Nature of Supramolecular Interactions – weak interactions

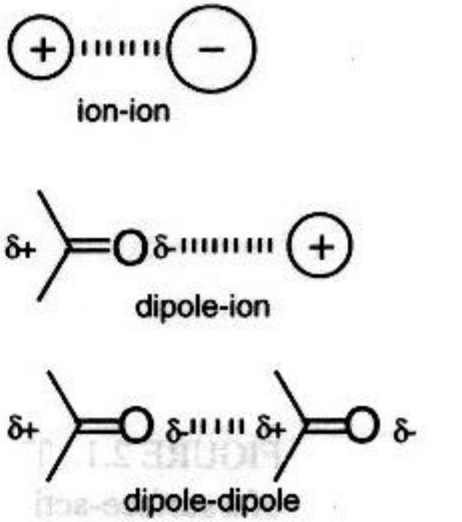
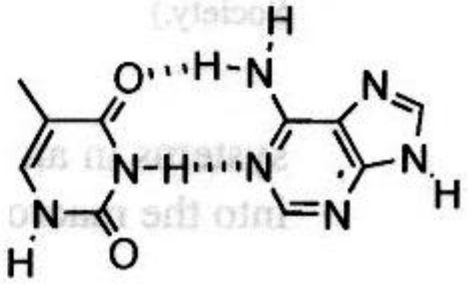
Weak interactions are relatively weak compared to normal chemical bonds, but play a fundamental role in fields as diverse as supramolecular chemistry, structural biology, polymer science, nanotechnology, surface science, and condensed matter physics.

ENERGIES OF SOME COVALENT BOND

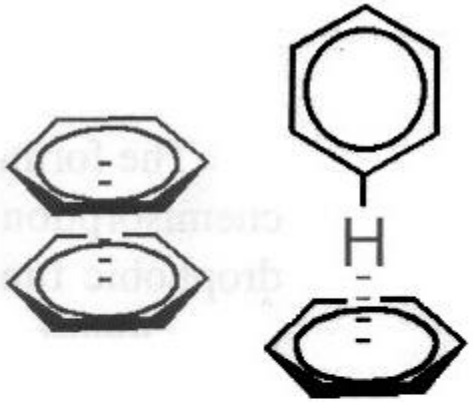
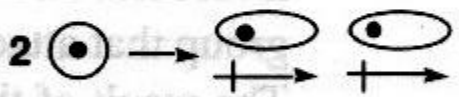
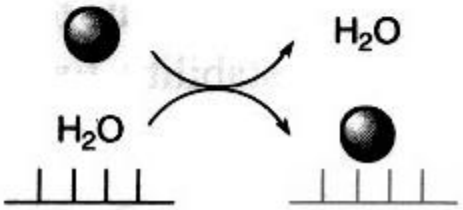
bond	energy	
	kcal mol^{-1}	kJ mol^{-1}
H-F	135	561,6
H-H	104	432,64
C-H	99	411,84
C-C	79	328,64
O-H	110	457,60
C=C	141	586,56
S-H	88	366,08

Nature of Supramolecular Interactions - Legami deboli

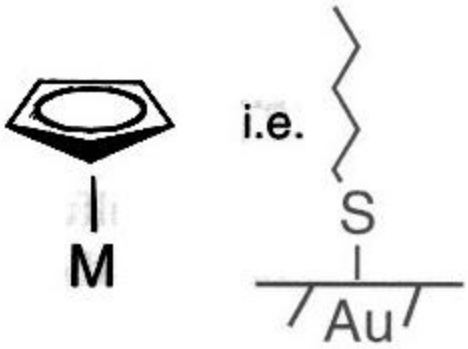
TABLE 2.1. Intermolecular interactions

Interaction	Interaction Strength[a] (kJ mol^{-1})	Description	Example
Electrostatics	>190 (ion-ion) 40–120 (ion-dipole) 5–40 (dipole-dipole)	coulombic interactions between opposite charges	
Hydrogen bonding	15–40 (strong) 5–15 (moderate <5(weak)	donor-acceptor interactions specifically involving hydrogen as the proton donor and a base as the proton acceptor	

Nature of Supramolecular Interactions - Legami deboli

Interaction	Interaction Strength[a] (kJ mol^{-1})	Description	Example
π-π Interactions	10–15 (face to face) 15–20 (edge to face)	attractive forces between electron-rich interior of an aromatic ring with the electron-poor exterior of an aromatic ring	
Dispersion forces Van der Waals	<5	momentary induced dipole-dipole interactions (also called London forces)	
Hydrophobic effects	varied 5–40	association of non-polar binding partners in an aqueous medium or vice versa	

Nature of Supramolecular Interactions - Legami deboli

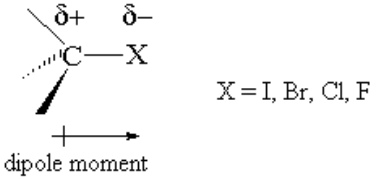
Interaction	Interaction Strength[a] (kJ mol^{-1})	Description	Example
Dative bonding	varied 20–380	coordination of a metal by a ligand donating two electrons	

[a] Association constants are for systems in chloroform.

Nature of Supramolecular Interactions - Legami deboli

Halogen Bond (def. *Pure Appl. Chem.* **2013**, *85*, 1711)

A halogen bond R−X···Y−Z occurs when there is evidence of a net attractive interaction between an electrophilic region on a halogen atom X belonging to a molecule or a molecular fragment R–X (where R can be another atom, including X, or a group of atoms) and a nucleophilic region of a molecule, or molecular fragment, Y−Z.

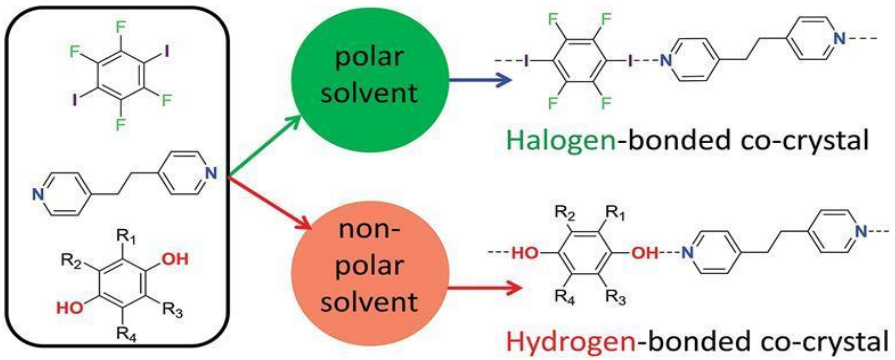


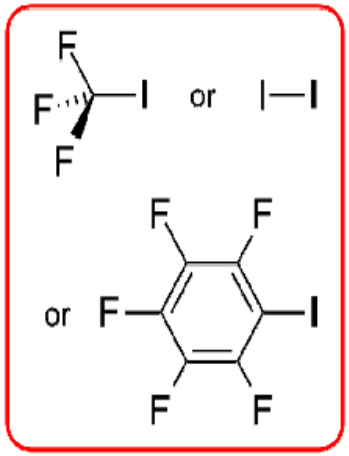
2.9 – 7.0 kJ mol^{-1} 0.7 – 1.7 kcal/mol

Halogen Bond Adducts

R–**X** -------- :LB

Halogen Bond Donor (Lewis Acid) *Halogen Bond Acceptor (Lewis Base)*





Cl^- or NH_3

Nature of Supramolecular Interactions – weak interactions

van der Waals forces

The attractive or repulsive forces between molecular entities (or between groups within the same molecular entity) other than those due to bond formation or to the electrostatic interaction of ions or of ionic groups with one another or with neutral molecules.

The term includes: dipole–dipole, dipole-induced dipole and London (instantaneous induced dipole-induced dipole) forces. The term is sometimes used loosely for the totality of nonspecific attractive or repulsive intermolecular forces.

http://goldbook.iupac.org/V06597.html (IUPAC Internation Union of Pure and Applied Chemistry)

Van der Waals forces define the chemical character of many organic compounds

They also define the solubility of organic substances in polar and non-polar media.

•In low molecular weight alcohols, the properties of the polar hydroxyl group dominate the weak intermolecular forces of van der Waals.

•In higher molecular weight alcohols, the properties of the nonpolar hydrocarbon chain(s) dominate and define the solubility.

Van der Waals-London forces grow with the length of the nonpolar part of the substance.

Nanomaterials – supramolecular chemistry

self-assembly

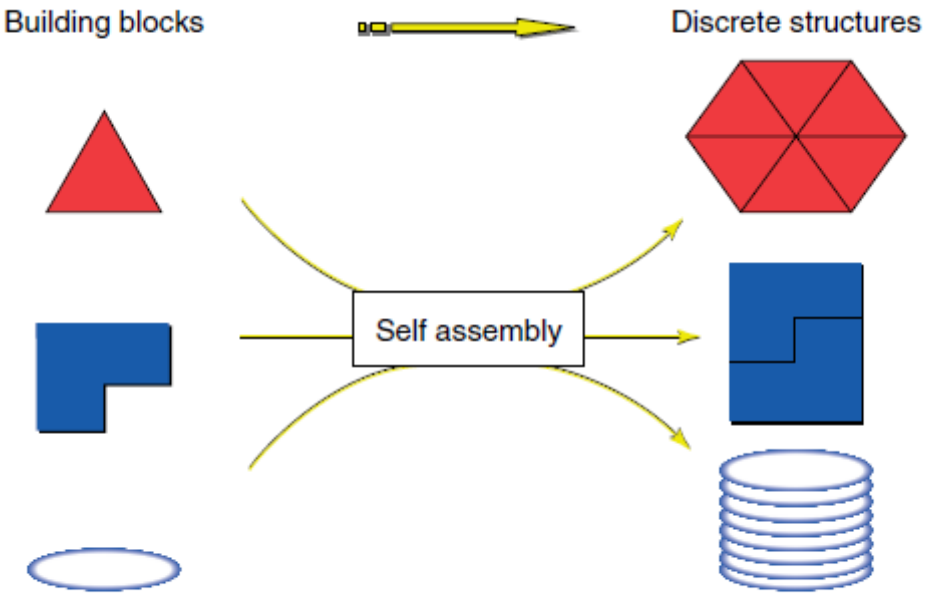


Figure 2 Schematic assembly of building blocks with various shapes to form discrete supramolecular structures.

supramolecular chemistry

the term “supramolecular chemistry” was coined by Jean Merie Lehn in 1969: the chemistry of molecular assembly and intermolecular bonds.

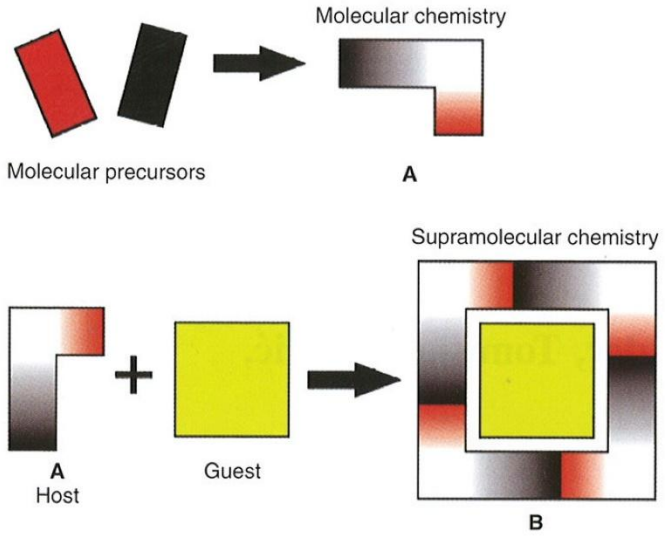


Figure 1 An illustration of molecular versus supramolecular chemistry.

supramolecular compounds are formed by additive and cooperative noncovalent interactions

Self-assembly: the spontaneous and reversible association of molecular species to form larger, more complex supramolecular entities according to the intrinsic information contained in the components

Weak interactions

1 cal = 4.16 Joule

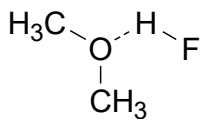
covalent bonds: > 80 kcal/mol

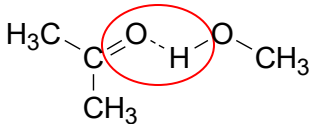
van der Waals interactions: less than 10 kcal/mol

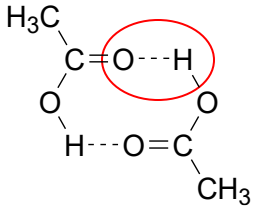
weak bonds: 2÷10 kcal/mol

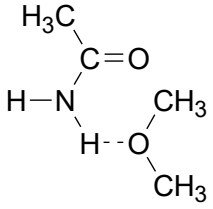
H-F 568 kJ/mol
C-C 348 kJ/mol

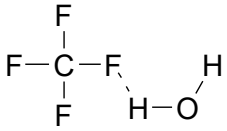
Hydrogen bonds

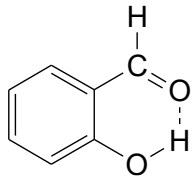


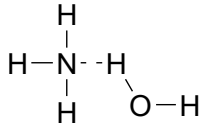


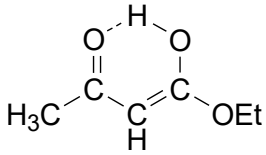


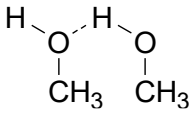












Hydrogen bonds

Table 2 Properties of hydrogen bonds.[8,16,43]

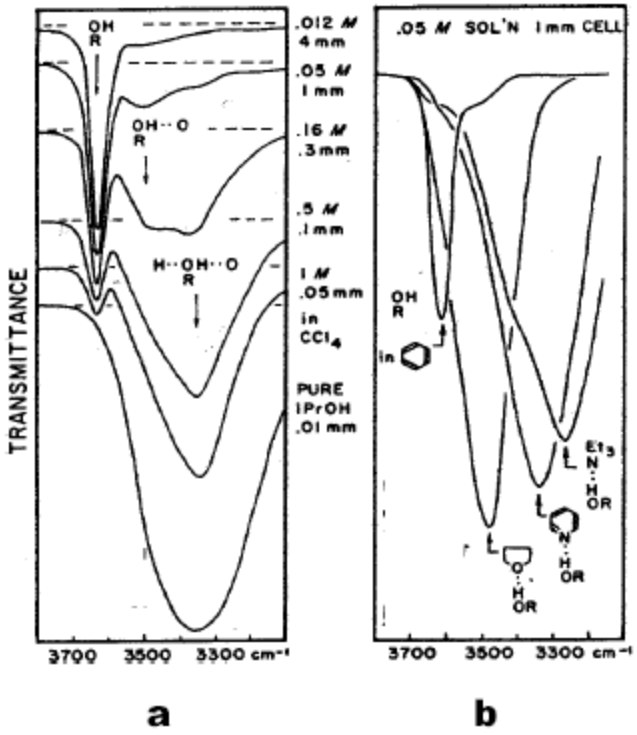
	Strong	Moderate	Weak
A–H···B	Partially covalent	Mostly electrostatic	Electrostatic
Energy	60–120 kJ mol^{-1}	16–60 kJ mol^{-1}	<12 kJ mol^{-1}
Lengths (Å)	A–H ~ H···B	A–H < H···B	A–H ≪ H···B
H···B	1.2–1.5	1.5–2.2	2.2–3.2
A···B	2.2–2.5	2.5–3.2	3.2–4.0
Angles (°)	175–180	130–180	90–150
Examples	Strong acids/bases; proton sponge; HF complexes	Acids; alcohols; biological molecules	Minor components of bifurcated bonds; C–H ···O, O–H ···π

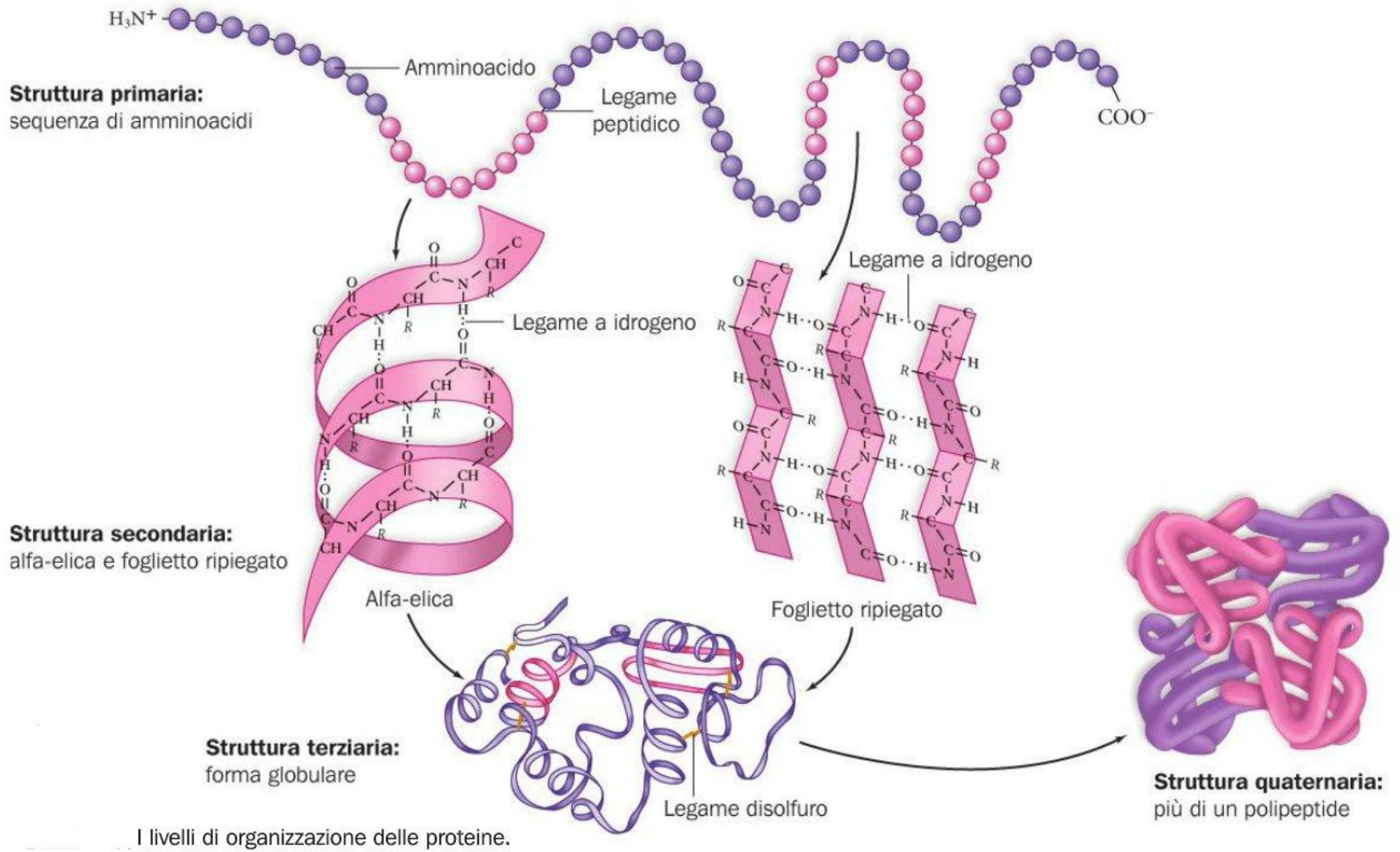
Hydrogen bonds

in soluzione la vita media di un legame H_3N--HOH è 2 x 10^{-12} s.

la loro presenza influenza il momento di dipolo, la solubilità, il p.f. o il p.e.

ed è stata messa in evidenza sia da misure chimico-fisiche che da studi di spttroscopia IR





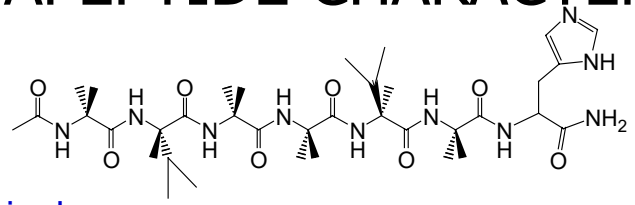
I livelli di organizzazione delle proteine.

Hierarchical assembly: a self-assembled system that comprises several levels of complexity which are built up over several, successive self-assembly processes. One level cannot exist without the preceding one being in place.

HEPTAPEPTIDE CHARACTERIZATION

in alfa-helix:
H-bond between C=O and NH i←i+4

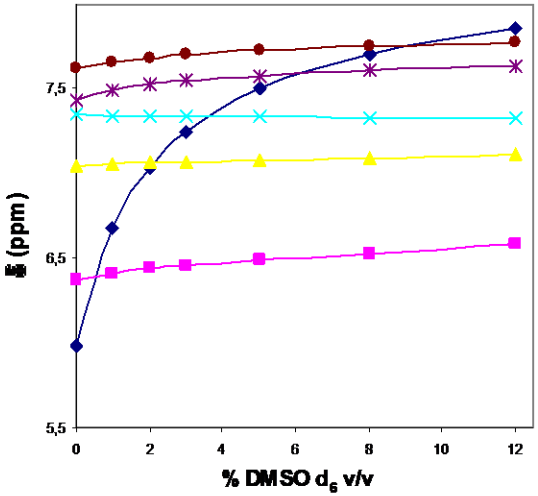
in 3_{10}-helix:
H-bond between C=O and NH *i* ←*i*+3

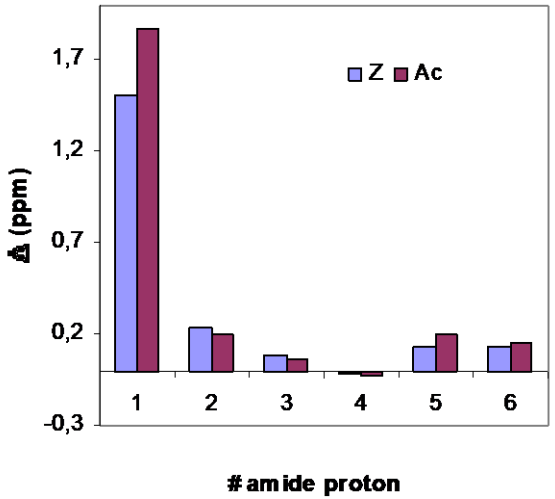


3_{10}-helix

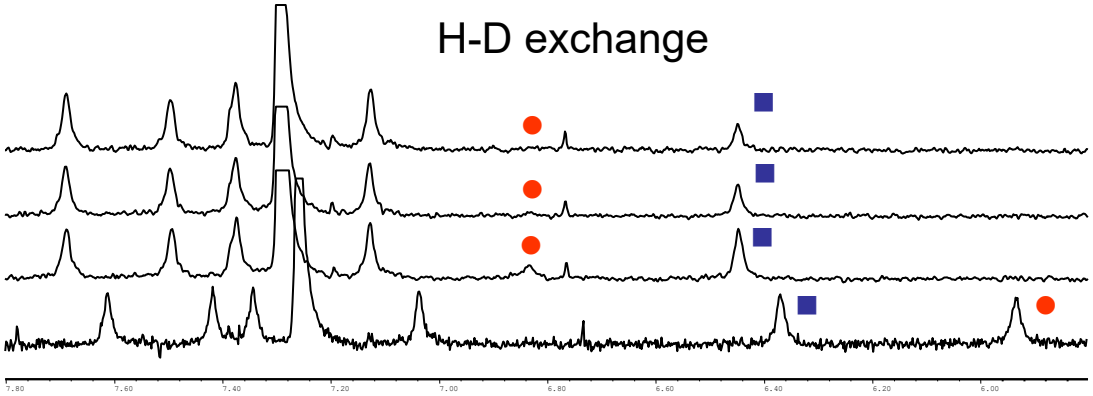
N-terminale

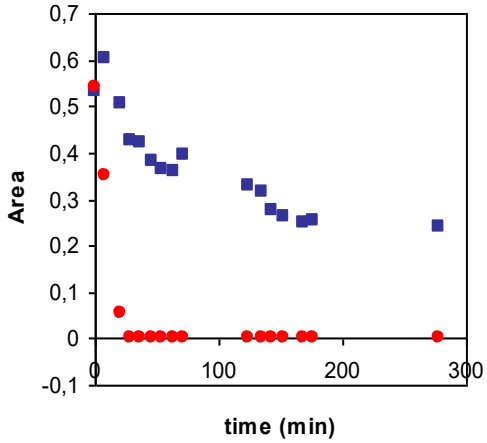
C-terminale





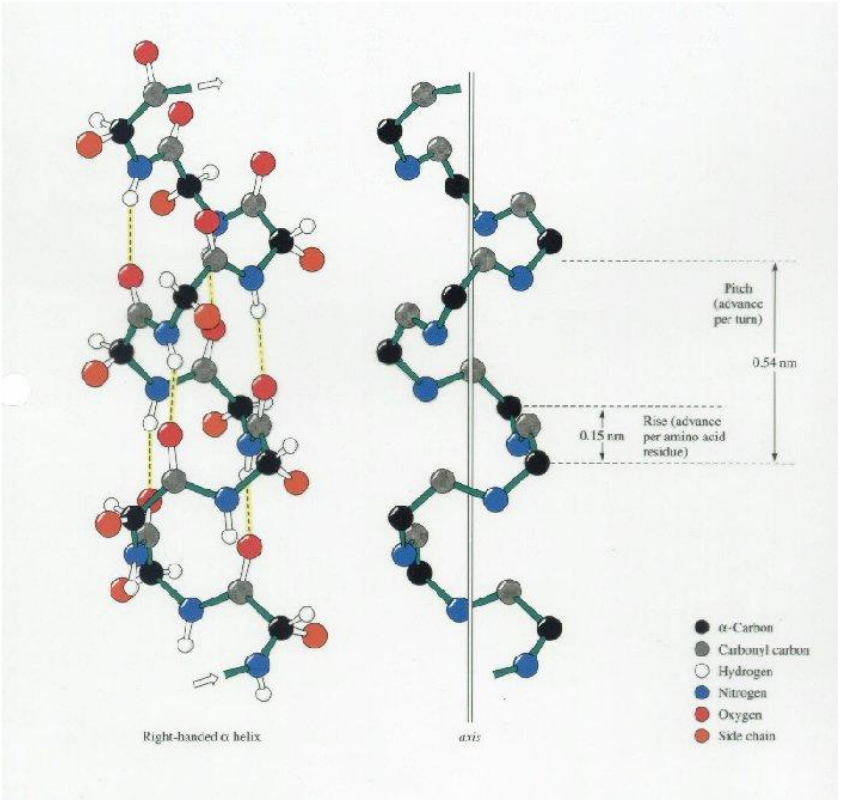
H-D exchange





Spectra recorded at 200 MHz, peptide concentration 2 mM solution in $CDCl_3$ before and after CD_3OD addition.

cinetica di scambio con deuterio, CD_3OD in $CDCl_3$.



heptapetide CD spectra

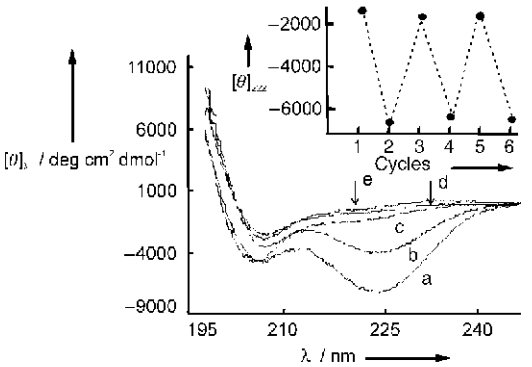
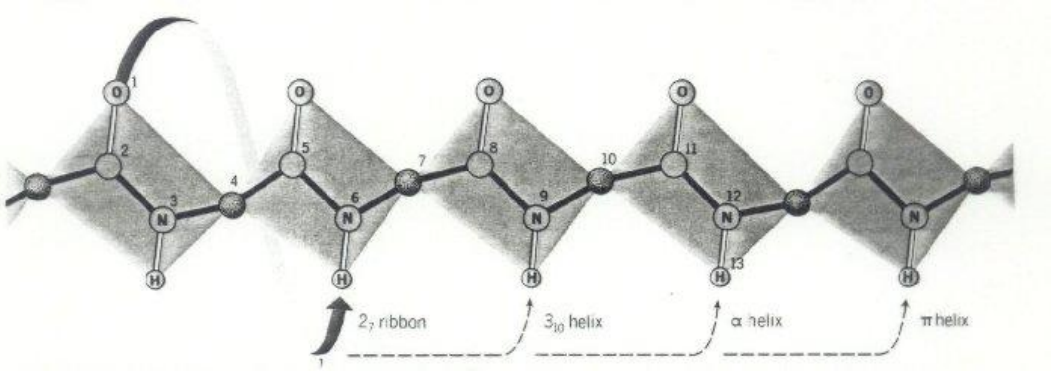


Figure 1. CD spectra of peptide 1 in the 200–250 nm region and in different solvents (a: HFIP; b: TFE; c: MeOH; d: EtOH; e: iPrOH). The concentration of 1 was 1 mm.[17] Inset: Change in the ellipticity at 222 nm on repeated cycles of dissolution in iPrOH (odd numbers) and HFIP (even numbers) followed, each time, by drying.



CD spectra in solvents of different polarity

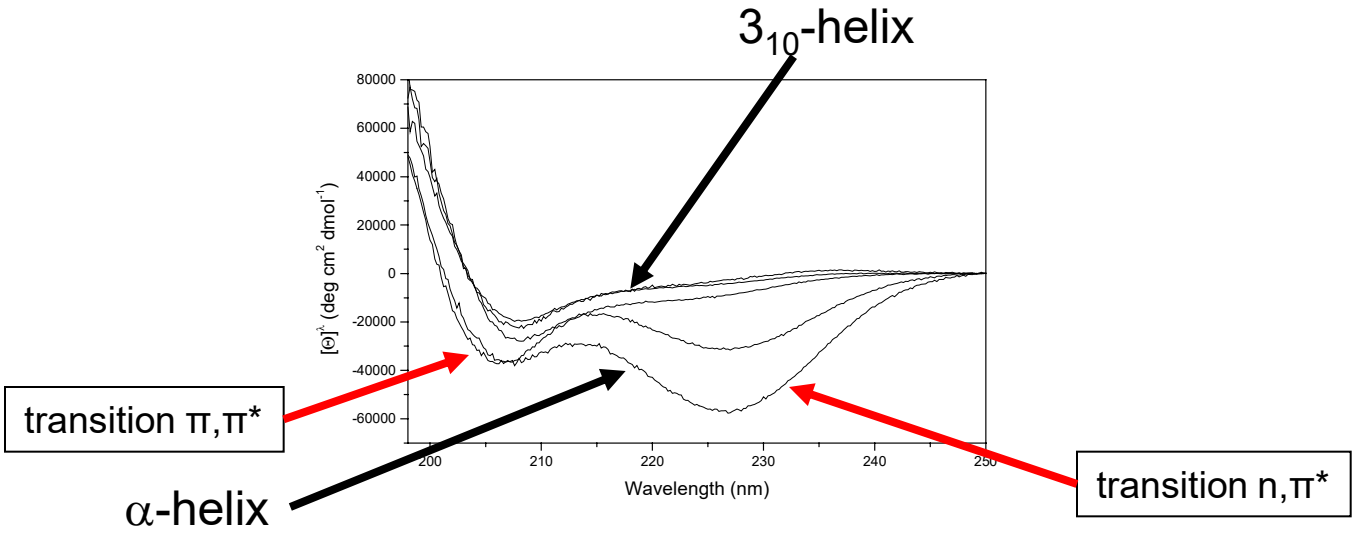
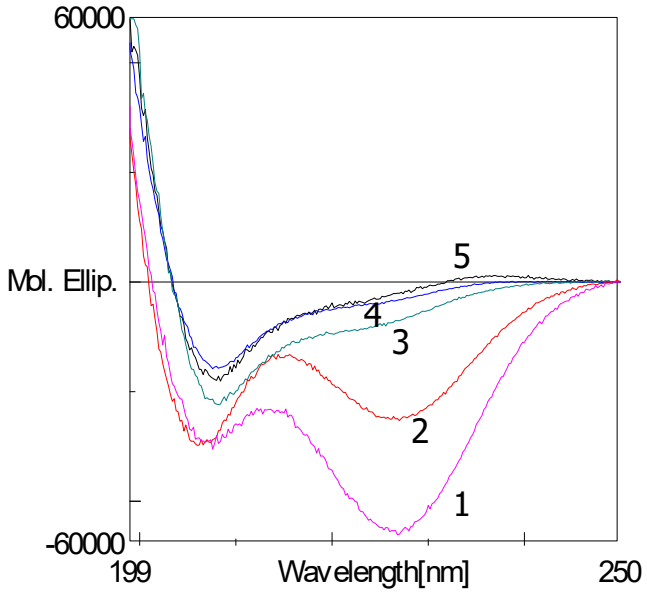


Figura 4.11. Spetti CD dell'eptapeptide **89** nei seguenti solventi in concentrazione circa 1 mM: a partire dal basso sono riportati gli spettri in HFIP, TFE, MeOH, EtOH, i-PrOH.

HEPTAPEPTIDE CHARACTERIZATION

CD in Pure solvents (alcohols)

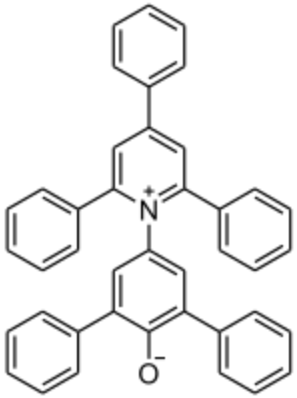


1. HFIP
2. TFE
3. Methanol
4. Ethanol
5. Isopropanol

Table S2. Values of the equilibrium constant between the α- and 3_{10}-helix ($K_{\alpha/310}$) used in Figure 2, bottom and derived from the interpolation of the experimental molar ellipticity data.

Solvent	E_T^N	$K_{\alpha/310}$=[α-helix]/[3_{10}-helix]
iPrOH	0.546	0.018
EtOH	0.654	0.035
MeOH	0.762	0.15
TFE	0.898	0.75
H_2O	1	1.8[a]
H_2O	1	3.3[b]
HFIP	1.068	5.49

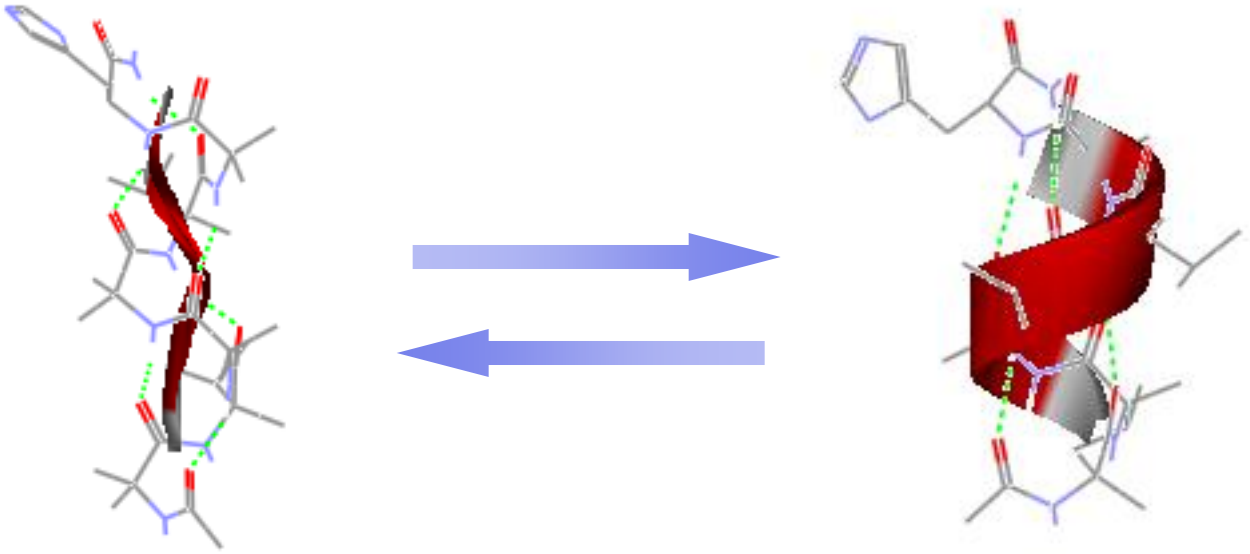
[a]Extrapolated from iPrOH/H_2O mixtures; [b]Extrapolated from MeOH/H_2O mixtures.



Reichardt's dye

Reichardt's dye (Betaine 30) is an organic dye belonging to the class of azomerocyanine betaines. This dye is notable for its solvatochromic properties, meaning it changes color depending on the solvent in which it is dissolved. It has one of the largest solvatochromic effects ever observed,[1] with color varying across the entire visible spectrum. As a result, it gives striking visual results for chemical demonstrations.

Solvent driven control of helical conformation



3_{10}-helix
(non polar solvents)

α-helix
(polar solvents)

Hydrogen bonds

- Legami ad idrogeno intermolecolari innalzano il punto di ebollizione della sostanza e spesso anche quello di fusione.

- Se è possibile avere legami ad idrogeno tra solvente e soluto, la solubiltà del soluto in tale solvente ne sarà enormemente aumentata. Spesso si potrà osservare persino solubilità infinita.

- I legami ad idrogeno provocano deviazioni dall'idealità nella fase gassosa e in miscela.

- Come già detto, i legami ad idrogeno modificano la posizione di assorbimento spettrale.

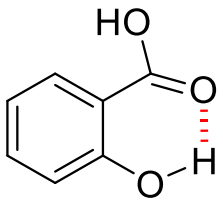
- I legami ad idrogeno, specialmente quelli intramolecolari, modificano alcune proprietà chimiche. Per esempio, sono responsabili della presenza di grandi quantità di enolo in alcuni equilibri tautomerici. Inoltre influenzano la conformazione delle molecole e spesso giocano un ruolo importante nel determinare la velocità di reazione. I legami ad idrogeno sono importanti anche per la loro funzione strutturale nelle proteine e negli acidi nucleici.

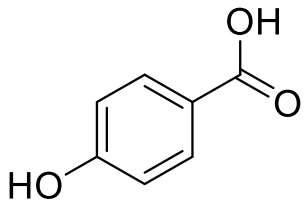
- Ci sono solo 3 tipi di legami ad idrogeno (deboli) che coinvolgono il carbonio: quando H è sufficientemente acido da formare H-bonds: R-C≡C-H, $CHCl_3$, H-CN.

Influenze strutturali sull'acidità e sulla basicità

- legami ad idrogeno intramolecolari

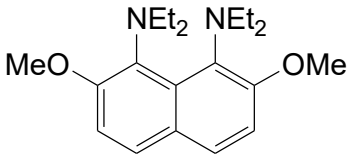
pk_a 2.98

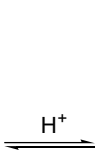


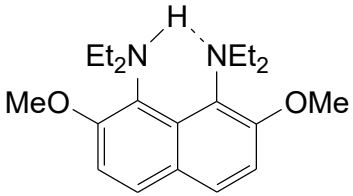


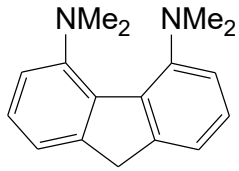
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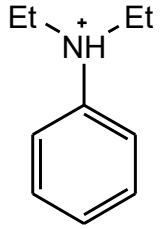
- effetti sterici











equilibrio lento che si può seguire con spettri UV-Vis

pk_a 16.3

pk_a 5.1

- ibridizzazione

$HC{\equiv}C^-$ sp

pKa 24

base più debole

$H_2C{=}C^-$ sp^2

pKa 44

$H_3C{-}CH_2^-$ sp^3

pKa 71 for isobutane

base più forte

addition complexes

complexes electron-donor-acceptor (EDA)

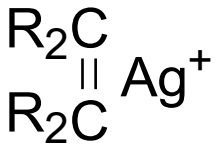
il donatore può usare un doppietto non condiviso (*n*-donor)
o un doppietto di elettroni in un doppio legame, orbitale π (π-donor)

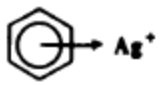
spettri UV-Vis che presentano bande dovute a **trasferimento di carica**

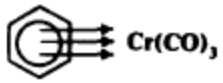
colored complexes

Esempi:

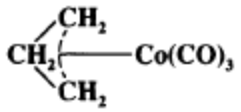
accettore: ione metallico
donatore: alchene o anello aromatico











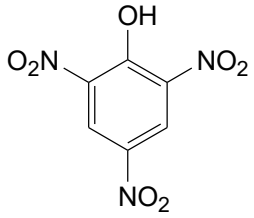
sono presenti 2 legami: **legame σ** (elettroni dell'orbitale π dell'alchene e orbitale 5s vuoto di Ag+)
legame π (orbitale 4d pieno di Ag+ e orbitale π* vuoto dell'alchene)

➡ trasferimento di densità elettronica da alchene allo ione metallico

Composti di addizione

- Complessi in cui l'accettore è una molecola organica

  la molecola organica deve essere povera di elettroni, esempio: acido picrico



1,3,5-trinitrofenolo

  il donatore è un sistema con elettroni π

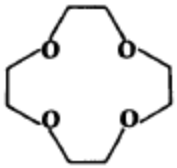
  composti solidi noti col nome di **picrati**

- Complessi in cui l'accettore è I_2, Br_2, Cl_2.
  Formano complessi con donatori **n** e π presumibilmente per espansione dell'ottetto.

Composti di addizione

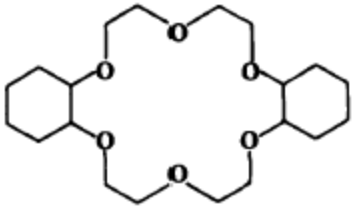
Complessi degli eteri corona

12-crown-4



Li^+

dicycloehexyl-18-crown-6

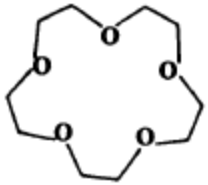


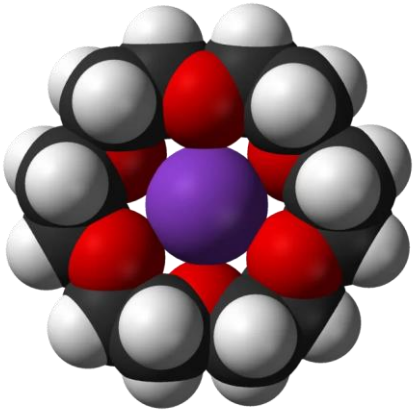
K^+

Hg^{2+}

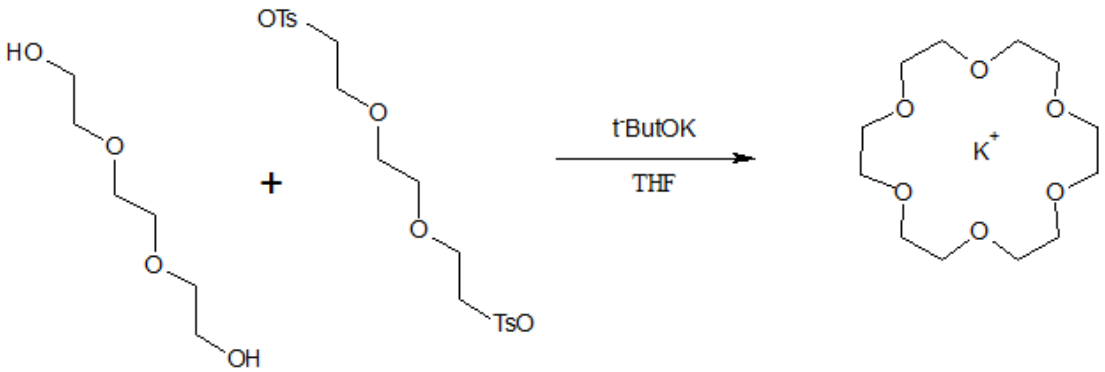
Sr^{2+}

15-crown-5

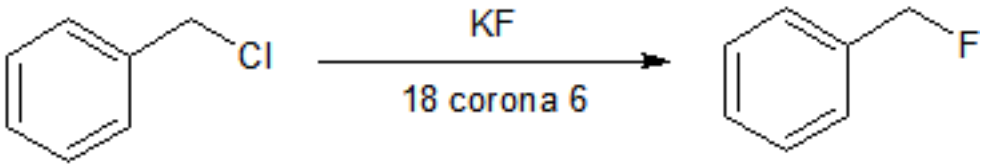


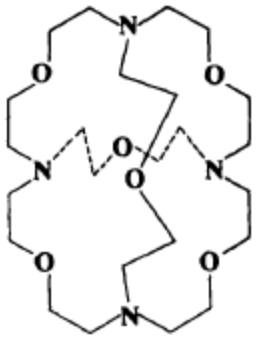


sintesi

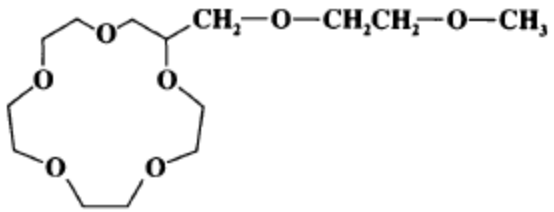


gli eteri corona riescono a rendere solubile un sale in solventi organici sequestrando il catione, per esempio.





carcerandi e sepolcreni



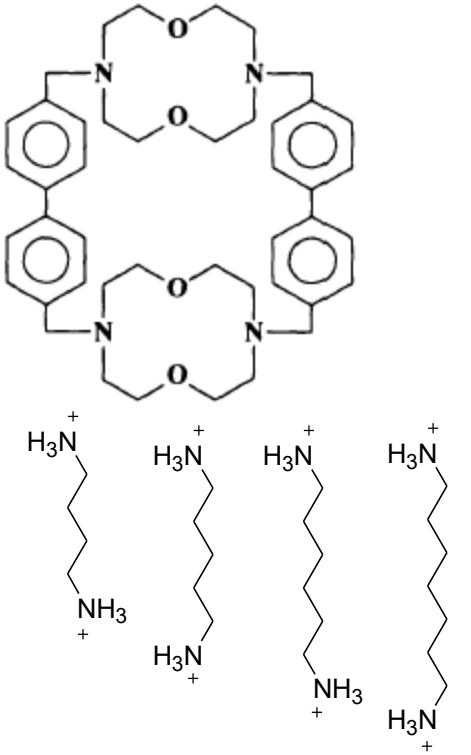
eteri lariati

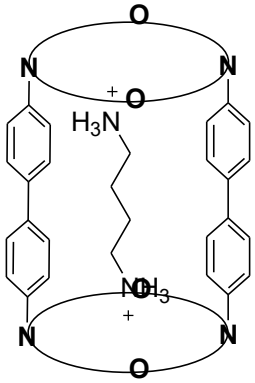
Composti di addizione

- il legame caratteristico di questi complessi è un'attrazione ione-dipole.

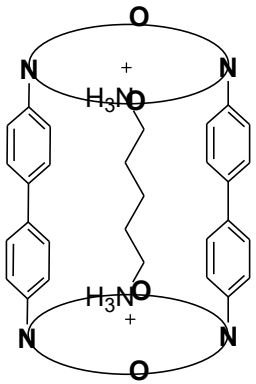
- si parla di **interazione host-guest**, le energie di binding possono essere determinate per mezzo di studi di spettroscopia NMR.

- la selettività osservata nel complessare prefererenzialmente uno ione piuttosto di un altro si chiama **riconoscimento molecolare.**

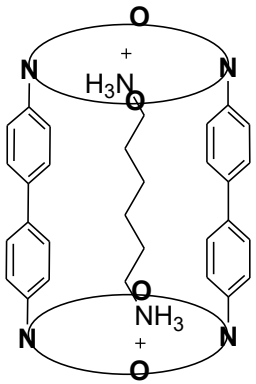




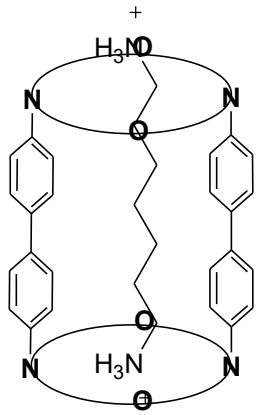
no



si

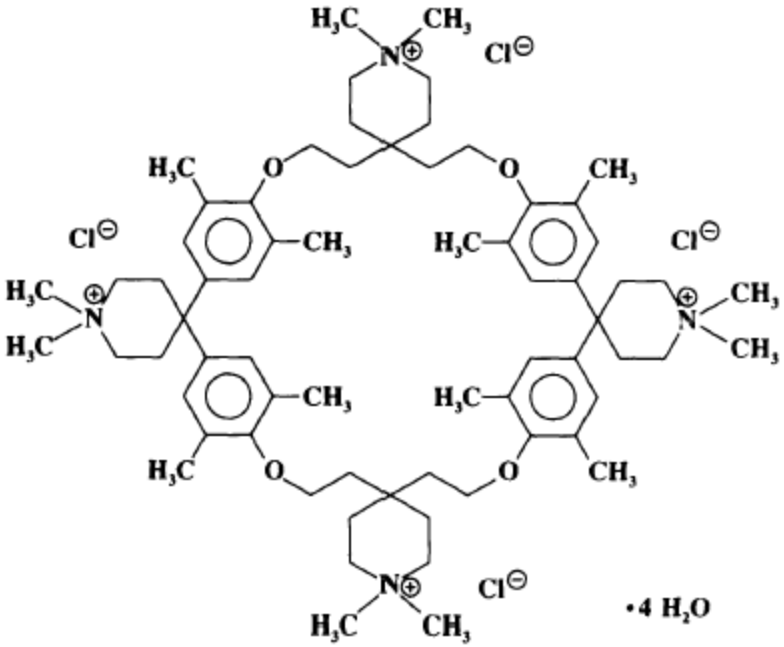


si



no

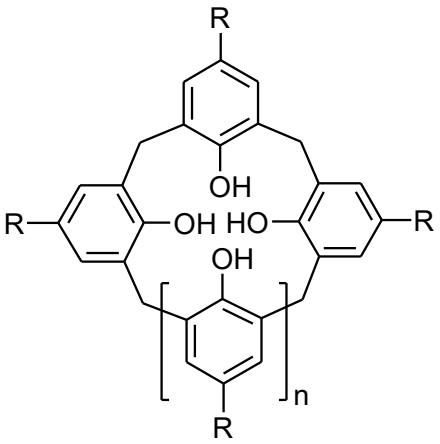
Composti di addizione

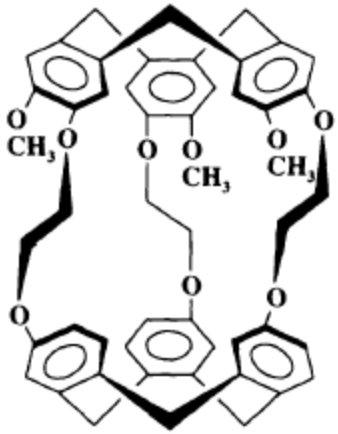


questa molecola complessa idrocarburi aromatici come pirene, bifenile, naftalene e li porta in soluzione acquosa

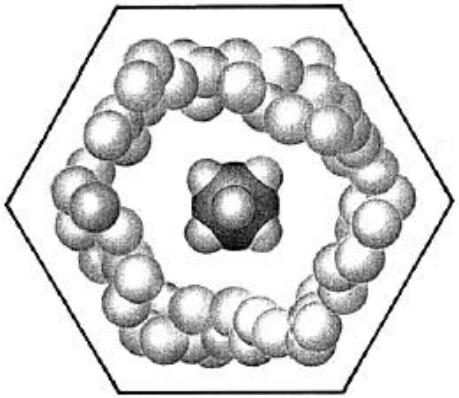
ciclofani

Calix[4]arene, n=1
Calix[6]arene, n=3
Calix[8]arene, n=5



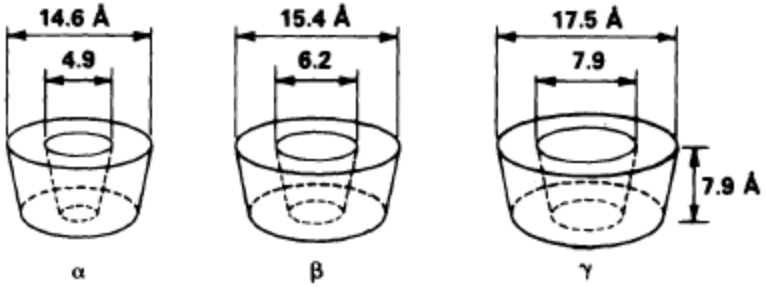


Composti di inclusione

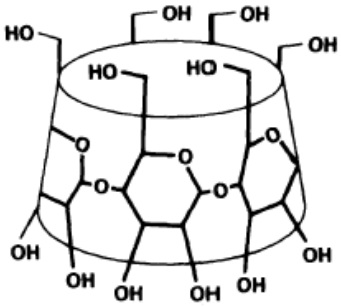


host molecule inside the crystal lattice of urea

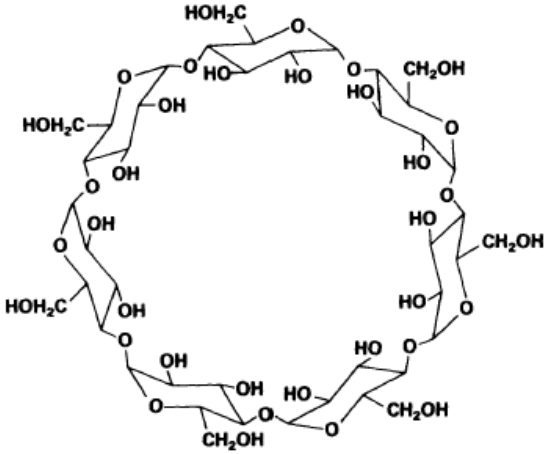
Cyclodextrins



6 7

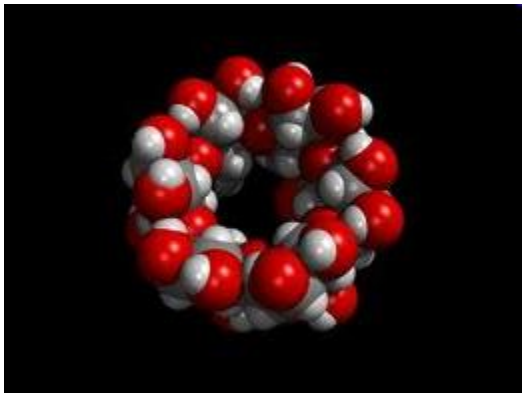


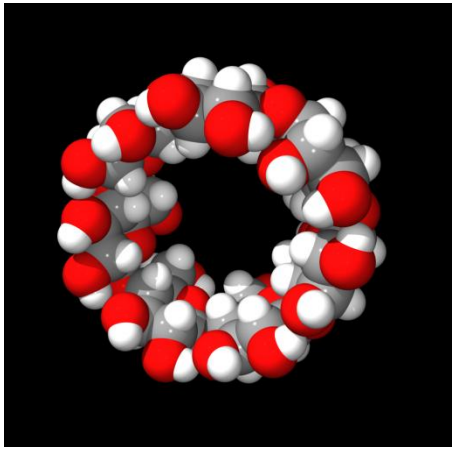
8 glucopyranoside units



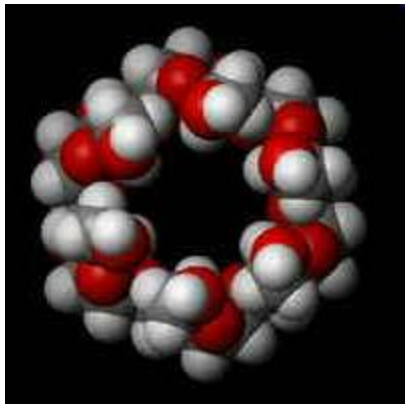
shape and size of α-, β- and γ-cyclodextrins

Ciclodestrine

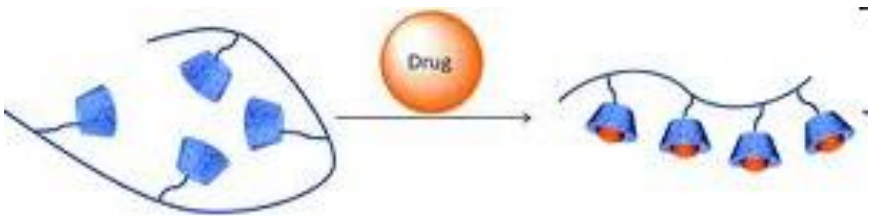




beta-ciclodestrina

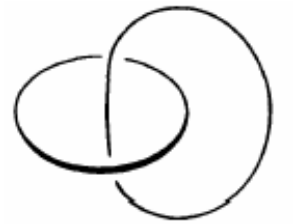


alfa-ciclodestrina

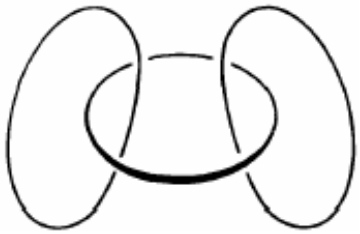


Cyclodextrin functionalized polymers as drug delivery system.

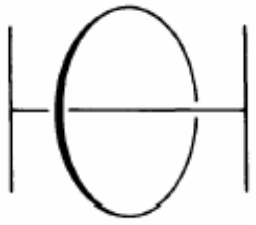
Catenani e rotassani



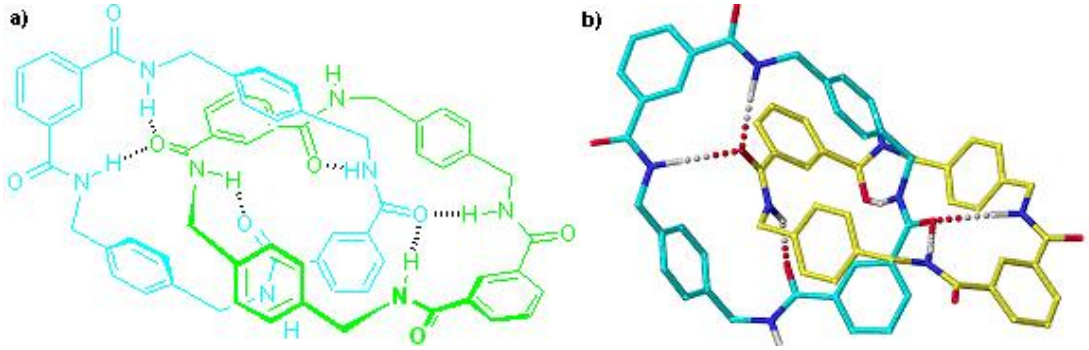
[2]-catenano



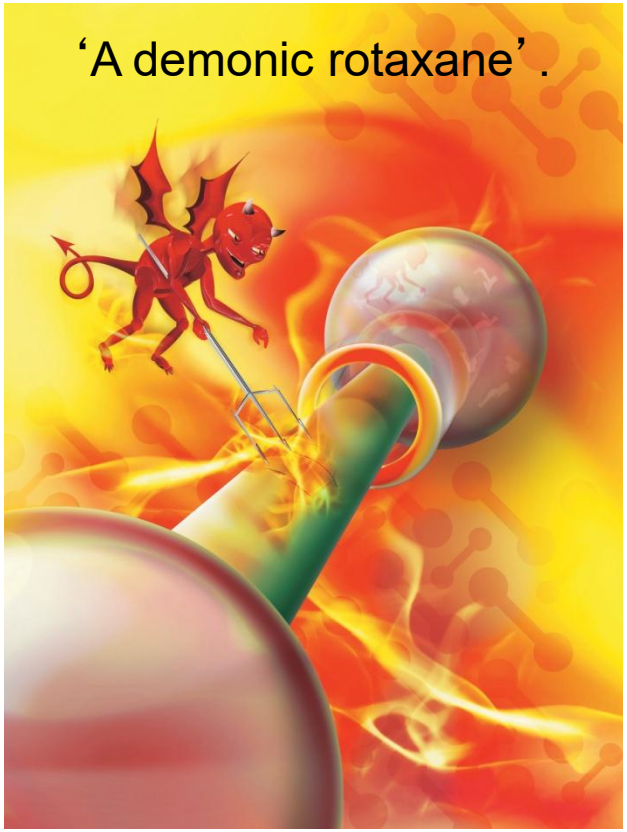
[3]-catenano



rotassano



a) Chemical structure of and b) X-ray crystal structure of a hydrogen-bonded [2]catenane. Crystal structure atoms: carbon (macrocycle A), light blue; carbon (macrocycle B), yellow; oxygen, red; nitrogen, dark blue; amide hydrogen, white.



A molecular information ratchet

V. Serreli1, C.-F. Lee, E. R. Kay D. A. Leigh NATURE| Vol 445| 1 February 2007, 523.

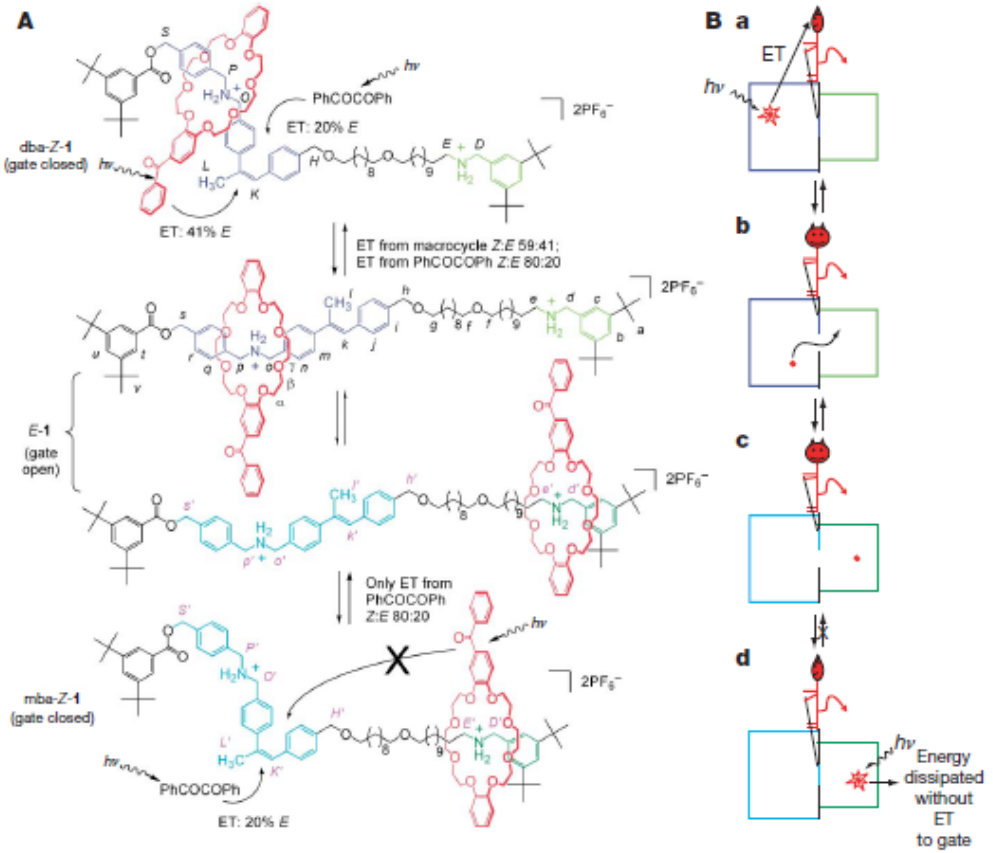


Figure 1 | A photo-operated molecular information ratchet. **A**, Irradiation of rotaxane **1** (1 mM) at 350 nm in CD_3OD at 298 K interconverts the three diastereomers of **1** and, in the presence of benzil (PhCOCOPh), drives the ring distribution away from the thermodynamic minimum, increasing the free energy of the molecular system without ever changing the binding strengths of the macrocycle or ammonium binding sites. For clarity, the photoinduced energy transfer (ET) pathways are only illustrated on the *Z*- (gate closed) forms of **1** although the same processes occur for the equivalent *E*- (gate open) translational isomers. When the macrocycle is on the mba binding site (green), intramolecular ET from the macrocycle is inefficient and intermolecular ET from benzil dominates (the cross on the intramolecular ET arrow is used to indicate that it is a rare event compared to other relaxation pathways). When the macrocycle is on the dba binding site (blue), both ET mechanisms can operate efficiently. The amount of benzil present determines the relative contributions of the two ET pathways and thus the nanomachine's effectiveness in pumping the macrocycle distribution away from equilibrium (see Fig. 3). The mechanism requires the shuttling of the ring between the two ammonium groups in *E*-**1** to be slow with respect to the lifetime of the macrocycle-sensitizer triplet excited state. The Greek and italicized lettering are the proton assignments for the ^{1}H NMR spectra shown in Figs 2 and 3. **B**, Cartoon illustration of the operation of **1** in terms of a non-adiabatic Maxwellian pressure demon[18,19]. See text for details.