

From the Editor's Desk**Super-Molecules: An Emerging Chemistry in Recent Science**

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Available online at: www.isca.in

Nature has played and continues to play a major role in the development of and progress in organic chemistry. All life processes are essentially achieved by arrays of molecules working together in synchronisation rather than by discrete molecules acting in isolation. In order to duplicate the diversity and complexity of the life processes, there is a need to understand the factors that control aggregation of molecules into assemblies performing specific functions. Thus, the quest for replicating even remotely similar systems to that of Nature led to the development of a totally new branch of chemistry called *Supramolecular Chemistry*, defined as 'the chemistry concerning the structures and functions of *Super-molecules* formed by association resulting from the molecular interactions between two or more molecules / chemical species, i.e., *chemistry beyond the concept of molecule*. This branch of chemistry, though nominally organic chemistry with respect to the species involved, has revolutionised the concept of synthesis, for it is no longer concerned with forming covalent bonds to create molecules alone, but also in harnessing non-covalent forces to create super-molecules.

Conceptually, supramolecular chemistry can be broadly classified into host-guest chemistry and self-assembly. The former involves species combining with one another in small integer ratios, comprising a host that specifically accommodates a guest, thus leading to molecular recognition. The latter describes the building up of non-covalent arrays of defined geometry from specifically engineered molecular components. Supramolecular chemistry' is, therefore, the chemistry of non-covalently bound species and non-covalent interactions play an important role in self-assembly and stabilisation of super-molecules. The forces encountered in supramolecular chemistry are electrostatic interactions, van der Waals interactions, hydrogen bonding and charge transfer interactions. Ever since the report of the discovery of the first synthetic ionophores by C. J. Pedersen in 1967, and more so since the awarding of the

Nobel prize to C. J. Pedersen, D. J. Cram and J.-M. Lehn, the pioneers of this field, there has been an impetus to synthesise more and more novel structures with fascinating micro and macroscopic architectures endowed with novel functions. Two decades later, supramolecular chemistry is an important, interdisciplinary branch of science encompassing ideas of physical and biological processes. The roots of this interdisciplinary science lie in more than one field.

Supramolecular chemistry is characterized by the specificity and selectivity of its reactions. The term used to describe this is molecular recognition, as if the reactions will only happen if the molecule recognizes each other. Therefore, a supramolecular interaction can only happen when the host and guest complement each other. (e.g. hydrogen bond donor/acceptor, Lewis acids/base, hardness or softness etc.) An analogy to the mechanism is the lock and key scenario coined by Emil Fischer in 1894. The host molecule serves as the lock and the guest molecule serves as the key. Only when the key matches the lock will the lock open (figure 1).

Molecular recognition at the supramolecular level is mediated by complementarily – even for like molecules it is the dissimilar portions of functional groups that interact with one another. An electropositive hydrogen bond donor approaches an electronegative acceptor ($D^{\delta-} \cdots H^{\delta+} \cdots A^{\delta-}$), cation \cdots anion electrostatic interaction in salts and metal complexes (M^+X^-), and bumps in one part of the molecule fit into hollows of another portion (hydrophobic interactions), and so on. Even as the fundamental recognition processes that guide supramolecular aggregation are governed by the same principles and forces, the chemical systems studied are broadly classified into two major categories (figure 1): molecular recognition in solution is generally referred to as supramolecular chemistry, and organized self-assembly in the solid state as crystal engineering.

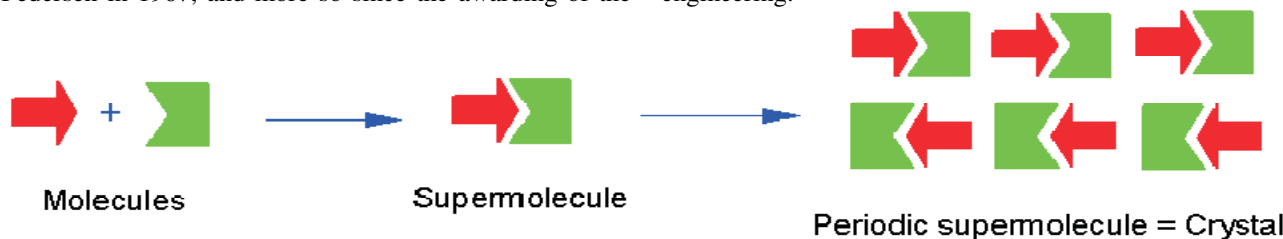


Figure-1

Molecular recognition of molecules to give super-molecule and periodic arrangement of super-molecules in a crystal lattice

Supramolecular chemistry is a highly interdisciplinary field of science covering the *chemical, physical, and biological features* of the chemical species of greater complexity than molecules themselves, which are held together and organized by means of intermolecular (non-covalent) binding interactions. This relatively young area has been defined, conceptualized, and structured into a coherent system. Its roots extend into organic chemistry and the synthetic procedures for molecular construction, into coordination chemistry and metal ion-ligand complexes, into physical chemistry and the experimental and theoretical studies of interactions, into biochemistry and the biological processes that all start with substrate binding and recognition, into materials science and the mechanical properties of solids. A major feature is the range of perspectives offered by the cross-fertilization of supramolecular chemical research due to its location at the intersection of *chemistry, biology, and physics*. Drawing on the physics of organized condensed matter and expanding over the biology of large molecular assemblies, supramolecular chemistry expands into a *supramolecular science*. Such wide horizons are a challenge and a stimulus to the creative imagination of the world scientists. Thus, supramolecular chemistry has been rapidly expanding at the interfaces of *chemical science* with *physical and biological phenomena*. Supramolecules can be classified by their generation on the time scale. Cyclodextrins and crown-ethers are the first and second generation supramolecules respectively. Calixarenes are a class of cyclo-oligomers formed by condensation between phenol and aldehyde and are classified as third generation supramolecules (figure 2).

Calixarenes, a class of cyclic phenolic compounds, are called so due to their shape and structure. The term calixarene was given by C. D. Gutsche in 1978. The name "calixarene" is derived from Greek word, *calix* meaning *vase or cone shaped* conformation. Two different zones can be distinguished in calixarenes, *viz.* the region of phenolic hydroxy groups and the *para*-position of the phenols, which are called the 'lower rim' and the 'upper rim' of the calixarene respectively (figure 3).

The major factor that has contributed for the proliferation of these research papers is the tailor-made structure of calixarenes for its use as complexing agents, for it is this possibility and its potential that has brought for calixarenes this recognition that they enjoy today. The use of these modified calixarenes as sensors for metal ion, organic/neutral molecules, and drugs recognition has brought calixarenes to limelight. They have become a wonder molecule at the hands of a chemist. This wonder molecule has its roots in host-guest chemistry.

Compared to all the supramolecular hosts mentioned above, cyclodextrins (CDs) are most important. Because of their inclusion complex forming capability, the properties of the materials with which they complex can be modified significantly. As a result of molecular complexation phenomena CDs are widely used in many industrial products, technologies and analytical methods. The negligible cyto-toxic effects of CDs are an important attribute in applications such as rug carrier,

food and flavours, cosmetics, packing, textiles, separation processes, environment protection, fermentation and catalysis.

Potential Applications of Supramolecules: This area, like cave art, has its origins in aesthetics. But very little separates the beautiful from the practical: if you can draw a deer, you can also draw a map *to* the deer! Here are some potential applications of these beautiful structures. Recognition, Catalysis, Molecular Traps, Synthetic antigens, Liquid-liquid extraction, Solid-phase extraction, an important new host molecule with interesting anion binding properties, new porous organic cages that act as building blocks for the construction of novel coordination polymers, and related triply-interlocked cages formed by dynamic covalent chemistry etc. are applications of super-molecules.

In Materials technology: Supramolecular chemistry and molecular self-assembly processes in particular have been applied to the development of new materials. Large structures can be readily accessed using bottom-up synthesis as they are composed of small molecules requiring fewer steps to synthesize. Thus most of the bottom-up approaches to nanotechnology are based on supramolecular chemistry.

As a Catalysis: A major application of supramolecular chemistry is the design and understanding of catalysts and catalysis. Non-covalent interactions are extremely important in catalysis, binding reactants into conformations suitable for reaction and lowering the transition state energy of reaction. Template-directed synthesis is a special case of supramolecular catalysis. Encapsulation systems such as micelles and dendrimers are also used in catalysis to create microenvironments suitable for reactions (or steps in reactions) to progress that is not possible to use on a macroscopic scale.

In Pharmaceutical Science: Supramolecular chemistry is also important to the development of new pharmaceutical therapies by understanding the interactions at a drug binding site. The area of drug delivery has also made critical advances as a result of supramolecular chemistry providing encapsulation and targeted release mechanisms. In addition, supramolecular systems have been designed to disrupt protein-protein interactions that are important to cellular function.

The fullerene family, and especially C60, has appealing photo, electrochemical and physical properties, which can be exploited in various medical fields. Fullerene is able to fit inside the hydrophobic cavity of HIV proteases, inhibiting the access of substrates to the catalytic site of enzyme. It can be used as radical scavenger and antioxidant. At the same time, if exposed to light, fullerene can produce singlet oxygen in high quantum yields. This action, together with direct electron transfer from excited state of fullerene and DNA bases, can be used to cleave DNA. In addition, fullerenes have been used as a carrier for gene and drug delivery systems. Also they are used for serum protein profiling as MELDI material for biomarker discovery.

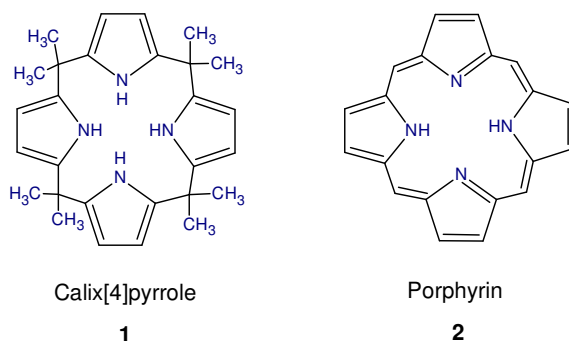
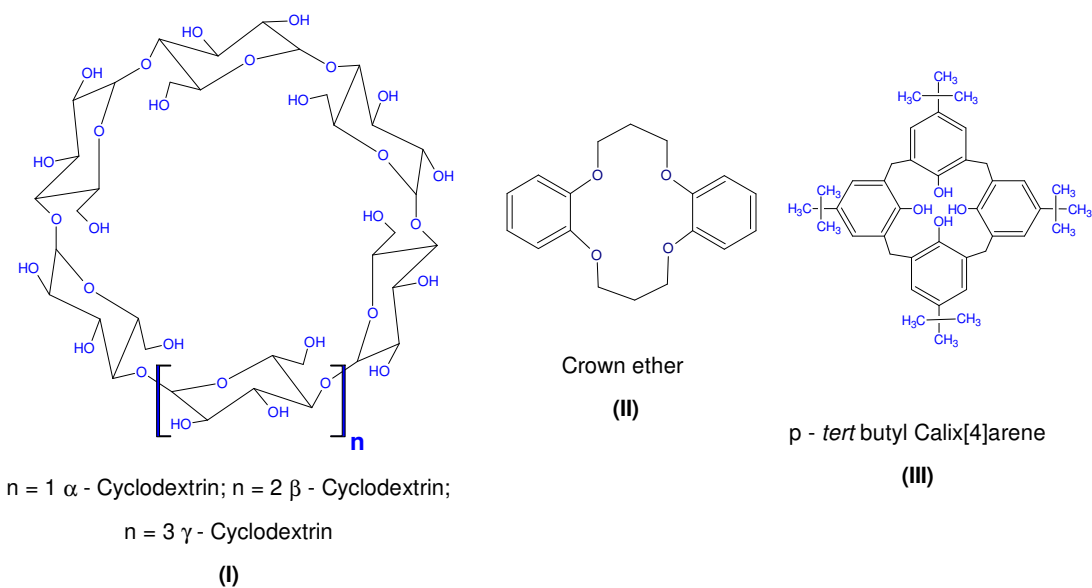


Figure-2
 Structure of Super-molecules [cyclodextrin (I), crown ether (II), calix[4]arene (III), calix[4]pyrrole (1) and porphyrin (2)]



Figure-3
 Different zones of calix[4]arene and Calix crater

In Data storage and processing: Supramolecular chemistry has been used to demonstrate computation functions on a molecular scale. In many cases, photonic or chemical signals have been used in these components, but electrical interfacing of these units has also been shown by supramolecular signal transduction devices. Data storage has been accomplished by the use of molecular switches with photochromic and photoisomerizable units, by electrochromic and redox-switchable units, and even by molecular motion. Synthetic molecular logic gates have been demonstrated on a conceptual level. Even full-scale computations have been achieved by semi-synthetic DNA computers.

In Green chemistry: Research in supramolecular chemistry also has application in green chemistry where reactions have been developed which proceeds in the solid state directed by non-covalent bonding. Such procedures are highly desirable since they reduce the need for solvents during the production of chemicals.

In Nanotechnology: The versatility of combining supramolecular nanoparticle assembly and top-down fabrication techniques in creating 2D and 3D nanoparticle architectures. Stable and ordered supramolecular nanoparticle structures with well-defined geometries and sizes open up new routes for applications in sensing and photonic devices.

In other devices and functions: Supramolecular chemistry is often pursued to develop new functions that cannot appear from a single molecule. These functions also include magnetic properties, light responsiveness, self-healing polymers, synthetic ion channels, molecular sensors, etc. Supramolecular research has been applied to develop high-tech sensors, processes to treat radioactive waste, and contrast agents for CAT scans.

There have been numerous patent applications filed using super-molecule architectures in fields ranging from adhesives, printing, cosmetics, personal care, to coatings, decontamination of wastewater, construction of electrodes, and membranes for transportation.

This broad field of research will continue to expand rapidly due to both the application of discoveries, and the crystallisation of new research ideas. This will ensure that supramolecular chemistry remains one of the most exciting, promising and multi-disciplinary fields of research in Science.

Supramolecular fields is one of the most vigorous and fast-growing chemistry in Science. Host-guests chemistry being the cornerstone of supramolecular chemistry has evoked interests from physicists, environmentalist, and microbiologist to biotechnologists. The behavior of hosts and their complexes with guests has fuelled a growing eagerness in the area to the extent that it is now a well-recognized field in scientific disciplines.