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Nanochemistry: An Overview about Nanoscale Particles for Environmental Remediation

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ABSTRACT

Nanohemistry is a scientific branch of nanoscience or nanotechnology which examines the complete study of chemical compounds at the nanoscale. Nanoscale systems lie at the threshold between classical and quantum behavior and exhibit behaviors that do not exist in larger devices. A nanostructure is an object of intermediate size between molecular and microscopic structures. Nanoparticle characterization is essential to establish the understanding and control of nanoparticle synthesis and applications. Characterization is done by a variety of different techniques, which are from materials science. Some common techniques are TEM, SEM, AFM, XRD, FTIR, MALDI-TOF etc.

The developed tools for nanochemistry are STM, AFM, High Resolution Scanning and Transmission Electron Microscopes, X-rays, Ion & Electron Beam Probes, and new methods for nanofabrication and lithography. Nanomaterials and nanotechnologies are projected to yield numerous health and health care advances, such as more targeted methods of delivering drug, new cancer therapies and methods of early detection of diseases. The main challenges to full utilization of nanochemistry centre on understanding new rules of behavior.

Keywords:—*Nanochemistry, Materials, Nanoscience, Nanotechnology, Nanoparticle.*

I. INTRODUCTION

Nanochemistry is a branch of nanoscience, deals with the chemical applications of nanomaterials in nanotechnology. Nanochemistry involves the study of the synthesis and characterization of materials of nanoscale size. Nanochemistry is a relatively new branch of chemistry concerned with the unique properties associated with assemblies of atoms or molecules of nanoscale (~1-100 nm), so the size of nanoparticles lies somewhere between individual atoms or molecules (the 'building blocks') and larger assemblies of bulk material which we are more familiar with.

Nanochemistry is the science of tools, technologies, and methodologies for novel chemical synthesis e.g. employing synthetic chemistry to make nanoscale building blocks of desired (prescribed) shape, size, composition and surface structure and possibly the potential to control the actual self-assembly of these building blocks to various desirable sizes. At this extremely small scale level, quantum effects can be significant, fascinating

and potentially scientifically very rewarding innovative ways of carrying out chemical reactions are possible.

History of Nanotechnology- Nanotechnology were first discussed in 1959 by renowned physicist Richard Feynman in his talk There's Plenty of Room at the Bottom, in which he described the possibility of synthesis via direct manipulation of atoms. The term "nano-technology" was first used by Norio Taniguchi in 1974, though it was not widely known.

Inspired by Feynman's concepts, K. Eric Drexler independently used the term "nanotechnology" in his 1986 book Engines of Creation: The Coming Era of Nanotechnology, which proposed the idea of a nanoscale "assembler" which would be able to build a copy of itself and of other items of arbitrary complexity with atomic control. Thus, emergence of nanotechnology as a field in the 1980s occurred through convergence of Drexler's theoretical and public work, which developed and popularized a conceptual framework for nanotechnology, and high-visibility experimental advances that drew additional wide-scale attention to the prospects of atomic control of matter.

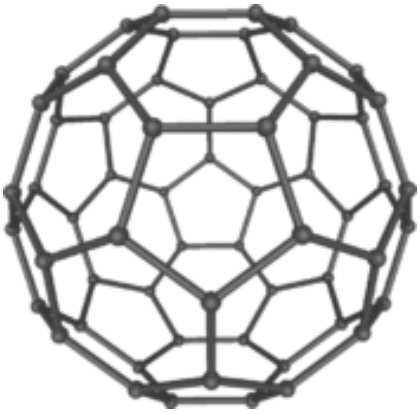

Figure 1: Buckminsterfullerene C_{60}

Buckminsterfullerene C_{60} also known as the buckyball, is a representative member of the carbon structures known as fullerenes. Members of the fullerene family are a major subject of research falling under the nanotechnology umbrella.

Fullerenes were discovered in 1985 by Harry Kroto, Richard Smalley, and Robert Curl, who together won the 1996 Nobel Prize in Chemistry. C_{60} was not initially described as nanotechnology; the term was used regarding subsequent work with related graphene tubes (called carbon nanotubes and sometimes called Bucky tubes) which suggested potential applications for nanoscale electronics and devices.

Governments moved to promote and fund research into nanotechnology, beginning in the U.S. with the National Nanotechnology Initiative, which formalized a size-based definition of nanotechnology and established funding for research on the nanoscale. By the mid-2000s new and serious scientific attention began to flourish. Projects emerged to produce nanotechnology roadmaps, which center on atomically precise manipulation of matter and discuss existing and projected capabilities, goals, and applications.

II. Techniques of Production or Methedology

1) "Bottom-up" Methodology - Bottom-up techniques build or grow larger structures atom by atom or molecule by molecule. These techniques include chemical synthesis, self-assembly and positional assembly. Dual polarisation interferometry is one tool suitable for characterisation of self assembled thin films. Another variation of the bottom-up approach is molecular beam epitaxy or MBE. Researchers at Bell Telephone Laboratories like John R. Arthur. Alfred Y. Cho, and Art C. Gossard developed and implemented MBE as a research tool in the late 1960s and 1970s. Samples made by MBE were key to the discovery of the fractional quantum Hall effect for which the 1998 Nobel Prize in Physics was awarded. MBE allows scientists to lay down atomically precise layers of atoms and, in the

process, build up complex structures. Important for research on semiconductors, MBE is also widely used to make samples and devices for the newly emerging field of spintronics.

2) "Top-down" Methodology - The top-down approach anticipates nanodevices that must be built piece by piece in stages, much as manufactured items are made. Scanning probe microscopy is an important technique both for characterization and synthesis of nanomaterials. Atomic force microscopes and scanning tunneling microscopes can be used to look at surfaces and to move atoms around. By designing different tips for these microscopes, they can be used for carving out structures on surfaces and to help guide self-assembling structures. By using, for example, feature-oriented scanning approach, atoms or molecules can be moved around on a surface with scanning probe microscopy techniques. At present, it is expensive and time-consuming for mass production but very suitable for laboratory experimentation.

3) Functional Methodology – In this methodology, the developed materials will have desired functionality without regard to how they are assembled like bottom-up or top-down approaches.

a) ***Molecular Electronics*** is a field in which the development of molecules with useful electronic properties are envisaged. These molecules could then be used as single molecule components in a nanoelectronic device like rotaxane. In this methedology, the developed materials have got specific functions to erform.

b) ***Synthetic Chemical Methods*** can be used to create synthetic molecular motors which are useful in nanocar-like devices.

4) Speculative Methedology- Ones in which futuristic way of expecting inventions in nanotechnology and the way in which the field of nanotechnology will progress in future and the proposals for the expansion of nanotechnology are drawn theoretically. These fields create a broader view of nanotechnology with more emphasis on its societal implications than the details of creations of such inventions actually in practice.

III. TOOLS AND TECHNIQUES

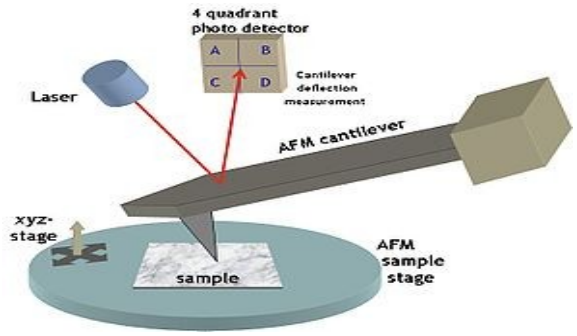

Figure 2: Typical AFM setup.

There are several important modern developments. The atomic force microscope (AFM) and the Scanning Tunneling Microscope (STM) are two early versions of scanning probes that launched nanotechnology. There are other types of scanning probe microscopy.

Various techniques of nanolithography such as optical lithography, X-ray lithography dip pen nanolithography, electron beam lithography or nanoimprint lithography were also developed. Lithography is a top-down fabrication technique where a bulk material is reduced in size to nanoscale pattern.

Another group of nanotechnological techniques include those used for fabrication of nanotubes and nanowires, those used in semiconductor fabrication such as deep ultraviolet lithography, electron beam lithography, focused ion beam machining, nanoimprint lithography, atomic layer

deposition, and molecular vapor deposition, and further including molecular self-assembly techniques such as those employing di-block copolymers.

Characterization- It is essential to establish the understanding and control of nanoparticle synthesis an dapplications. Characterization is done by variety of different techniques, which are from material science. Some are-

- Electron Microscopy (TEM, SEM)
- Atomic Force Microsocy (AFM)
- Dynamic Light Scattering (DLS)
- X-ray Photoelectron Spectroscopy (XPS)
- Powder X-ray Diffractometry (XRD)
- Fourier Transform Infrared Spectroscopy (FTIR)
- Matrix-Assisted Laser-Desorption Time-of-Light Mass Spectrometry (MALDI-TOF)
- Ultraviolet-Visible Spectroscopy.

Implications- An area of concern is the effect that industrial-scale manufacturing and use of nanomaterials would have on human health and the environment, as suggested by nanotoxicology research. Public health research agencies, such as the National Institute for Occupational Safety and Health are actively conducting research on potential health effects stemming from exposures to nanoparticles.

Public deliberations on risk perception in the US and UK carried out by the Center for Nanotechnology in Society found that participants were more positive about nanotechnologies for energy applications than for health applications, with health applications raising moral and ethical dilemmas such as cost and availability.

Health and Environmental Concerns- Nanofibers are used in several areas and in different products, in everything from aircraft wings to tennis rackets. Inhaling airborne nanoparticles and nanofibers may lead to a number of pulmonary diseases, e.g. fibrosis. Researchers have found that when rats breathed in nanoparticles, the particles settled in the brain and lungs, which led to significant increases in biomarkers for inflammation and stress response and that nanoparticles induce skin aging through oxidative stress in hairless mice.

A two-year study at UCLA's School of Public Health found lab mice consuming nano-titanium dioxide showed DNA and chromosome damage to a degree "linked to all the big killers of man, namely cancer, heart disease, neurological disease and aging".

A major study published more recently in Nature Nanotechnology suggests some forms of carbon nanotubes – a poster child for the "nanotechnology revolution" – could be as harmful as asbestos if inhaled in sufficient quantities. Anthony Seaton of the Institute of Occupational Medicine in Edinburgh, Scotland, who contributed to the article on carbon nanotubes said "We know that some of them probably have the potential to cause mesothelioma. So those sorts of materials need to be handled very carefully." In the absence of specific regulation forthcoming from governments, Paull and Lyons (2008) have called for an exclusion of engineered nanoparticles in food. A newspaper article reports that workers in a paint factory developed serious lung disease and nanoparticles were found in their lungs.

Regulation- The regulation of engineered nanoparticles requires a widely agreed definition of such particles. Nanoparticles are routinely defined as particles with sizes between about 1 and 100 nm that show properties that are not found in bulk samples of the same material. Calls for tighter regulation

of nanotechnology have occurred alongside a growing debate related to the human health and safety risks of nanotechnology.

Stakeholders concerned by the lack of a regulatory framework to assess and control risks associated with the release of nanoparticles and nanotubes have drawn parallels with bovine spongiform encephalopathy ("mad cow" disease), thalidomide, genetically modified food, nuclear energy, reproductive technologies, biotechnology, and asbestosis.

The Royal Society report identified a risk of nanoparticles or nanotubes being released during disposal, destruction and recycling, and recommended that "manufacturers of products that fall under extended producer responsibility regimes such as end-of-life regulations publish procedures outlining how these materials will be managed to minimize possible human and environmental exposure". Reflecting the challenges for ensuring responsible life cycle regulation, the Institute for Food and Agricultural Standards has proposed that standards for nanotechnology research and development should be integrated across consumer, worker and environmental standards. They also propose that NGOs and other citizen groups play a meaningful role in the development of these standards.

The Center for Nanotechnology in Society has found that people respond differently to nanotechnologies based upon application – with participants in public deliberations more positive about nanotechnologies for energy than health applications – suggesting that any public calls for nano regulations may differ by technology sector.

Nanotechnology Applications: The applications of nanochemistry have a wide range which covers-

1) Medicine-Researchers are developing customized nanoparticles the size of molecules that can deliver drugs directly to diseased cells in your body. When it's perfected, this method should greatly reduce the damage treatment such as chemotherapy does to a patient's healthy cells.

2) Electronics- Nanotechnology holds some answers for how we might increase the capabilities of electronics devices while we reduce their weight and power consumption.

3) Food- Nanotechnology is having an impact on several aspects of food science, from how food is grown to how it is packaged. Companies are developing nanomaterials that will make a difference not only in the taste of food, but also in food safety, and the health benefits that food delivers.

4) Fuel Cells- Nanotechnology is being used to reduce the cost of catalysts used in fuel cells to produce hydrogen ions from fuel such as methanol and to improve the efficiency of membranes used in fuel cells to separate hydrogen ions from other gases such as oxygen.

5) Solar Cells- Companies have developed nanotech solar cells that can be manufactured at significantly lower cost than conventional solar cells.

6) Batteries- Companies are currently developing batteries using nanomaterials. One such battery will be a good as new after sitting on the shelf for decades. Another battery can be recharged significantly faster than conventional batteries.

7) Space- Nanotechnology may hold the key to making space-flight more practical. Advancements in nanomaterials make lightweight spacecraft and a cable for the space elevator possible. By significantly reducing the amount of rocket fuel required, these advances could lower the cost of reaching orbit and traveling in space.

8) Fuels- Nanotechnology can address the shortage of fossil fuels such as diesel and gasoline by making the production of fuels from low grade raw materials economical, increasing the mileage of engines, and making the production of fuels from normal raw materials more efficient.

9) Better Air Quality- Nanotechnology can improve the performance of catalysts used to transform vapors escaping from cars or industrial plants into harmless gasses. That's because catalysts made from nanoparticles have a greater surface area to interact with the reacting chemicals than catalysts made from larger particles. The larger surface area allows more chemicals to interact with the catalyst simultaneously, which makes the catalyst more effective.

10) Cleaner Water- For the removal of industrial wastes, such as a cleaning solvent called TCE, from groundwater. Nanoparticles can be used to convert the contaminating chemical through a chemical reaction to make it harmless. Studies have shown that this method can be used successfully to reach contaminates dispersed in underground ponds and at much lower cost than methods which require pumping the water out of the ground for treatment.

11) Chemical Sensors- Nanotechnology can enable sensors to detect very small amounts of chemical vapors. Various types of detecting elements, such as carbon nanotubes, zinc oxide nanowires or palladium nanoparticles can be used in nanotechnology-based sensors. Because of the small size of nanotubes, nanowires, or nanoparticles, a few gas molecules are sufficient to change the electrical properties of the sensing elements. This allows the detection of a very low concentration of chemical vapors.

12) Sporting Goods- Current nanotechnology applications in the sports arena include the manufacture of tennis balls.

13) Fabric- For the making of composite fabric with nano-sized particles or fibers allows improvement of fabric properties without a significant increase in weight, thickness, or stiffness. This might have been the case with previously-used techniques.

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