The Art of Building Small

from molecular switches to motors

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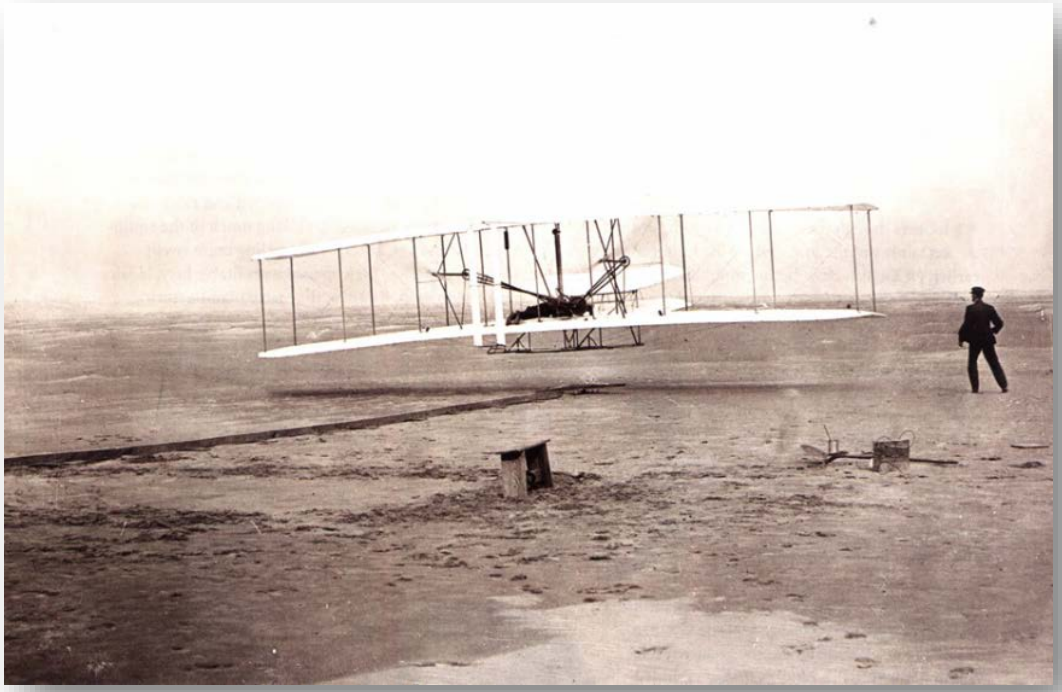
university of groningen

Stockholm

december 8th, 2016

Bioinspired Motion

the early days



17th of December 1903 at Kitty Hawk

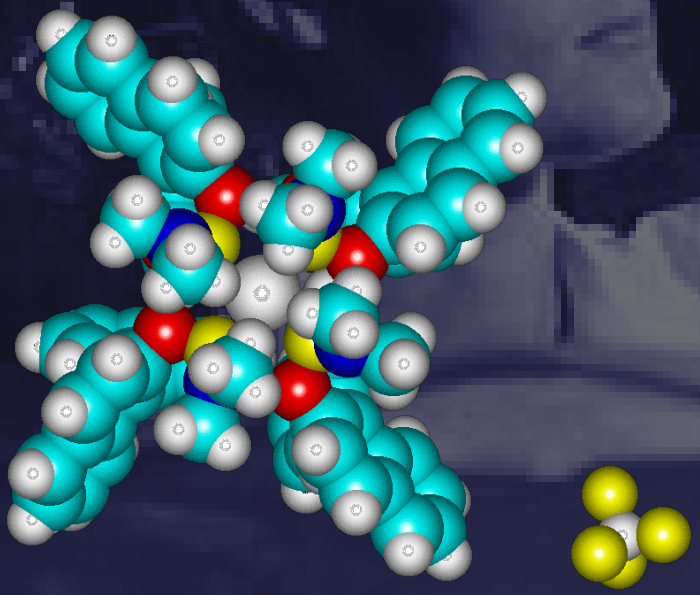
fascinated by…

…but no copy or mimic!

heading for…..?

The Art of Building Small

Chemical Synthesis

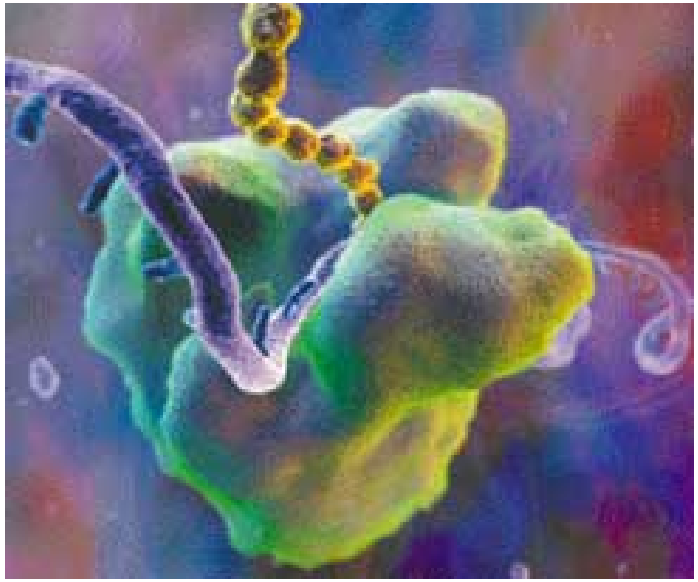


Nano

Macro

Natural Robot

Artifical Robot



± 24 nm =
0.000000024 m

± 2 m

effect of length scales

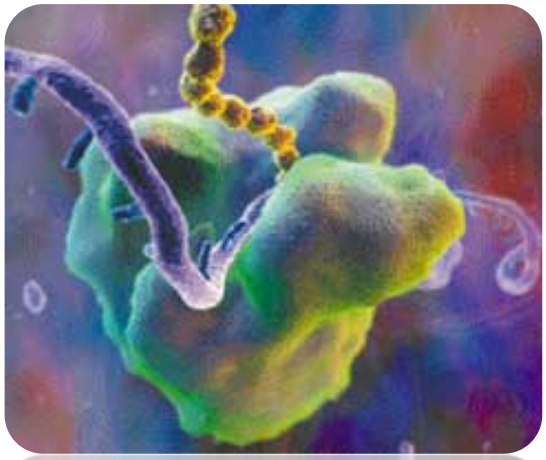
soft

hard

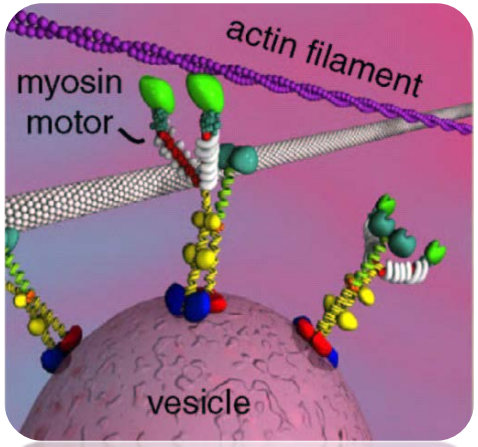
Low Reynolds number
Brownian motion

Biomolecular Machines

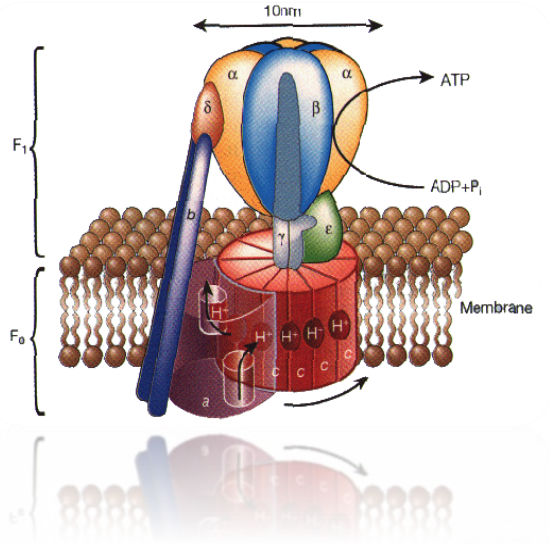
Ribosome
protein synthesis



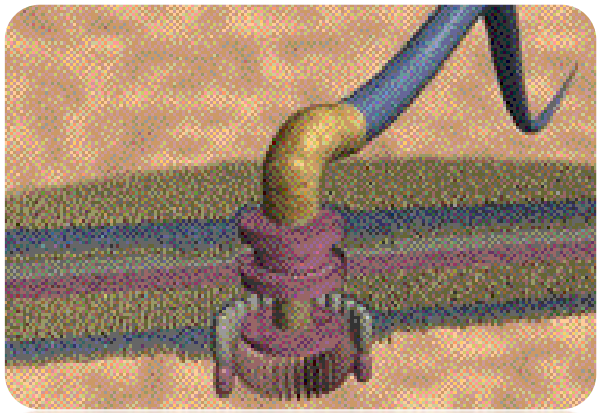
Bio-Nanomotors
transport – muscle function



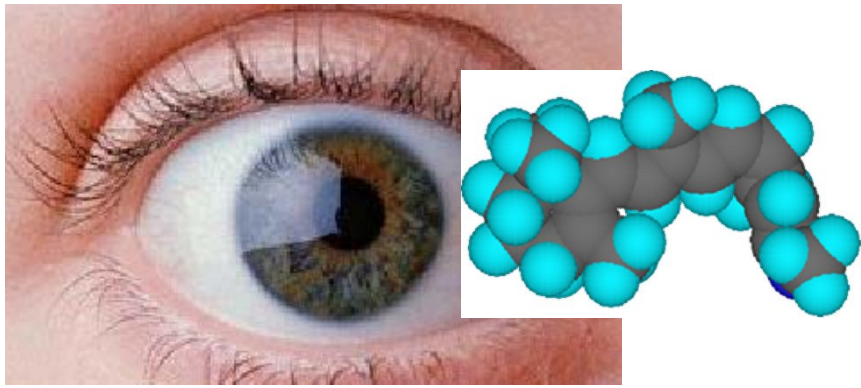
Rotary Motor
transport-catalysis



Bacterial Flagellar Motor
propulsion



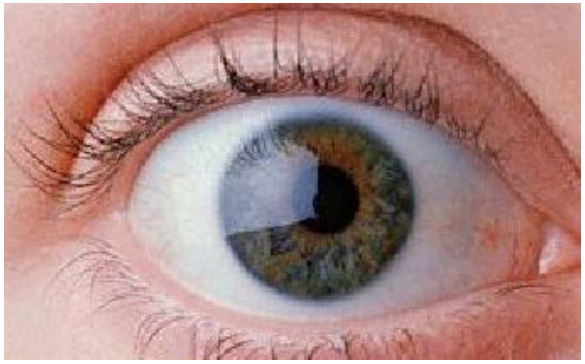
Optical Switching
Information

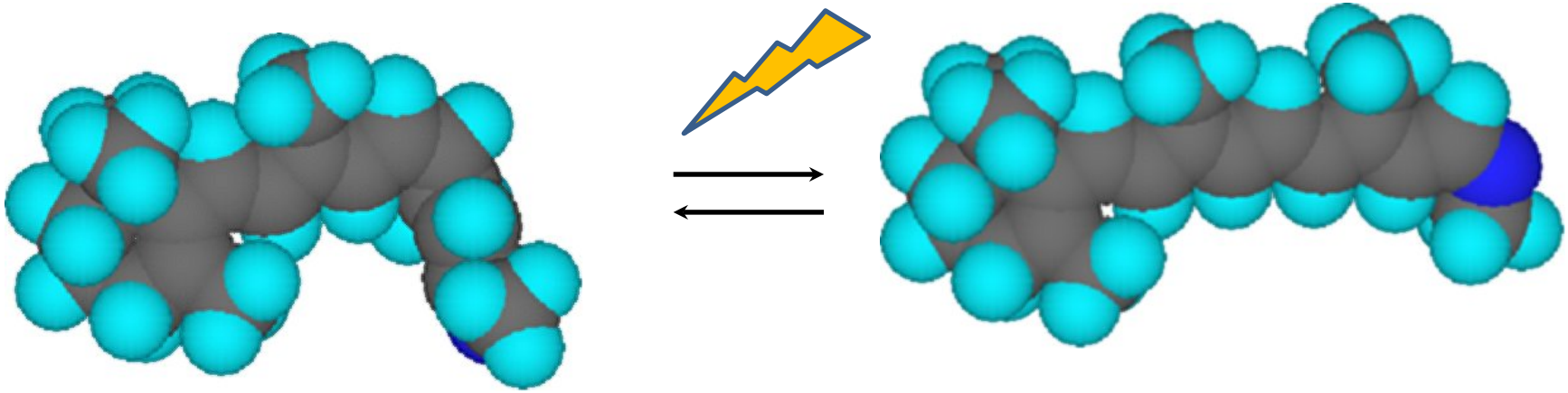


Molecular Nanoscience

molecular light switch

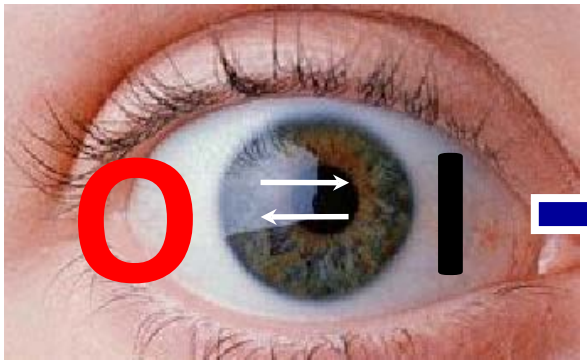
0 ⇌ 1

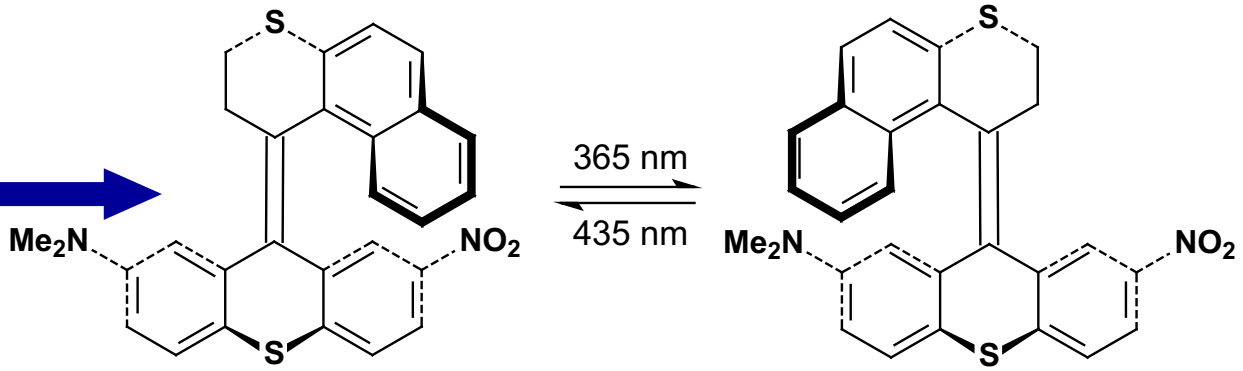




Optical Molecular Switch

Binary System at the Molecular Level



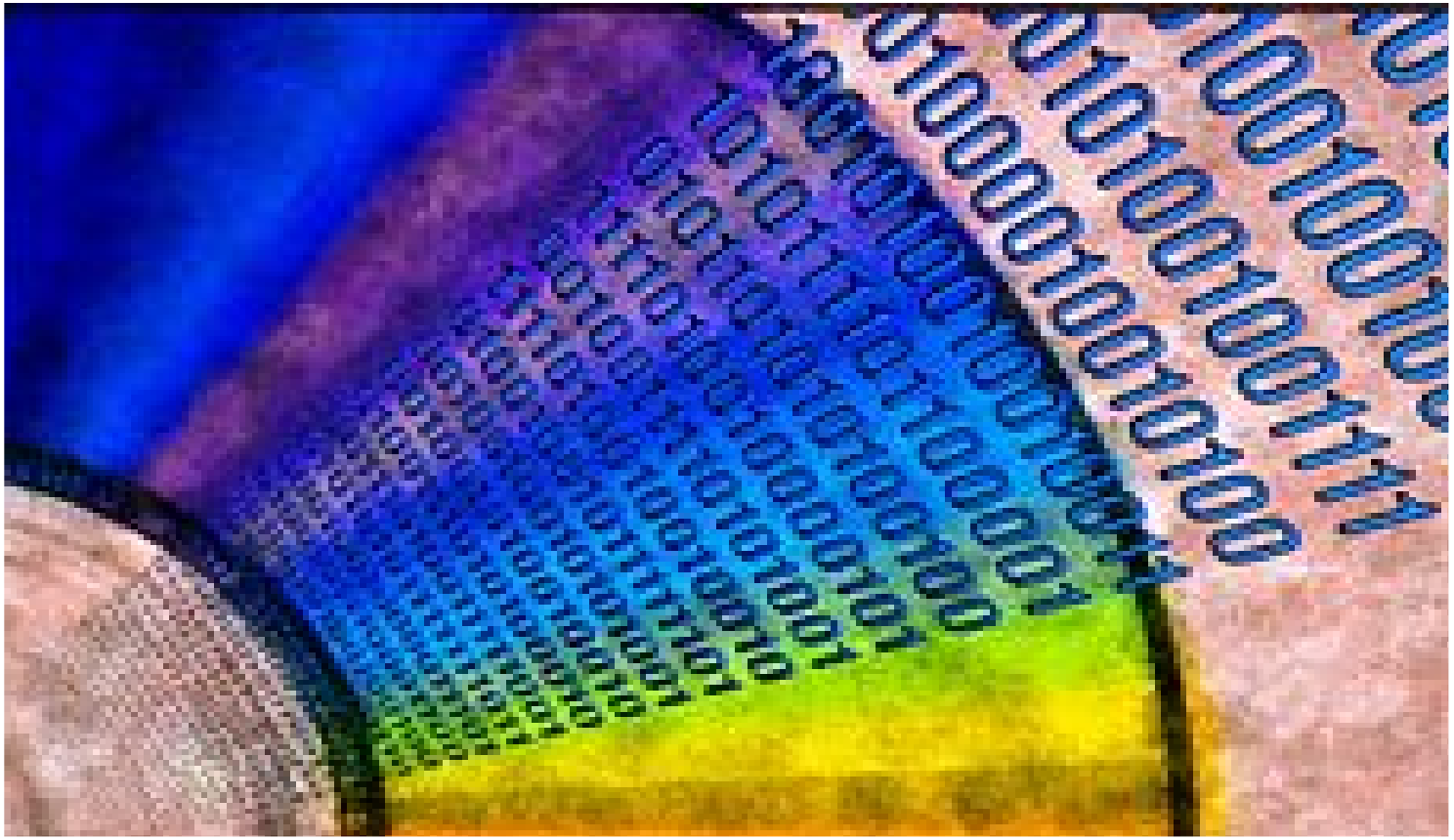


Information Storage

Non-destructive read-out

Left (0) **Right (1)**

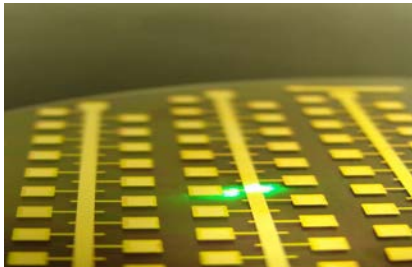
Potential of Molecular Nanotechnology



Storage capacity of one CD:

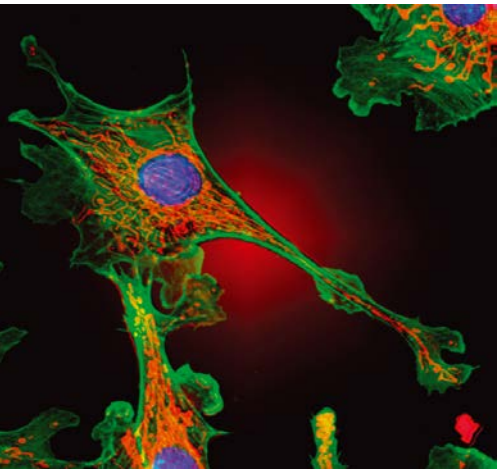
1.125.000.000 MB = > 240 years of music

Molecular Electronics



Challenges

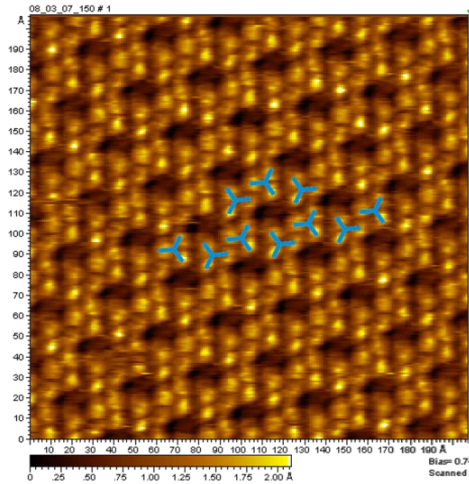
from Molecules to Dynamic Molecular Systems out of Equilibrium



Cell

Self-assembly ?
Trigger & Response ?
Motion ?

Responsive Materials

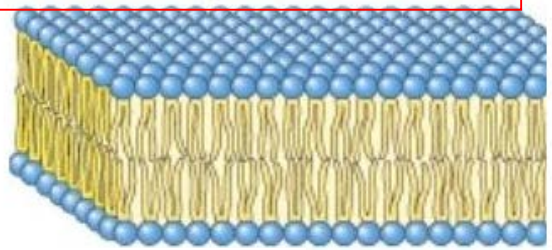


Smart Drugs

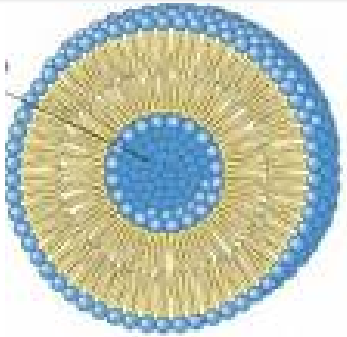
Soft Robotics

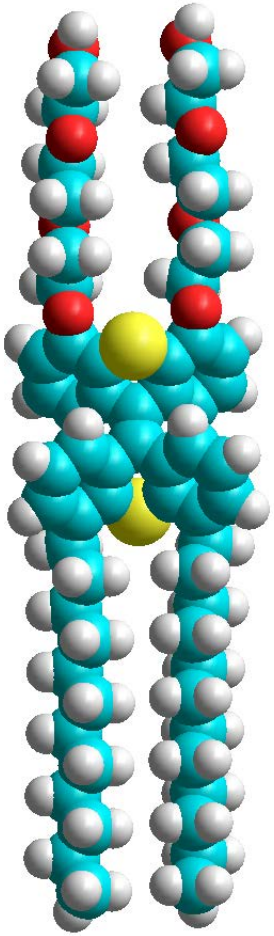
MEMBRANE

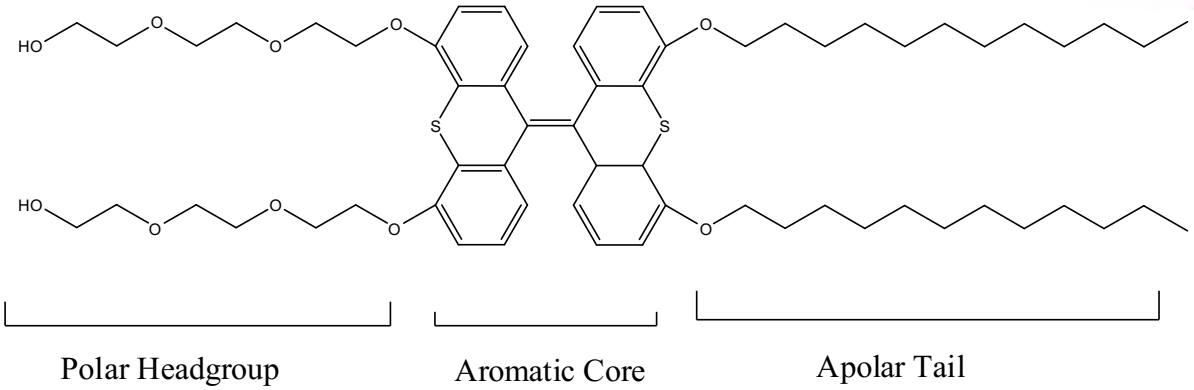
Self-Assembly

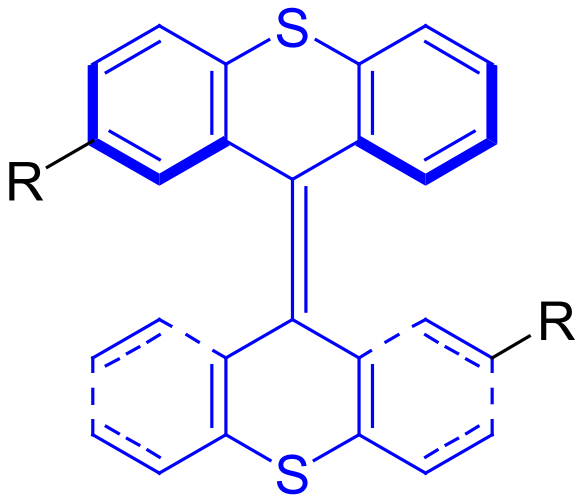


amphiphile





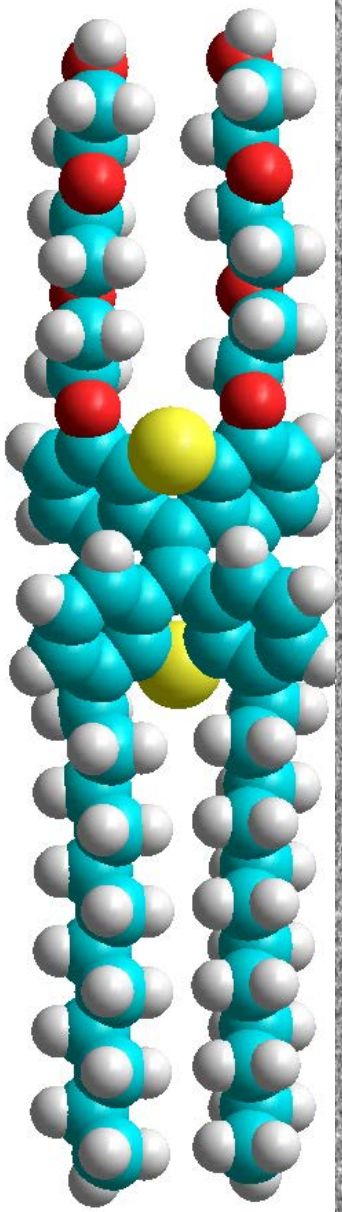


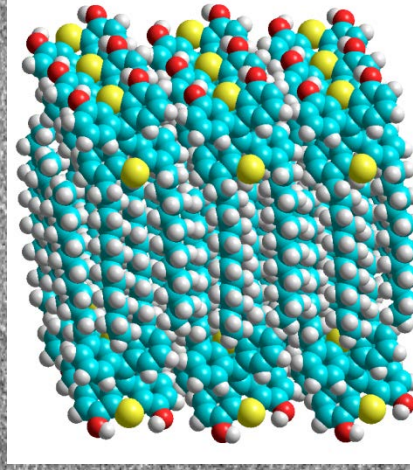


Molecular switch

photo- and electro-chemical switching

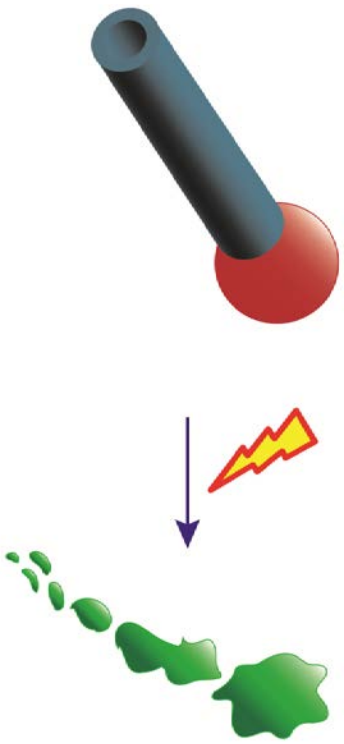
Nanotube by self-assembly

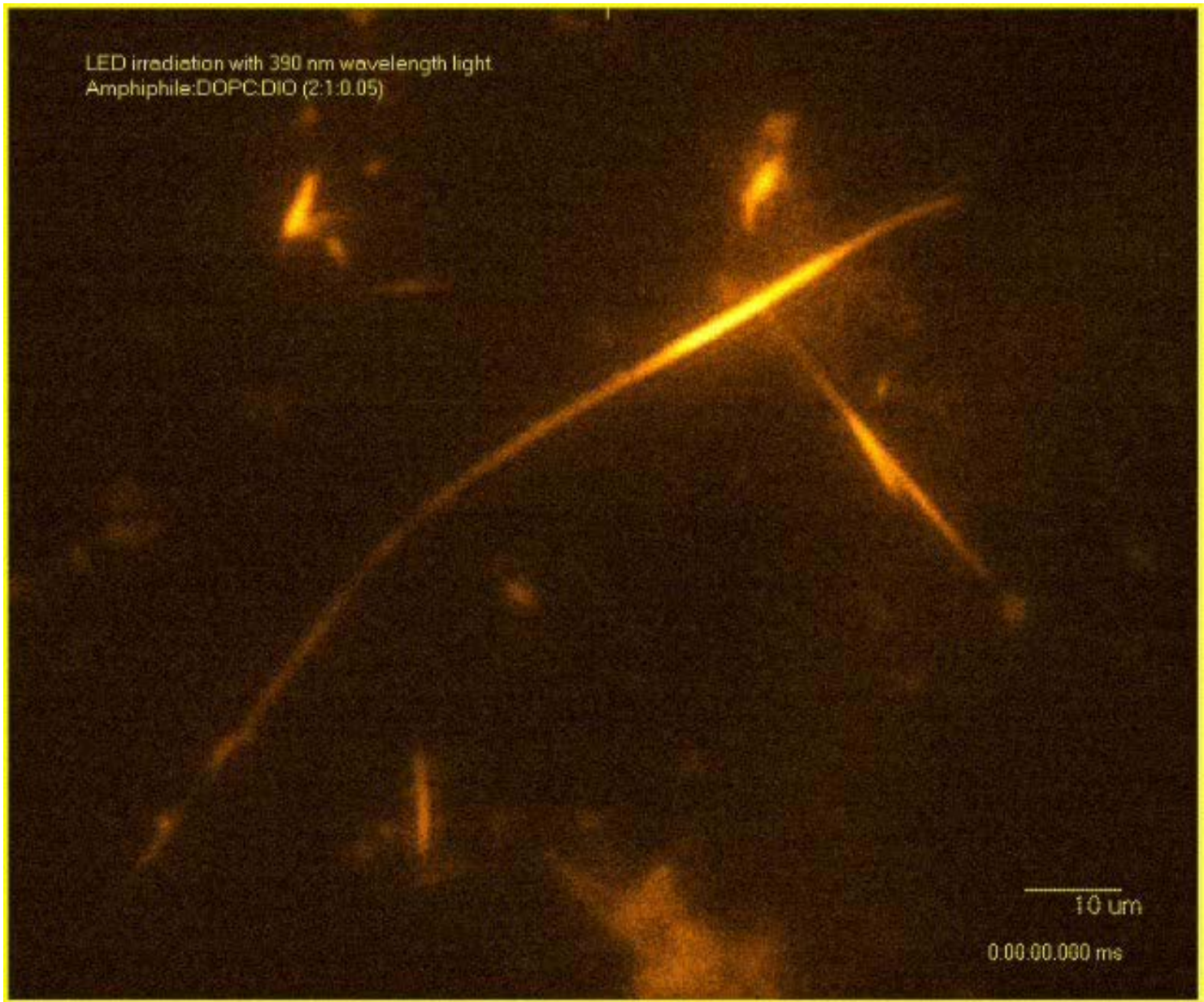




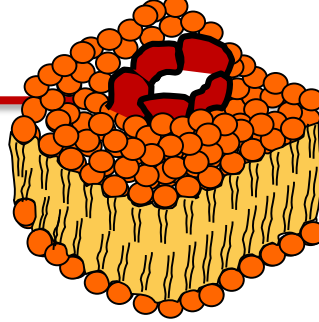
Controlling the disassembly

of a Nanotube with light



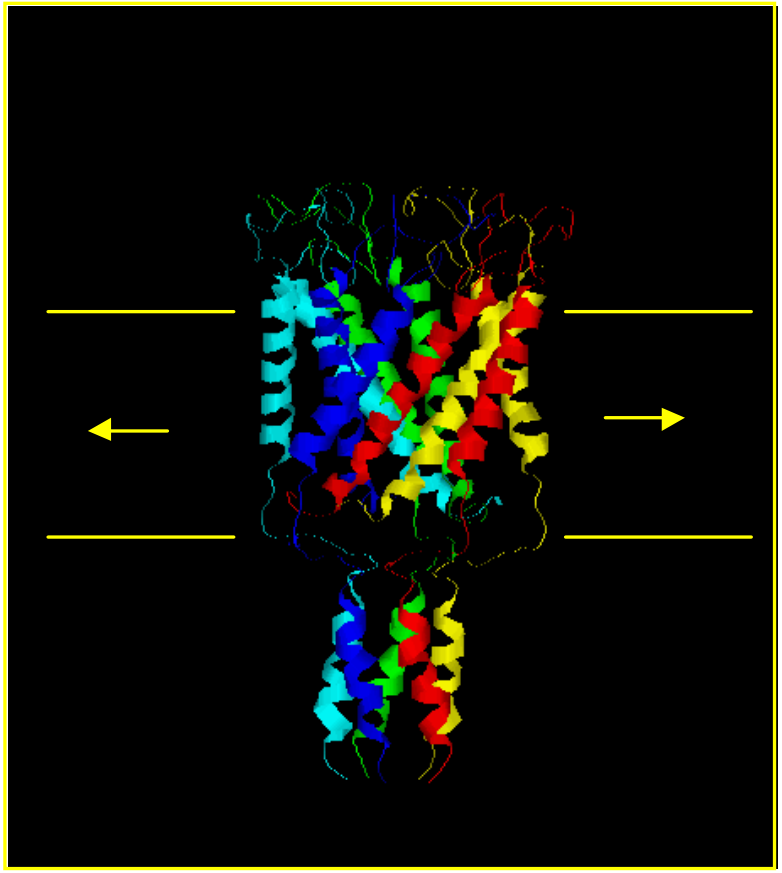


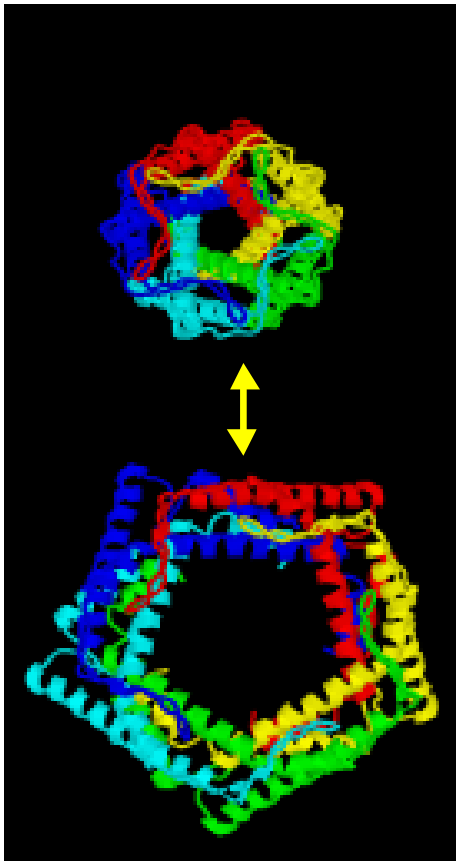
Nano-channel: trigger & response



open & close with light ??

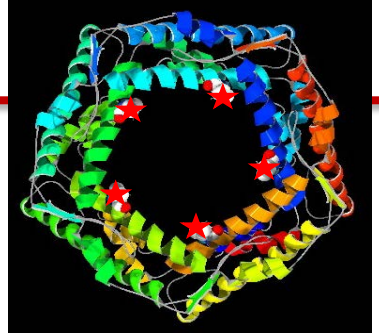
Mechanosensitive Channel from *E. coli* bacterium

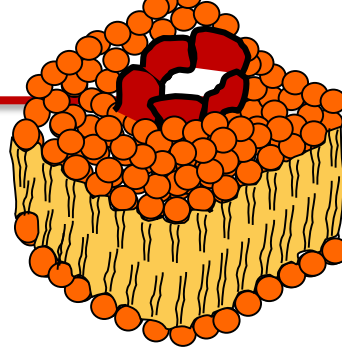




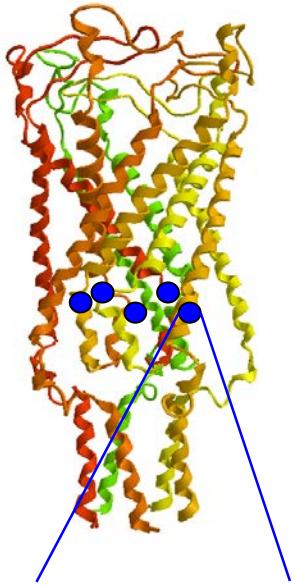
3-4 Nm channel in open state

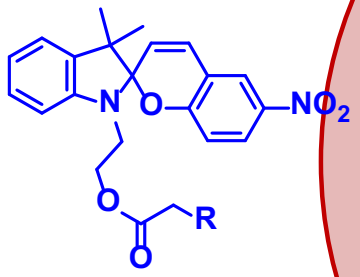
Molecular Device



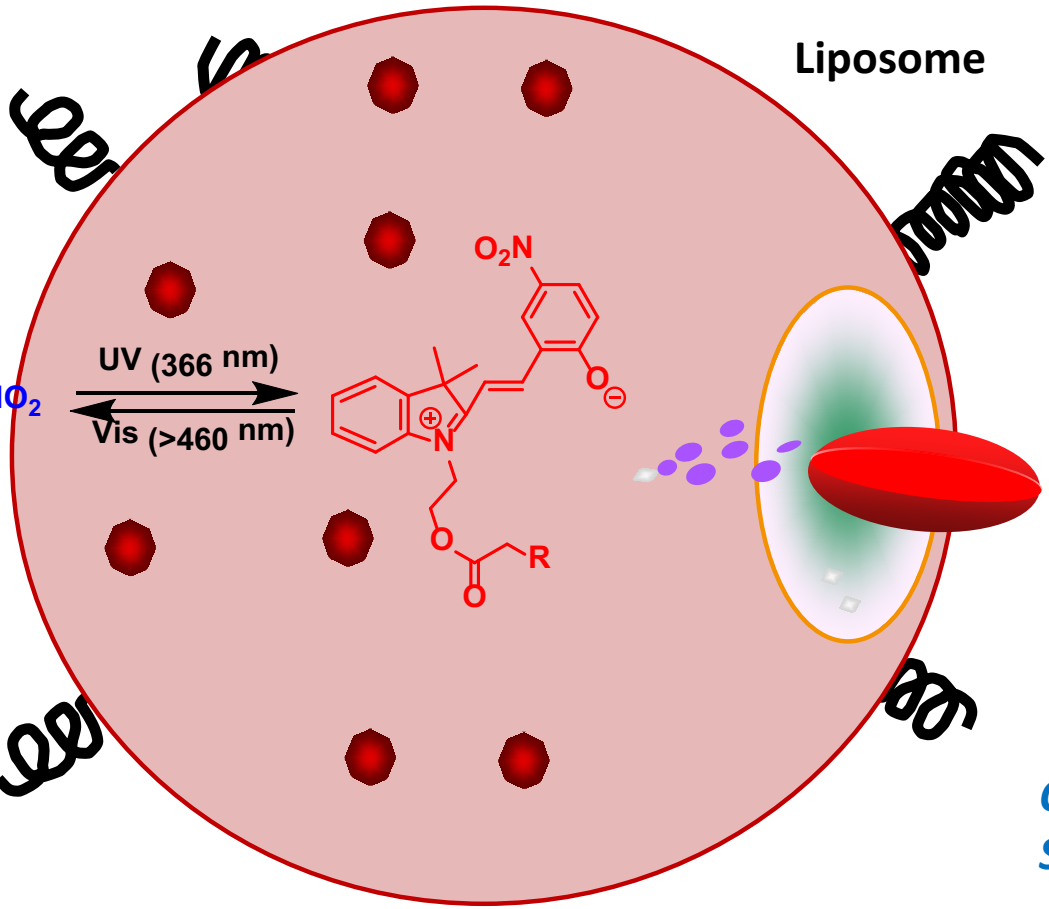


MscL channel protein

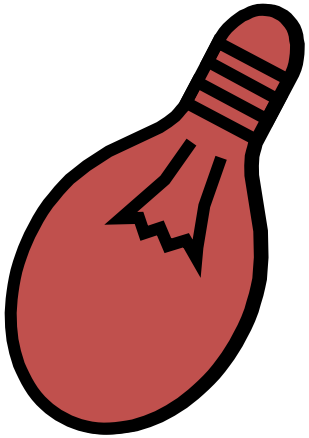




Switch

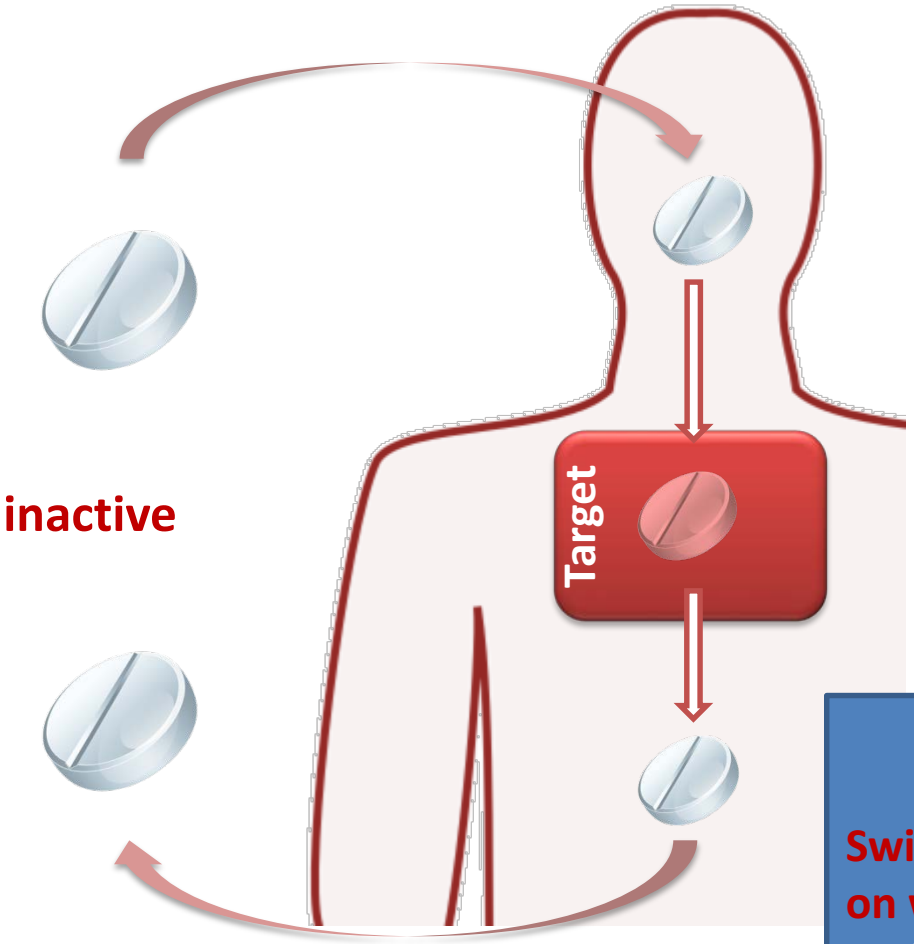


Liposome



Controlled drug delivery
Self-healing materials

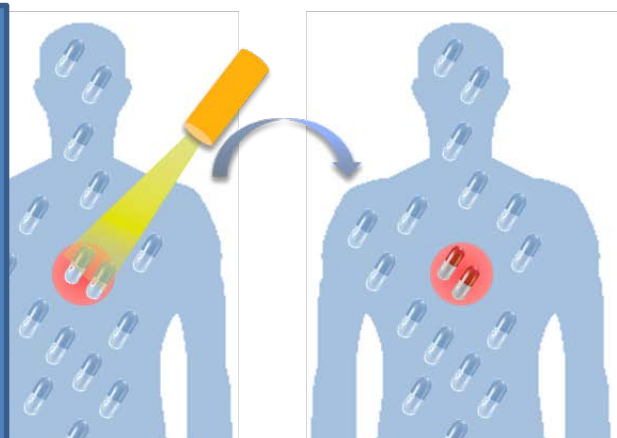
Smart Pharmaceuticals



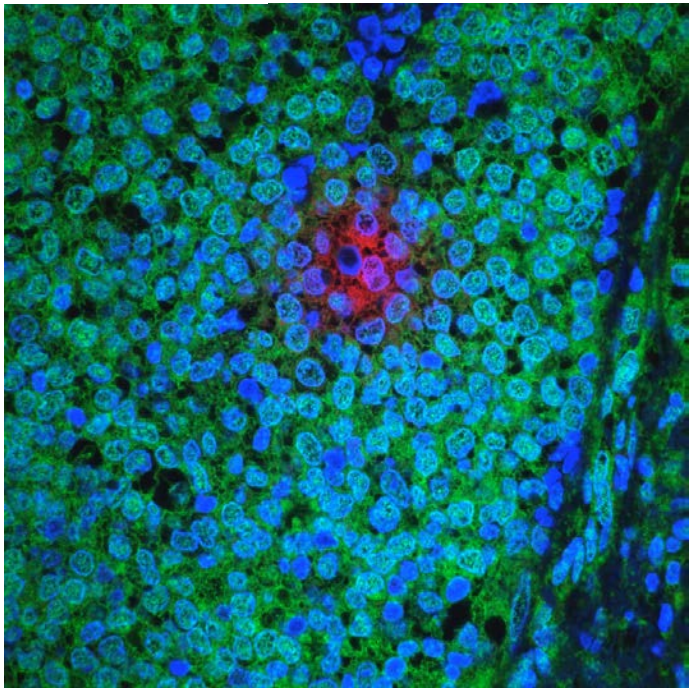
0 ⇌ **1**

(off) **(on)**

Switching a medicine on with a light signal
High precision in therapeutic action



World Health Organization



Bacterial Resistance

one of humanity's "ticking time-bombs"

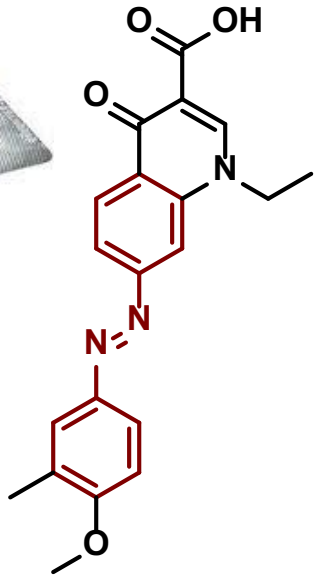
http://www.who.int/mediacentre/factsheets/fs194/en/

Cancer Treatment

chemotherapy

http://www.who.int/cancer/en/

Photocontrolled Antibiotic

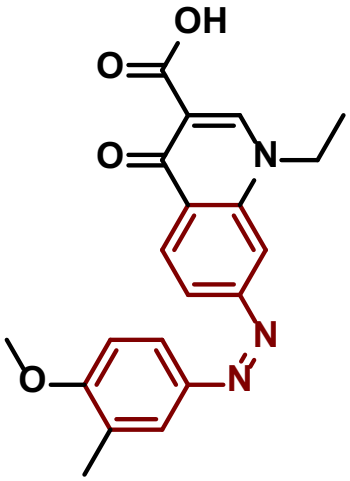


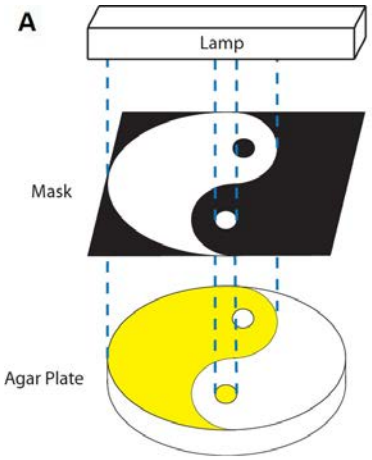
Activation with light

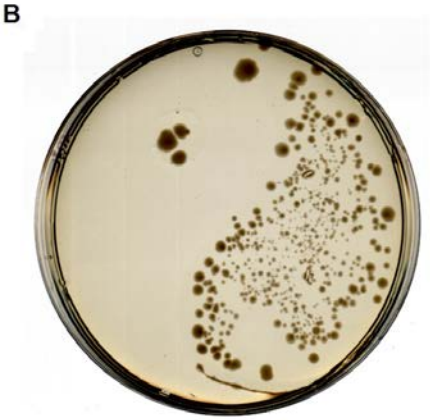
Auto-inactivation

0 ⇌ **1**

(off) **(on)**

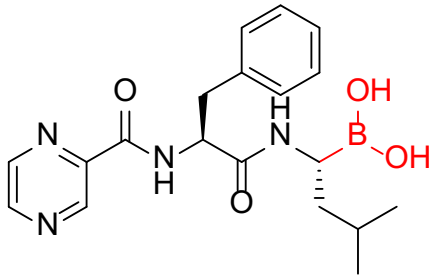






No resistance build-up
Control biofilm formation

Photocontrolled Chemotherapeutic Agent

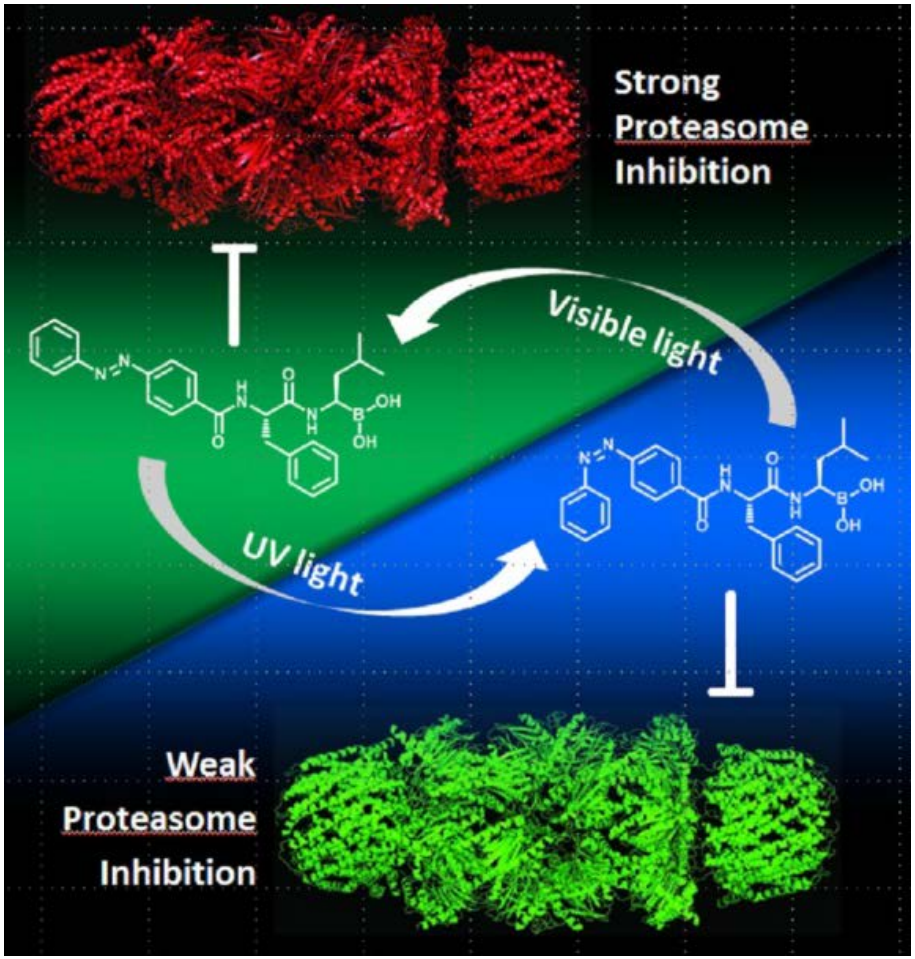


Bortezomib

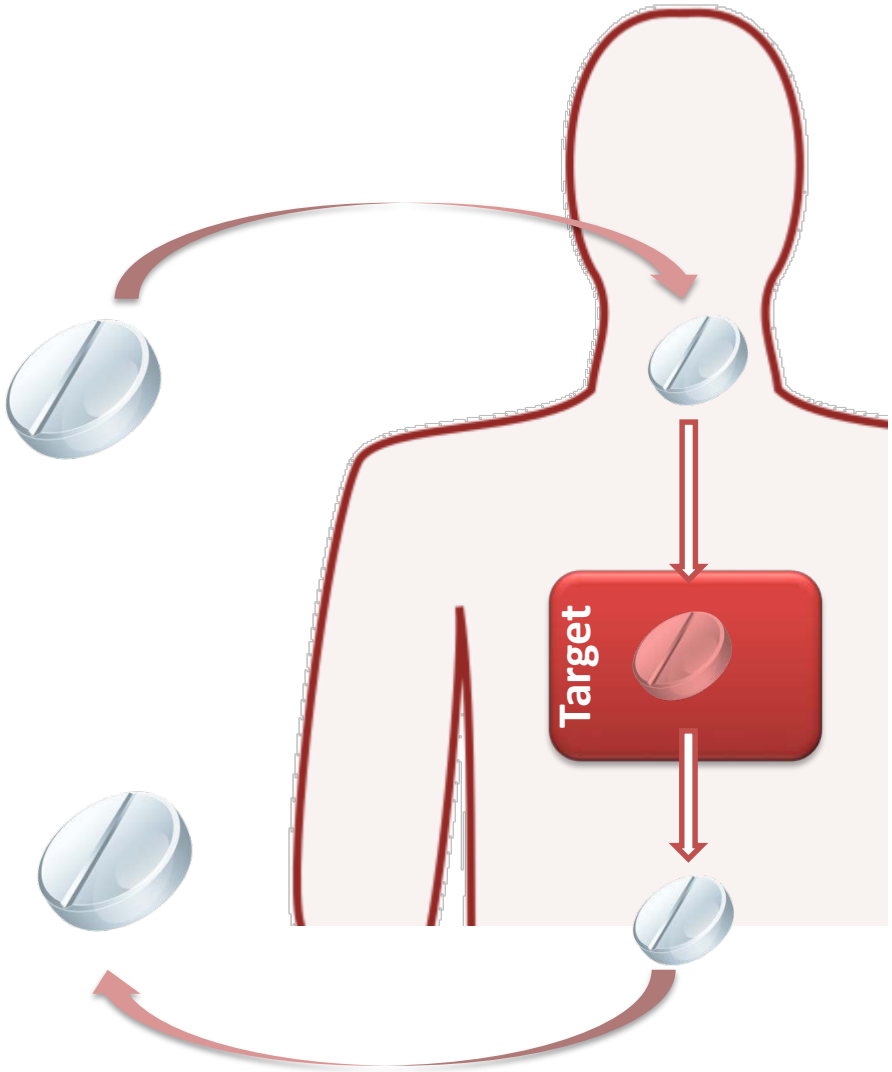
On the market (US; 2003) for the treatment of mantle cell cancer and multiple myeloma

Avoiding severe side-effects in chemotherapy

© Simon Jarratt/Corbis



Photopharmacology



0 ⇌ **1**

(off) **(on)**

Triggering

activation with non-invasive light signal

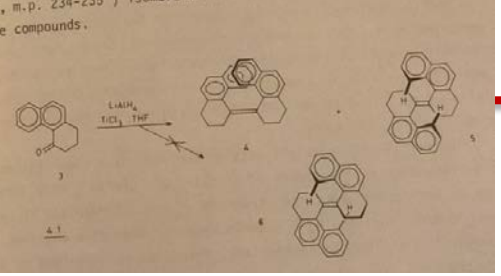
Response

Spatio-temporal precision in action

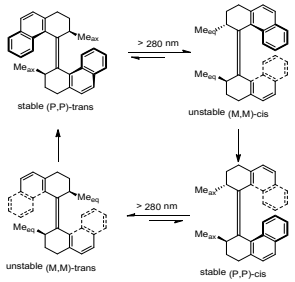
Smart Pharmaceuticals

Challenges: near-infrared light
imaging > drug activation

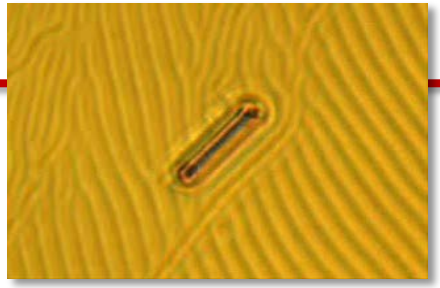
Molecular Motor



1977
(PhD thesis, p 61)
First synthesis of
Overcrowded alkene

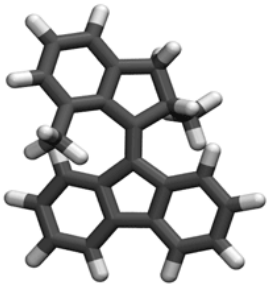


1999
Unidirectional
molecular motor



2006
Unidirectional
molecular motor
controlled
liquid crystals

First electric car
`to Stockholm
2016



1991
Chiroptical
Overcrowded alkene
switch

Chiroptical Molecular Switch

Ben L. Feringa,* Wolter F. Jager, and Ben de Lange
Department of Organic Chemistry
University of Groningen
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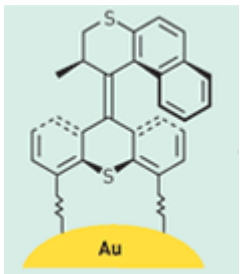
Egbert W. Meijer†
Philips Natuurkundig Laboratorium
Post Office Box 80.000
5600 JA Eindhoven, The Netherlands
Received January 30, 1991
Revised Manuscript Received May 8, 1991

Photochemically switchable bistable molecules have recently attracted much attention due to possible applications in reversible optical data storage and optical computing.1,2 To be suitable for optical memory devices, such molecules should meet the following requirements: (a) thermal stability of both isomers, (b) a repeatable switching cycle without loss of activity, and (c) ready

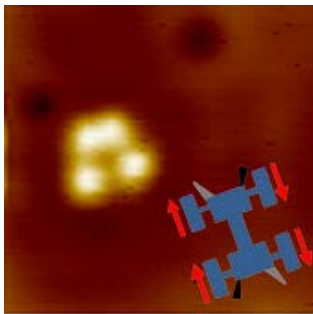
† Present address: DSM Research, P.O. Box 18, 6160 MD Geleen, The Netherlands.
(1) Emmelius, M.; Pawlowski, G.; Vollmann, H. W. *Angew. Chem., Int. Ed. Engl.* **1989**, *28*, 1445.
(2) Engler, E. M. *Adv. Mater.* **1990**, *2*, 166.

J. Am. Chem. Soc. **1991**, *113*, 5468–5470

2005
Unidirectional
Motor on a
surface



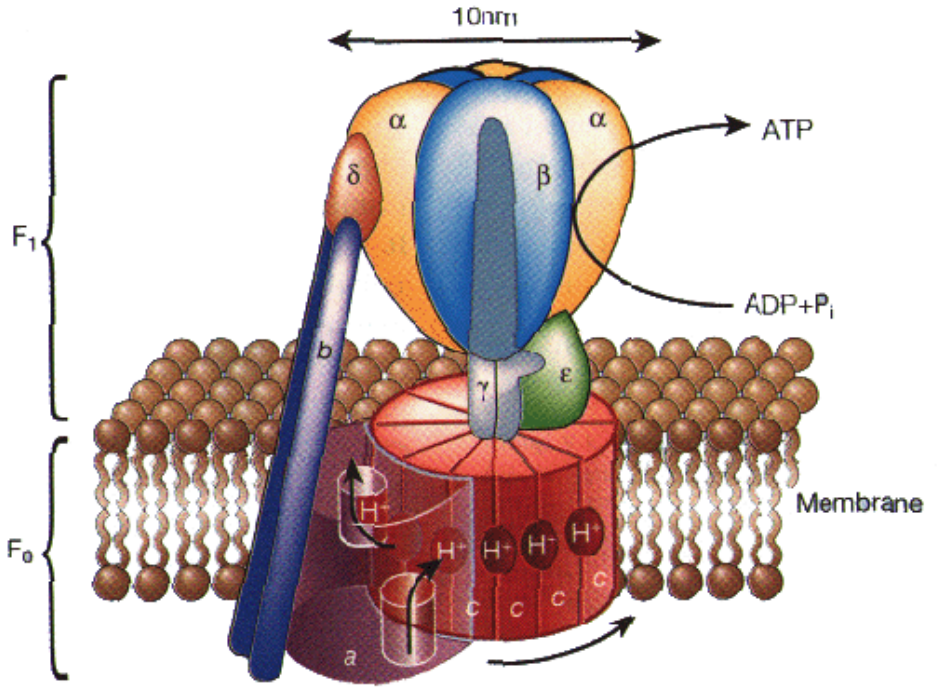
2011
Molecular nanocar
Powered translational
motor on surface

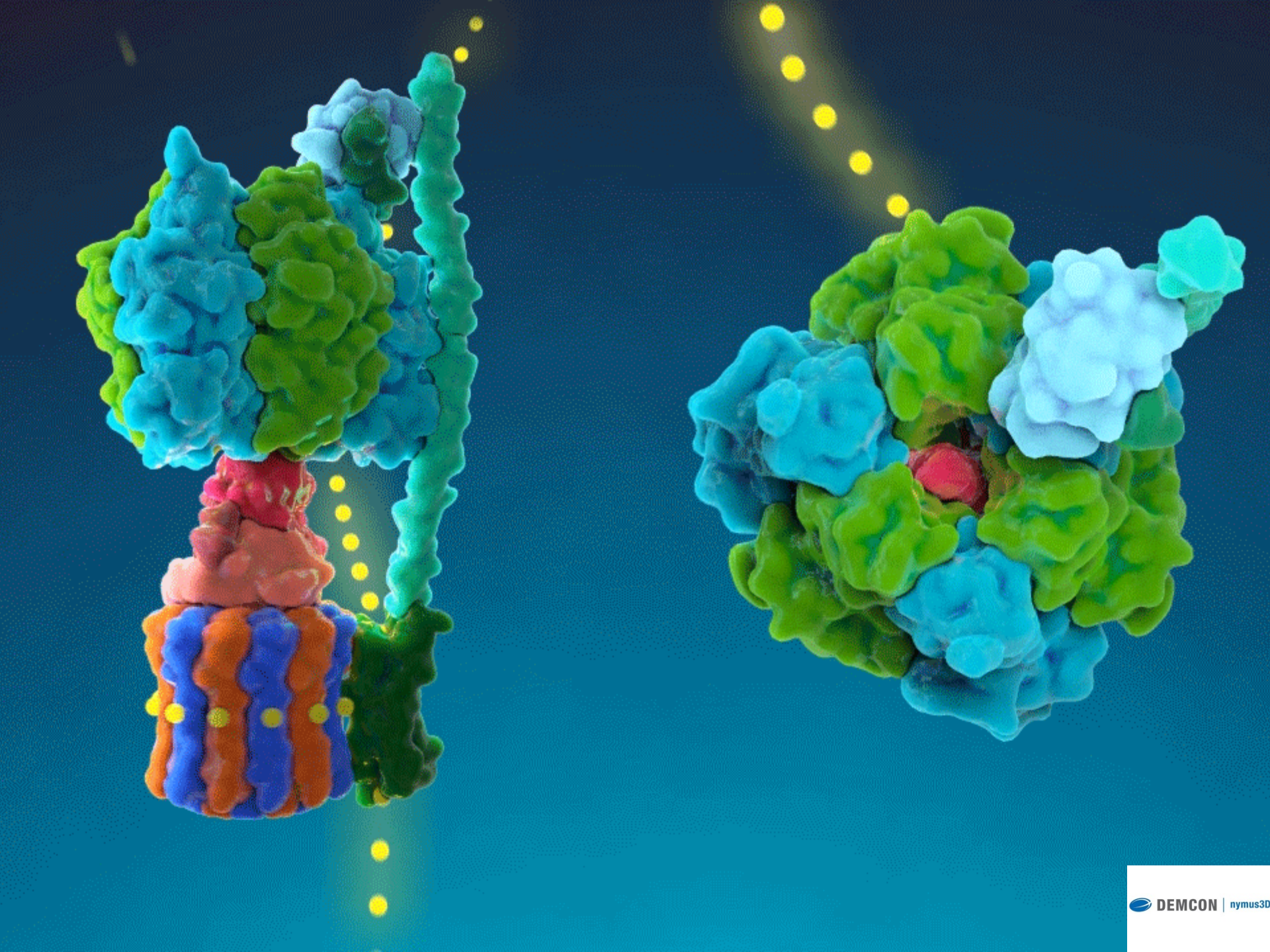


Man's Motor vs. Nature's Motor

Motor

ATP - ase



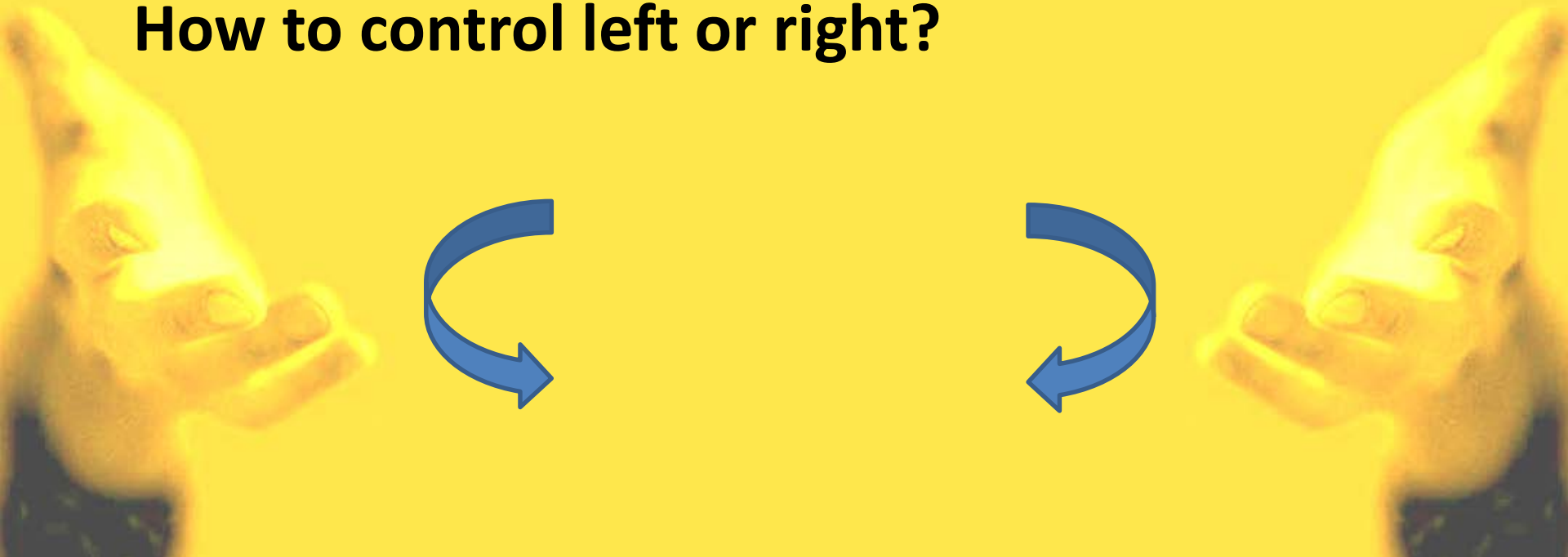

DEMCON | nymus3D

Molecular Motor

How to control rotary motion?

in the nanoworld

How to control left or right?

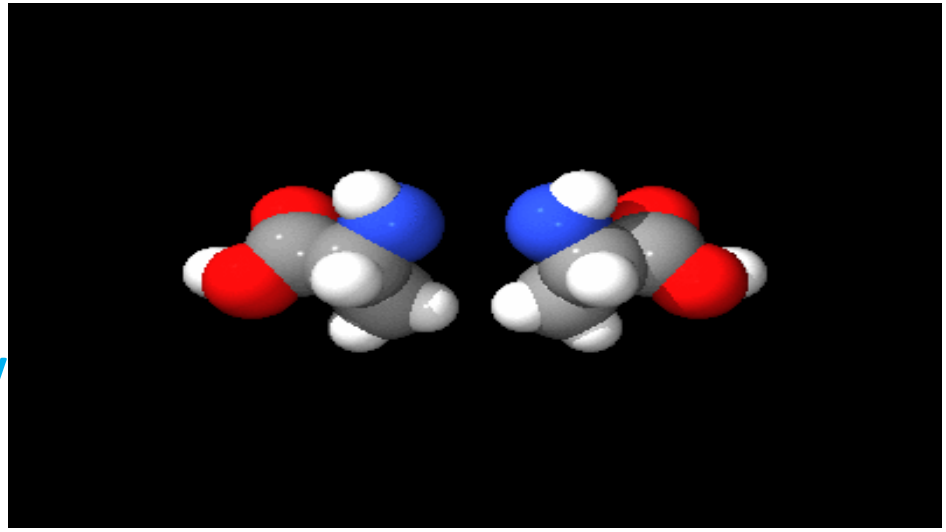


My Teachers and Hero's

Jacobus van 't Hoff

Hans Wijnberg

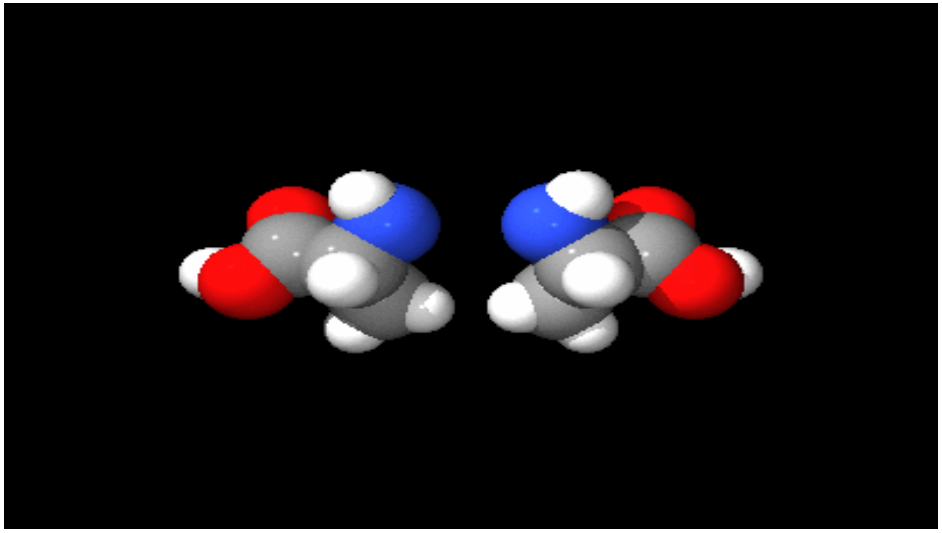
Stereochemistry



mirror image symmetry
"a signature of life"

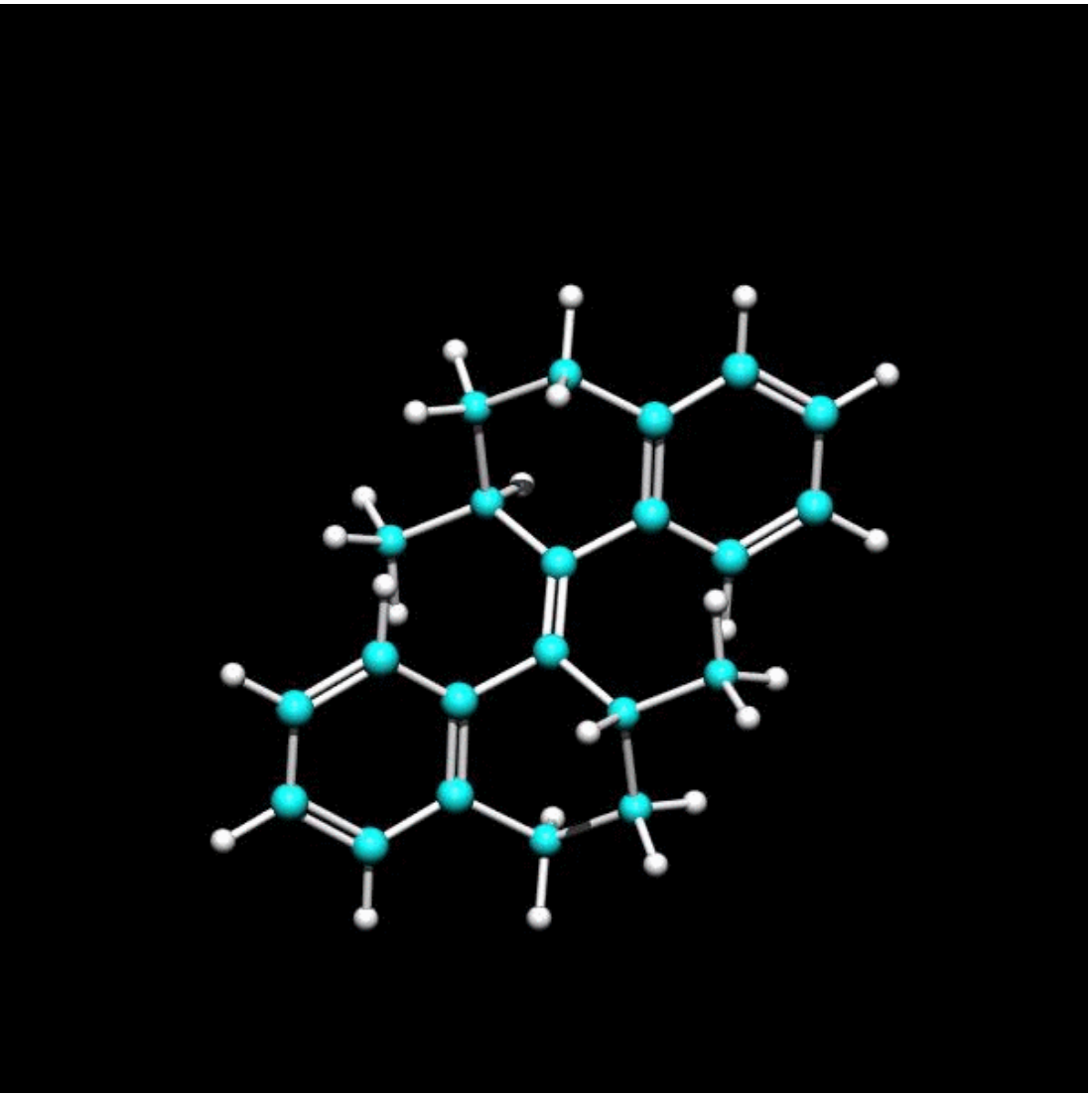
Mirror Image

Breaking Symmetry



Unidirectional Rotary Molecular Motor

Powered by Light

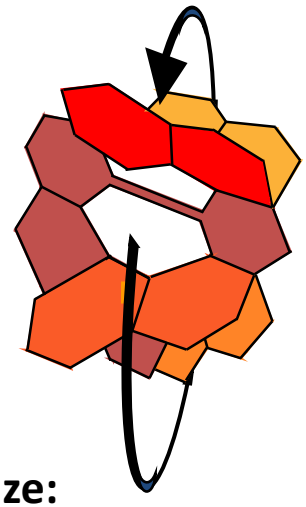


DEFINITION:

A rotary motor is a device that is able to convert energy input into controlled, directional, rotary motion in a continuous fashion

REQUIREMENTS:

- Controlled Motion
- Consumption of Energy
- Directional Movement
- Repetitive (Continuous) Process

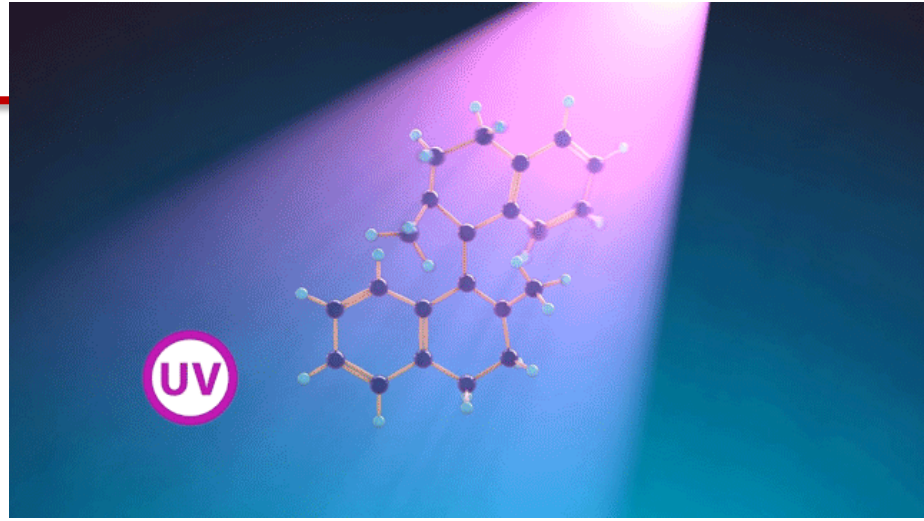


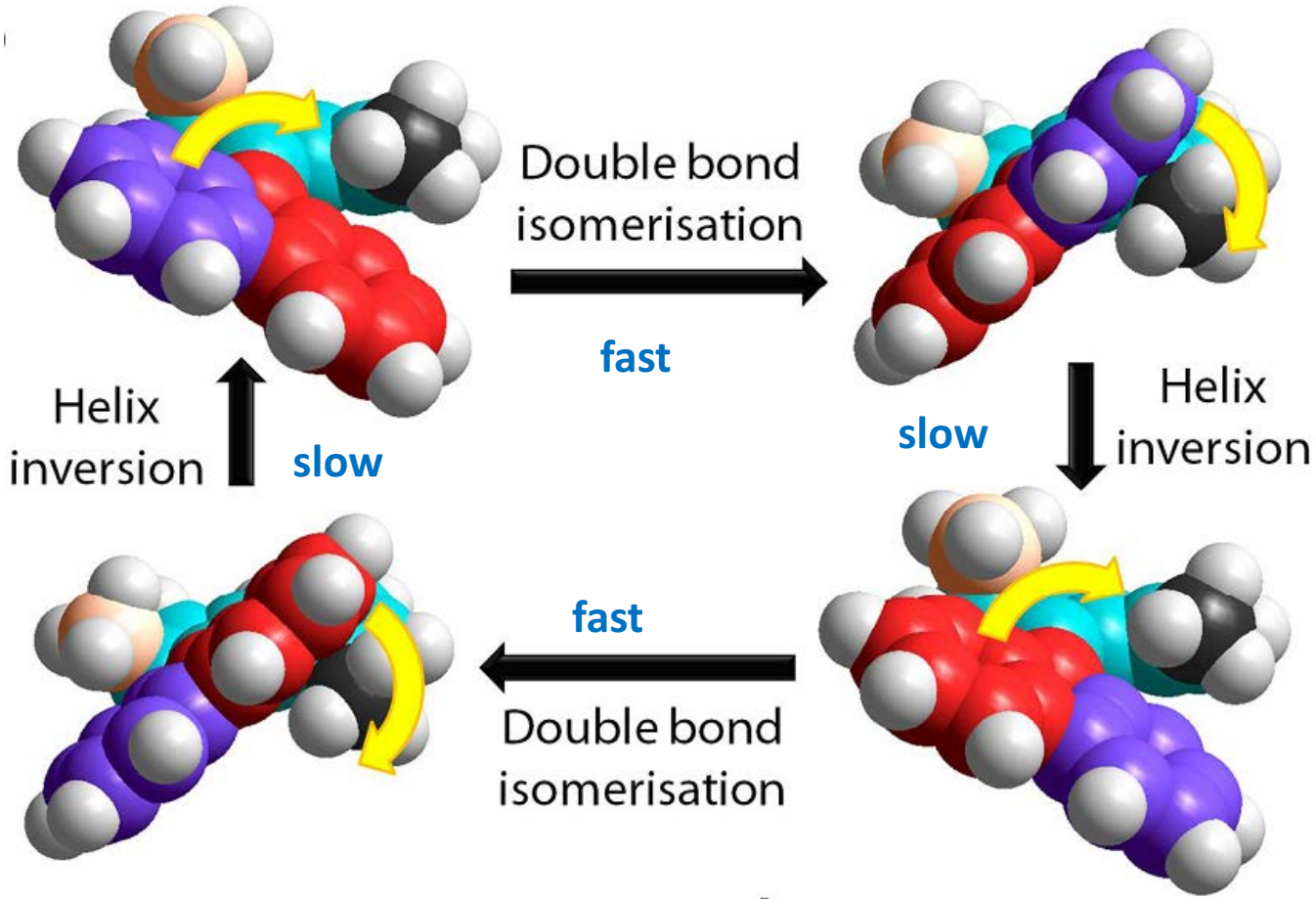
Size:
1 nanometer

a power-stroke motor

Molecular Motor

powered by light

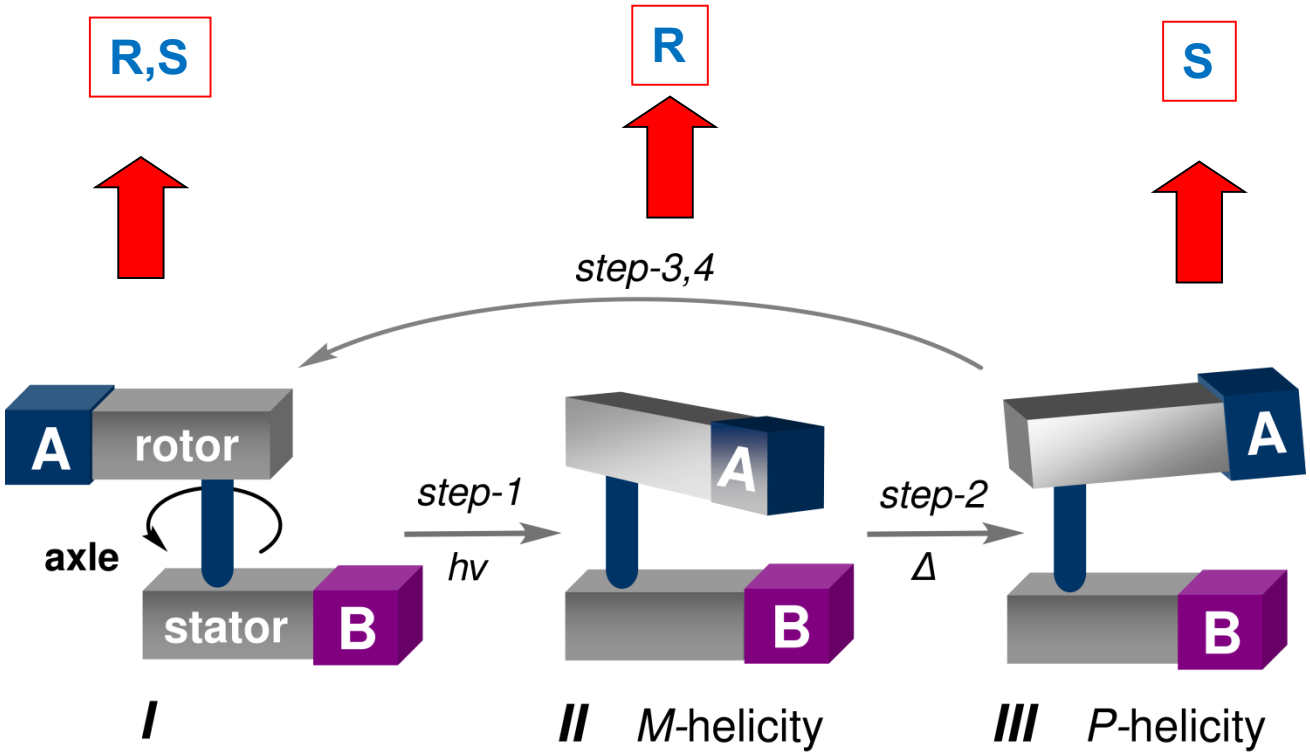


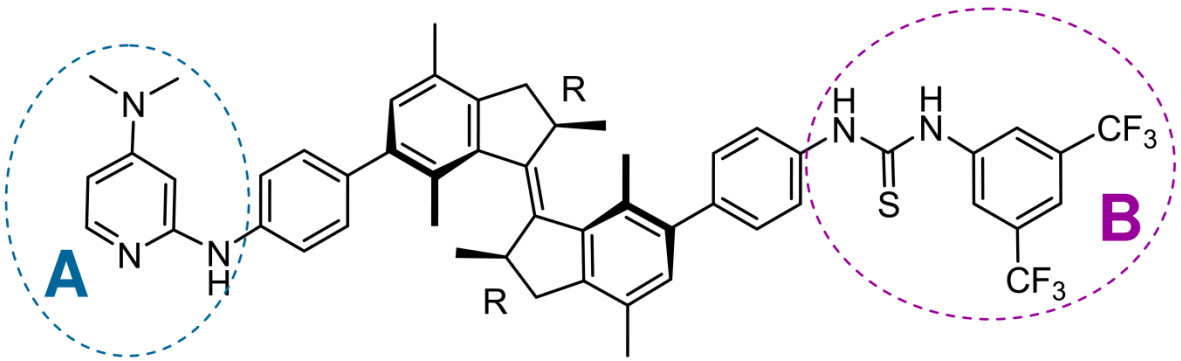


Responsive Catalysts

dynamic control of chiral space using a molecular motor

product chirality

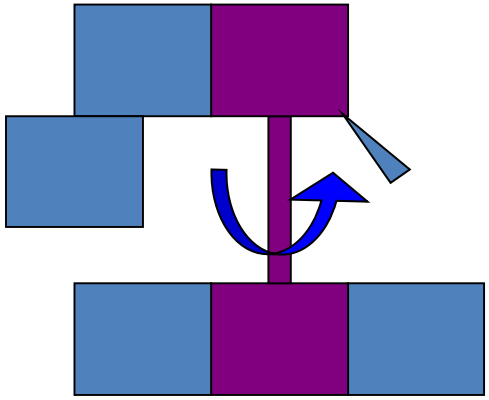




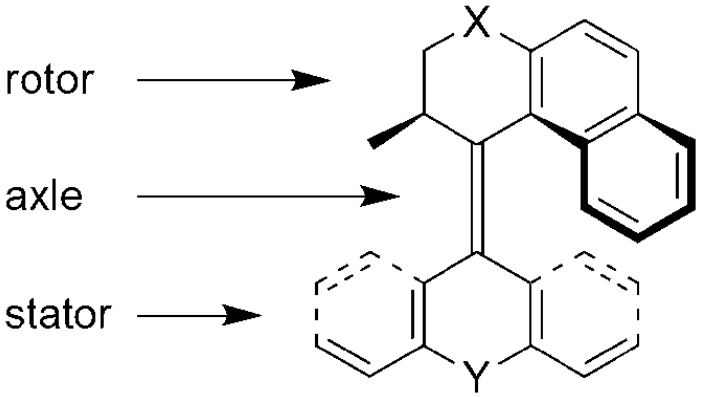
(2*R*,2′*R*)-(*P*,*P*)-*trans*-**1**

multitasking organo-catalyst sequence control

Second Generation Molecular Motor



Molecular Design



enhancing the speed

from
1 rotation/hour

to
more than 10 million rotations/sec

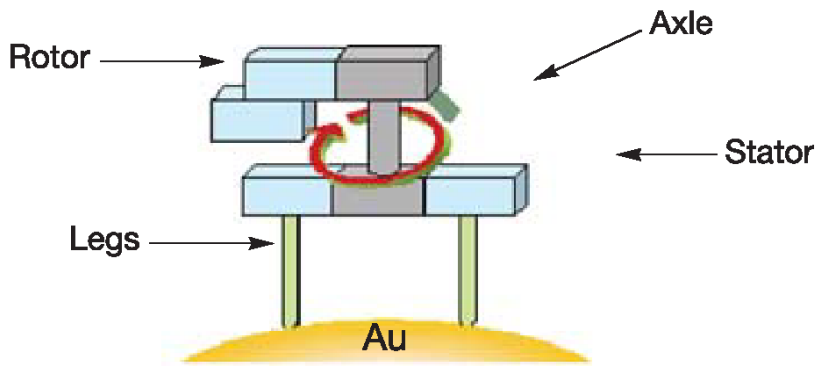
Control of Motion

Molecular

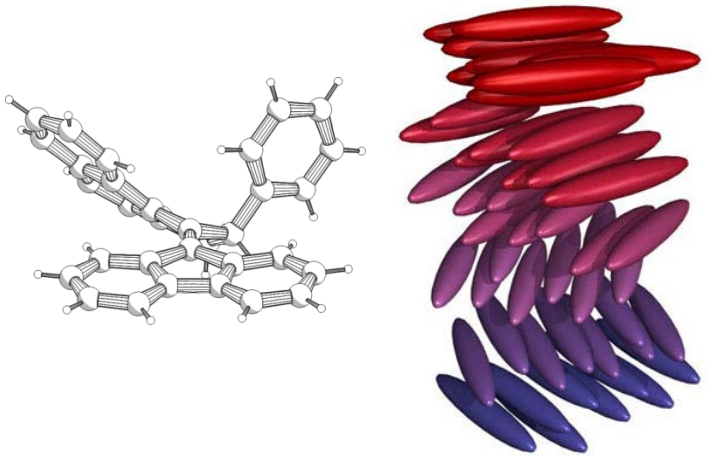
dynamics & length scales

Mesoscopic

surfaces & catalysts

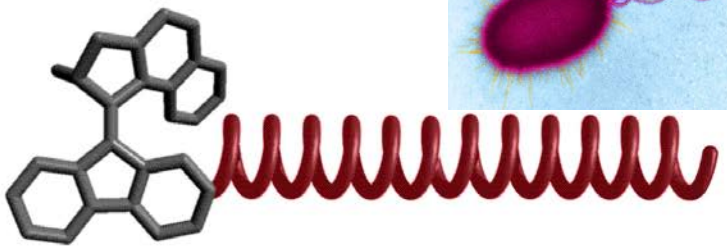


micro-objects & droplets



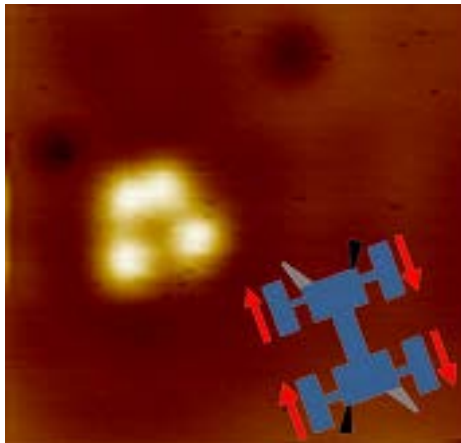
Macromolecular

polymer helicity



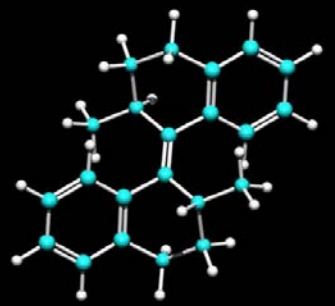
Nano

single molecule movement



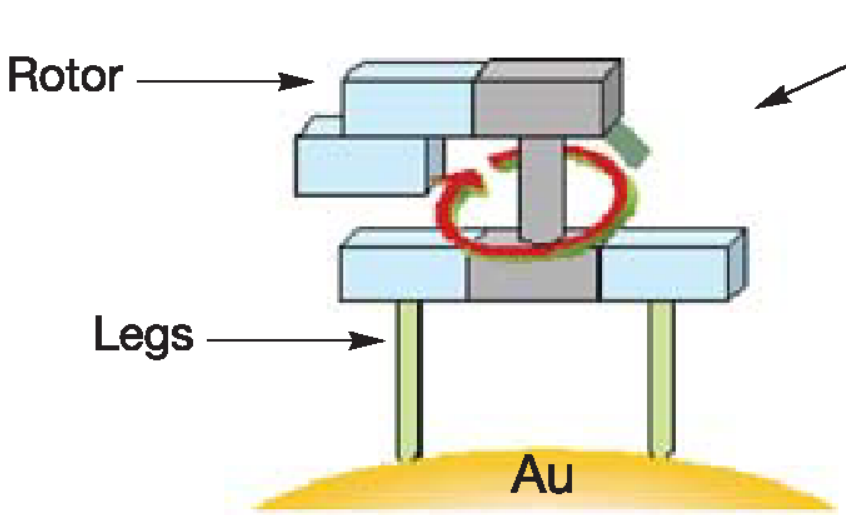
Rotation of a micro object

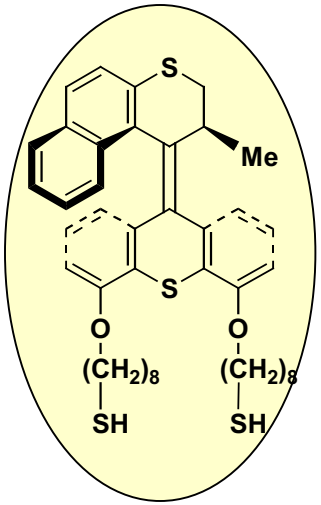
Molecular motor 1nm



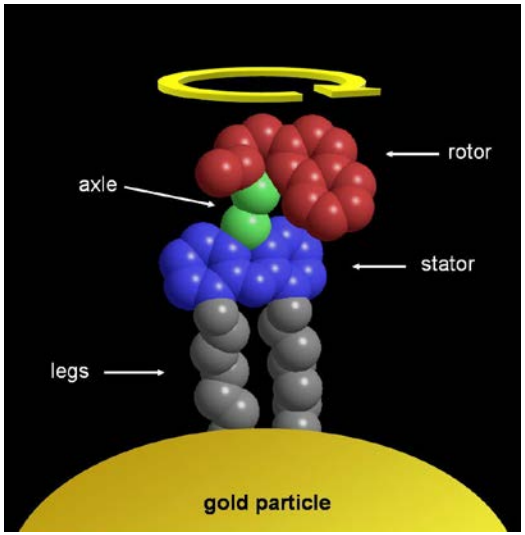
Glass rod, 5 x 28 μm

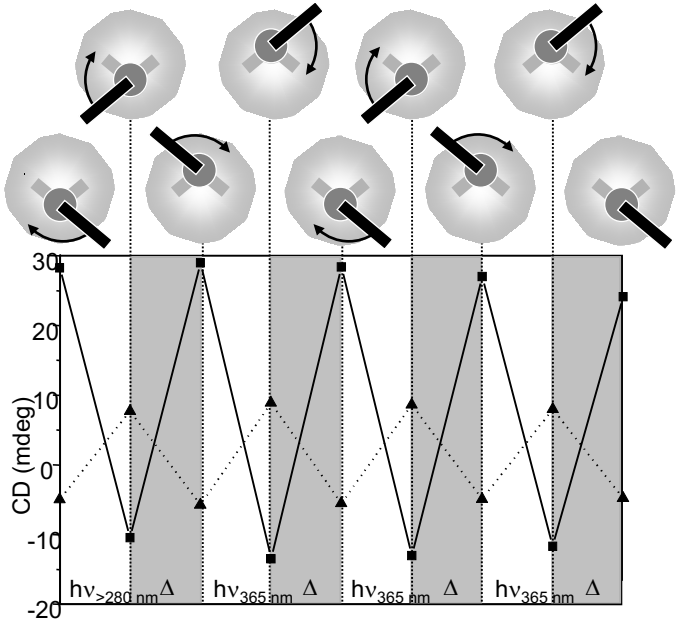
Design of Molecular Motors on Surfaces





Target Motor Molecule

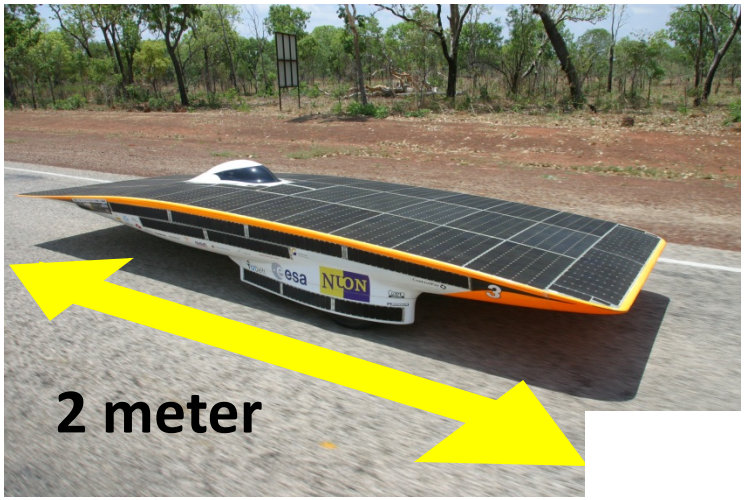




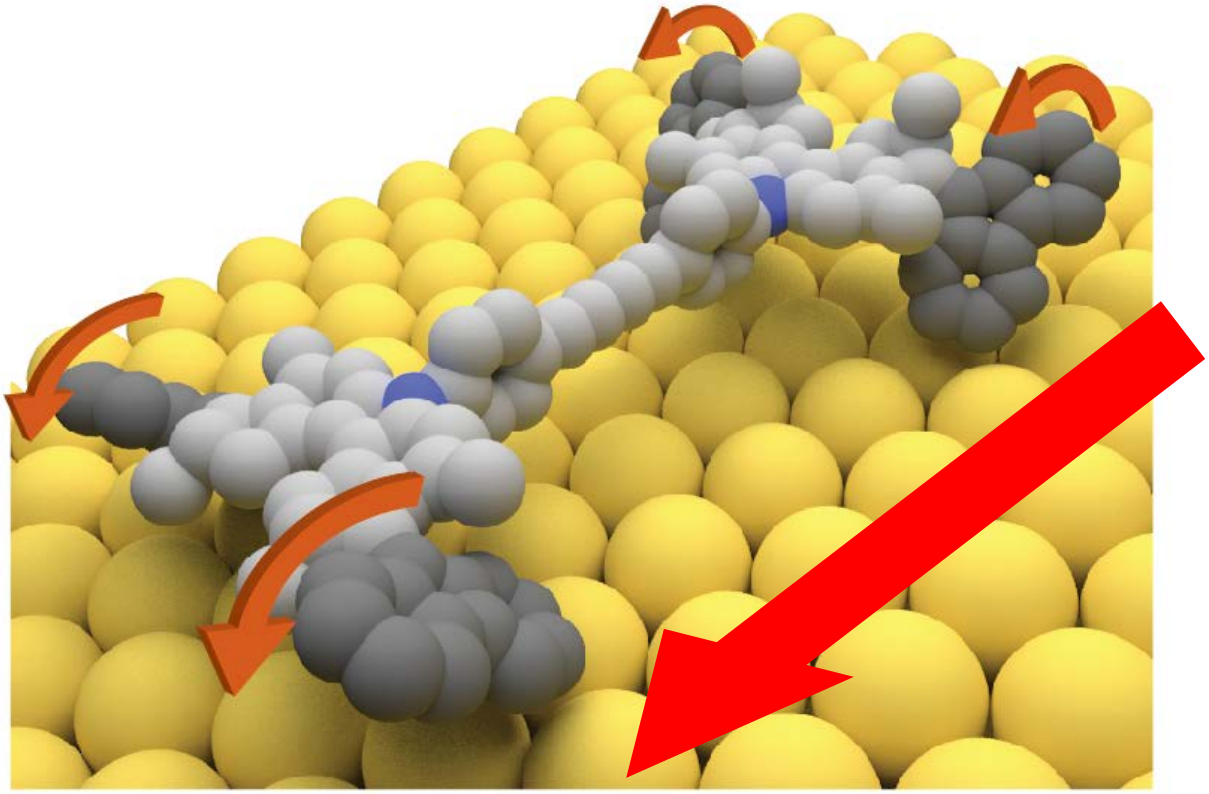
Responsive Surfaces


rotor
axle
stator
legs

Molecular Car

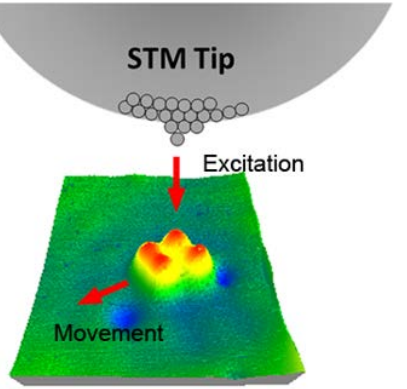


0.000000002 meter

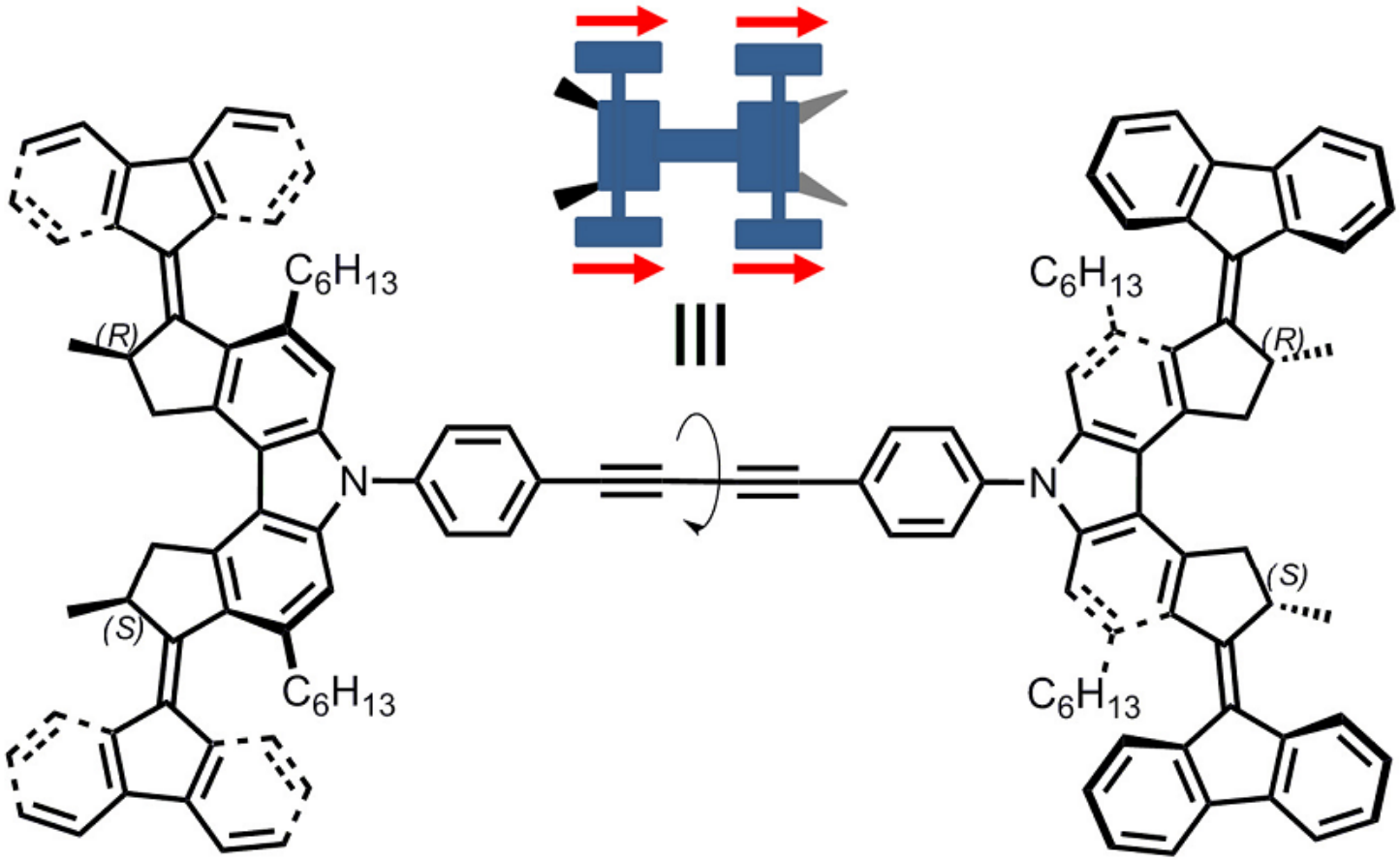


Four-wheel drive

Four Wheel Drive Molecular Car



meso-(*R,S*-*R,S*) isomer



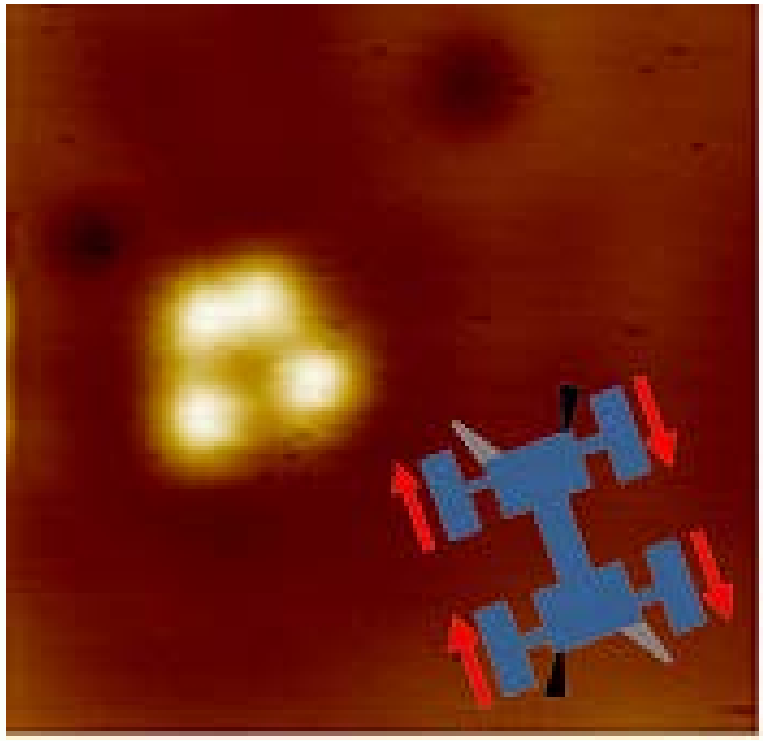
Nano Car

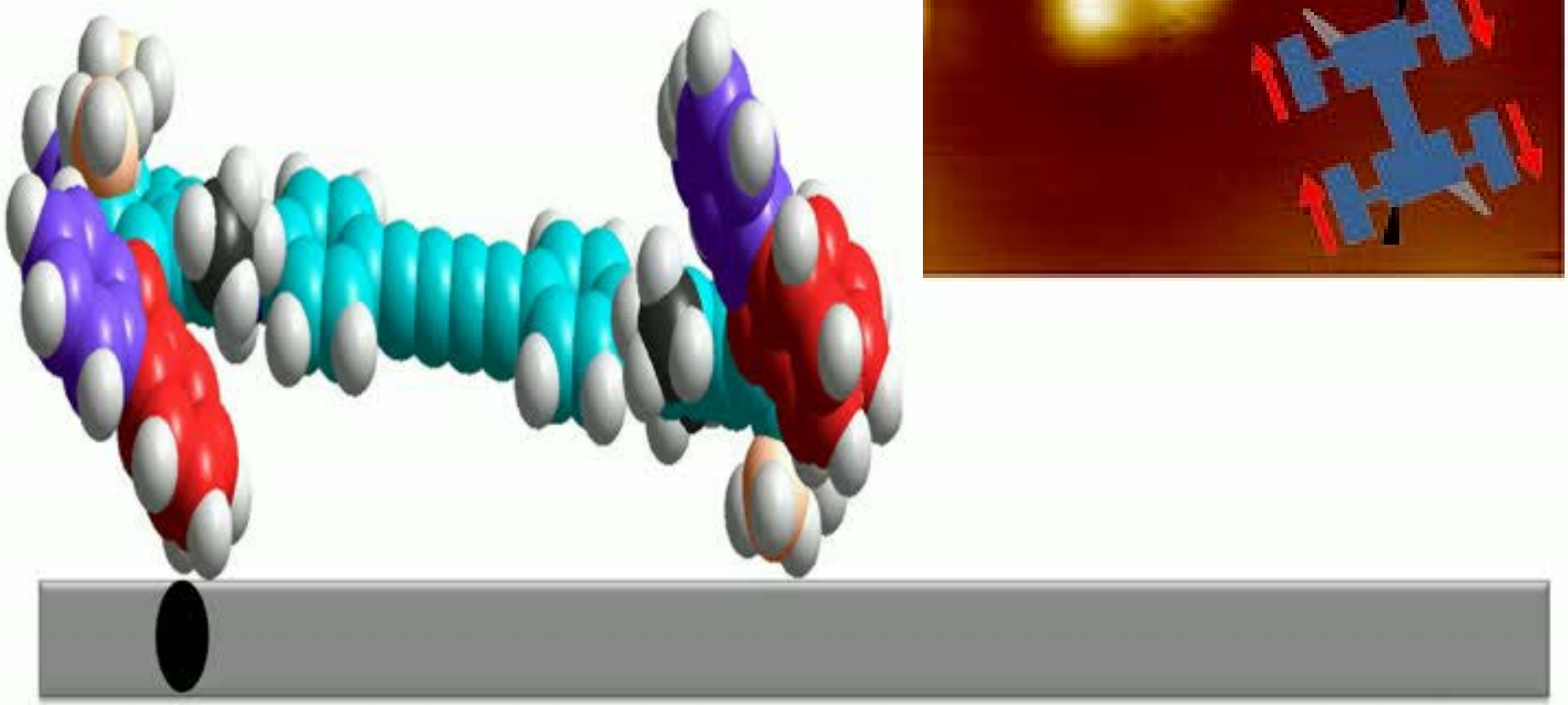
How to convert rotary motion into translational motion???

Single molecule motion!!!

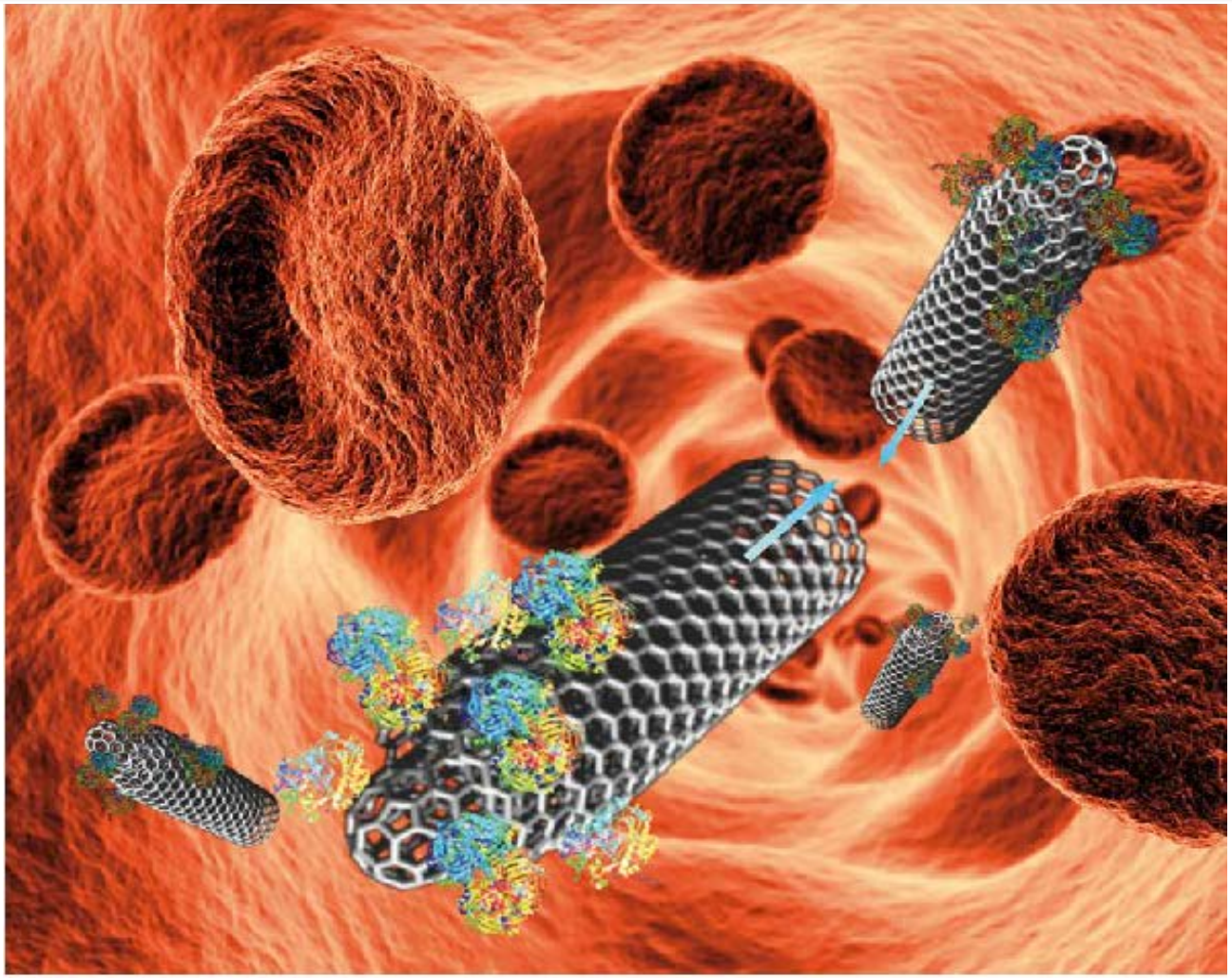
Molecular Car

Single Molecule Nano Car on Surface





Autonomous Propulsion System

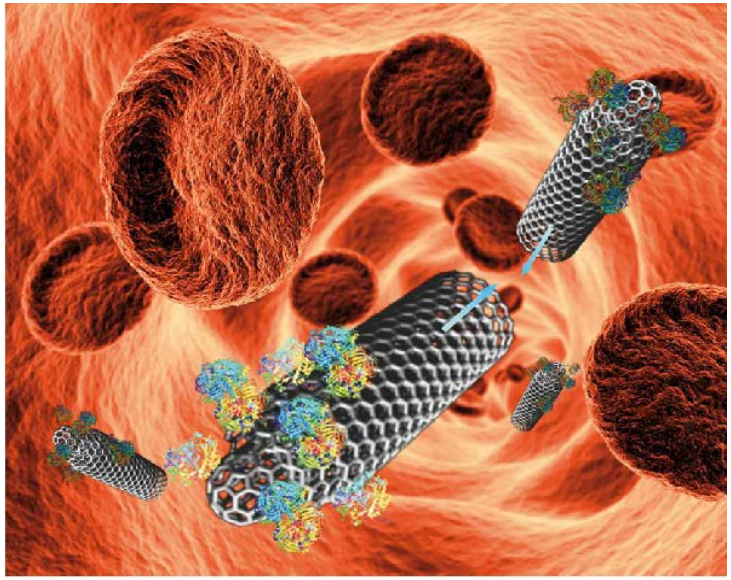


Chemical Catalysis

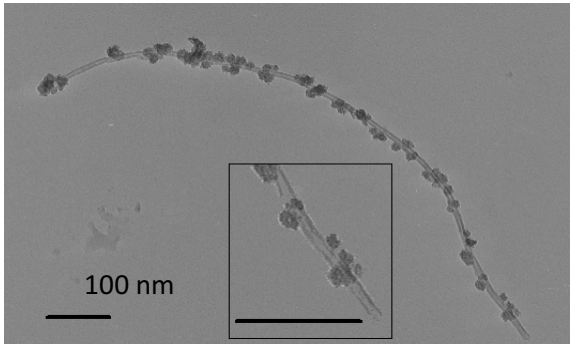
Glucose as fuel ?

Fantastic Voyage

Nano-Swimmer

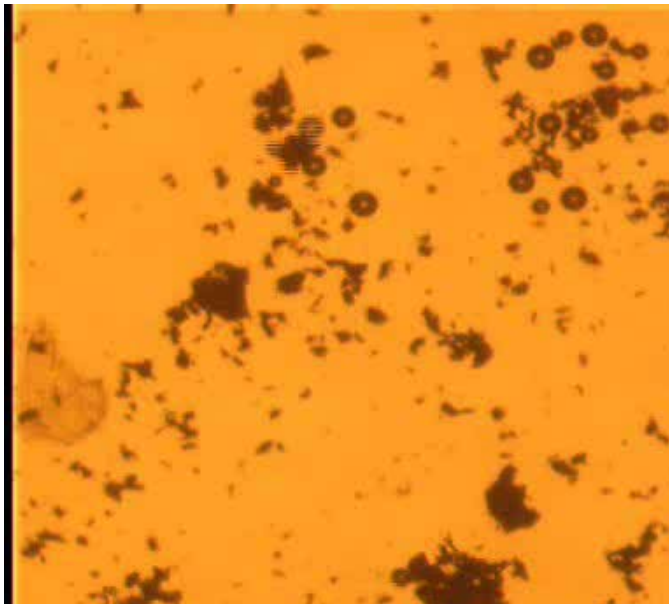


Fuel: sugar



Applications:

- roving sensors
- delivery systems
- micro-nano-robots



Nanorobots, science or science fiction

“The best way to predict the future is to invent it.“

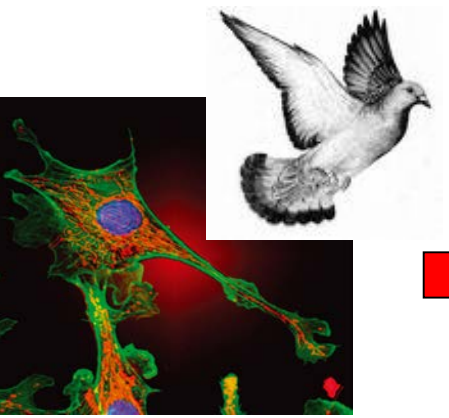
Alan Kay

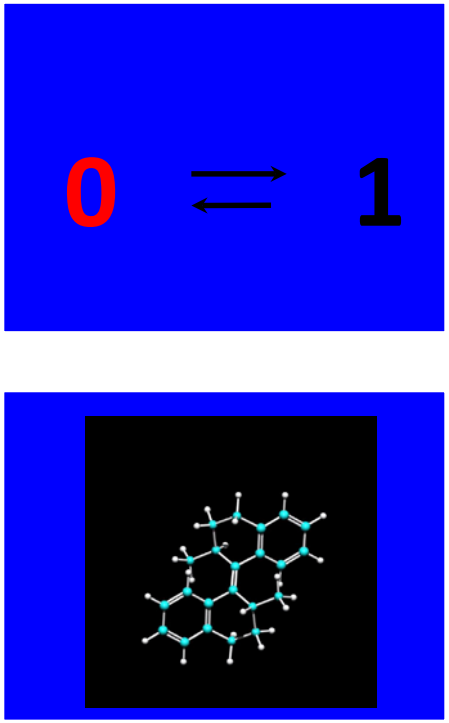
The Art of Building Small

programming molecules

→ **responsive & adaptive functions**

→ **motion** → **dynamic systems**





Perspective

Information systems
Responsive materials
Smart surfaces
Self-healing materials
Delivery systems
Precision therapeutics
Adaptive catalysts
Roving sensors
NanoEnergy converters
Soft-robotics
.....

Acknowledgment

generations students & co-workers, colleagues & staff, collaborators, mol machine comm, family

erc

European Research Council

ROYAL SOCIETY OF CHEMISTRY

NWO
Nederlandse Organisatie voor Wetenschappelijk Onderzoek

Koninklijke Nederlandse Akademie van Wetenschappen

Alexander von Humboldt Stiftung/Foundation

university of groningen

SOLVAY

Research Center for Functional Molecular Systems
Gravitation Program - The Netherlands

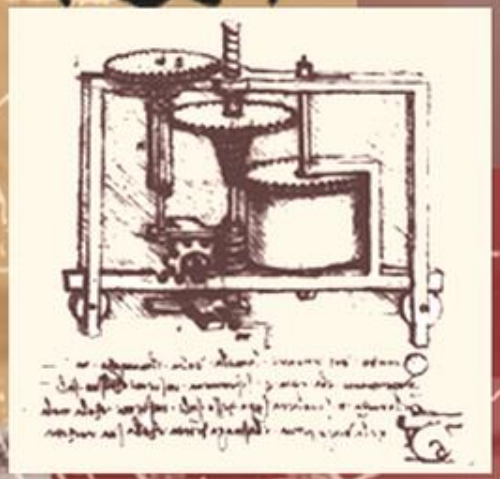
fondation Simone et Cino del Duca
INSTITUT DE FRANCE

GDCh
Gesellschaft Deutscher Chemiker

AC Cope Foundation

Leonardo da Vinci

"Where Nature finishes producing its own species man begins,with the help of Nature, to create an infinity of species"



Imagine the unimaginable