# Molecular Machine

## Literature Review
## Sep 18, 2017


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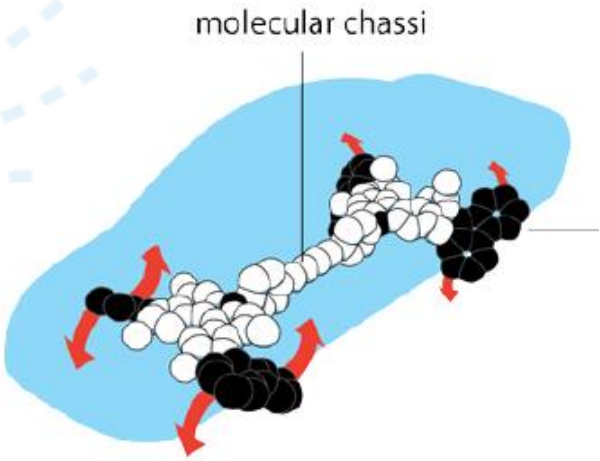
## The Yu Laboratory
## The Scripps Research Institute


**Outline:**

1. Background
2. Design and synthesis
   - a) catenane
   - b) rotaxane
   - c) molecular motor
3. Applications



# The Nobel Prize in Chemistry 2016

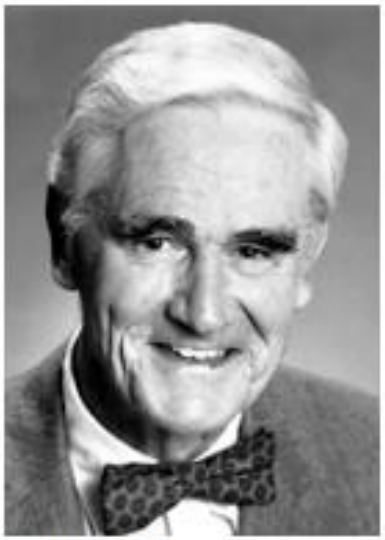
Photo: A. Mahmoud
**Jean-Pierre Sauvage**
**Prize share:** 1/3

Photo: A. Mahmoud
**Sir J. Fraser Stoddart**
**Prize share:** 1/3

Photo: A. Mahmoud
**Bernard L. Feringa**
**Prize share:** 1/3

The Nobel Prize in Chemistry 2016 was awarded jointly to Jean-Pierre Sauvage, Sir J. Fraser Stoddart and Bernard L. Feringa *"for the design and synthesis of molecular machines"*.

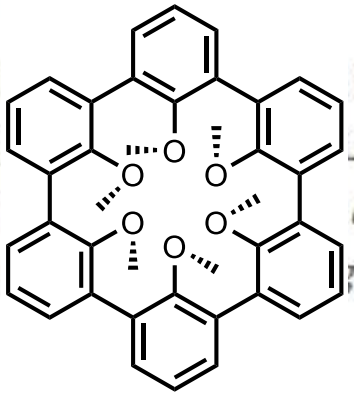
# The Nobel Prize in Chemistry 1987



**Donald J. Cram**
Prize share: 1/3

**Jean-Marie Lehn**
Prize share: 1/3

**Charles J. Pedersen**
Prize share: 1/3



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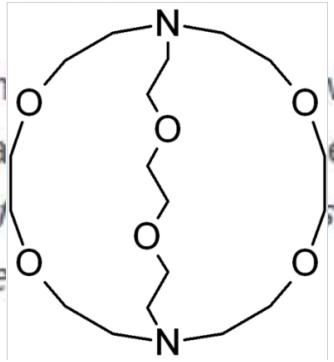
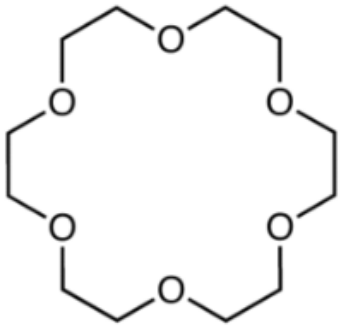



Cryptand




Crown ether

# Molecular Machine

A **molecular machine**, or **nanomachine**, refers to any discrete number of molecular components that produce quasi-mechanical movements (output) in response to specific stimuli (input).

Controlled, large amplitude or directional mechanical motion of one component relative to another (or of a substrate relative to the machine) which results in a net task being performed

Venturi et al, *Acc. Chem. Res.*, **2001**, *34*, 445–455

# The Nobel Prize in Chemistry 2016

Photo: A. Mahmoud
Jean-Pierre Sauvage
Prize share: 1/3

The first step towards a molecular machine was taken by Jean-Pierre Sauvage in 1983, when he succeeded in linking two ring-shaped molecules together to form a chain, called a *catenane*. Normally, molecules are joined by strong covalent bonds in which the atoms share electrons, but in the chain they were instead linked by a freer *mechanical bond*. For a machine to be able to perform a task it must consist of parts that can move relative to each other. The two interlocked rings fulfilled exactly this requirement.

# The Nobel Prize in Chemistry 2016

Photo: A. Mahmoud
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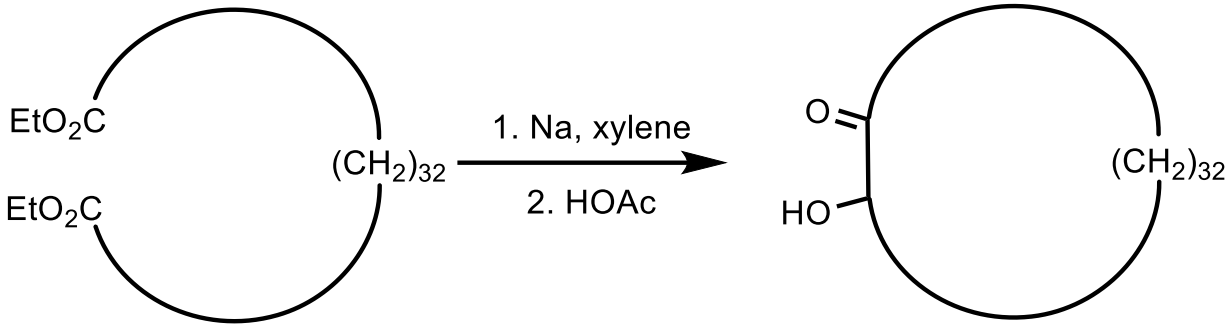
# Catenane




Wasserman et al, *J. Am. Chem. Soc.* **1960**, *82* (16), 4433–4434.

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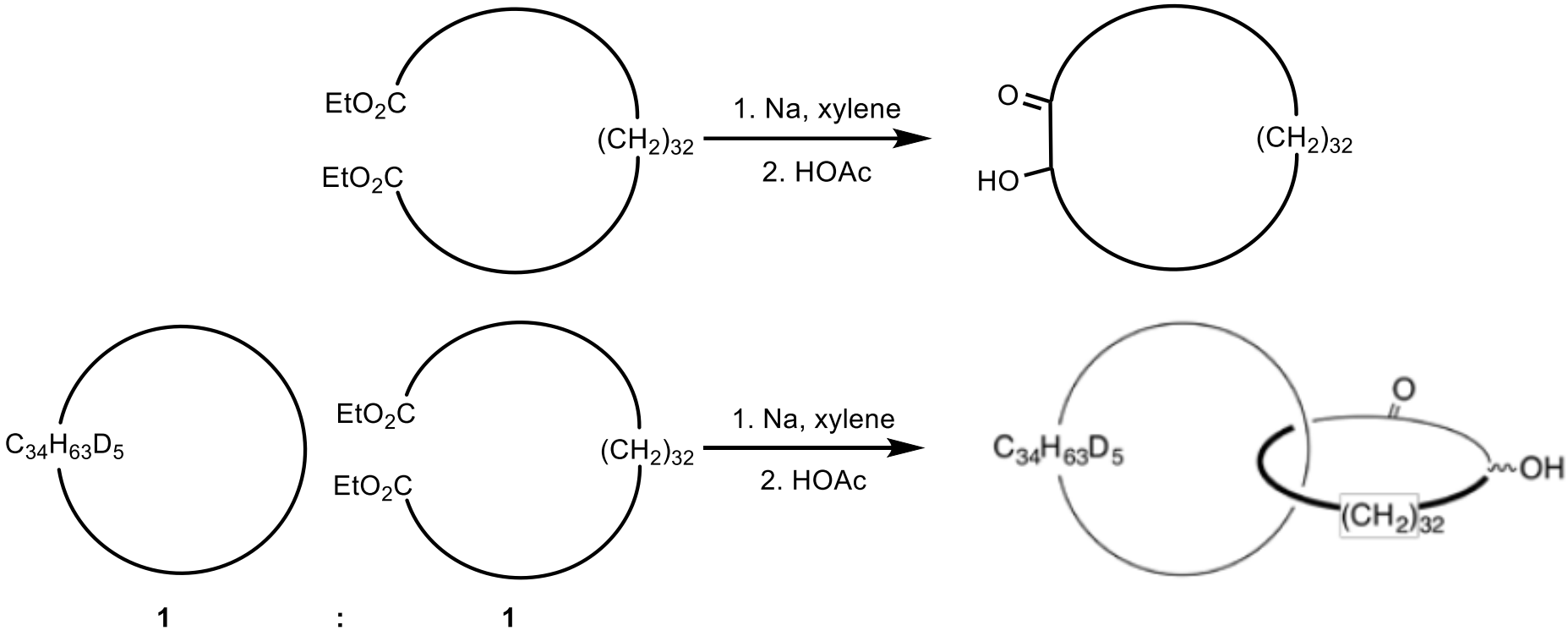


Wasserman et al, *J. Am. Chem. Soc.* **1960**, *82* (16), 4433–4434.

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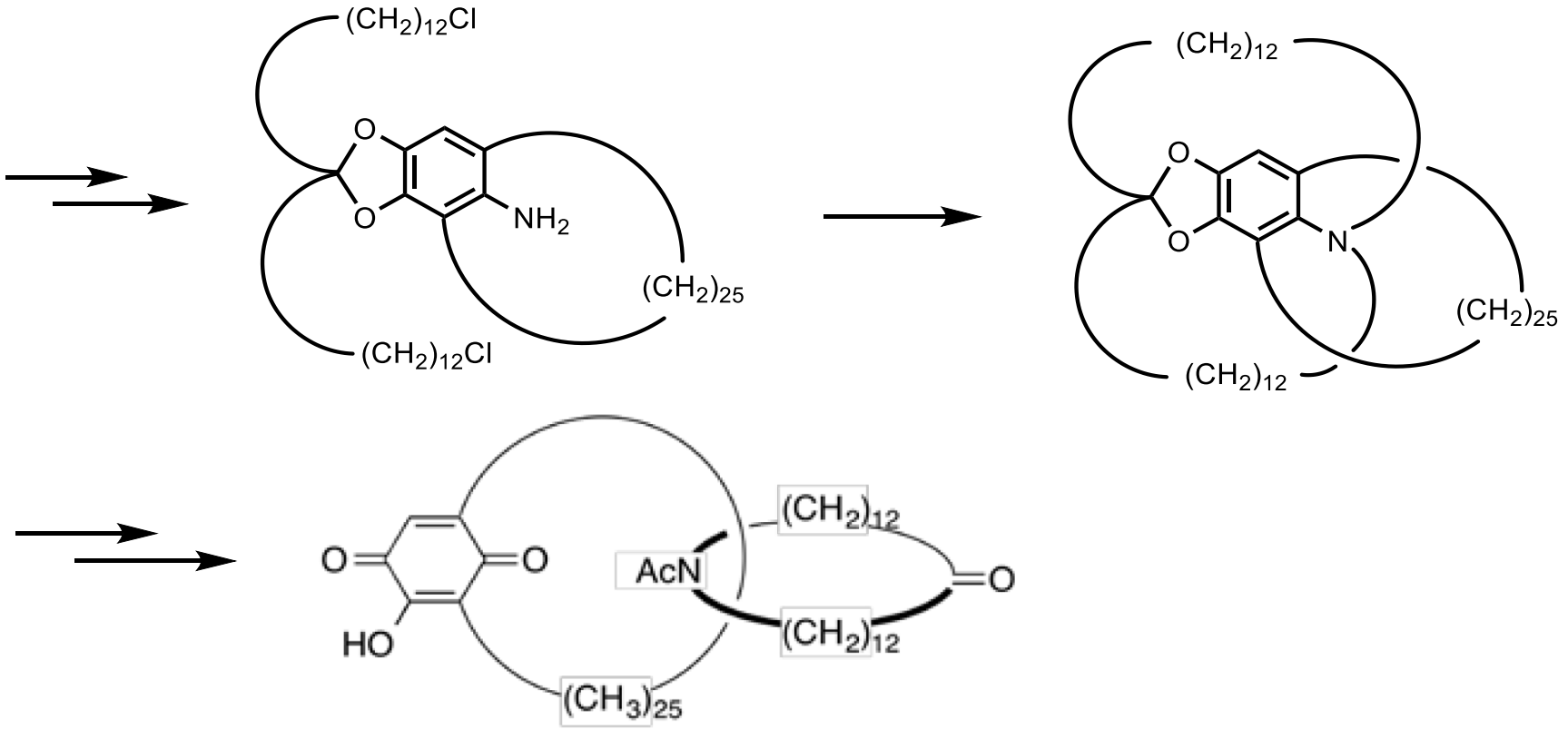


Lüttringhaus et al, *Angew. Chem. Int. Ed.* **1964**, *3* (8), 546–547

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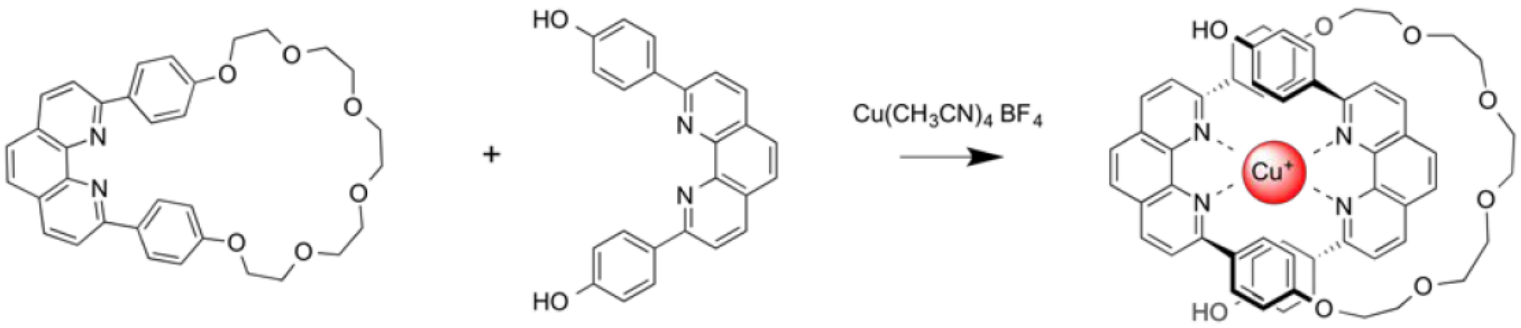
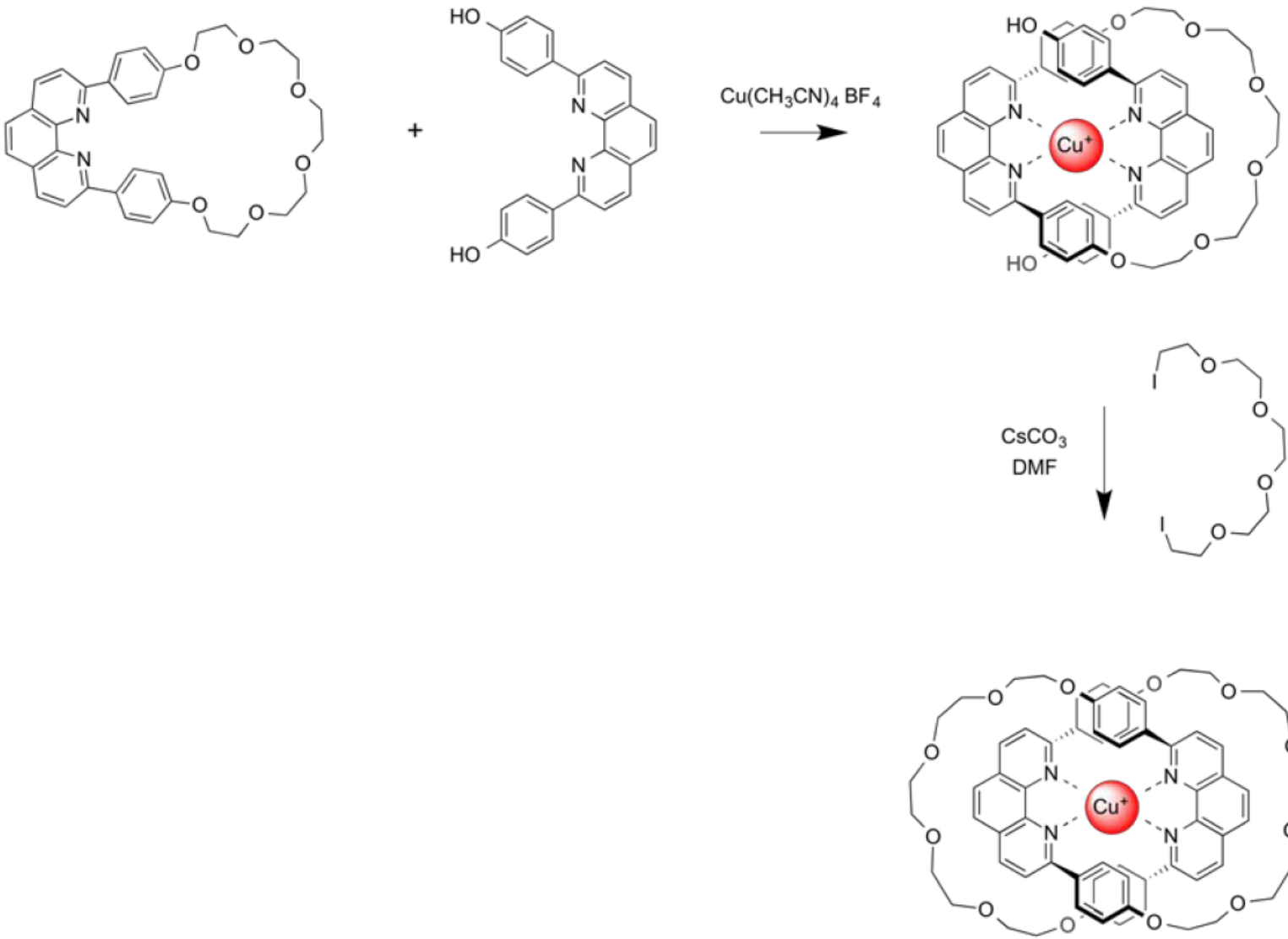



Sauvage et al, *Tetrahedron Lett.* **1983**, *24* (46), 5095–5098.

# Catenane




Sauvage et al, *Tetrahedron Lett.* **1983**, *24* (46), 5095–5098.

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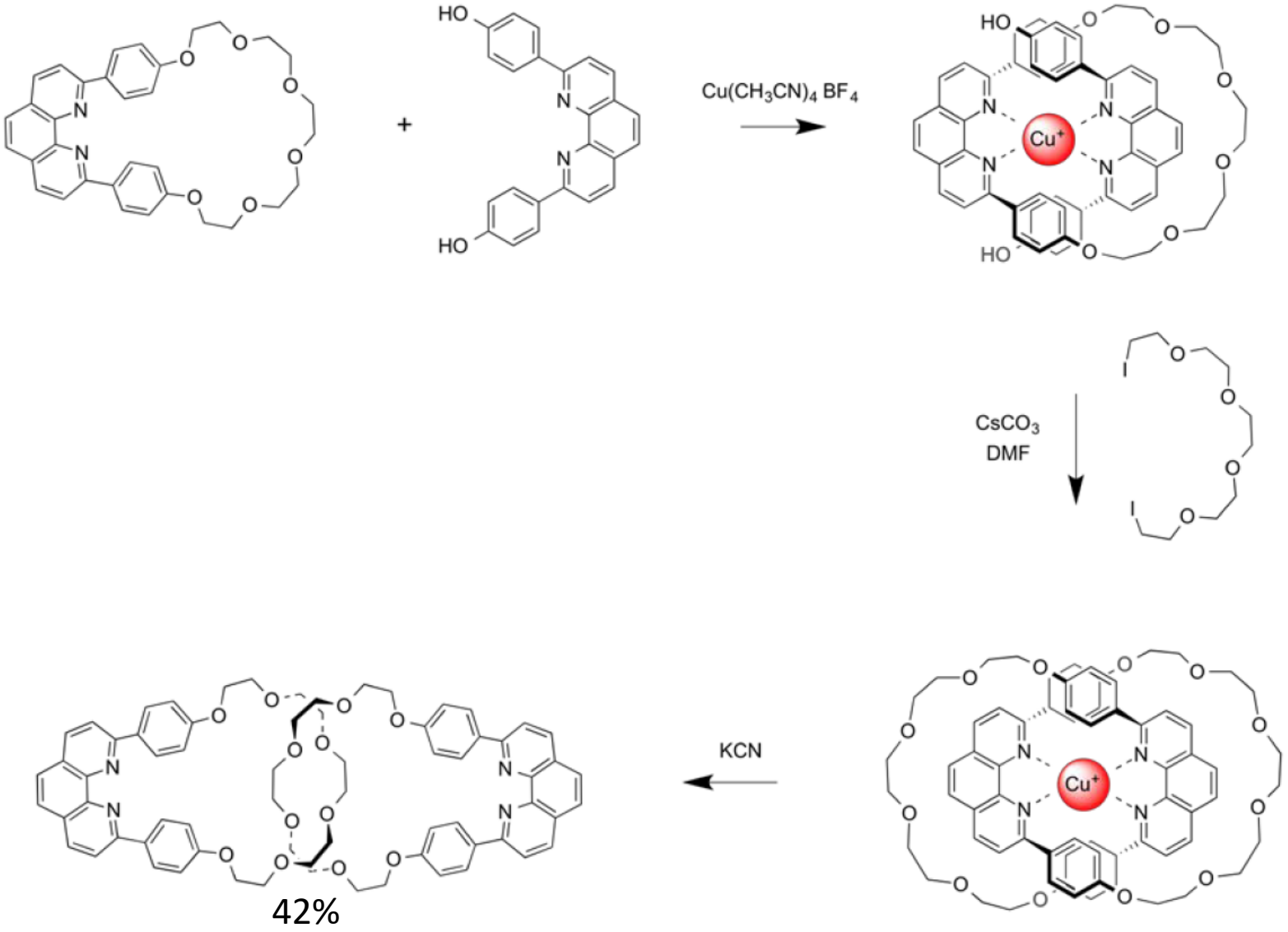
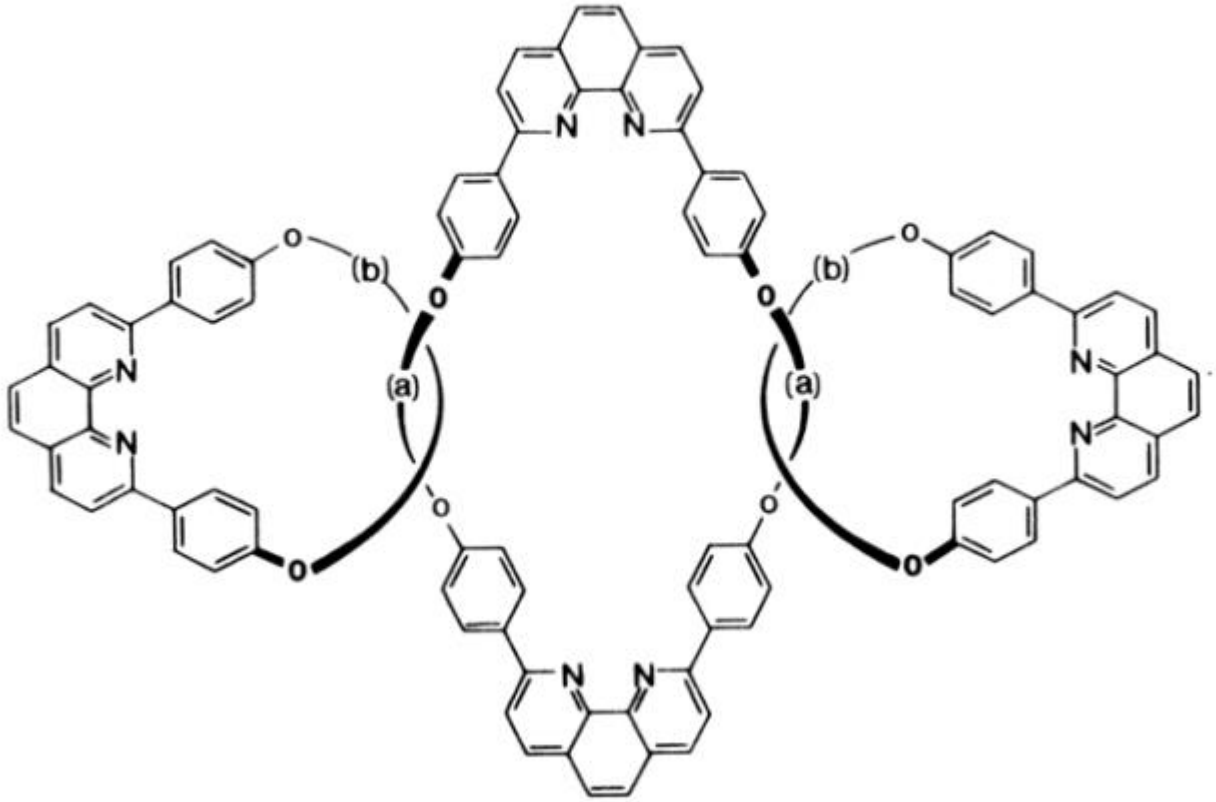



Sauvage et al, *Tetrahedron Lett.* **1983**, *24* (46), 5095–5098.

# Catenane




[3]catenane

Sauvage et al, *J. Am. Chem. Soc.* **1985**, *107*, 6108–6110.

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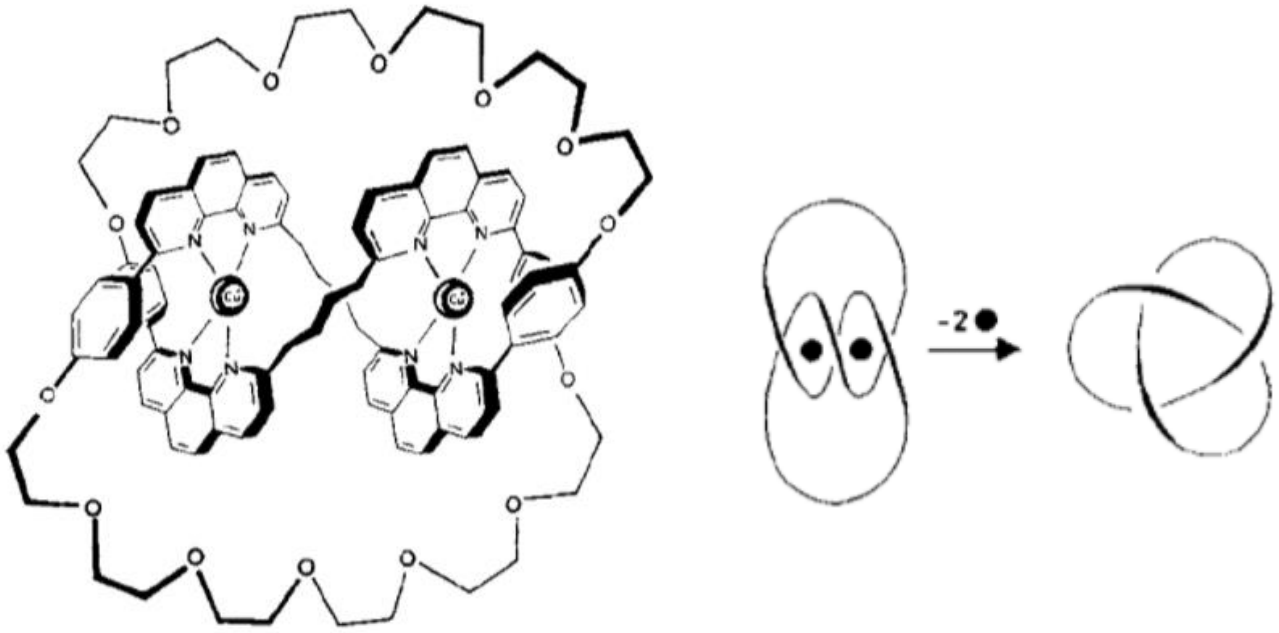


trefoil knot

Sauvage et al, *Angew. Chem. Int. Ed.* **1989**, *28* (2), 189–192.

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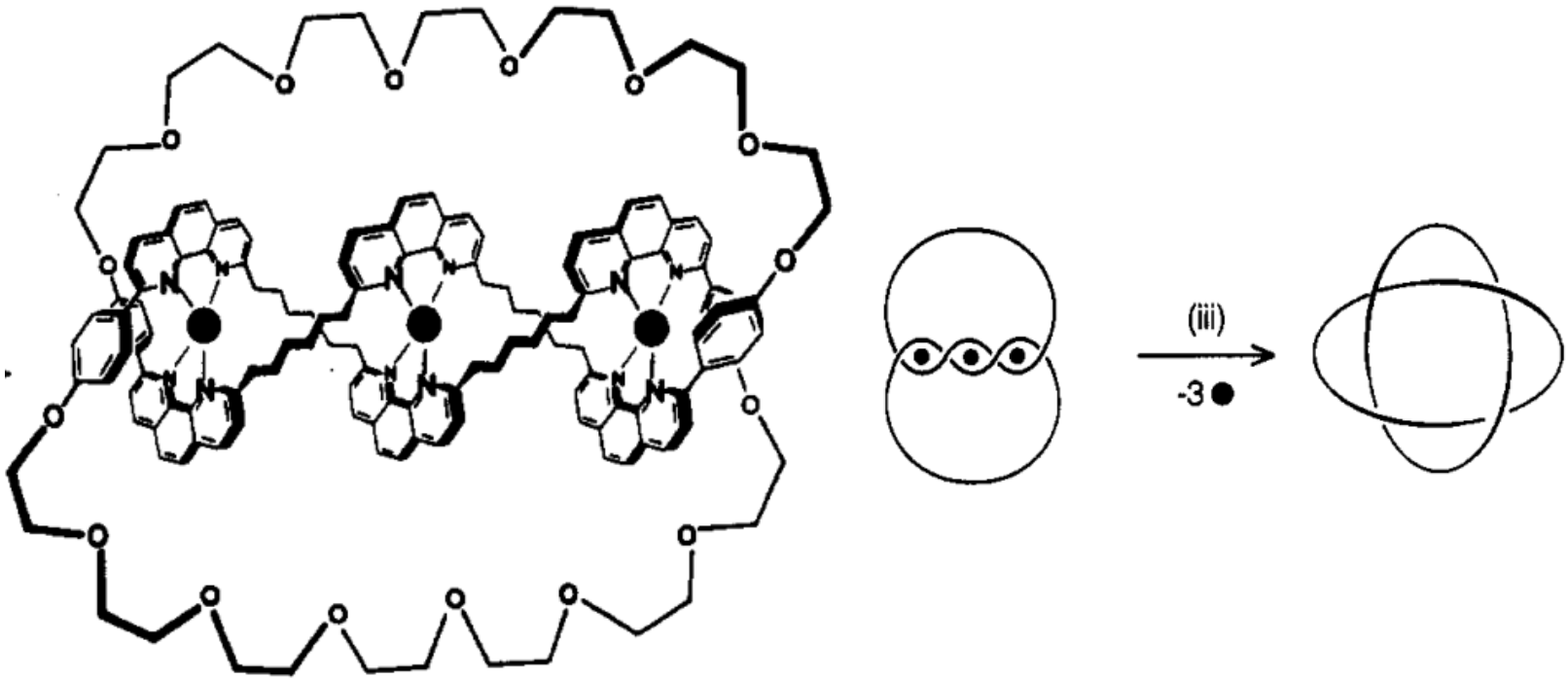


Solomon link

Sauvage et al, *J. Am. Chem. Soc.* **1994**, *116*, 375–376.

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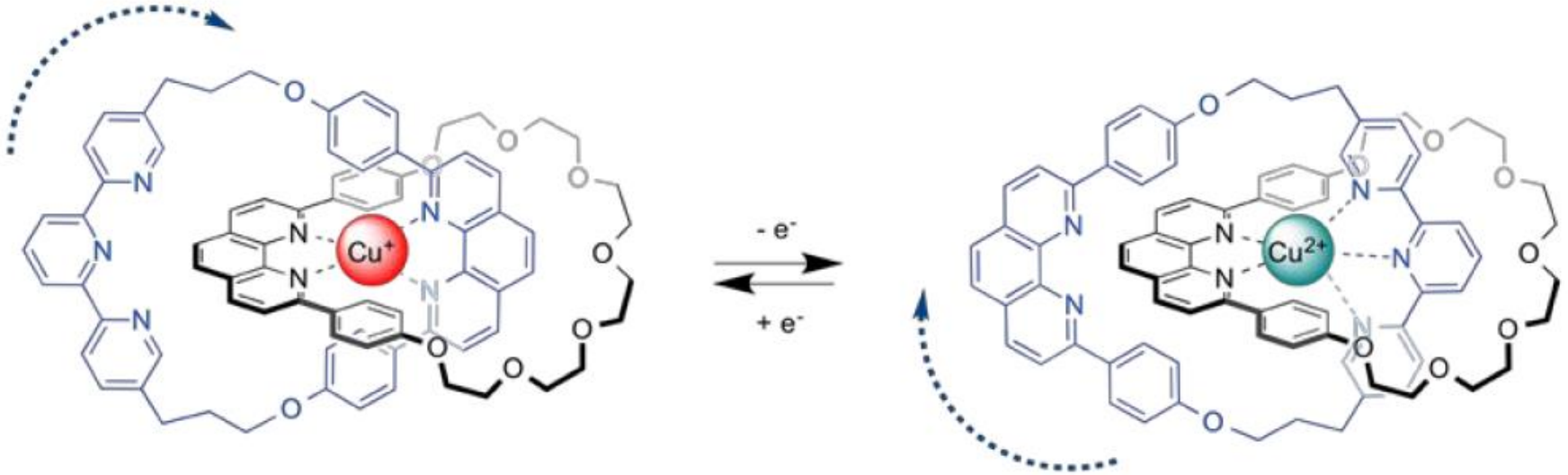


Sauvage et al. *J. Am. Chem. Soc.* **1994**, *116* (20), 9399–9400.

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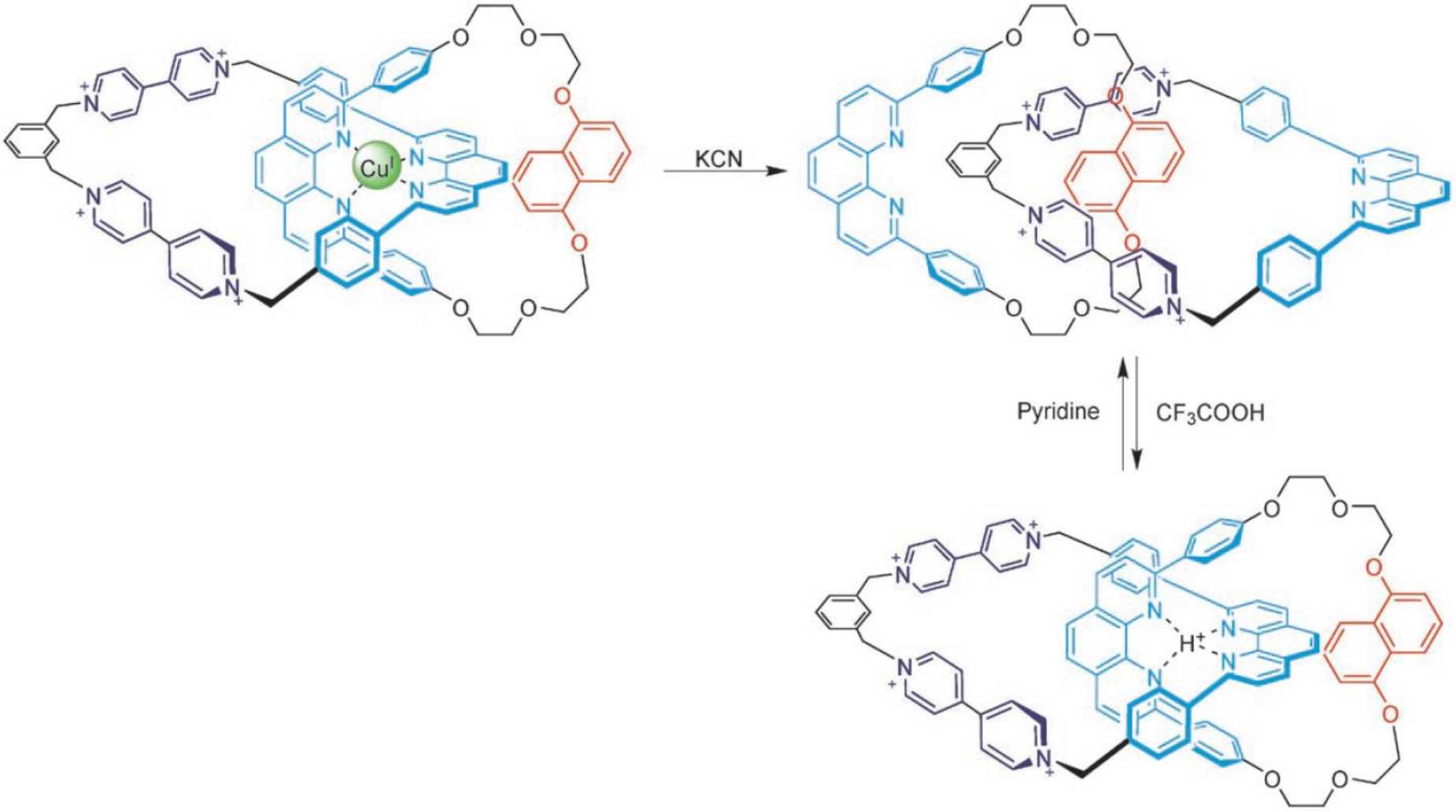


Sauvage & Stoddart et al, *J. Am. Chem. Soc.* **1996**, *118*, 3905 – 3913.

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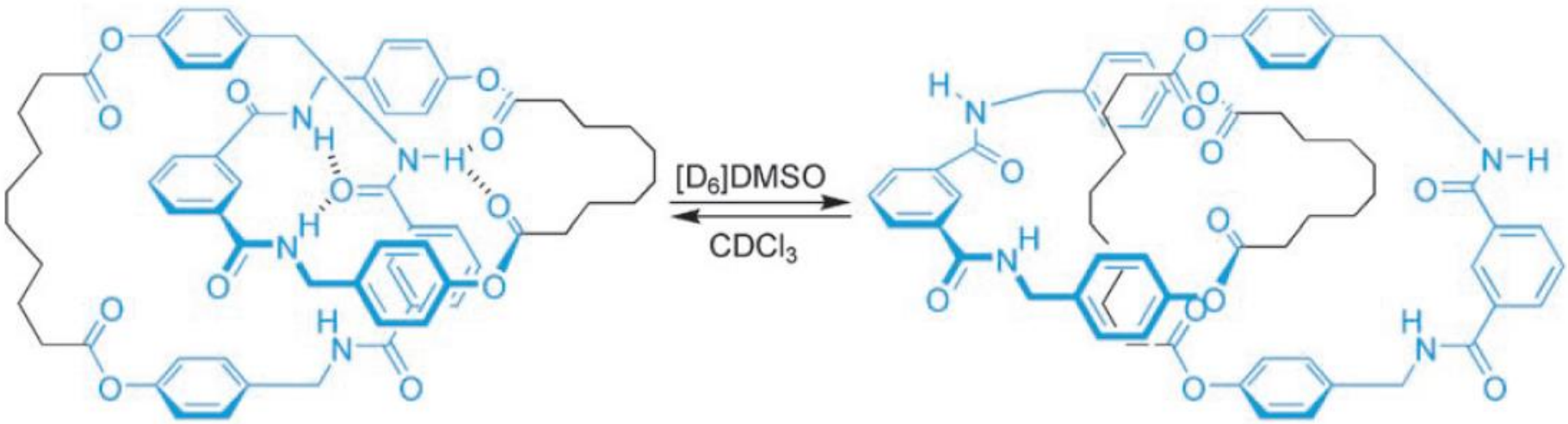


Slawin et al, *Angew. Chem. Int. Ed. Engl.* **1996**, *35*, 306-310..

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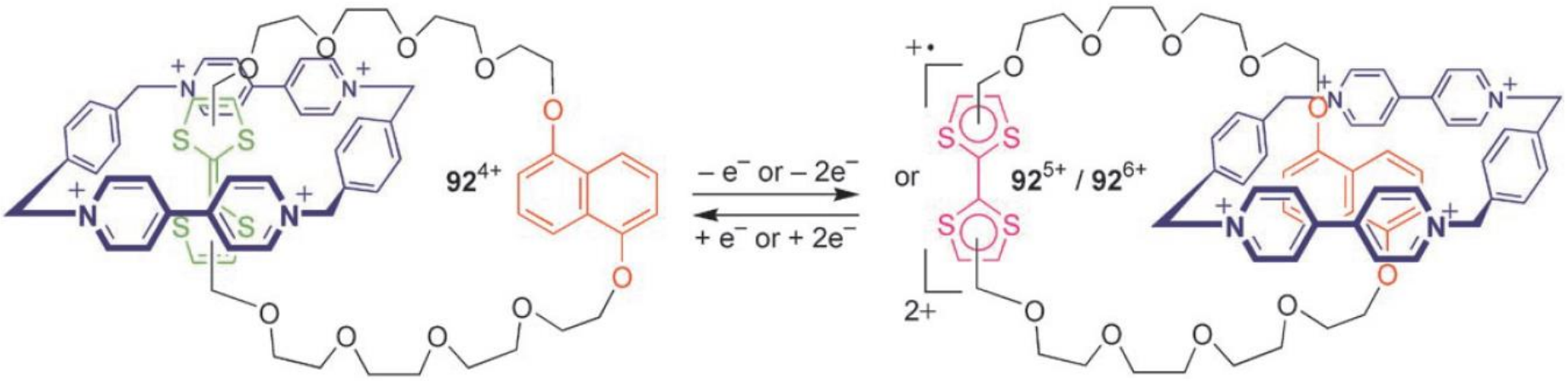


Stoddart et al, *J. Org. Chem.* **2000**, *65*, 1924 – 1936.

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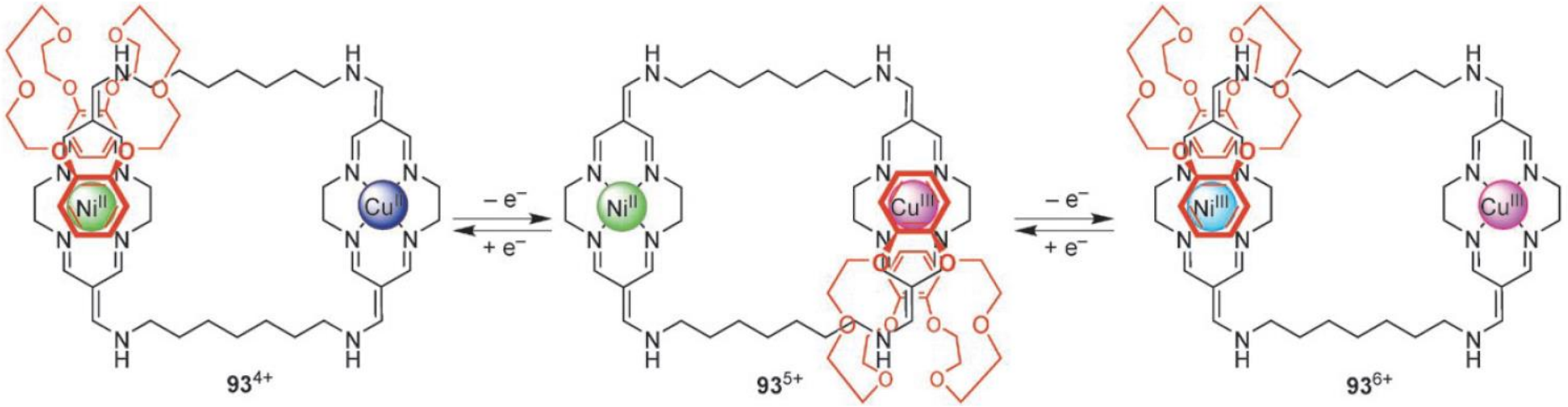


Woz´niak et al, *Angew. Chem. Int. Ed.* **2004**, *43*,1668 – 1672.

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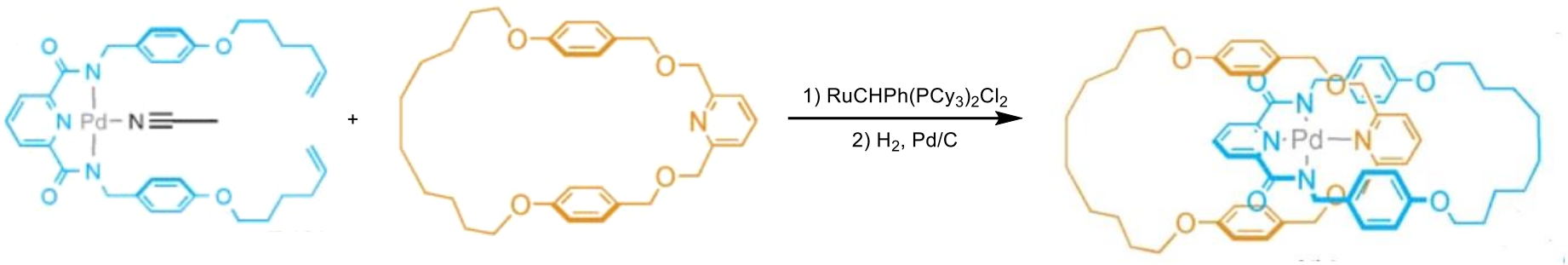


Walkera et al. *Chem. Commun*. **2005**,4919 – 4921.

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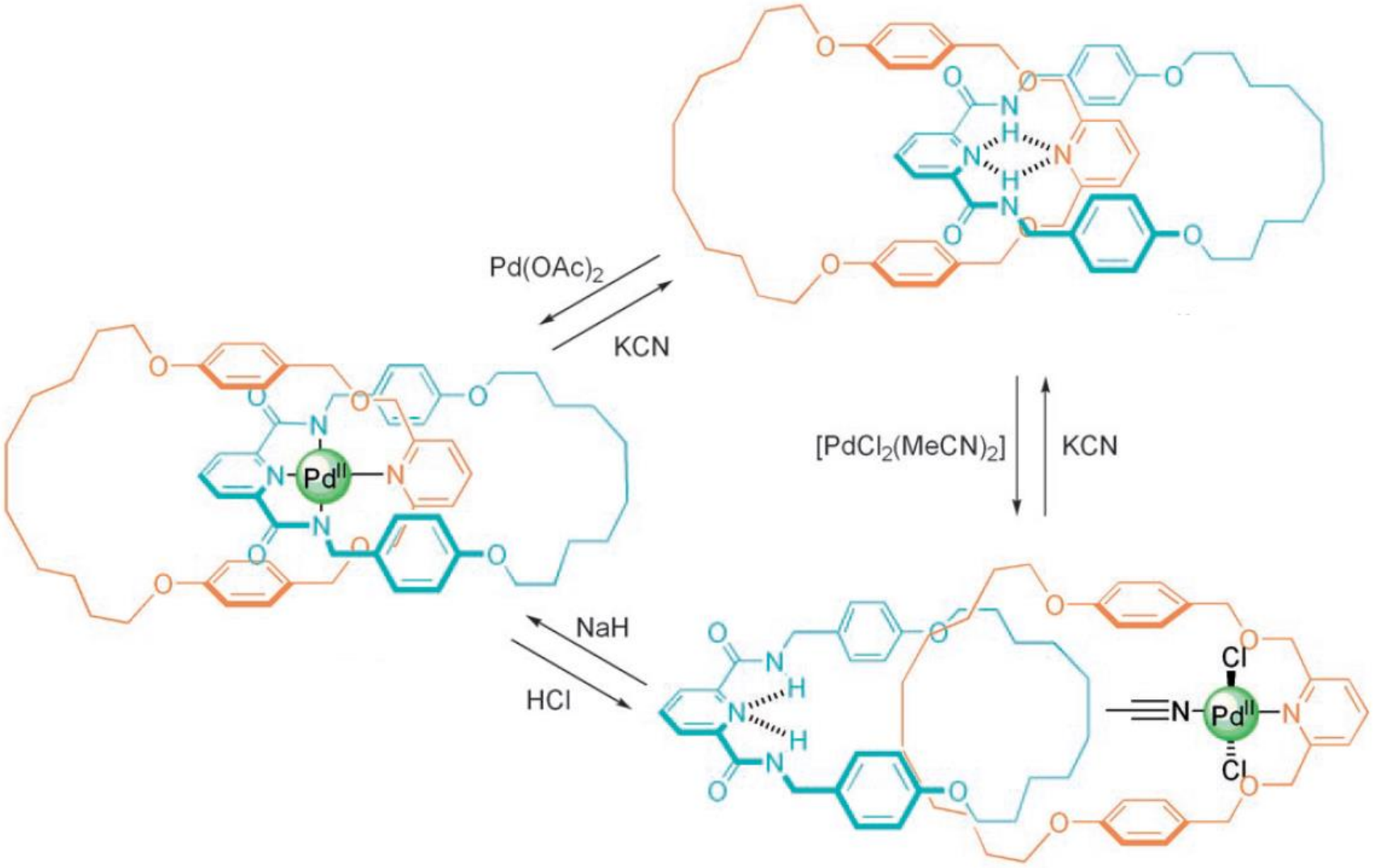


Walkera et al. *Chem. Commun*. **2005**,4919 – 4921.

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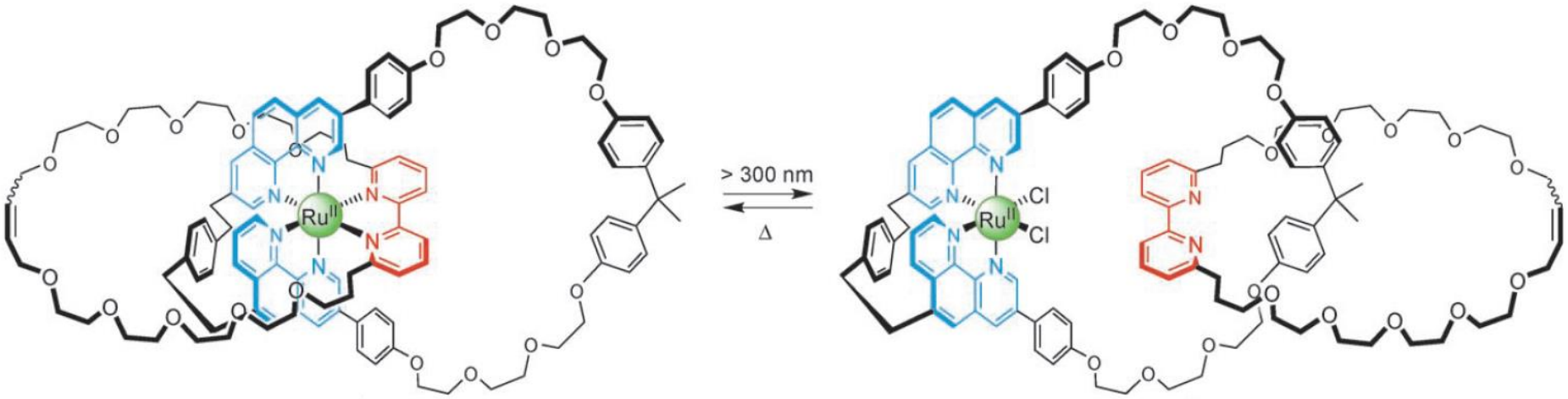


Sauvage et al. *Angew. Chem. Int. Ed.* **2004**, *43*, 2392 – 2395.

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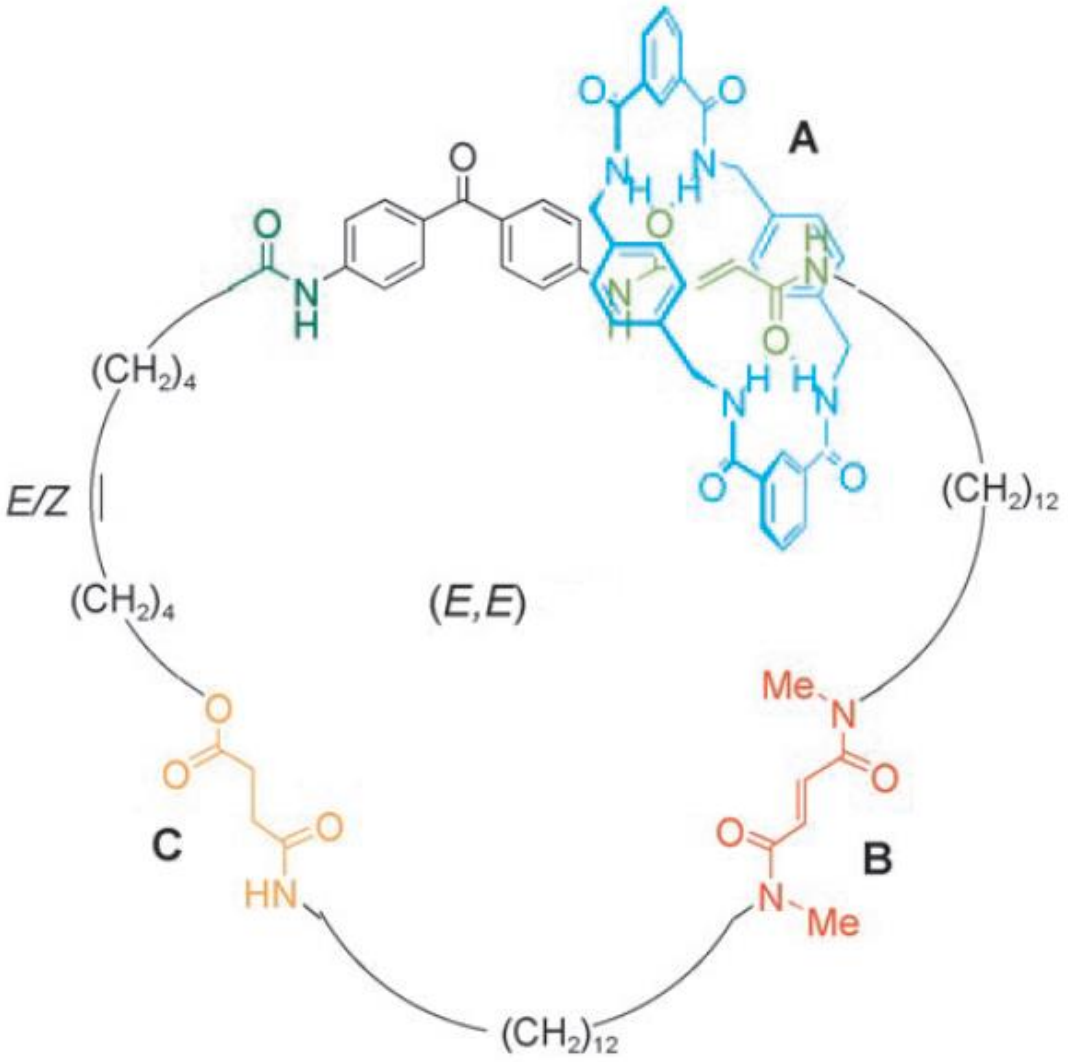


Sauvage et al. *J. Am. Chem. Soc.* **1996**, *118*,11 980 – 11981.

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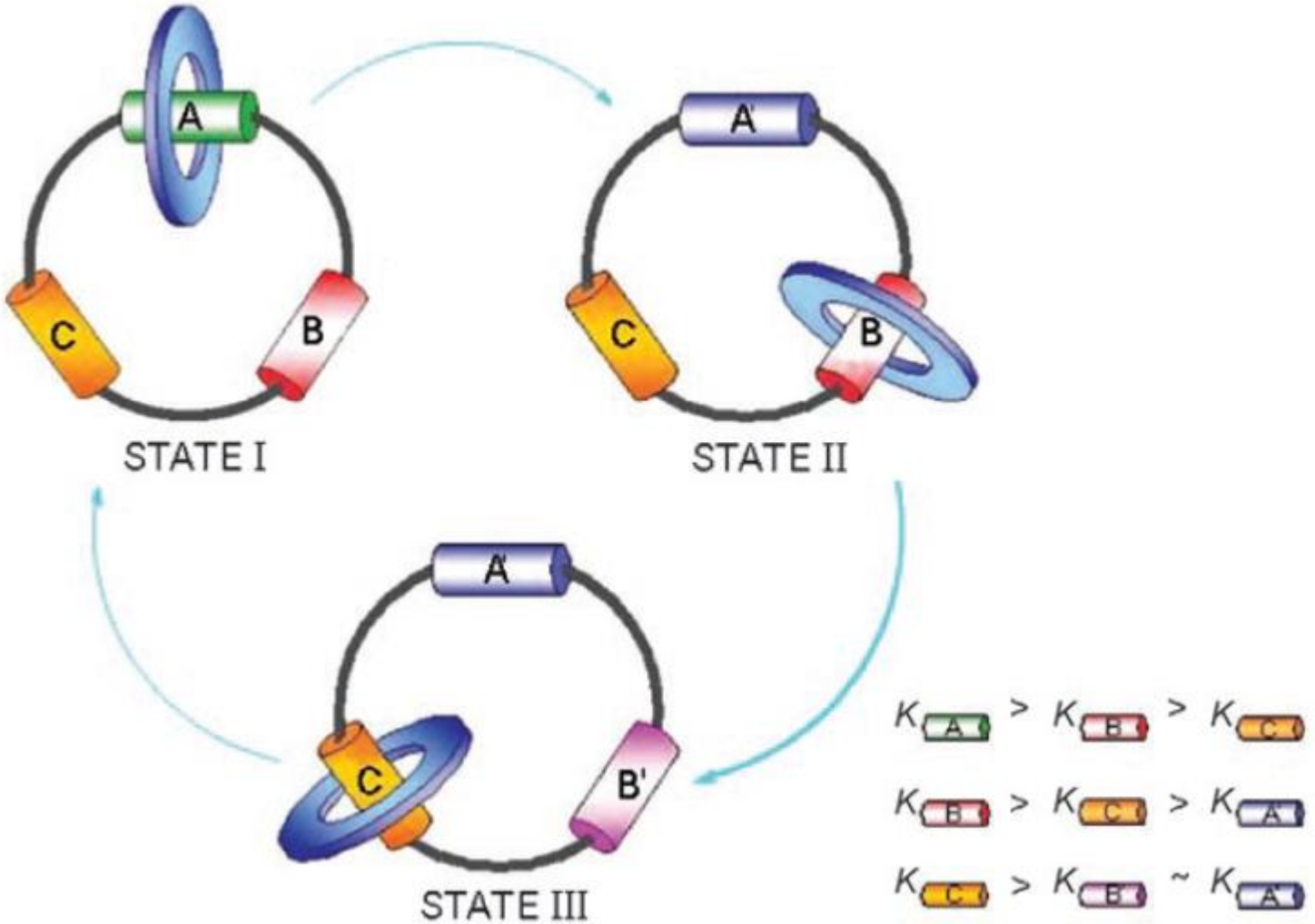


Sauvage et al. *J. Am. Chem. Soc.* **1996**, *118*,11 980 – 11981.

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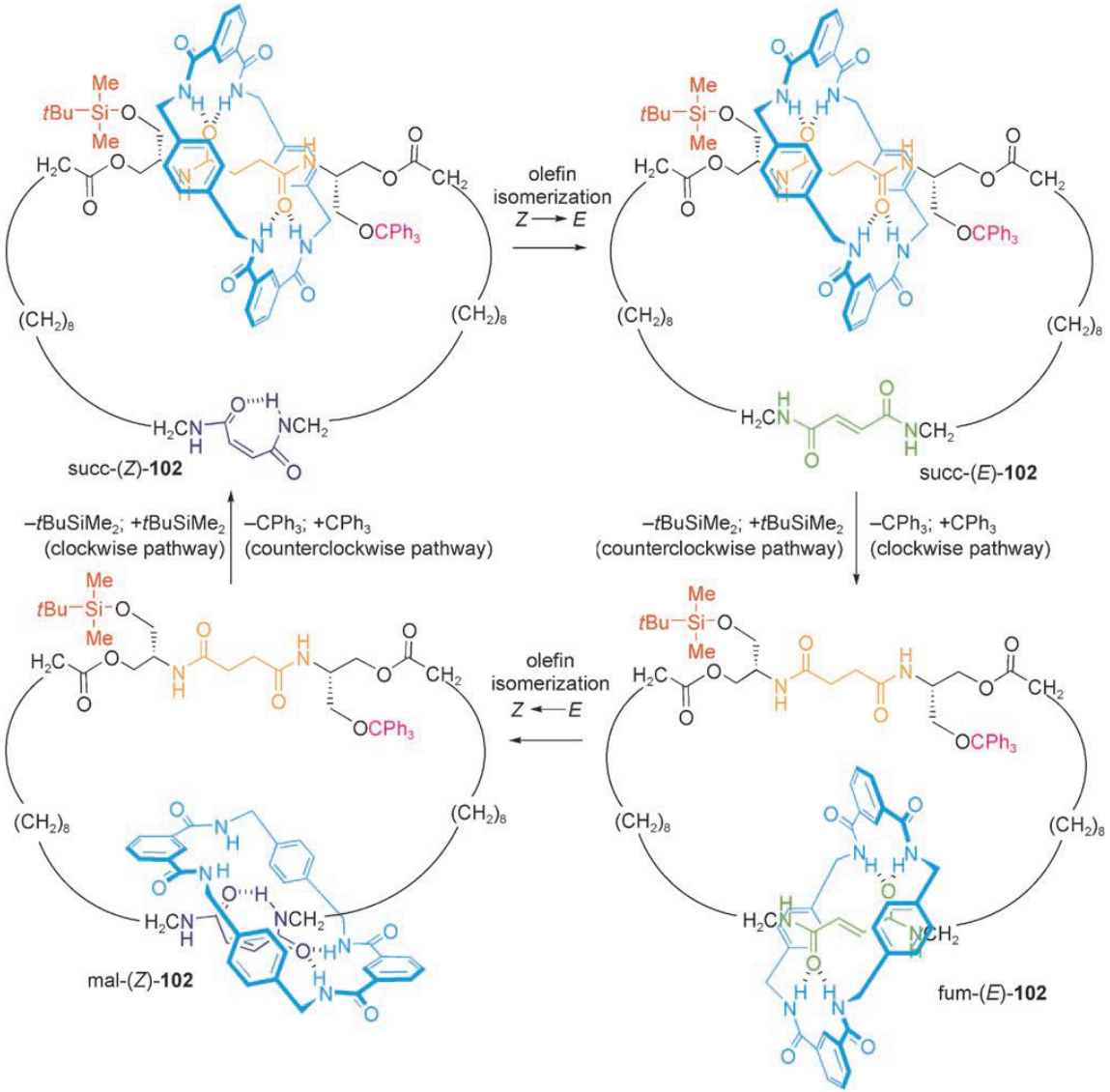
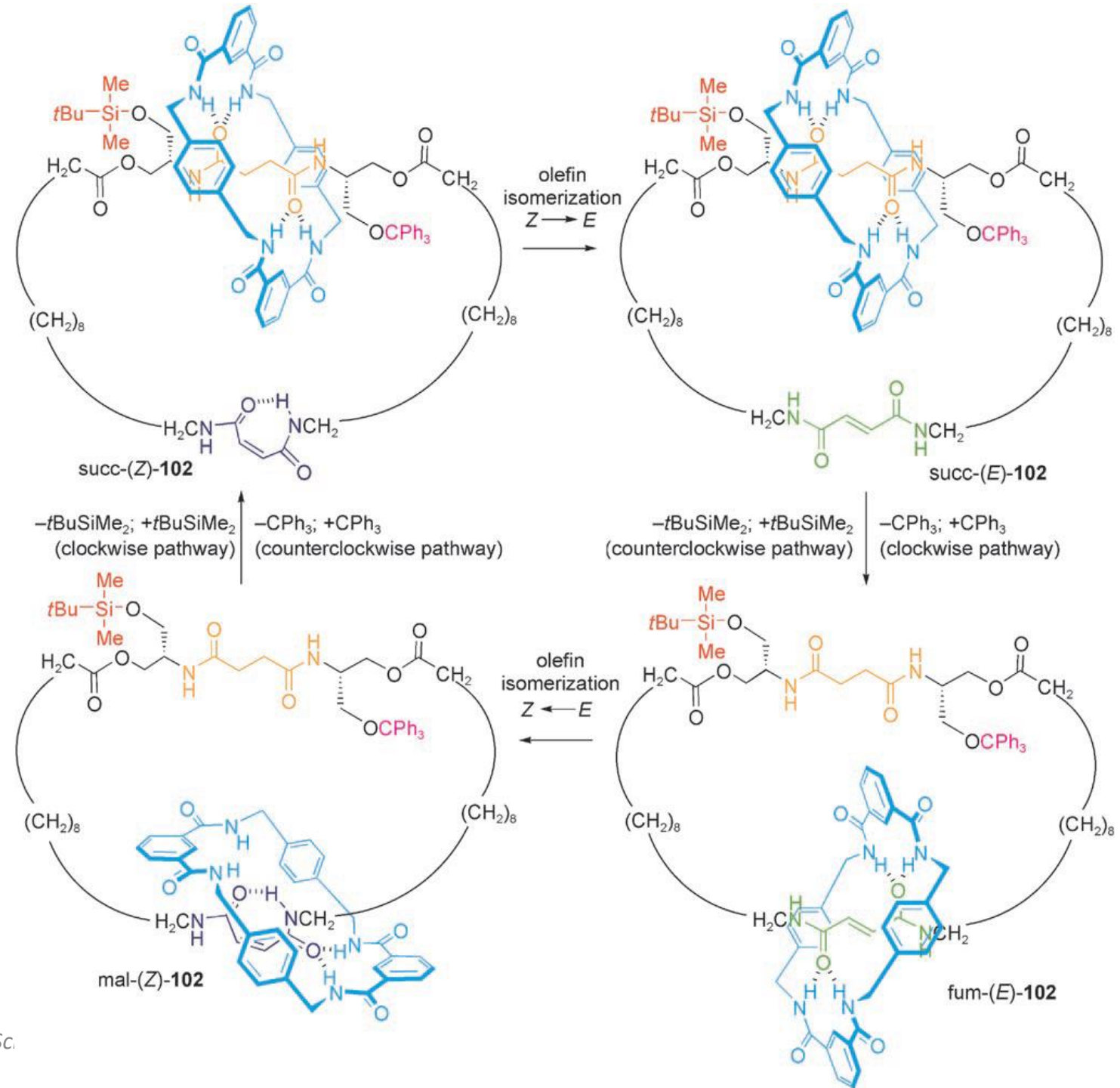
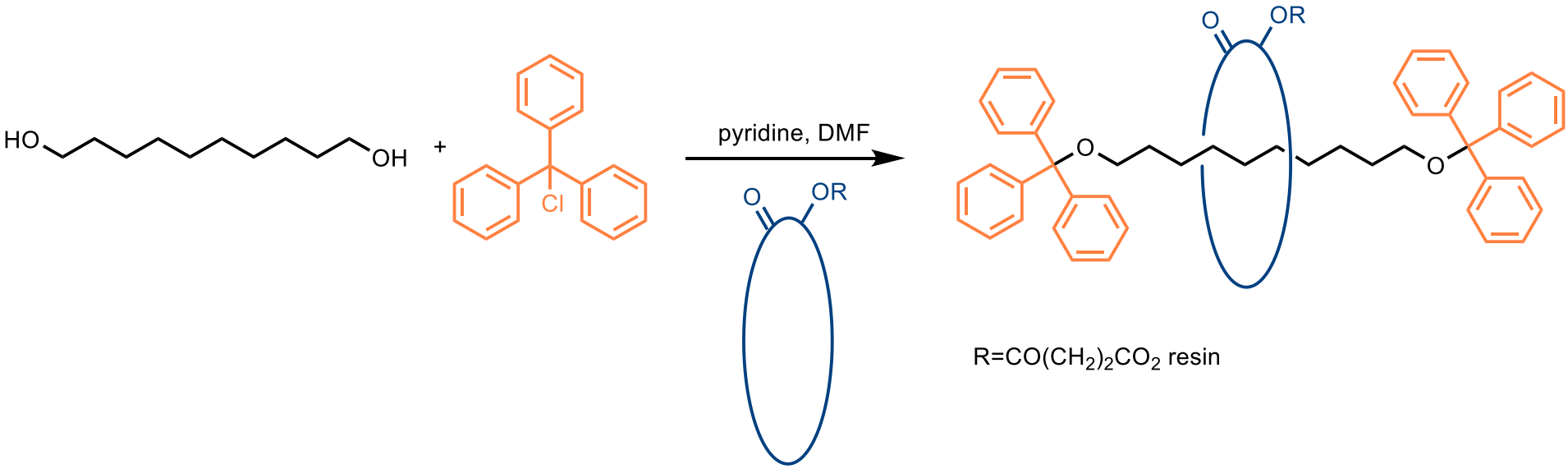



Leigh et al. *Science* **2004**, *306*, 1532 – 1537.




Leigh et al. *Sc*

# Rotaxane




Harrison et al, *J. Am. Chem. Soc.* **1967**, *89 (22),* 5723–5724.

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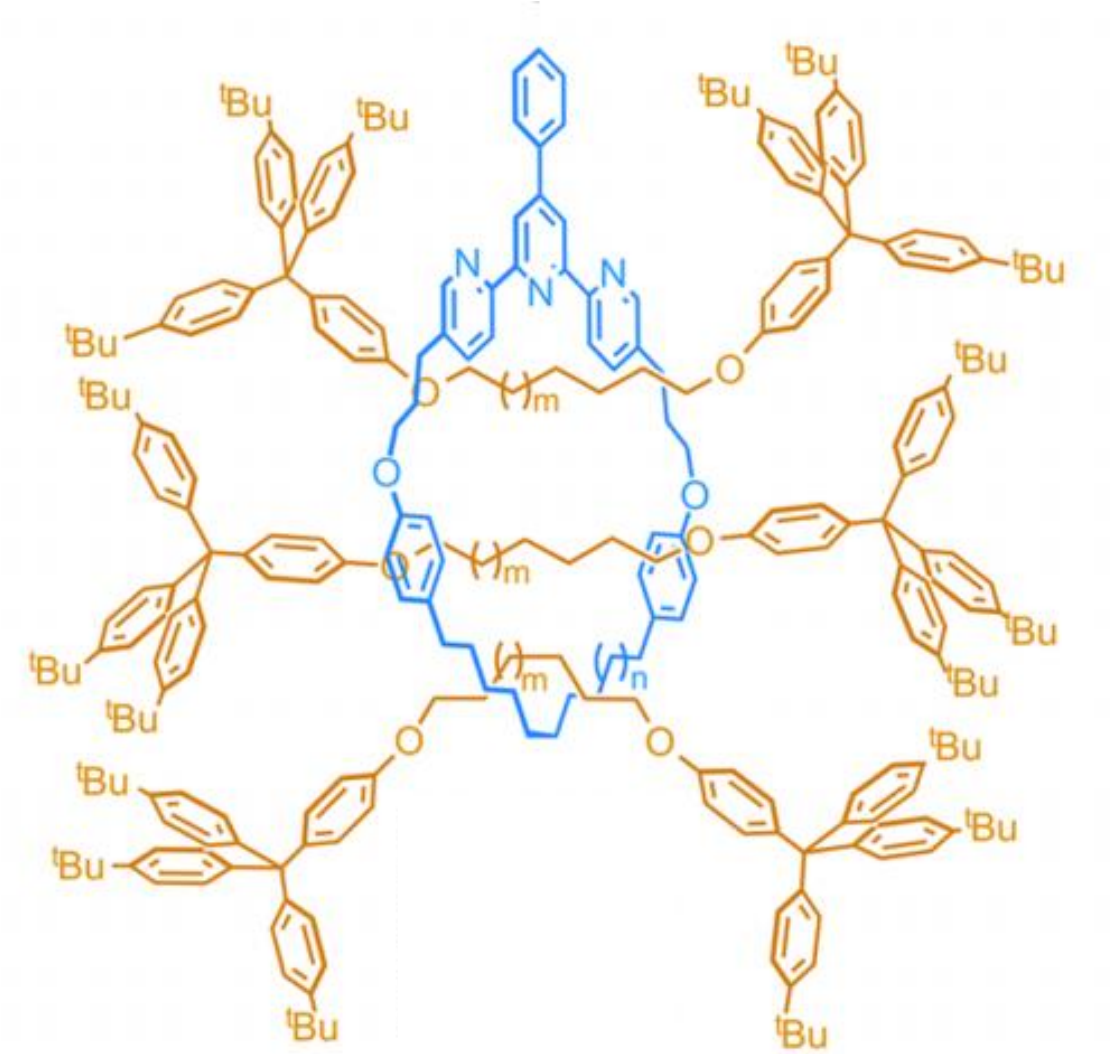


Wu et al, *J. Am. Chem. Soc.*, **2016**, *138*, 12643–12647

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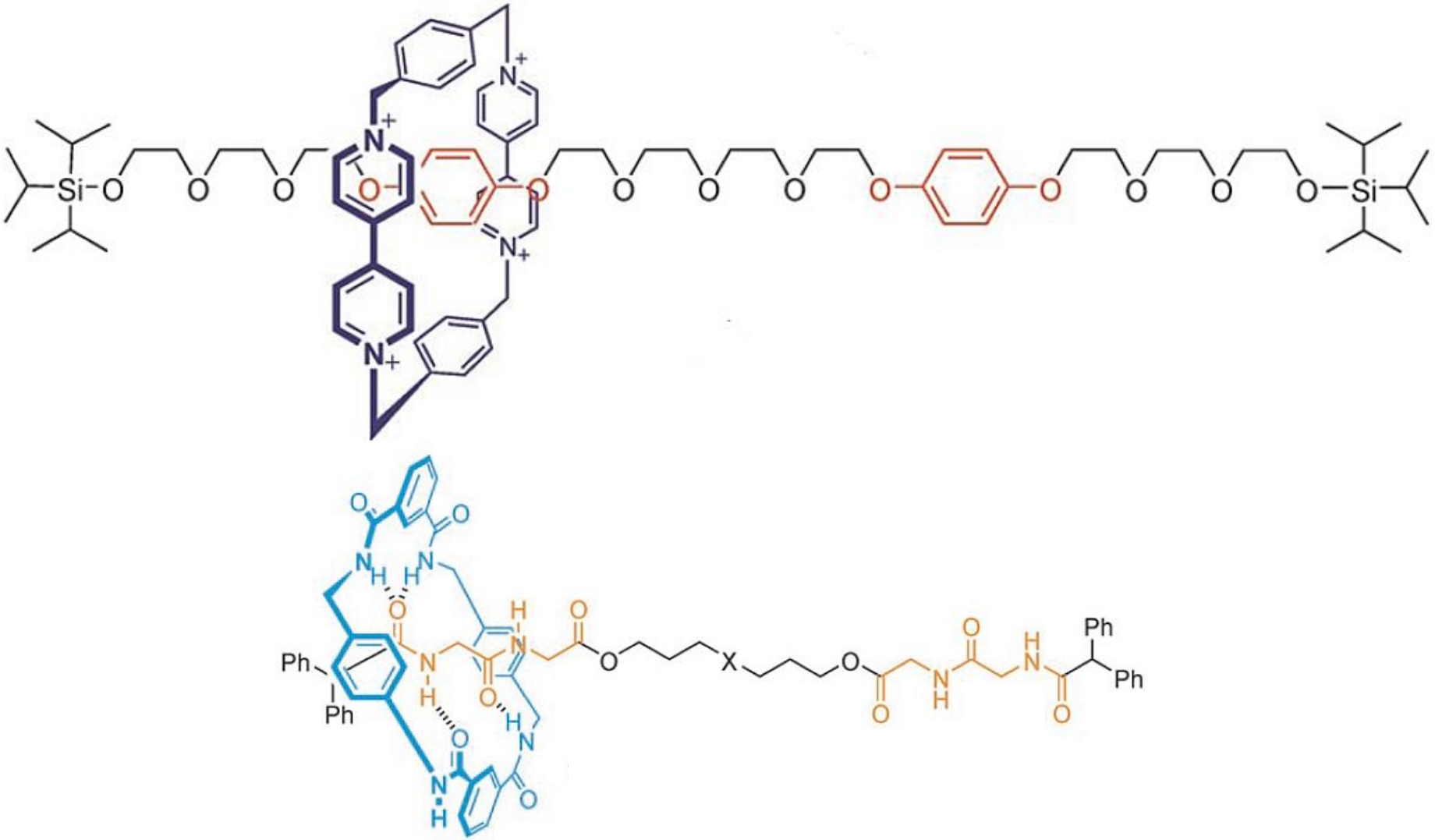
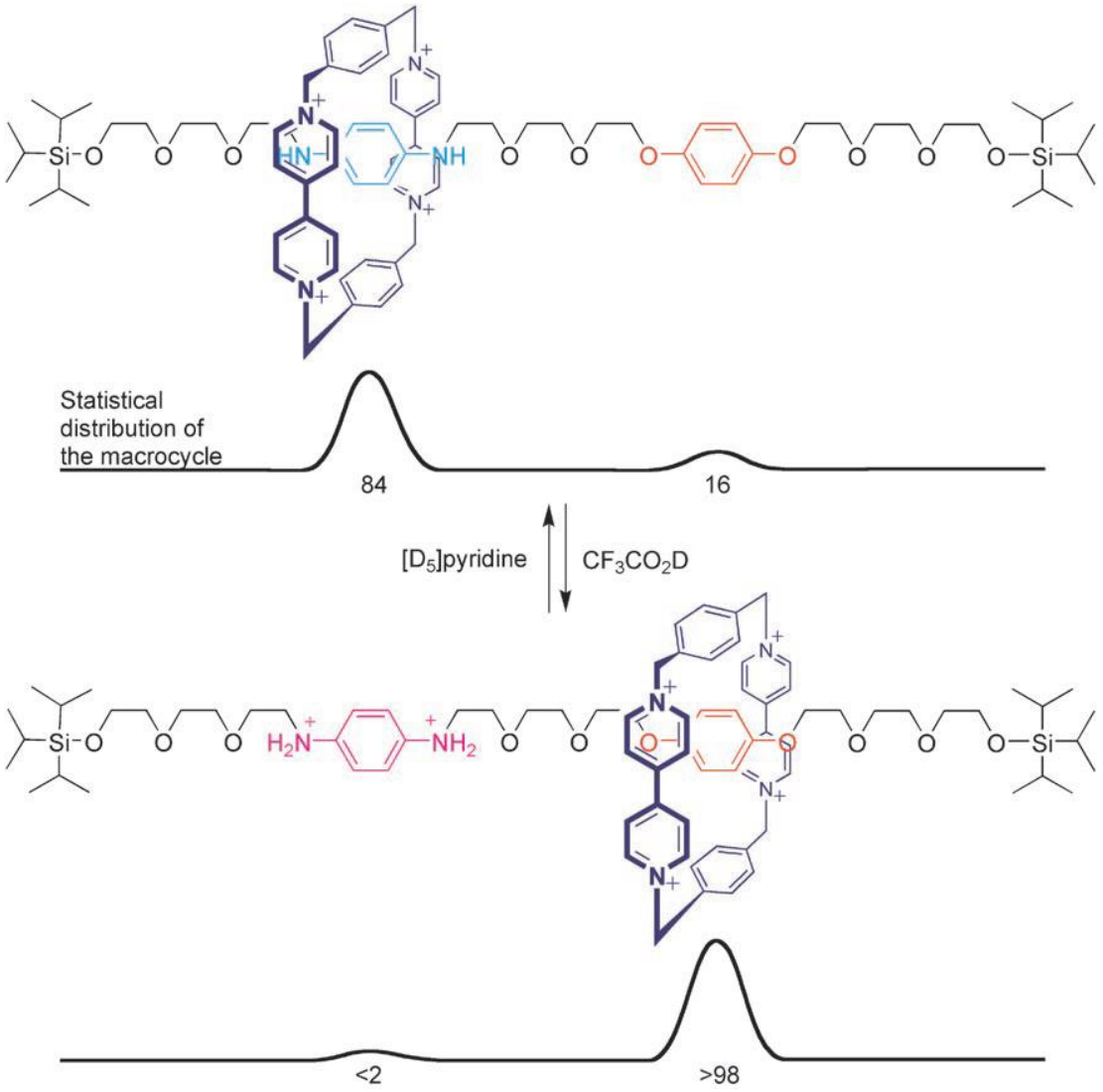


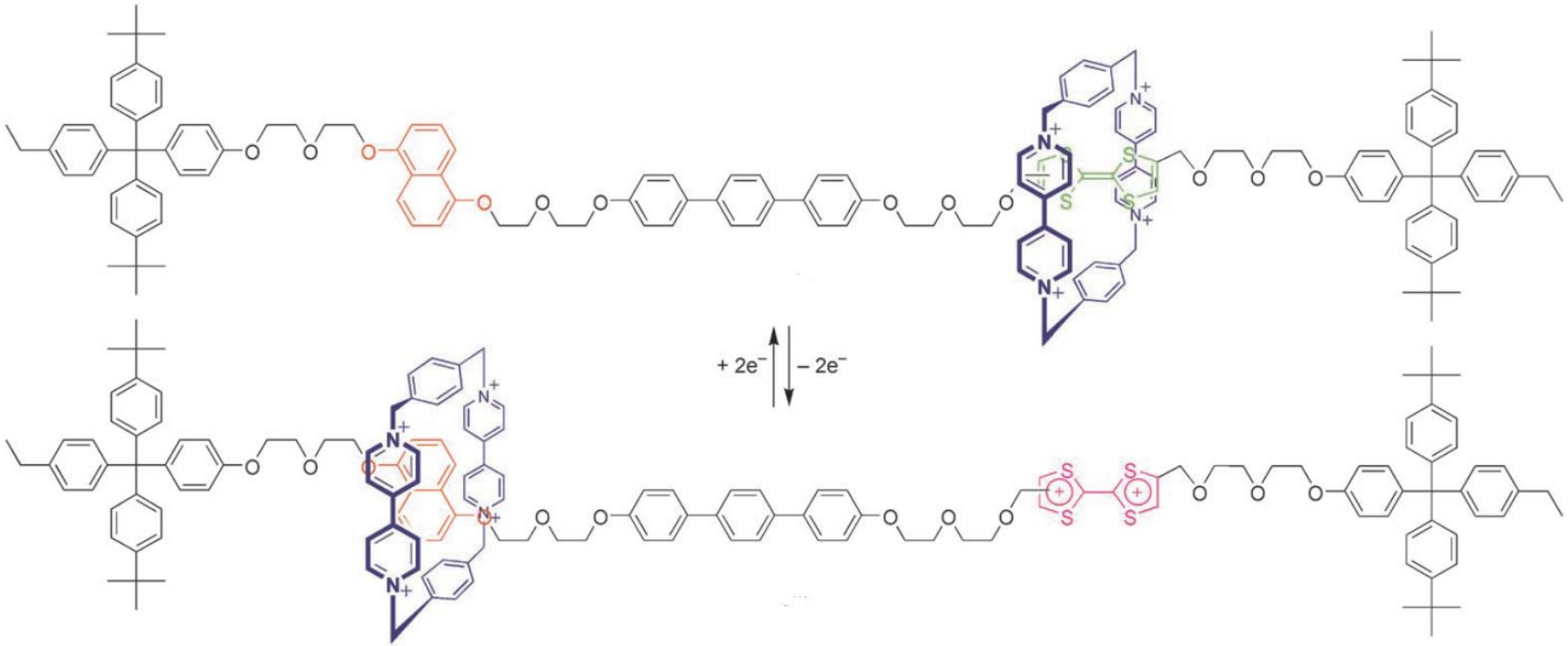

Stoddart et al, *J. Am. Chem. Soc.* **1991**, *113*, 5131 – 5133.
Leigh et al, *J. Am. Chem. Soc.* **1997**, *119*, 11092 – 11093.

# Rotaxane - Molecular Shuttle



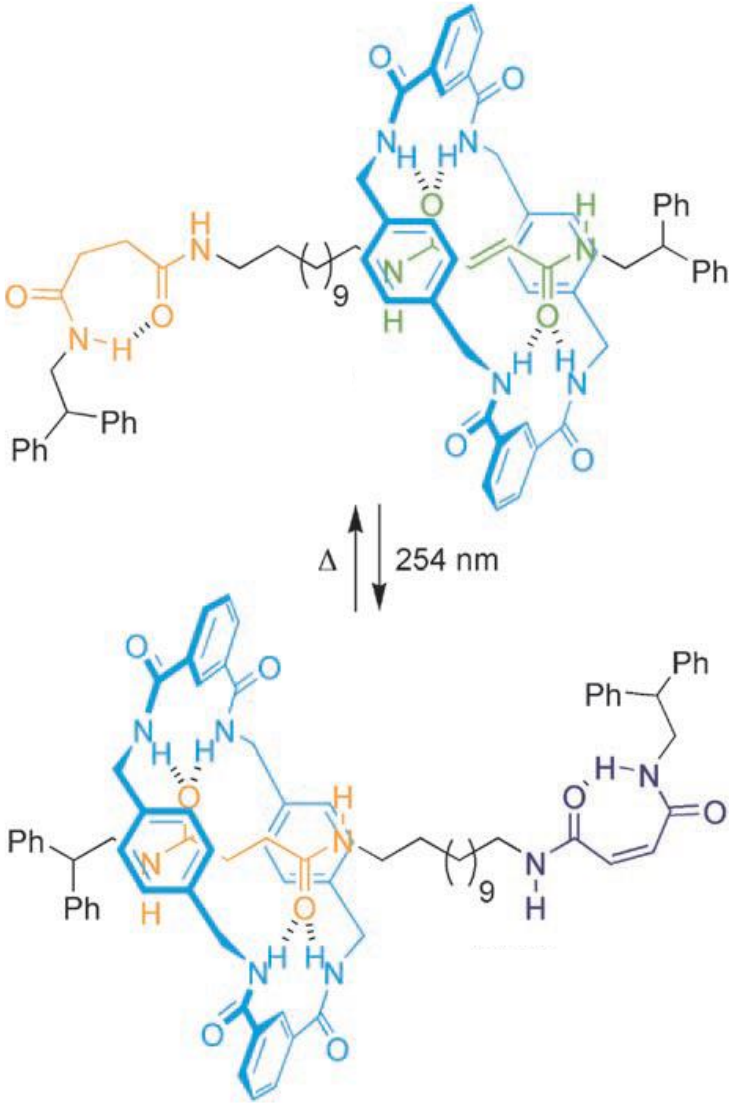

Stoddart et al, *Nature*, **1994**, *369*, 133 – 137.

# Rotaxane - Molecular Shuttle




Stoddart et al, *Angew. Chem. Int. Ed.* **2003**, *42*, 1491 – 1495.

# Rotaxane - Molecular Shuttle




Leigh et al, *Angew. Chem. Int. Ed.* **2003**, *42*, 2296 – 2300.

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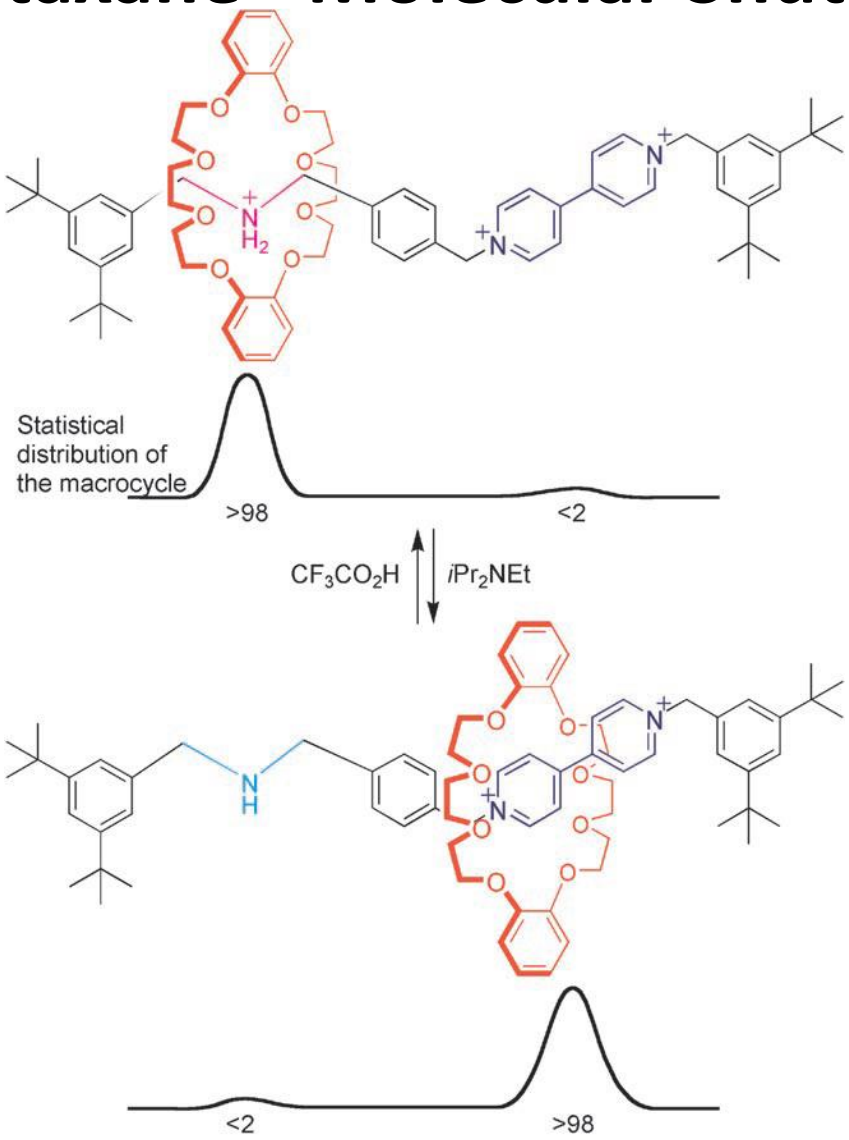
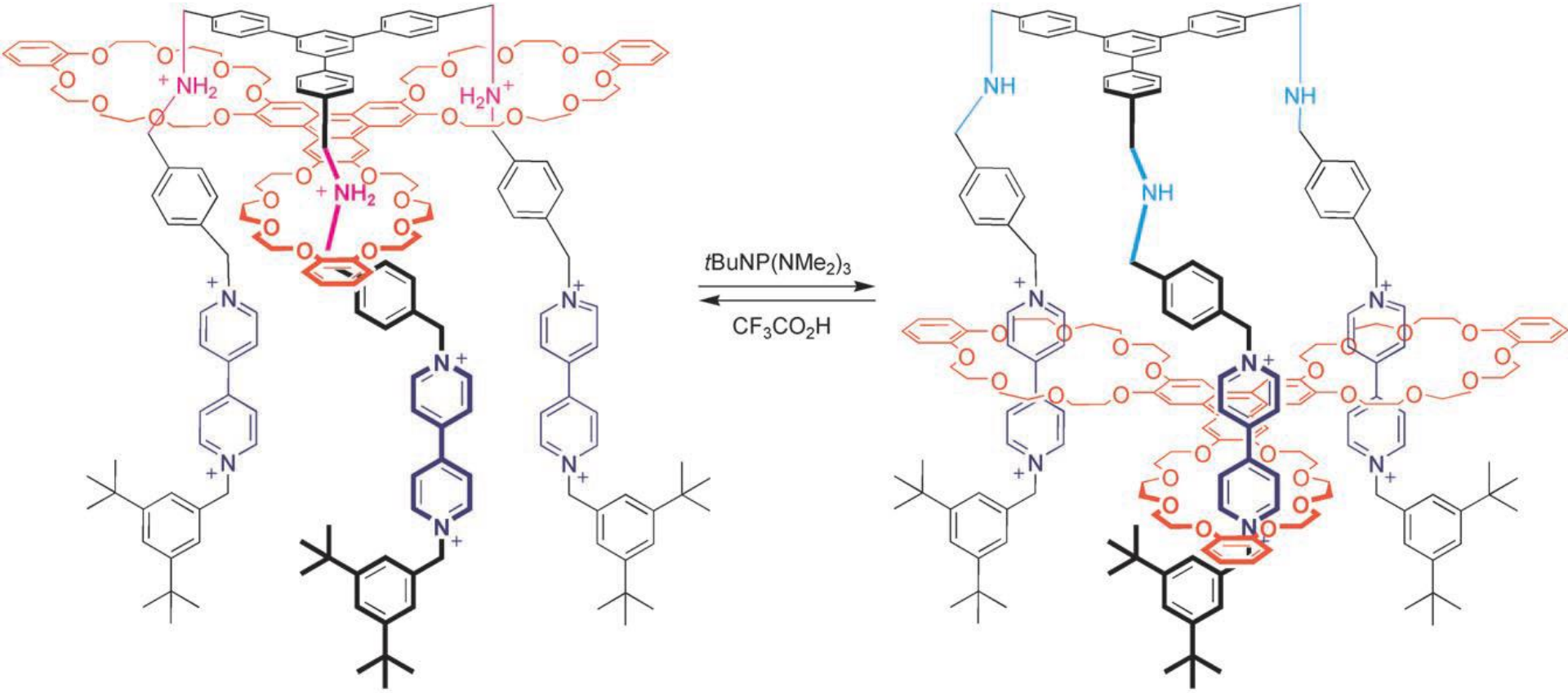


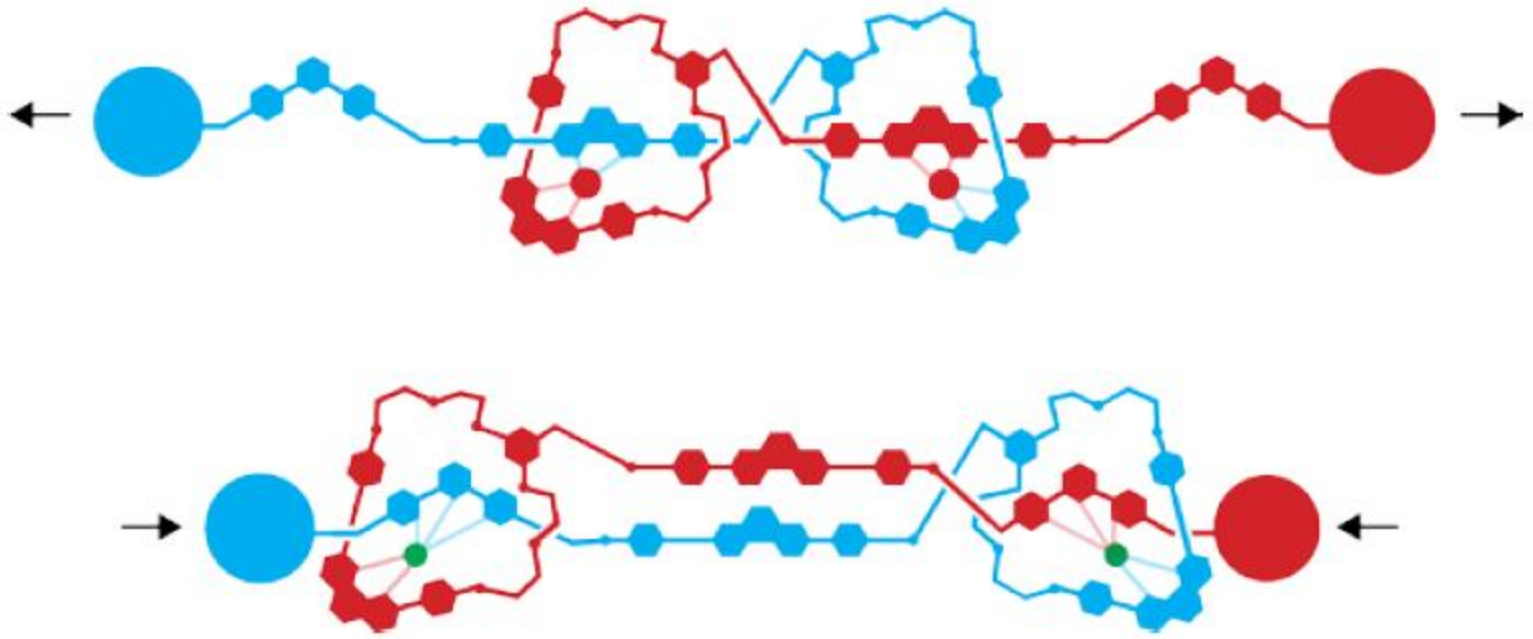

Stoddart et al, *Angew. Chem.* **1997**, *109*, 1991 – 1994

# Rotaxane - Molecular elevator



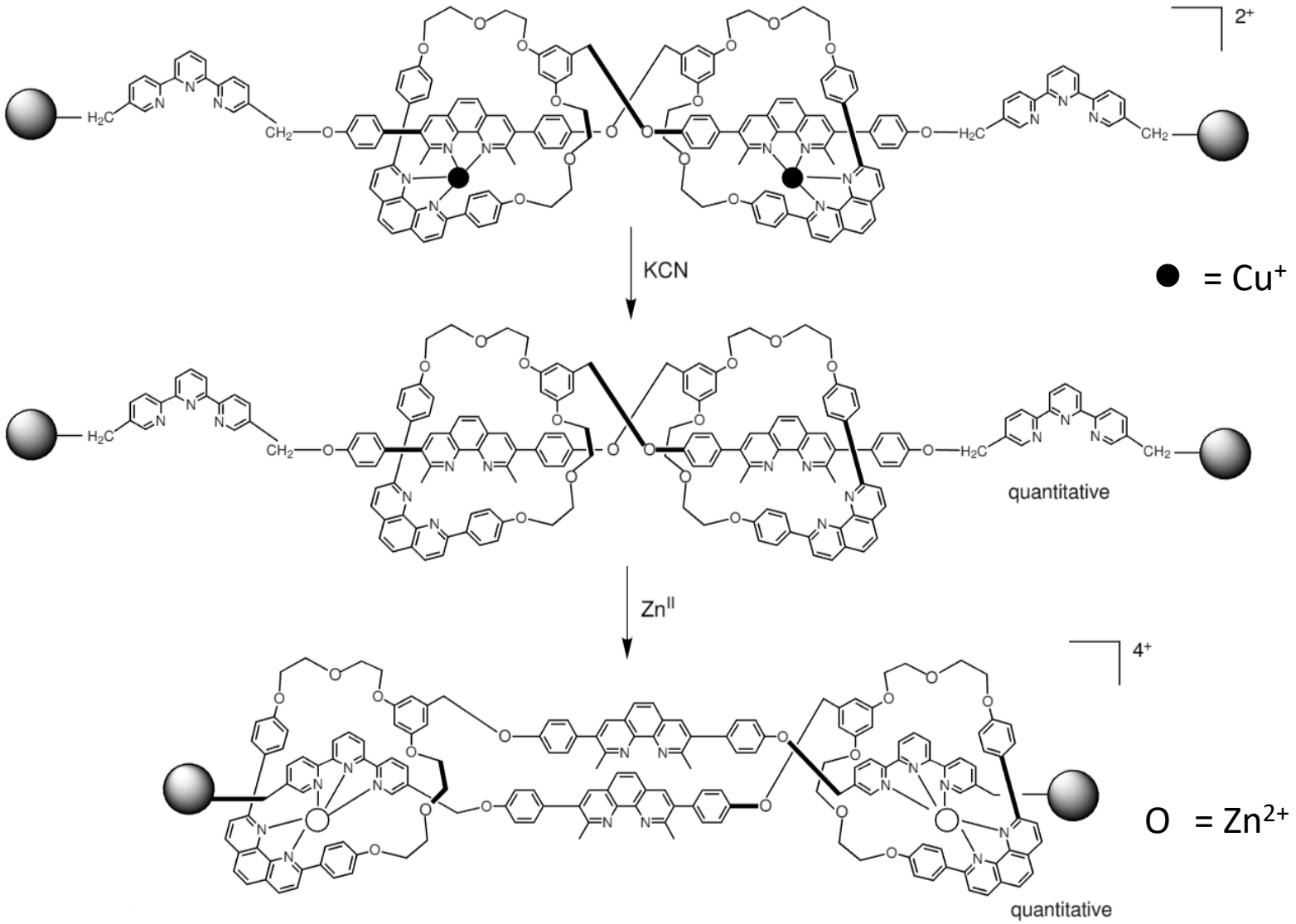

Stoddart et al, *Science* **2004**, *303*, 1845 – 1849

# Rotaxane – Molecular muscles



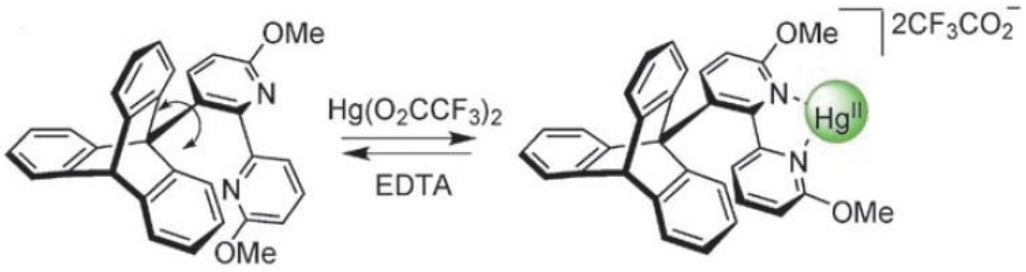
Sauvage et al, A*ngew. Chem. Int. Ed.* **2000**, *39* (18), 3284–3287.

# Rotaxane – Molecular muscles



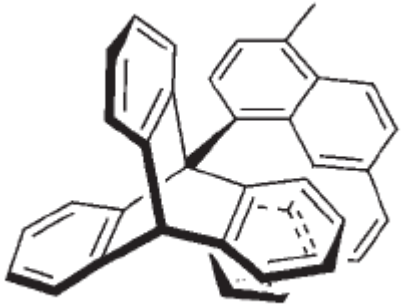

Sauvage et al, A*ngew. Chem. Int. Ed.* **2000**, *39* (18), 3284–3287.

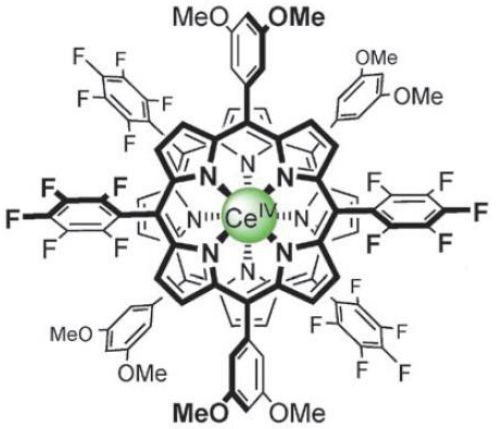
# Molecular motor




"Brake off"

"Brake on"

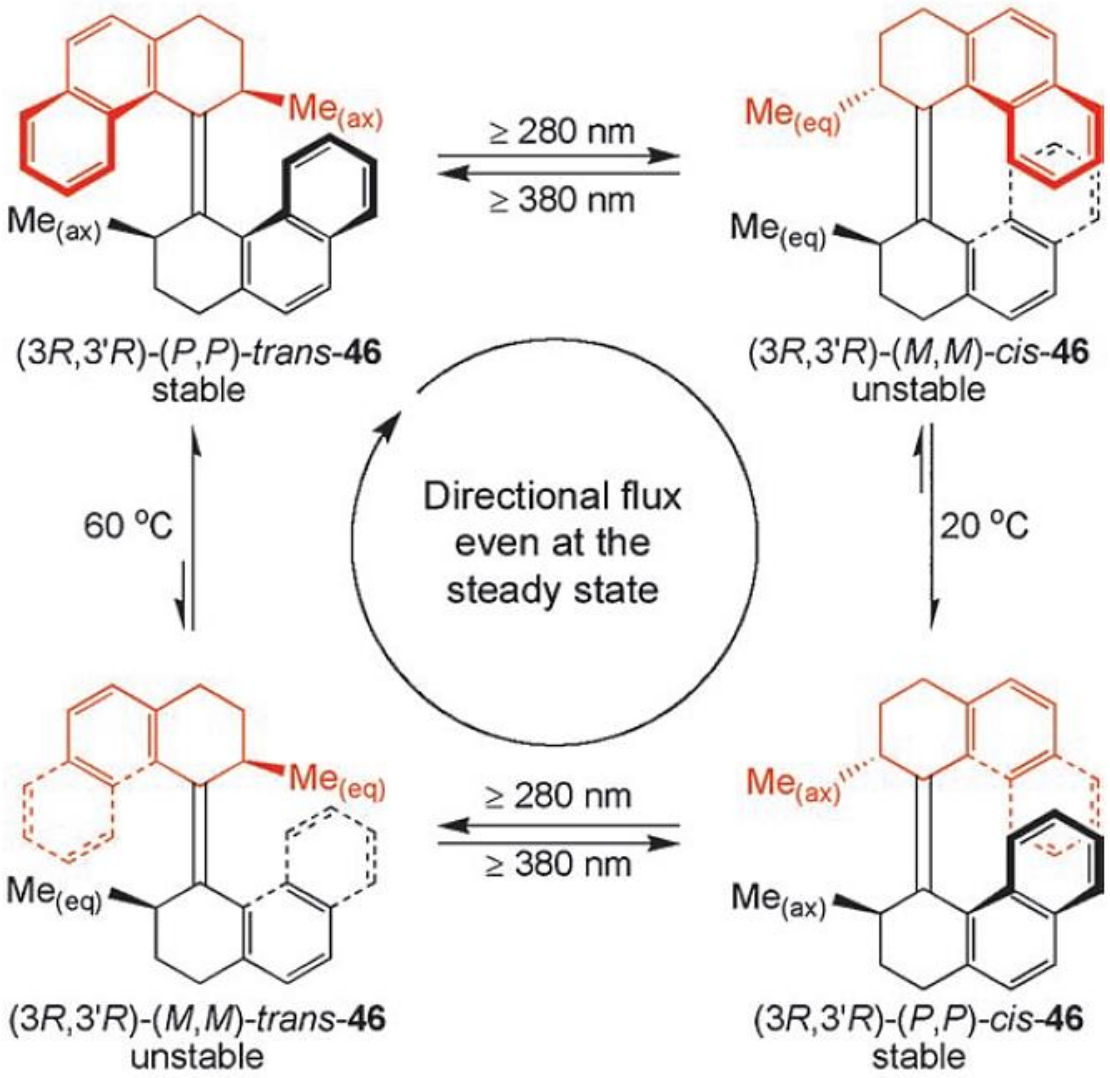






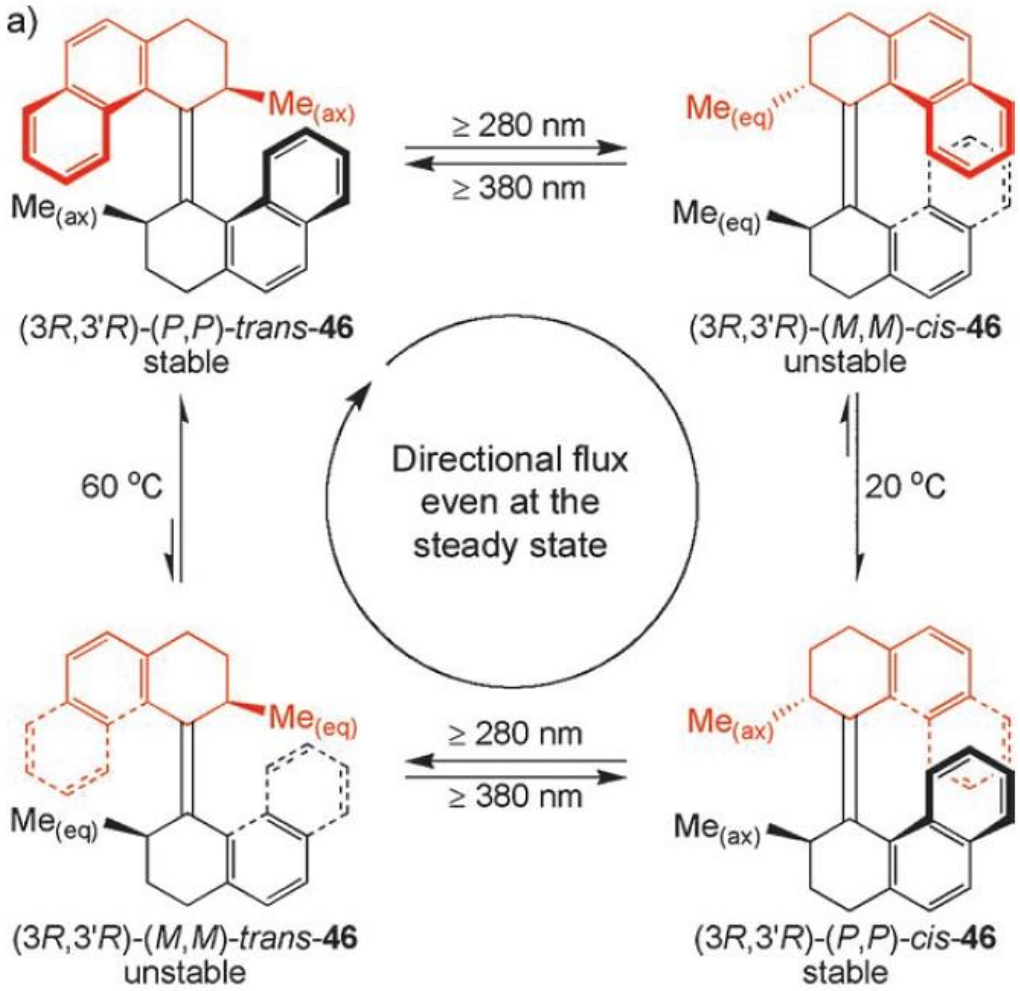
Jette et al, *J. Am. Chem. Soc.* **1994**, *116*, 3657 – 3658.
Kelly et al, *Angew. Chem. Int. Ed. Engl.* **1997**, *36*, 1866 – 1868.
Aida et al, *Angew. Chem. Int. Ed. Engl.* **1997**, *36*, 856 – 858

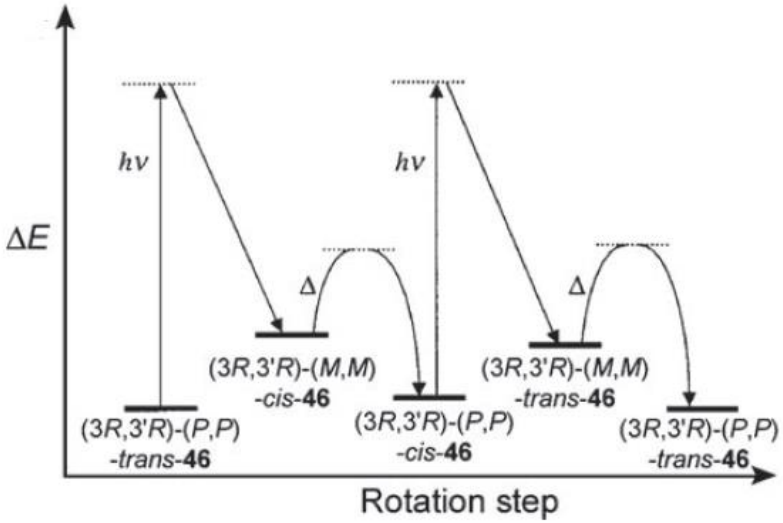
# Molecular motor




Feringa et al, *Nature* **1999**, *401* (6749), 152–155.

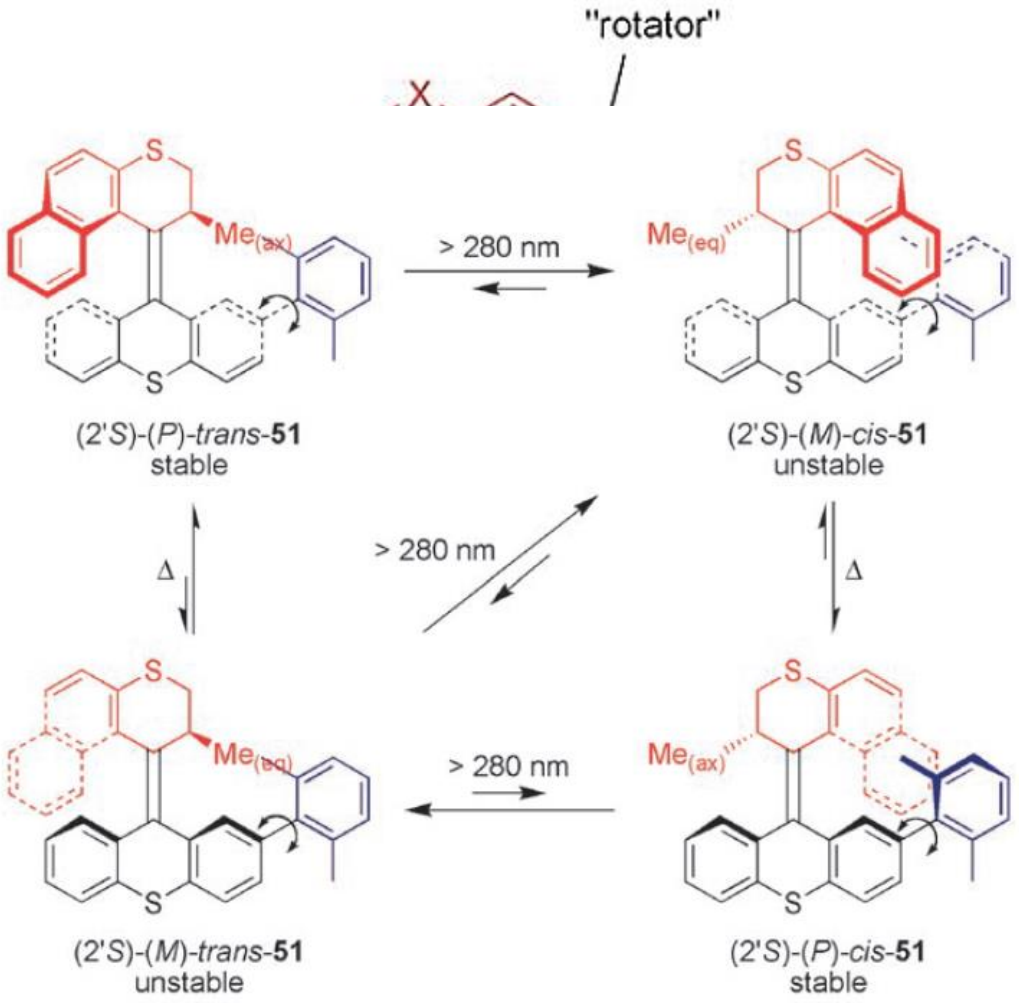
# Molecular motor



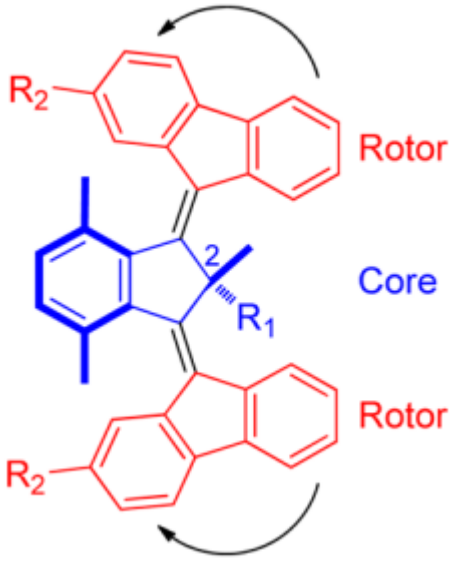

Feringa et al, *Nature* **1999**, *401* (6749), 152–155.

# Molecular motor- 2nd generation



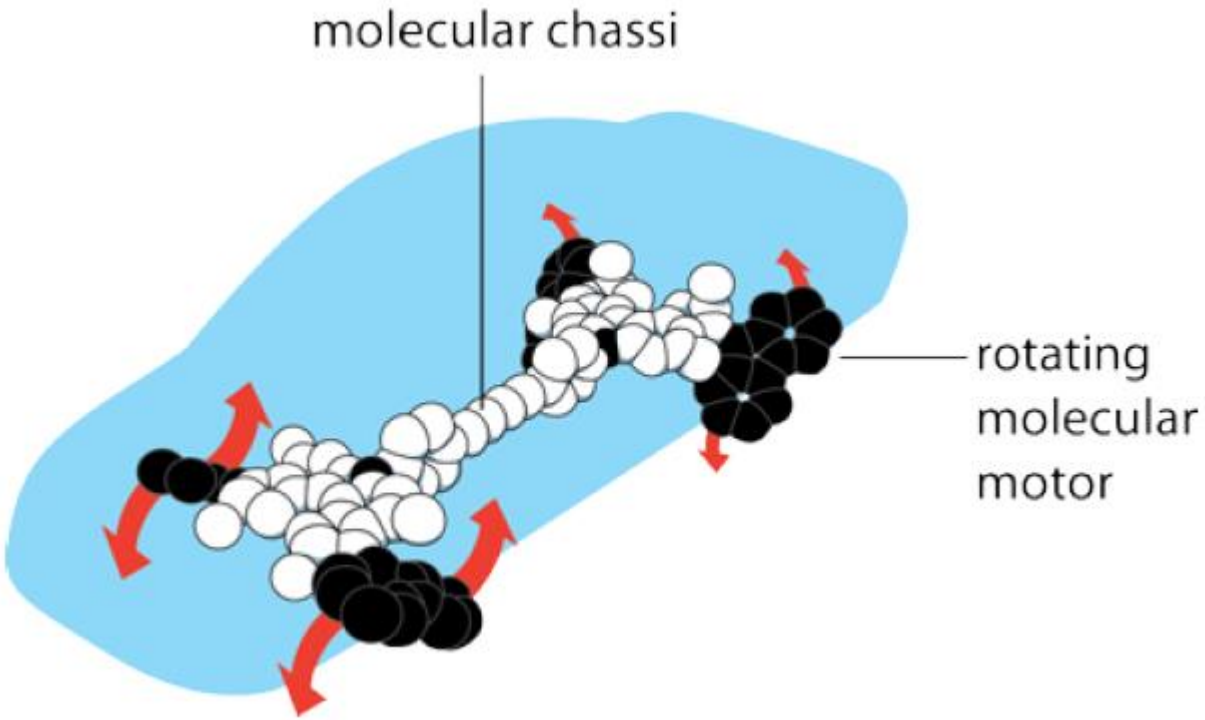

Feringa et al, *J. Am. Chem. Soc.* **2000**, *122*, 12005 – 12006

# Molecular motor- 3nd generation



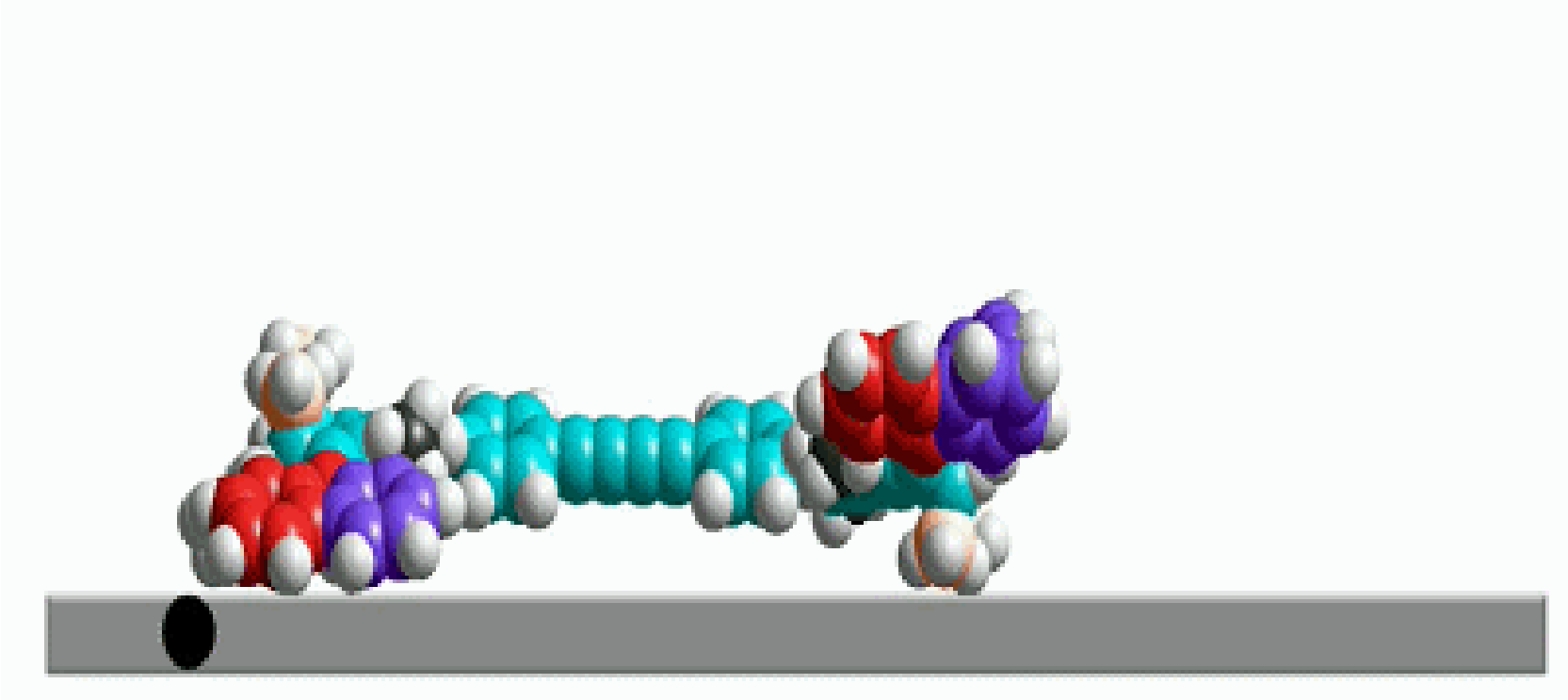

Feringa et al, *J. Am. Chem. Soc.*, **2017**, *139*, 9650–9661

# Application - Molecular Car



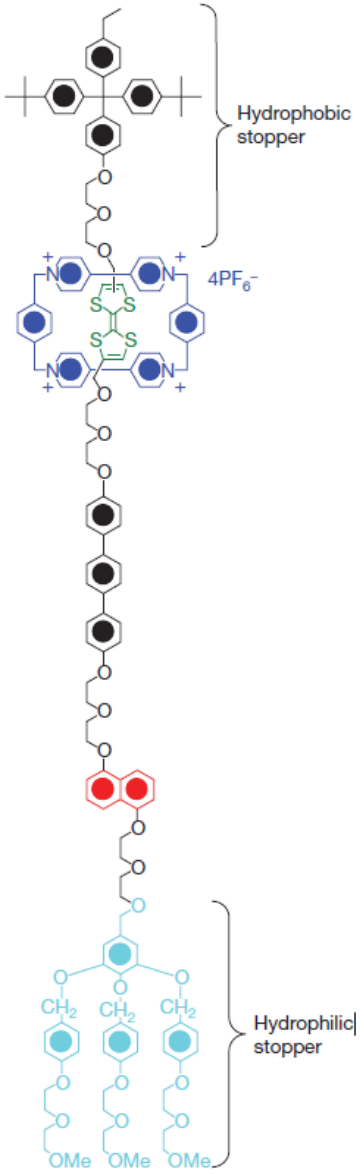

Feringa et al, *Nature* **2011**, *479* (7372), 208–211.

# Application - Molecular Car



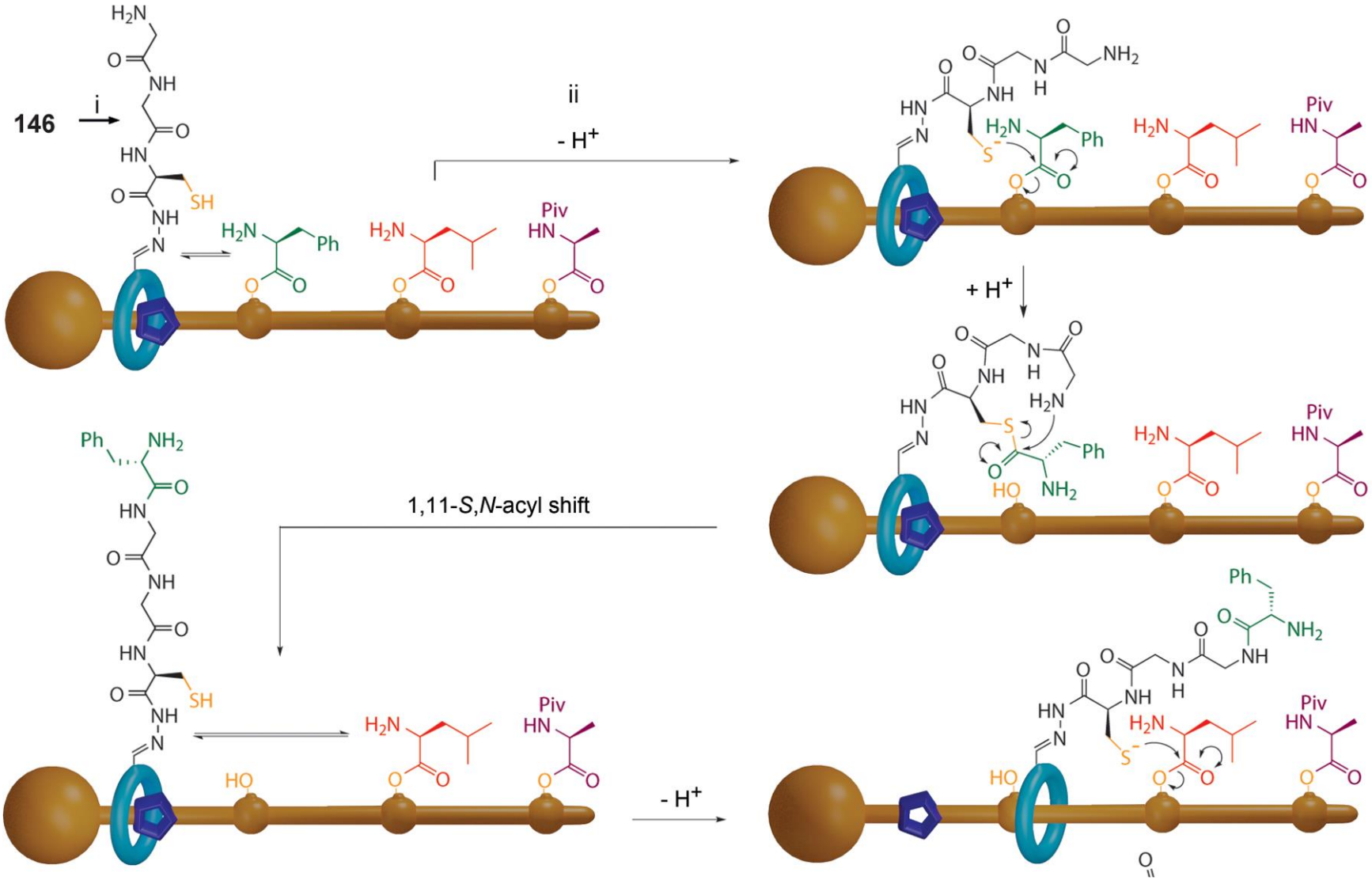
Feringa et al, *Nature* **2011**, *479* (7372), 208–211.

# Application - molecular electronic memory



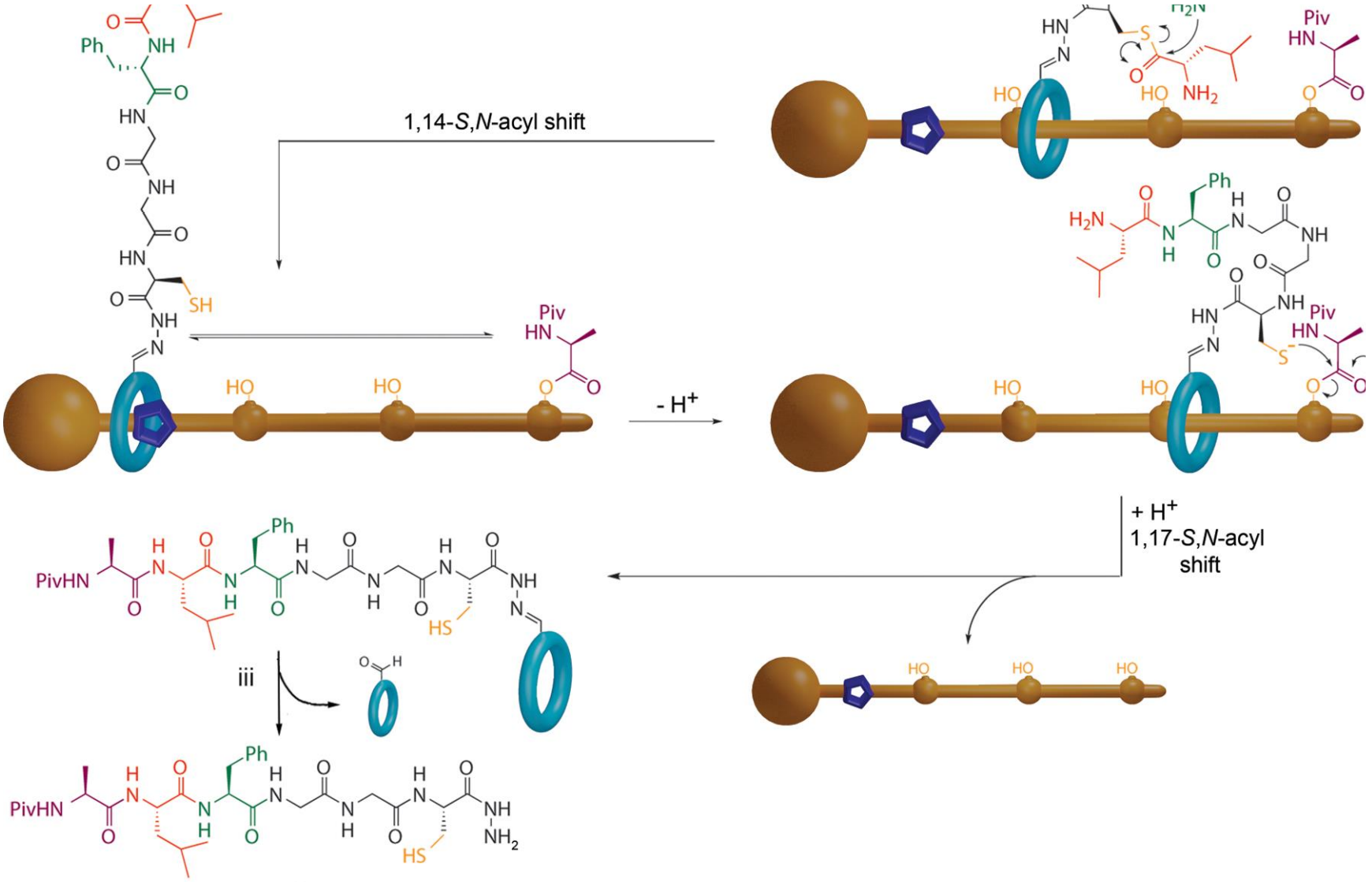

Stoddart et al, *Nature*, **2007**, *445*, 414-417

# Application - Peptide Synthesizer



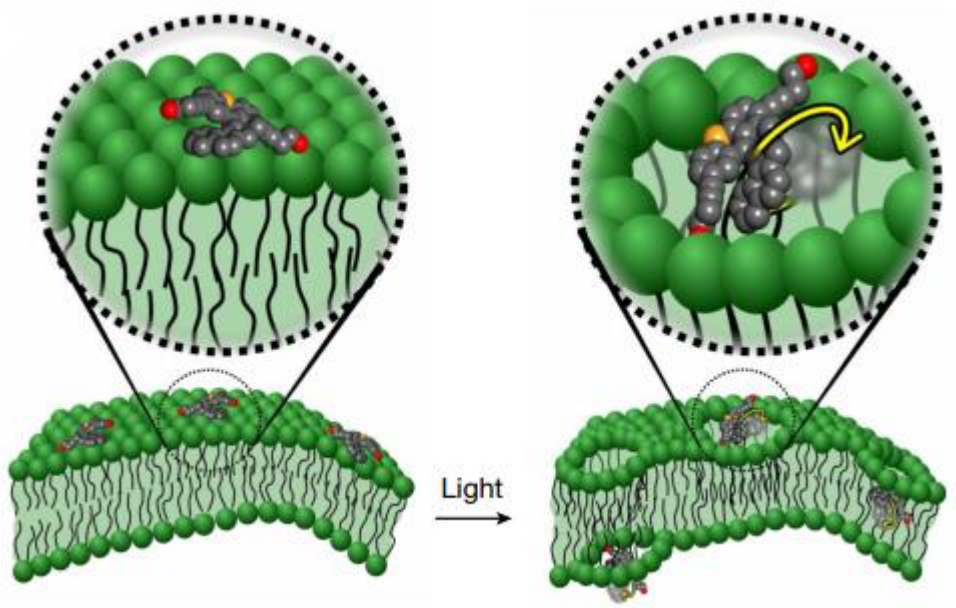

Leigh et al, *Science* **2013**, *339*, 189–193.

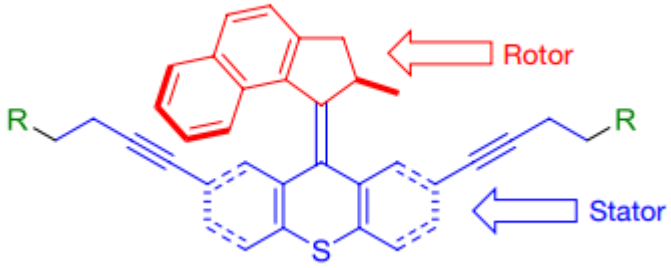
# Application - Peptide Synthesizer




Leigh et al, *Science* **2013**, *339*, 189–193.

# Application – Cell killer




Tour et al, *Nature*, **2017**, *548*, 567-572