KUNGL. VETENSKAPS-AKADEMIEN
THE ROYAL SWEDISH ACADEMY OF SCIENCES

The Royal Swedish Academy of Sciences has decided to award the Nobel Prize in Chemistry 2016 to **Jean-Pierre Sauvage, Sir J. Fraser Stoddart** and **Bernard L. Feringa** "for the design and synthesis of molecular machines".

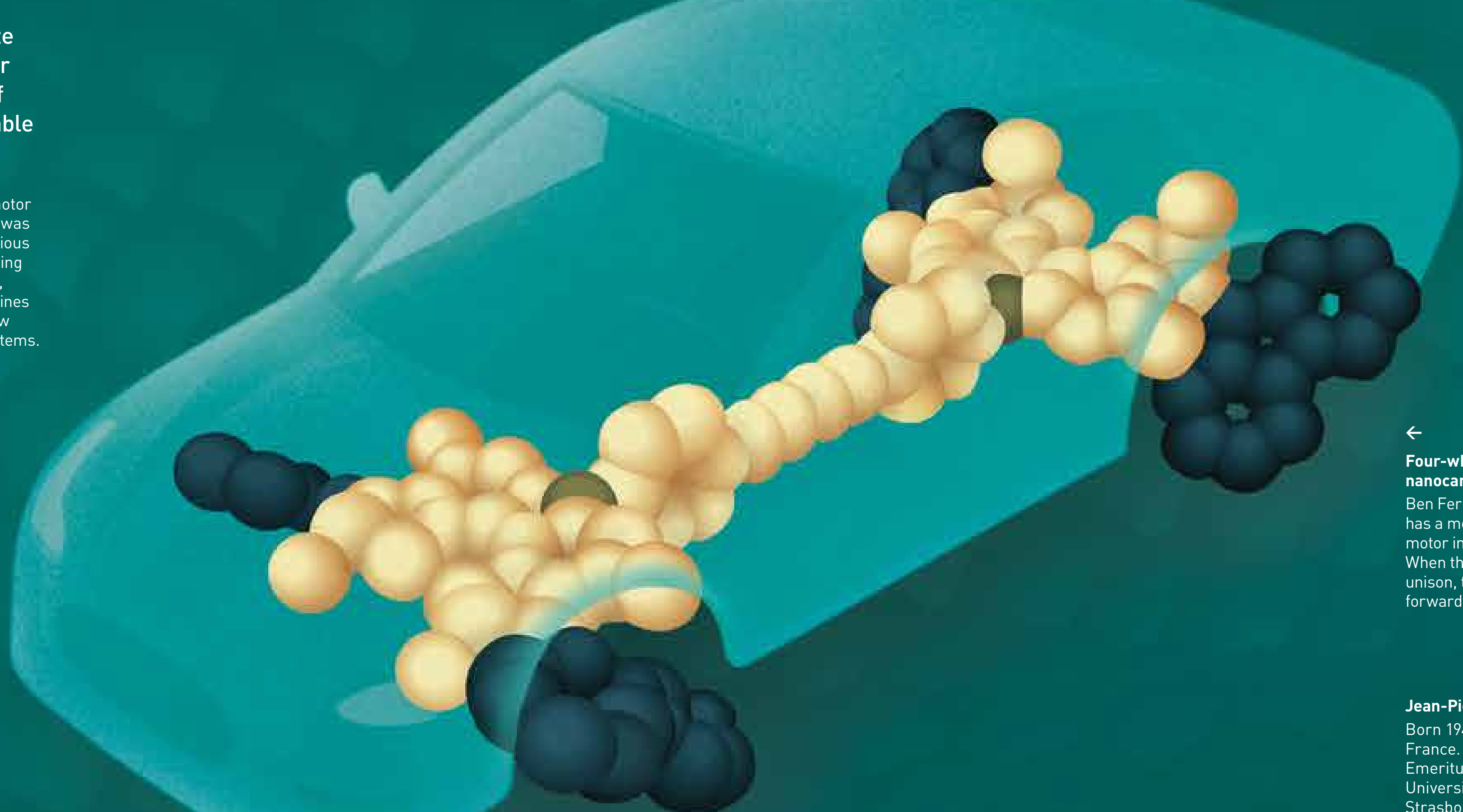
The Nobel Prize 2016 **in Chemistry**

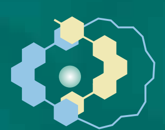
They built the world's smallest machines

A tiny lift, artificial muscles and minuscule motors. The Nobel Prize in Chemistry 2016 is awarded to Jean-Pierre Sauvage, Sir J. Fraser Stoddart and Bernard L. Feringa for their design and production of molecular machines. They have developed molecules with controllable movements, which can perform a task when energy is added.

The development of computers demonstrate how the miniaturisation of technology can lead to a revolution. The 2016 Nobel Laureates in Chemistry have developed machines that are thousand times thinner than a strand of hair. Normally, all movements in chemical systems are governed by chance. In the molecular machines that are now being rewarded, movement is ordered and has a direction, which is necessary for them to be able to perform a task.

In terms of development, the molecular motor is at the same stage as the electric motor was in the 1830s. Scientists then displayed various spinning cranks and wheels without knowing that they would lead to washing machines, fans and food processors. Molecular machines will probably be used in things such as new materials, sensors and energy storage systems.

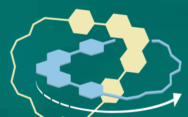




1. Molecules that will form a chain gather around a copper ion.

2. A third molecule is linked to the crescent-shaped molecule.

3. The molecules are linked by a mechanical bond. The copper ion is removed.



4. One molecule can be made to move in a controlled manner around the other.

↑

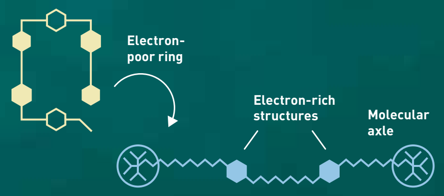
Sauvage moves chemistry away from chance

In order for a machine to perform a task, it must consist of parts that can move in relation to each other. Jean-Pierre Sauvage produced a molecule that fulfilled this requirement in 1983, when he linked two ring-shaped molecules together to make a chain, called a *catenane*. Thanks to the chain's mechanical bond, the rings are free to move. In 1994, Sauvage succeeded in making one ring rotate around the other in a controlled manner.

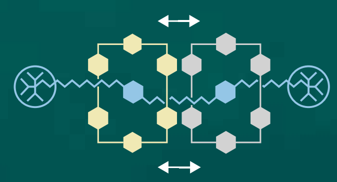
→

Stoddart develops a molecular lift

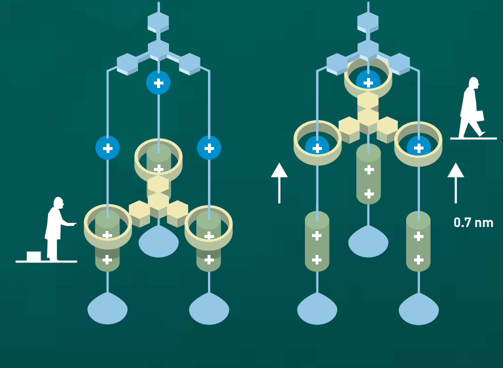
In 1991, Fraser Stoddart threaded a molecular ring onto a thin molecular axle and, in 1994, he was able to control the ring's movement along the axle. He has used similar molecules, called *rotaxanes*, to develop a molecular lift, a molecular muscle and a molecule-based computer chip.



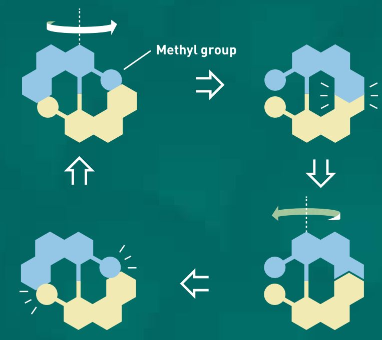
1. A ring threads onto a molecular axle and closes around it.



2. The ring stays on the axle. When heat is added, the ring jumps between the two electron-rich areas of the axle.



3. Stoddart's molecular lift is made from three linked rotaxanes. It can raise itself 0.7 nanometres.



1. UV light makes one rotor blade spin 180 degrees.

2. This creates tension in the molecule.

3. The tension is released when one rotor blade snaps over the other. Backward rotation is prevented. UV light leads to a new rotation.

4. The temperature is raised. The methyl groups snap over the rotor blades. Backward rotation is prevented.

←

Four-wheel drive nanocar

Ben Feringa's nanocar has a molecular motor in each corner. When they rotate in unison, the car moves forward.

↑

Feringa develops the first molecular motor

In 1999, Ben Feringa succeeded in making a molecular rotor blade spin in one and the same direction. He has optimised the motor so it can spin at 12 million revs per second. Using molecular motors, he has designed a nanocar and rotated a glass cylinder that is 10,000 times bigger than the actual motor, among other things.

Jean-Pierre Sauvage
Born 1944 in Paris, France. Professor Emeritus at the University of Strasbourg and Director of Research Emeritus at the National Center for Scientific Research (CNRS), France.

Sir J. Fraser Stoddart
Born 1942 in Edinburgh, UK. Board of Trustees Professor of Chemistry at Northwestern University, Evanston, IL, USA.

Bernard L. Feringa
Born 1951 in Barger-Compascuum, the Netherlands. Professor in Organic Chemistry at the University of Groningen, the Netherlands.

FURTHER READING More information on the Nobel Prize in Chemistry 2016: *http://kva.se/nobelchemistry2016* and *http://nobelprize.org* **ARTICLES:** ● **Capecelatro, A. N.** (2007). From Auld Reekie to the City of Angels, and all the Meccano in between: A Glimpse into the Life and Mind of Sir Fraser Stoddart. *The UCLA USJ., 20*, 1–7. ● **Stoddart, J. F.** (2009). The Master of Chemical Topology. *Chem. Soc. Rev., 38*, 1521–1529. ● **Weber, L.,** & **Feringa, B. L.** (2009). We Must be Able to Show How Science is Beneficial to Society. *Chimia, 63*(6), 352–356. ● **Feringa, B. L.** (2011). Ben L. Feringa. *Angew. Chem. Int. Ed., 50*, 1470–1472. ● **Peplow, M.** (2015). The Tiniest Lego: a tale of nanoscale motors, rotors, switches and pumps. *Nature, 525*, 18–21. **VIDEOS:** ● **NorthwesternU** (2008, May 28). *Nanotechnology Town Hall Meeting – Sir J. Fraser Stoddart. https://www.youtube.com/watch?v=oOVXeRHnTAg* ● **Francis Villatoro** (2011, Nov. 9). *A four-wheeled molecule moving on a metal surface. https://www.youtube.com/watch?v=I5JgJsjq3Q4* ● **Elsevier Journals** (2016, Sept. 7). *Tetrahedon Prize 2016. https://www.youtube.com/watch?v=F-HNDwZrISA* ● **International Institute for Nanotechnology at Northwestern University** (2016, Oct. 10). *Nobel Laureate, Sir Fraser Stoddart, Speaking at 2016 IIN Symposium. www.youtube.com/watch?v=jHVjFNYu6_Y*

Editors: Gunnar von Heijne, Olof Ramström and Sara Snogerup Linse, The Nobel Committee for Chemistry, The Royal Swedish Academy of Sciences; Ann Fernholm, Science Writer; Clare Barnes, Translator; Carl-Victor Heinold, Editor, and Annika Dahlqvist, Nobel Assistant, The Royal Swedish Academy of Sciences. **Graphic design:** Ritator **Illustrations:** Johan Jarnestad/Infographics.se **Print:** Åtta45

Printing and distribution made possible by VOLVO