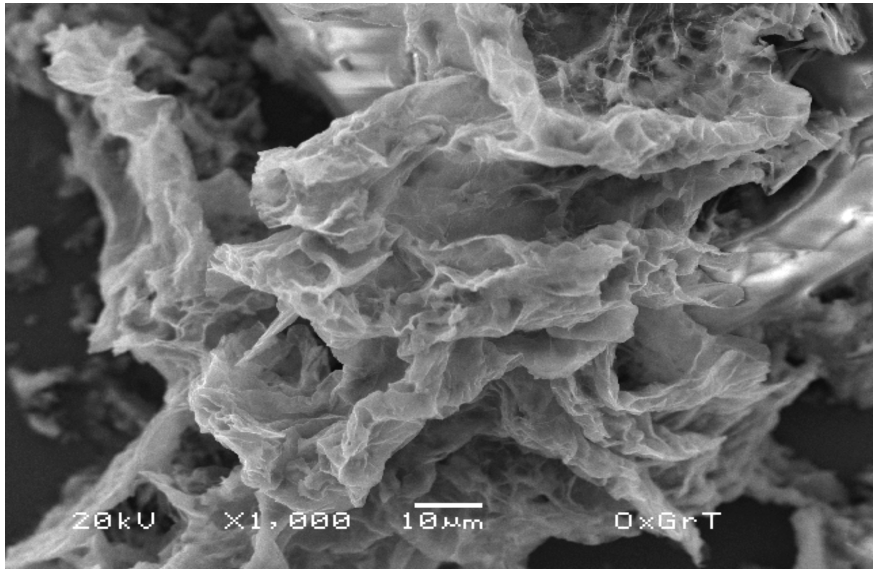
J. Coleman. Scalable production of large quantities of defect-free few-layer graphene by shear exfoliation in liquids. Nature Materials (2014). https://doi.org/110.1038/NMAT3944

ELECTROCHEMICAL METHOD OF GRAPHENE OXIDE SYNTHESIS

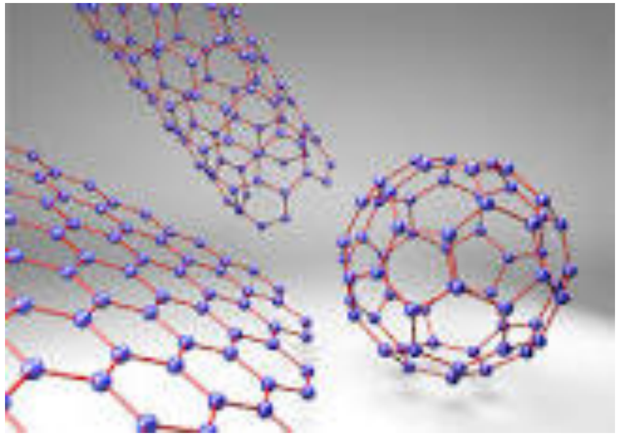


0,5 M   10 V

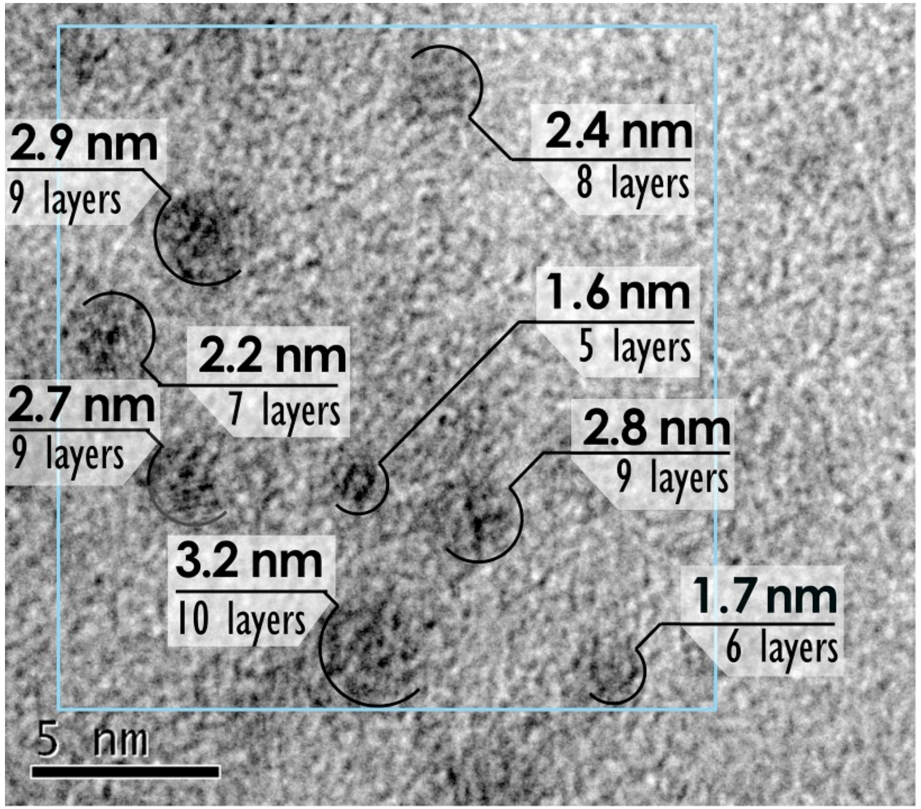




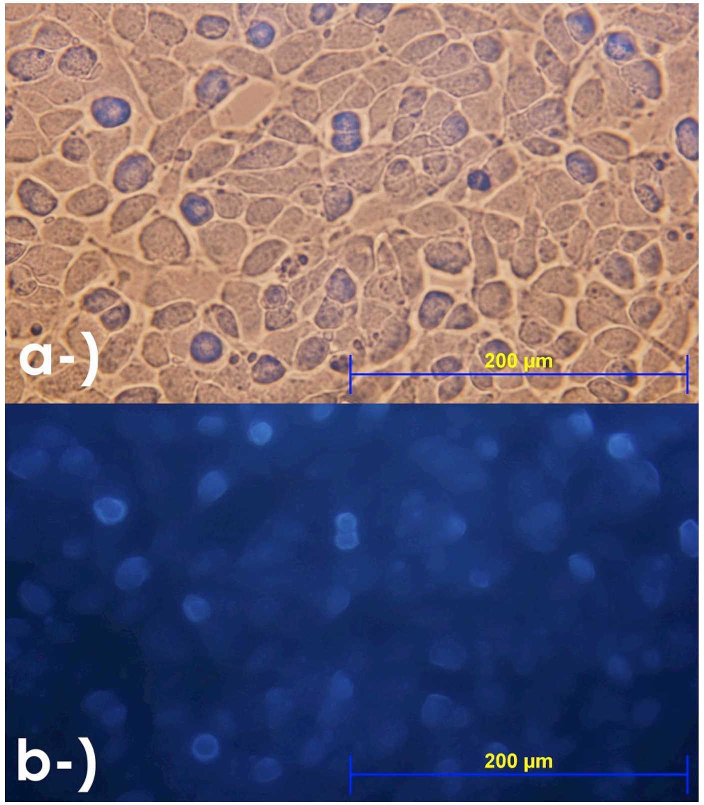
APPLICATIONS OF CARBON NANOSTRUCTURES IN ENVIRONMENT, MATERIALS AND LIFE SCIENCES



QUANTUM DOTS AS A FLUOROPHORE FOR BIOLOGICAL RESEARCH



CDs high magnification HRTEM image shows the approximate diameters and the estimated number of layers of the CQDs depicted

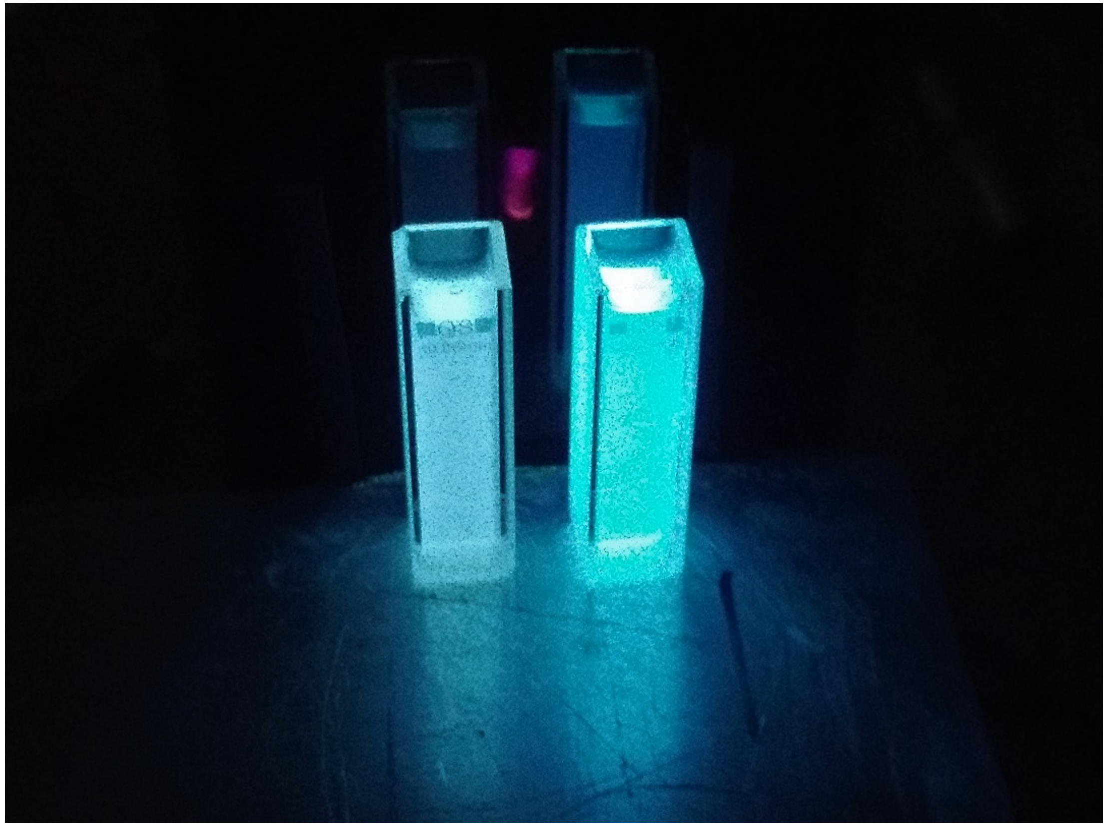


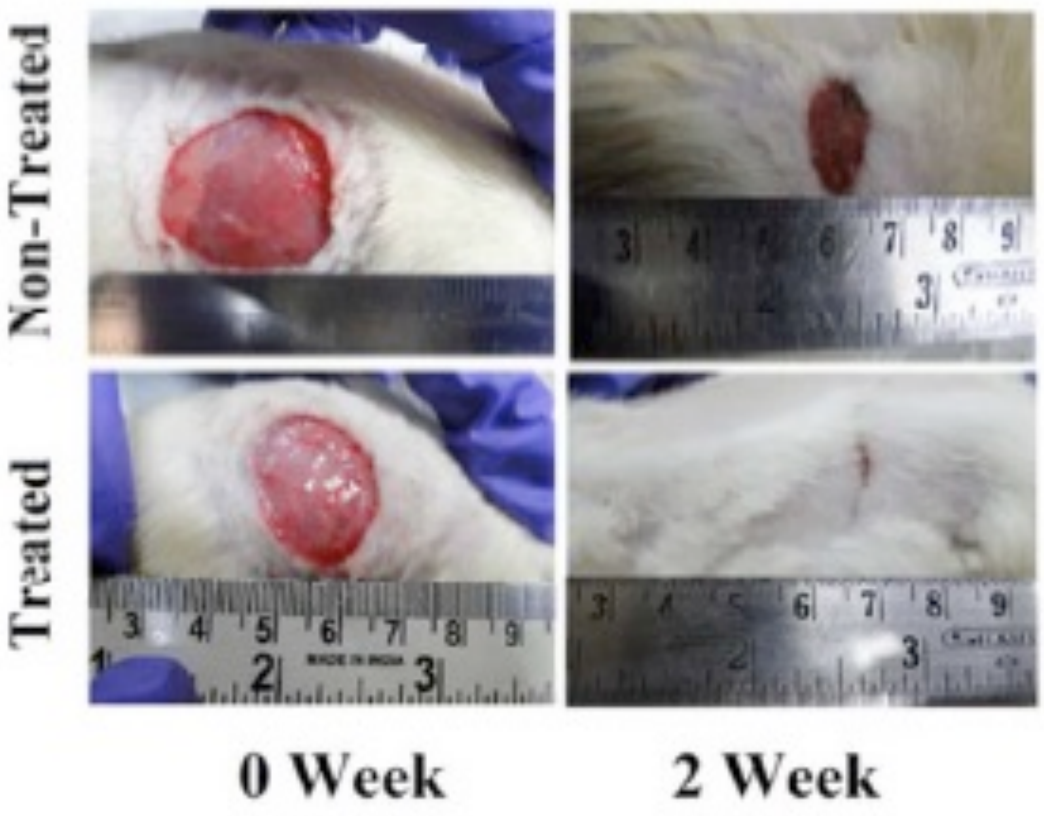
Fluorescent microscopy images under UV excitation of a sample of L929 fibroblast cells treated with SADW CQDs for 2 h: (a) half–half, transmission/fluorescence illumination. (b) just full fluorescence illumination.

L.F. Desdin-García, et. al. Carbon quantum dots by submerged arc discharge in water: Synthesis, characterization, and mechanism of formation”.

J. of Applied Physics (AIP)129, 163301 (2021), https://doi.org/10.1063/5.0040322

CARBON QUANTUM DOTS TO ACCELERATE THE HEALING OF SKIN WOUNDS





B.D. Datta, et.al. Onion derived carbon nano dots for live cell imaging and accelerated skin wound healing. J. Mater. Chem. B, 2017, https://doi.org/10.1039/C7TB00869D.

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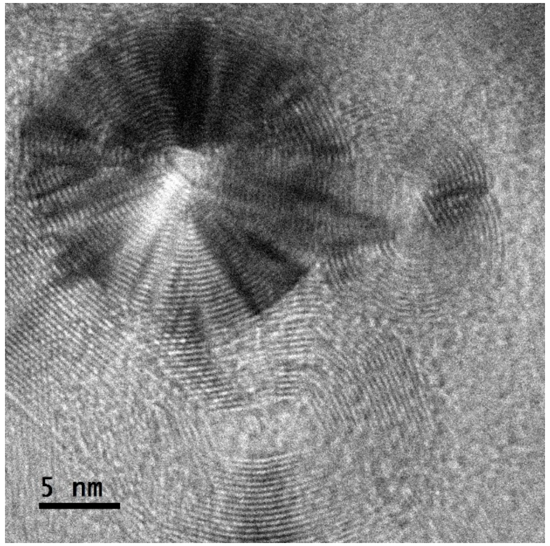
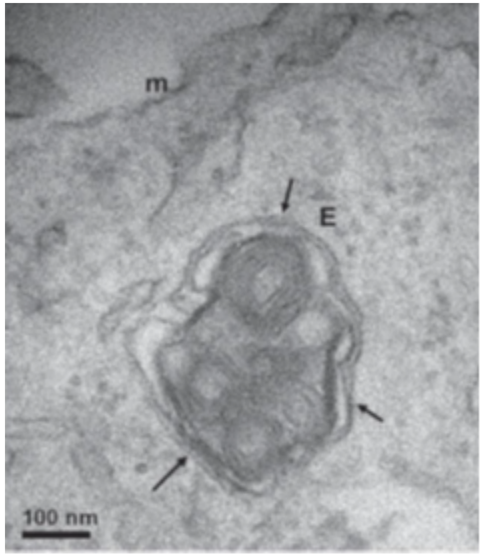
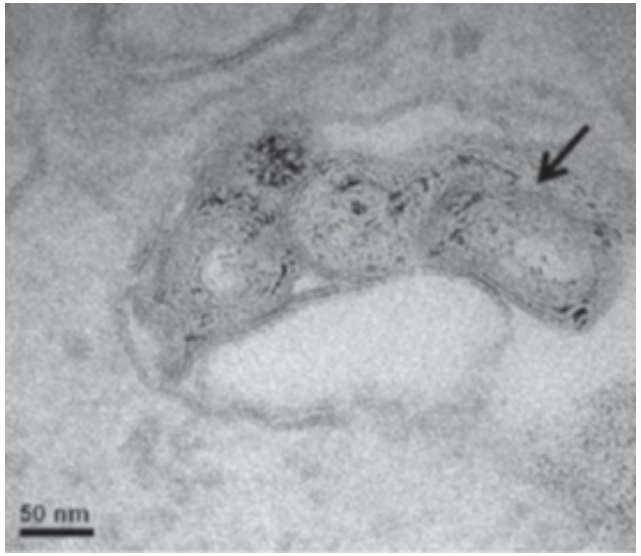
nanociencia CEADEN

PROTEOMIC ANALYSIS IN CELLS TREATED WITH PRISTINE CARBON NANO-ONIONS (CNOs) AND ITS CELLULAR LOCALIZATION - (HUMAN KERATINOCYTE CELLS)



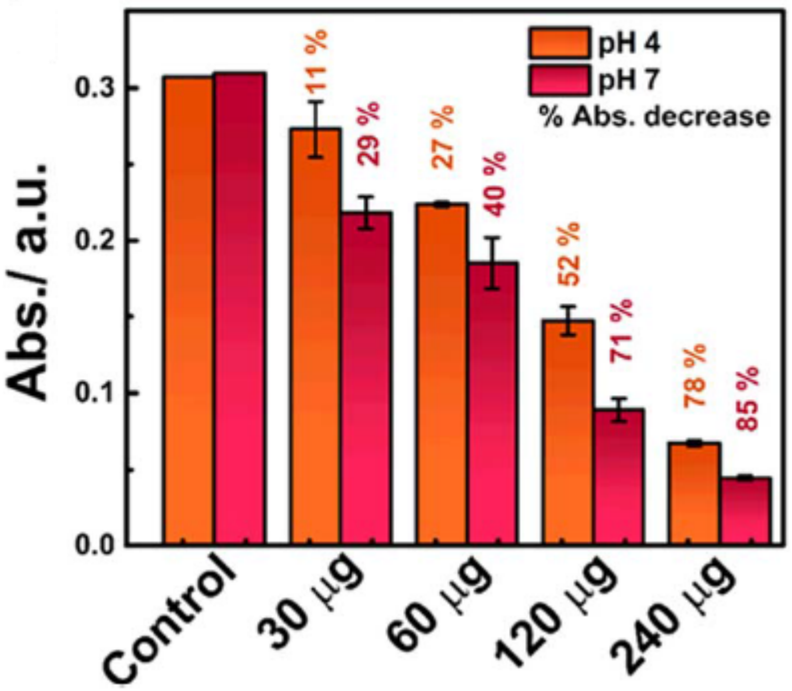




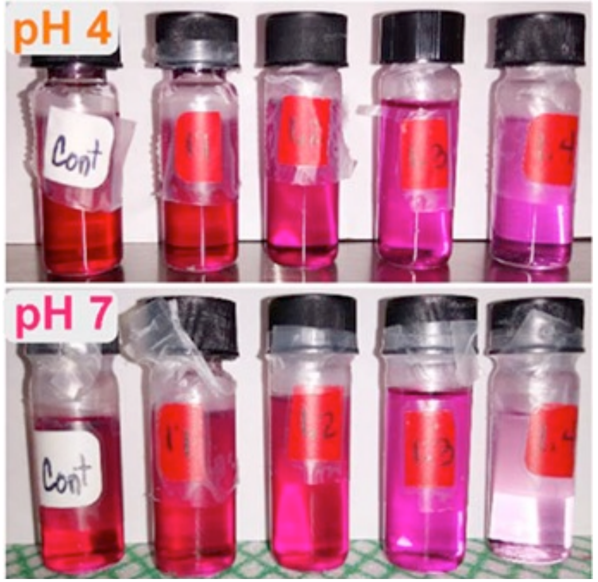
- **CNOs were localized within early an late endosomes**
- **The down - regulation of EGFR by > 4 - fold, which indicates that the nano-onions might serve as therapeutics for EGFR – overexpressing epithelial cancers, such > 20% of the breast cancer.**
- **CNOs – Nanomedicina platform for cancer therapy, especially ephithelially derived cancers**

L. Garcia-Hernández, F. Chao, L.F. Desdín-Garcia, et. al. "Proteomic analysis in cells treated with pristine carbon nano-onions and its subcellular localization". Advances in Natural Sciences: Nanoscience and Nanotechnology (IOP) 10, 3, 035011 (2019). https://doi.org/10.1088/2043-6254/ab3dfd

NEUTRAL RED DYE ADSORPTION ON CARBON NANOONIONS



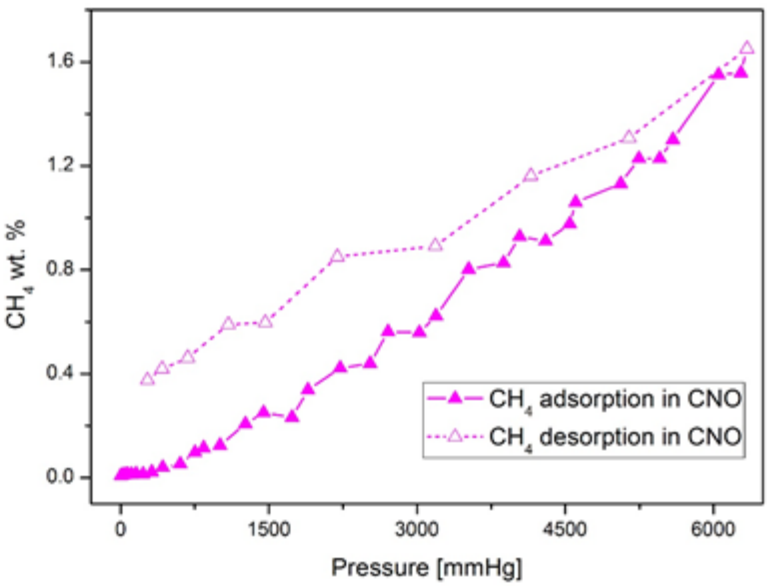
Normalised absorbance for each dosage (Norm. Abs. Versus CNOs dosage) and absorbance decrease percent.

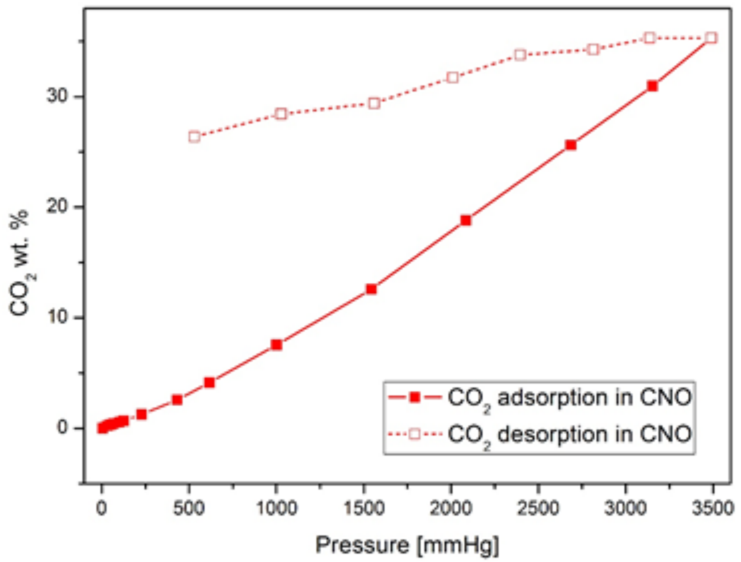


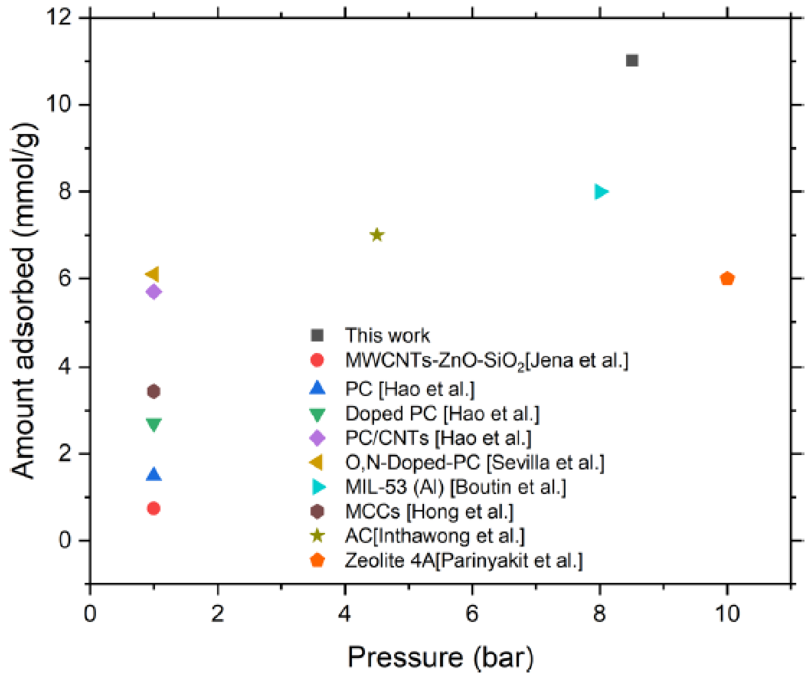
NR solutions after adsorption process at pH 4 and 7.

L.F. Desdin-Garcia, et.al. Neutral red dye adsorption on carbon nanoonions: viability assay interference and adduct characterization. Adv. Nat. Sci.: Nanosci. Nanotechnol. 13, 045001 (2022). https://doi.org/10.1088/2043-6262/ac8ded

METHANE AND CARBON DIOXIDE ADSORPTION ON CARBON NANOONIONS







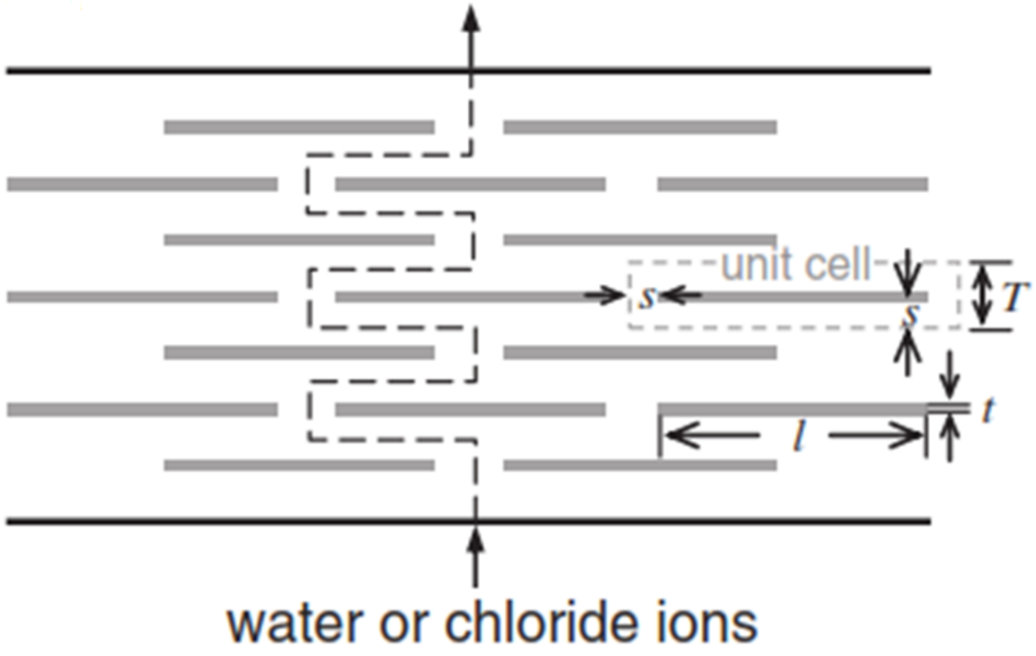
L.F. Desdin-Garcia, et.al. methane and carbon dioxide adsorption on carbon nanoonions. Adsorption (2023).
https://doi.org/10.1007/s10450-023-00432-9

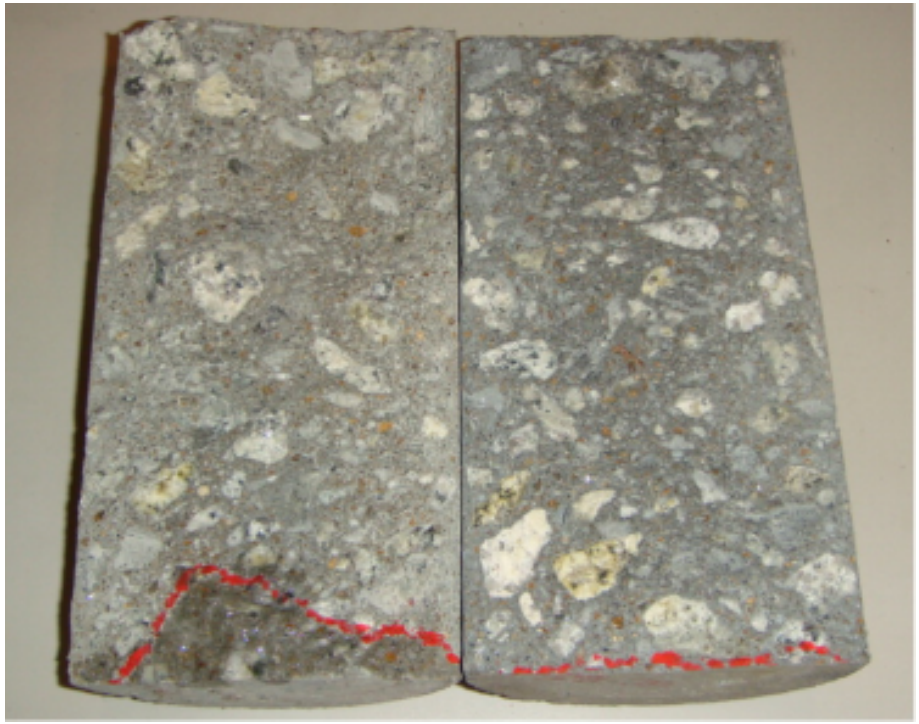
CARBON NANOMATERIALS FOR THE DEVELOPMENT OF SUPERCAPACITORS

Polyaniline (PANI), and poly(vinyl alcohol) (PVA)

L.F. Desdin-Garcia, L. Echogoyen, E. Reguera, et. al. In Situ Aniline-Polymerized Interfaces on GO−PVA Nanoplatforms as Bifunctional Supercapacitors and pH-Universal ORR Electrodes. ACS Appl. Energy Mater. 3, 4727−4737 (2020). https://dx.doi.org/10.1021/acsaem.0c00361

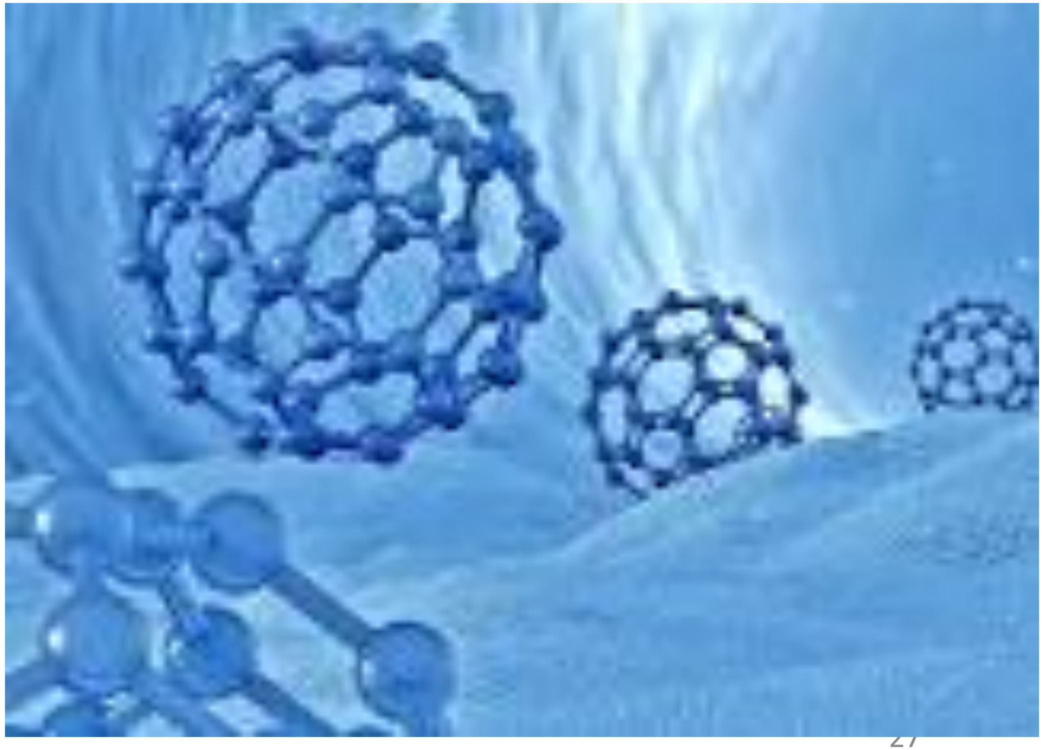
Durability Evaluation of Reinforced Concrete Modified with Graphene Oxides; for Possible Use in Nuclear Industry Structures



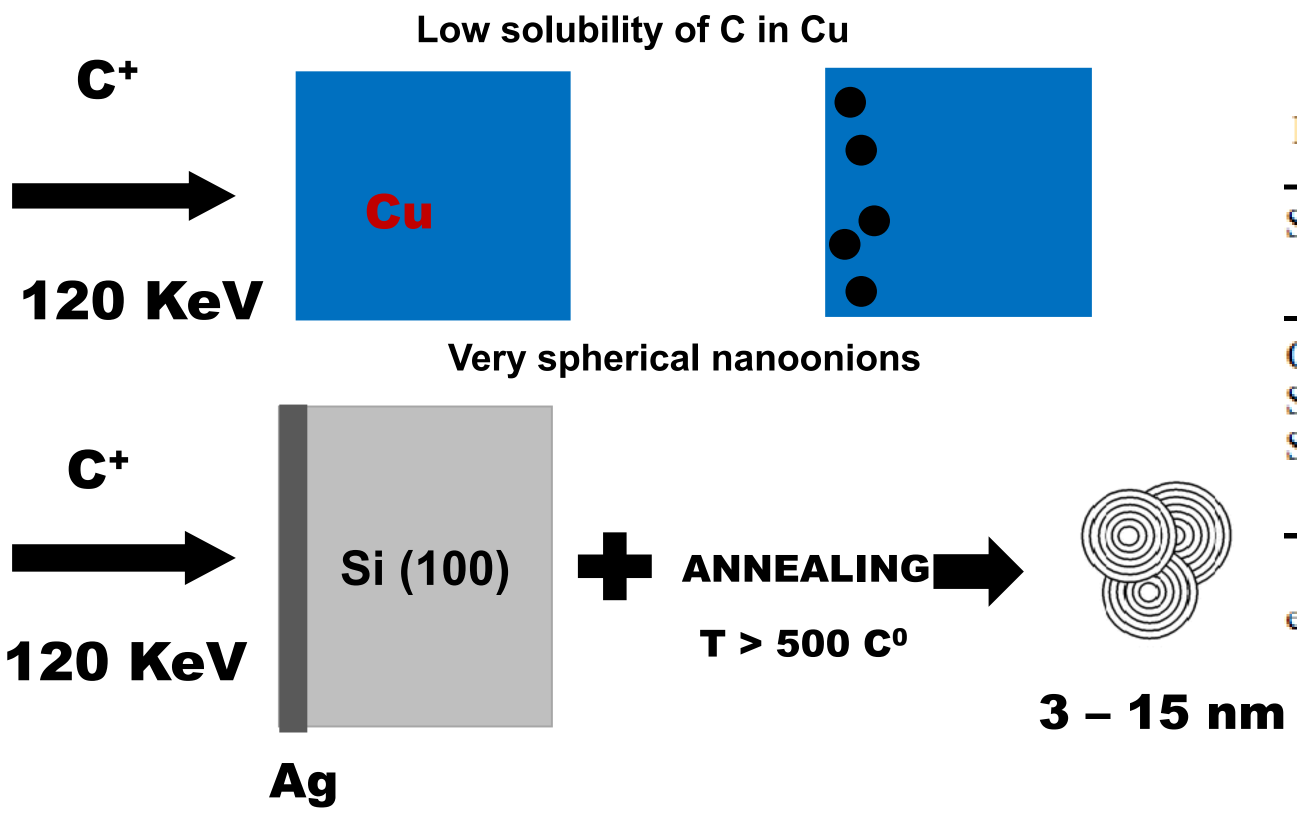


Water penetration in concrete without graphene and concrete with 1.5% graphene platelets

NUCLEAR METHODS AND CARBON NANOSTRUCTURES



SYNTHESIS OF CARBON NANOONIONS WITH A CARBON ION BEAM



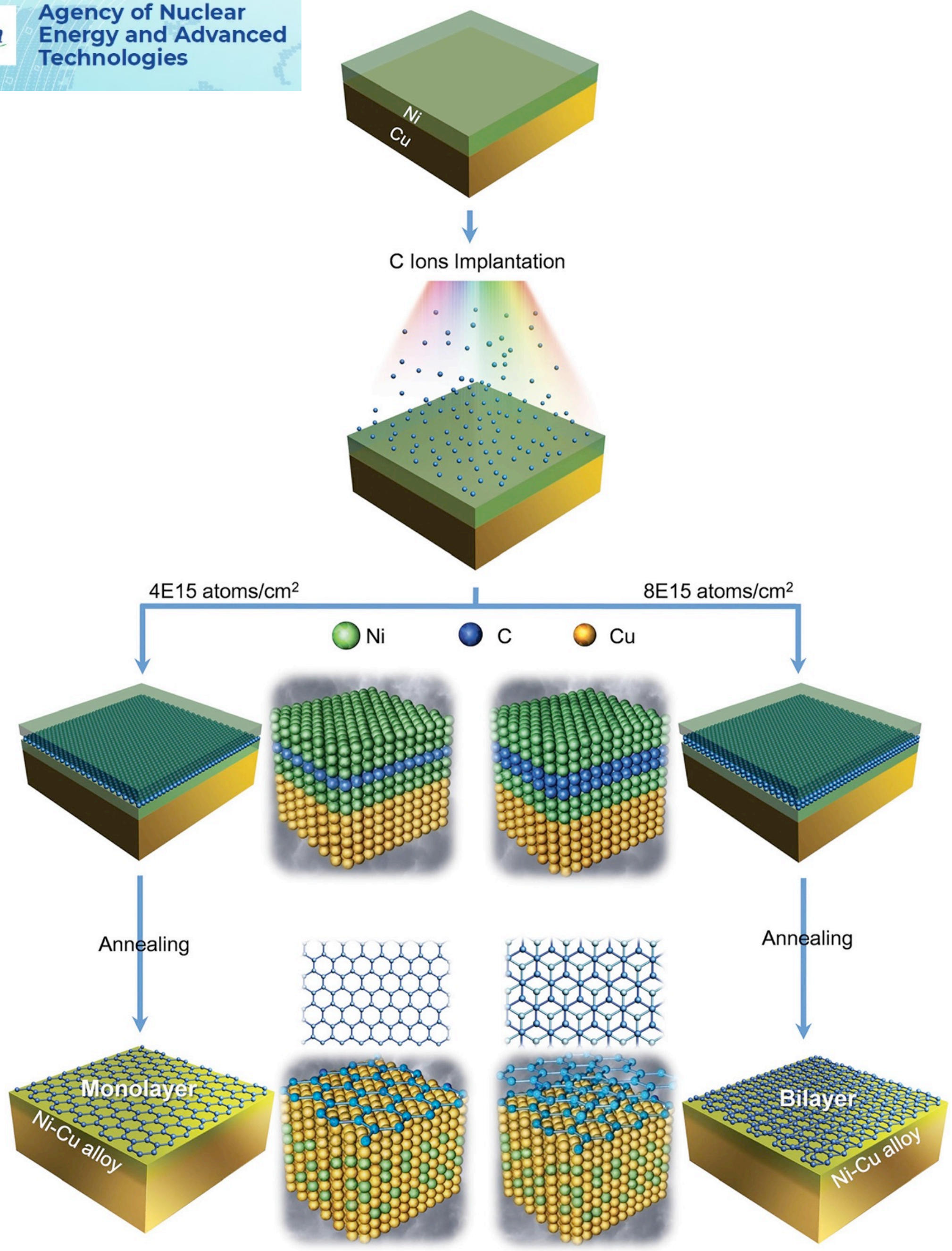
Implantation parameters used for the carbon ion implantations[a]

Substrate	Temperature (°C)	Fluence ($\times 10^{17}$ ions cm^{-2})	Ion flux (μA cm^{-2})
Copper	600–1000	1–5	1–3
Silver	400–800	0.1–3	1–50
Silver thin film on silica	500	0.2–3	6–12

[a] The energy of the $^{12+}_{12}$C ions is kept constant (120 keV) for all the experiments.

T. Cabioch, et. al. Carbon onions formation by high-dose carbon ion implantation into copper and silver. Surface and Coatings Technology 128-129, 43- 50 (2000). https://doi.org/10.1016/S0257-8972(00)00655-1

SYNTHESIS OF 2D MATERIALS



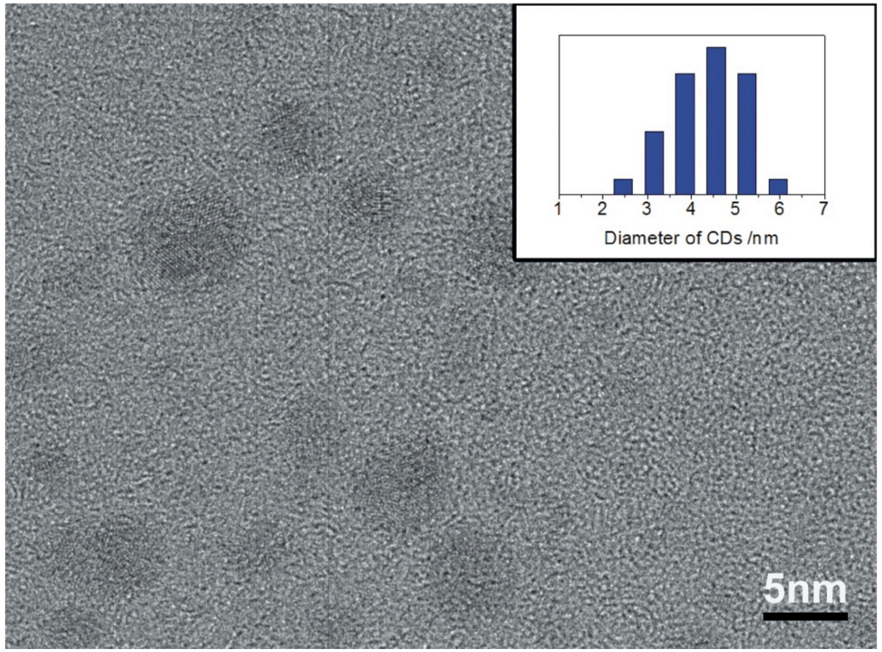
In recent years, ion implantation has been recognized as a controllable and transfer-free technique for the synthesis of 2D materials, especially graphene

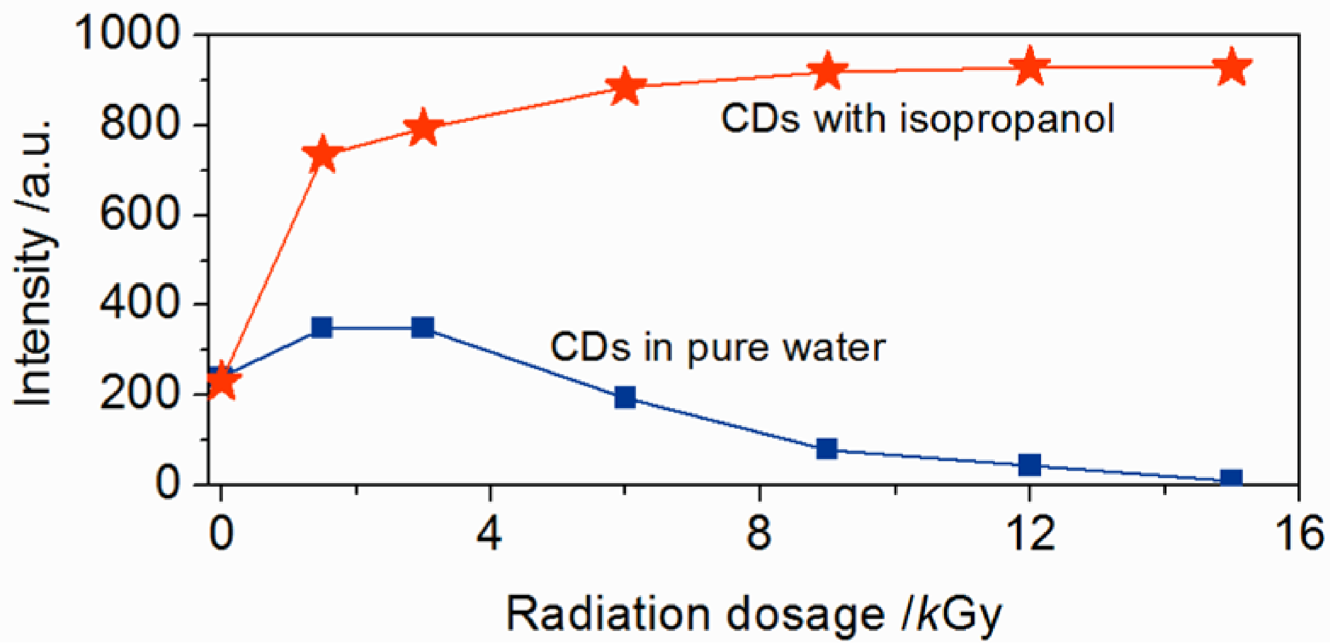
Schematic illustration of the steps of the graphene synthesis procedure on the Ni/Cu bilayer substrate. The subsequent annealing is performed under H2 and Ar gas flow.

Z. Li, F. Chen. Ion beam modification of two-dimensional materials: Characterization, properties, and applications. Applied Physics Reviews 4, 011103 (2017). https://doi.org/10.1063/1.4977087

IRRADIATION OF CARBON QUANTUM DOTS WITH GAMMA QUANTUMS

CDs could be either easily decomposed to small molecules or enhanced in fluorescence quantum yields in selective aqueous γ-irradiation systems

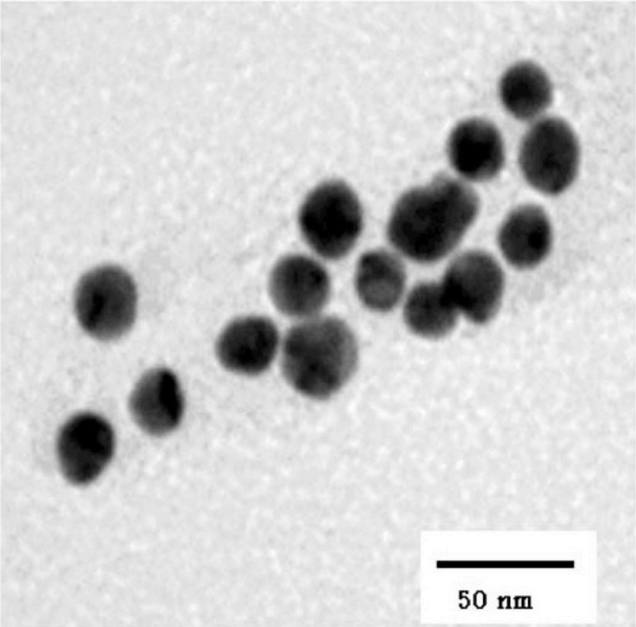


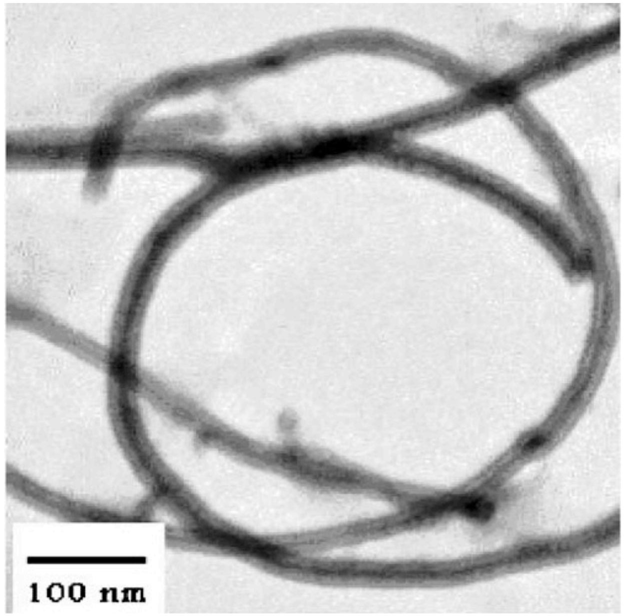


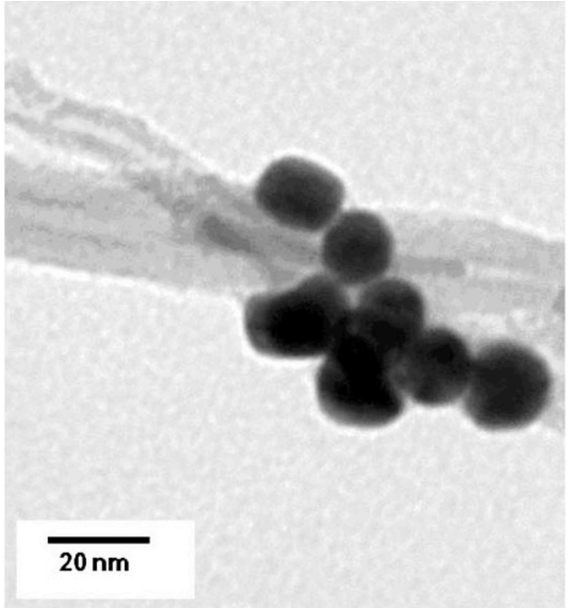
R. Shen, et. al. Fluorescence Enhancement and Radiolysis of Carbon Dots through Aqueous γ Radiation Chemistry. J. Phys. Chem. C 116, 15826−15832 (2012). https://doi.org/10.1021/jp304541q

FUNCTIONALIZATION OF CARBON NANOSTRUCTURES WITH GAMMA IRRADIATION

- **Gold nanoparticles were successfully attached to the surface sites of carbon nanotubes (CNT).**
- **Both nanostructured materials were functionalized by gamma - ray irradiation without chemical treatments for creating active sites.**
- **78Gy with a dose rate of 1.5Gy/h at room temperature from a 662 keV 137Cs gamma-ray source**



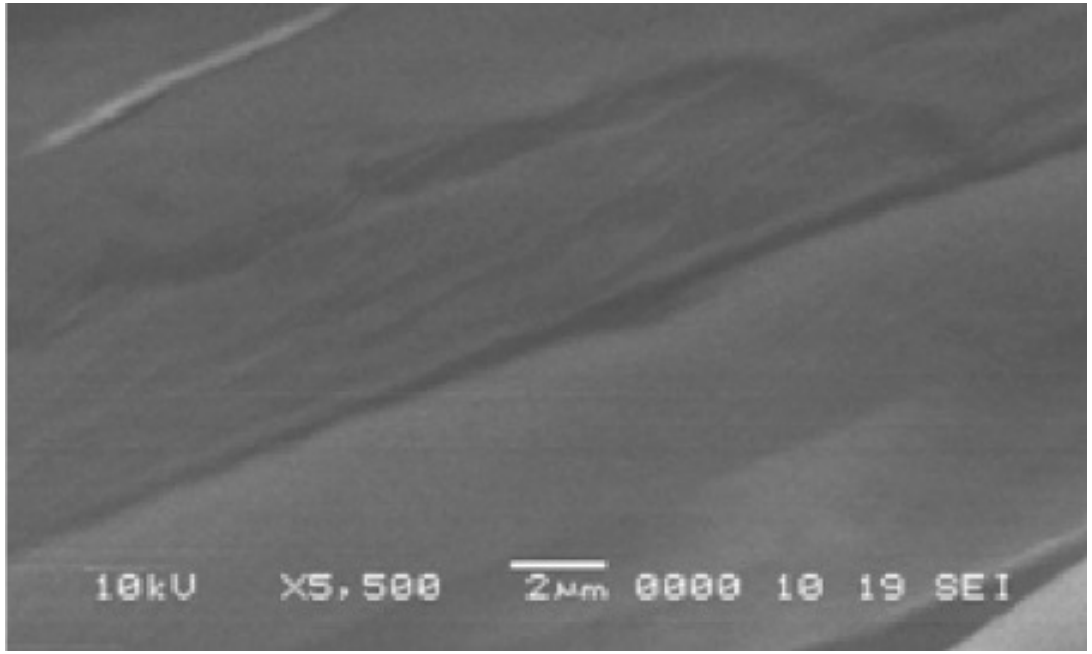


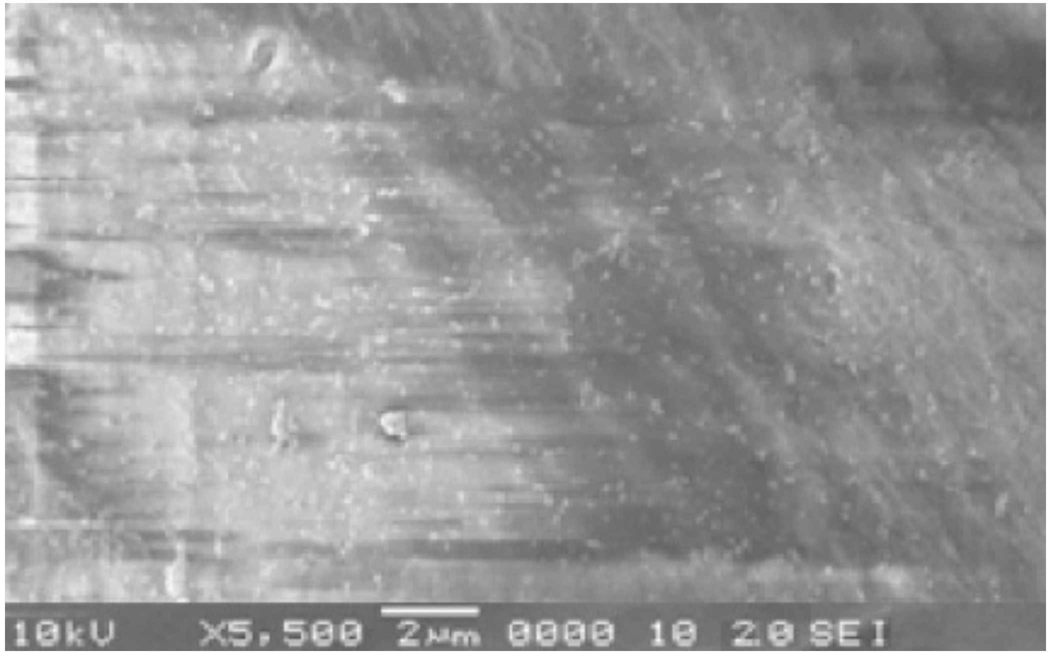


N. Salah, et.al. Functionalization of gold and carbon nanostructured materials using gamma-ray irradiation. Radiation Physics and Chemistry 78 910–913 (2009). https://doi.org/10.1016/j.radphyschem.2009.06.012

FUNCTIONALIZATION OF CARBON NANOSTRUCTURES WITH METAL NANOPARTICLES USING GAMMA IRRADIATION

Antibacterial fabrics - surgical gowns

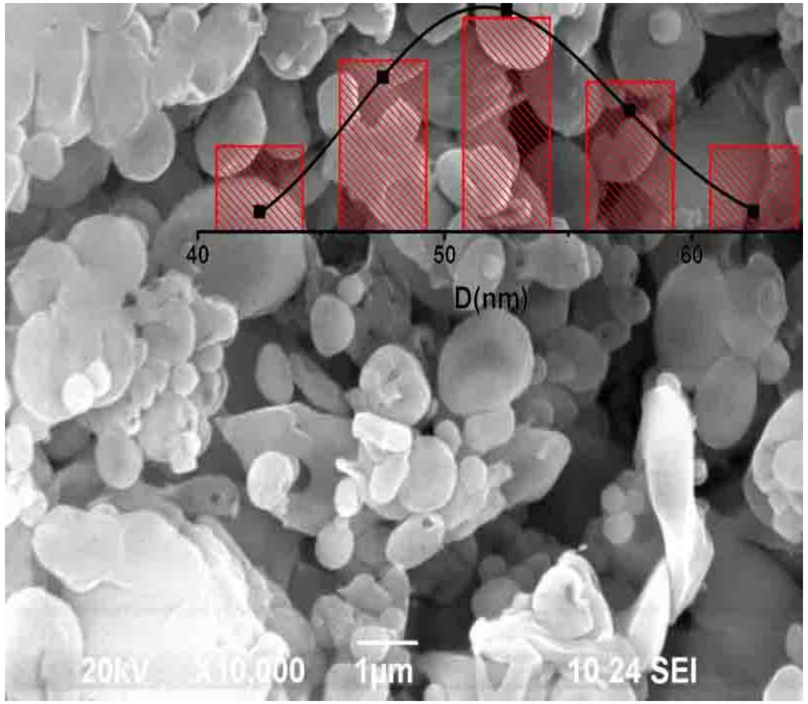




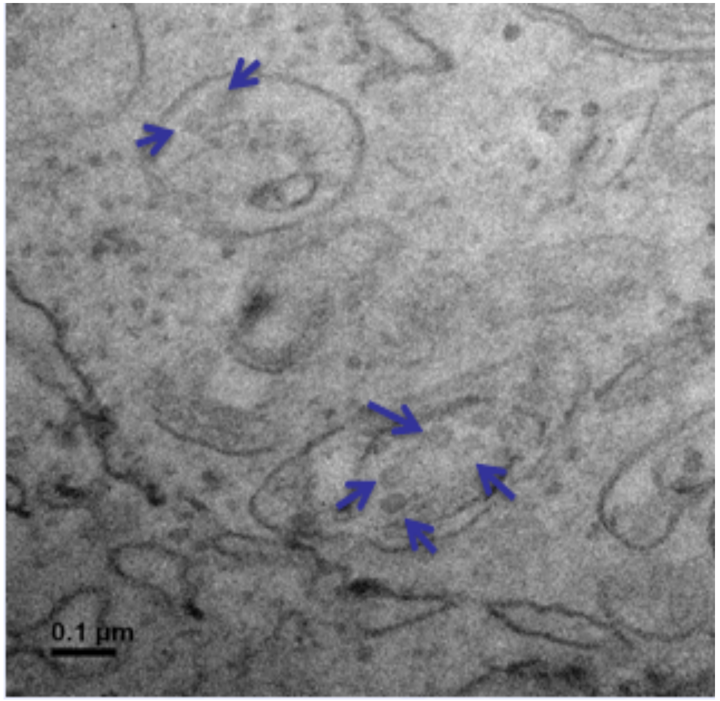
T.T. Hanh, et. al. Gamma irradiation of cotton fabrics in AgNO3 solution for preparation of antibacterial fabrics. Carbohydrate Polymers (2014) 1243– 1248 (2014). http://dx.doi.org/10.1016/j.carbpol.2013.10.069

POLYVINYLPYRROLIDONE NANOGLELS OBTAINED BY GAMMA IRRADIATION TECHNIQUES

CANDIDATES AS RELEASE SYSTEMS



Range 34 – 154 nm

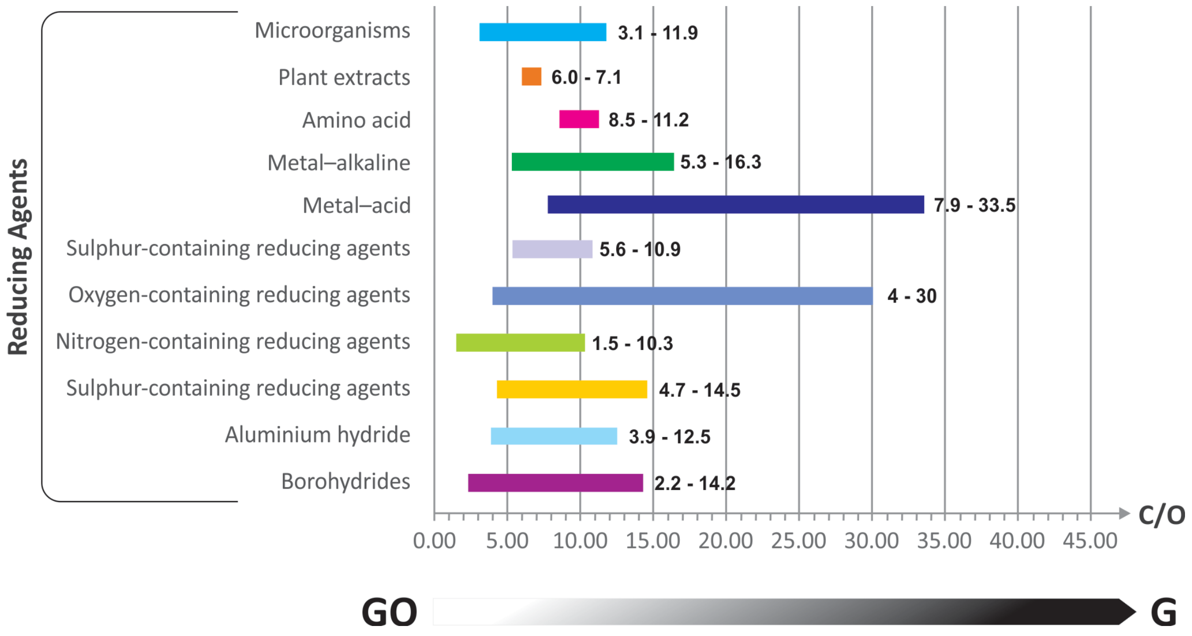


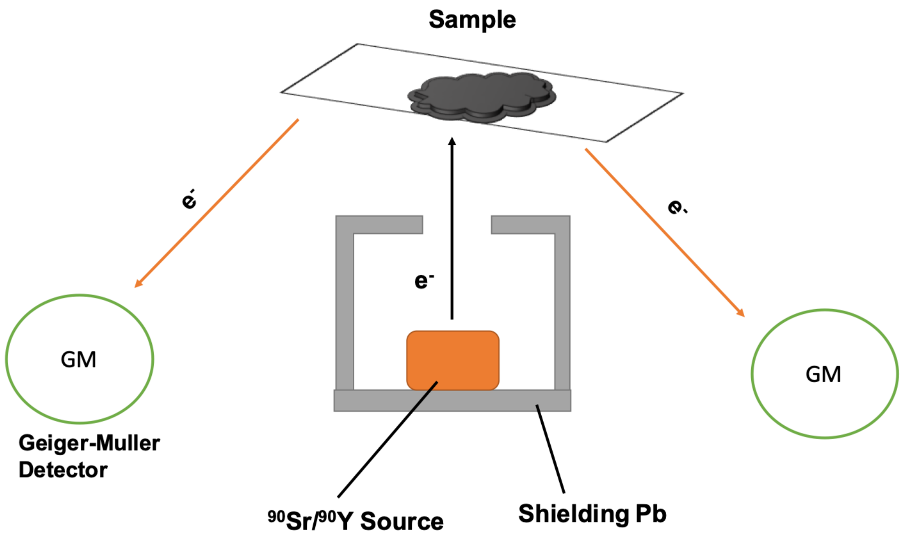
TEM image of a human monocyte cell with nanogels trapped inside an endosome

CHARACTERISTICS

- Polymeric Matrices
- Nanometers scale
- Colloidal stability
- Inert to blood flow
- Conducive to incorporation drugs
- Not toxicity
- Protective and stimulating effect on cells viability

ESTIMATION OF THE C/O RATIO IN GO AND rGO BY FAST ELECTRON BACKSCATTERING





APPLICATIONS OF NANOSCIENCE IN NUCLEAR TECHNOLOGY AND OF NUCLEAR SCIENCES IN NANOTECHNOLOGY

Nanoscience in Nuclear Technology

- **Treatment of radioactive waste with nanostructures**
- **Boron neutron capture therapy**
- **MWCNT - Channeling of low energy ions (< 100eV)**
- **A Hybrid Nanoparticle Probe for Dual-Modality (MRI+PET, CDs + PET)**
- **Fullerene-like defects in high-temperature neutron-irradiated nuclear graphite**
- **Radiation Resistance of High-Entropy Nanostructured (Ti, Hf, Zr, V, Nb)N Coatings**
- **Gold nanoparticles as X-ray contrast agent**
- **Nanofluids for Enhanced Economics and Safety of Nuclear Reactors**

Nuclear Sciences in Nanotechnology

- **Preparation of the Nanostructured Radioisotope Metallic Oxide by Neutron Irradiation for Use as Radiotracers**
- **Defect engineering in nanostructures**
- **Radiological Protection Experience - Nanosafety**
- **Synthesis, functionalization and decoration of nanostructures**
- **Reduction of 1/f noise in graphene after electron-beam irradiation**
- **TO/C atomic ratios in films of GO rGO by RBS of H+ ions**
- **Positron annihilation characterization of nanostructures**
- **Nuclear nanoprobe development for visualization of three-dimensional nanostructures**

CONCLUSIONS

- CARBON NANOSTRUCTURES ARE ONE OF THE FASTEST GROWING FIELDS IN SCIENCE AND TECHNOLOGY.
- THERE IS A WIDE VARIETY OF CARBON NANOSTRUCTURE SYNTHESIS METHODS THAT CAN BE GROUPED INTO TOP-DOWN OR BOTTOM-UP APPROACHES.
- CARBON NANOSTRUCTURES HAVE WIDE APPLICATIONS IN THE ENVIRONMENT, MATERIALS AND LIFE SCIENCES.
- THERE IS AN INTERESTING SYNERGY BETWEEN NANOSCIENCE AND NUCLEAR SCIENCES IN THE FIELD OF CARBON NANOSTRUCTURES

Joint Institute for Nuclear Research
International Intergovernmental Organization
Agency of Nuclear Energy and Advanced Technologies

NUMAR- 2024. FEBRUARY 25 – 28 2024, VARADERO, CUBA

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THE FIELD OF CARBON NANOSTRUCTURES IS MULTIDISCIPLINARY BY NATURE

DOUBTS??