2016 Nobel Prize in Chemistry – They Developed The World's Smallest Machines!

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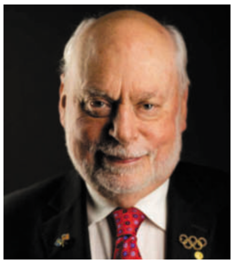
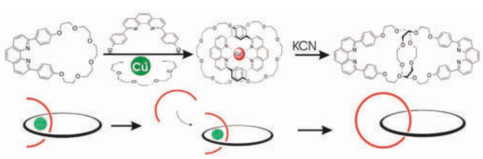
Jean-Pierre Sauvage


J. Fraser Stoddart


Bernard L. Feringa

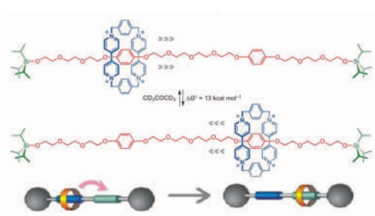
Machines are an integral part of development, helping us to perform tasks that often fall beyond human capacities. The limit of this endeavour is to make molecular-sized machines, that are a thousand times thinner than a hair strand. Rightly, the contributions in this area bagged the Nobel Prize in Chemistry -2016 and is awarded jointly to *Jean-Pierre Sauvage* (France), *Sir J. Fraser Stoddart* (USA) and *Bernard L. Feringa* (Netherlands) ***for the design and synthesis of molecular machines***. Their work has formed the basis for an entirely new field of research that successfully demonstrated that rational design and synthesis of molecular machines are indeed possible and here is how they succeeded in linking molecules together to design everything from a tiny lift to motors and minuscule muscles, nanocars etc.

The first step towards a molecular machine was taken by Jean-Pierre Sauvage in 1983, when his group succeeded in linking two ring-shaped molecules together, called a catenane (**I**). Sauvage was able to show how such interlocked rings can

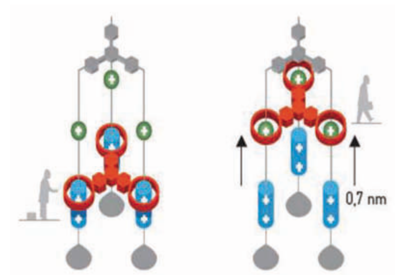


(I) Synthesis of [2]catenane using metal coordination

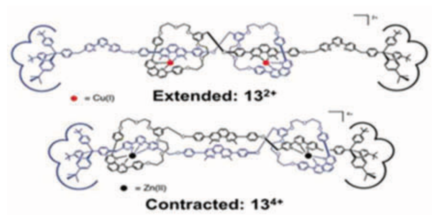
undergo controlled motion with an external stimulus. The contribution from Fraser Stoddart became notable in 1991, when he developed a rotaxanes (**II**). He designed molecules that are attracted to each other. His research group built an open ring that lacked electrons, and a long rod, (or axle), that had electron-rich structures in two places (**II**). When the two molecules met in a solution, electron-poor was attracted to


(II) *Ring on axle*

electron-rich, and the ring threaded onto the axle, mimicking piston like movement. Later on Stoddart's group used various such rotaxanes to construct numerous molecular machines, including a lift, which can raise itself 0.7 nanometres above a surface (**III**), and an artificial muscle (**IV**), where rotaxanes bend a thin gold lamina.

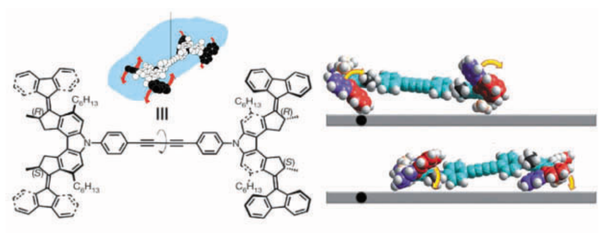


(III) Molecular Lift



(IV) Movement like 'muscle'

Propelling single molecules in a controlled manner along an unmodified surface remains extremely challenging as it requires molecules that can use light, chemical or electrical energy to modulate their interaction with the surface in a way that generates motion. Bernard Feringa utilized isomerisable bonds and molecular asymmetry concepts and succeeded in demonstrating directional motion of a four-wheeled molecule on a metal surface, simulating a four-wheel drive "nanocar" (**V**).


(V) Movement in a nanocar

An important point in the Nobel Prize in Chemistry-2016 is that researchers have driven molecular systems away from the equilibrium to get the work done. Just like the molecules of life (*proteins, carbohydrates, lipids and nucleic acids*), Sauvage's, Stoddart's and Feringa's artificial molecular systems perform a controlled task. The challenge; these molecular machines will have to be organized into large assemblies and connected to the macroscopic world to realize functional devices operating at visible dimensions.