Chiral recognition in hydrogen bonded complexes

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Pisa-2005

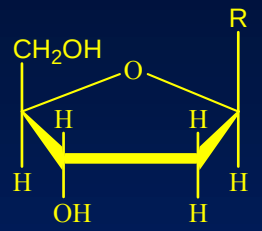
Chirality

Chiro (χειρο) = Hand

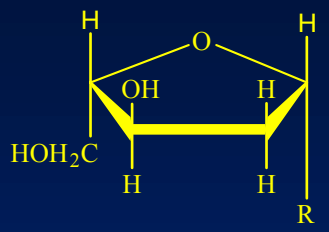
mirror images
non-superimposible

Parity violation principle
(Yang & Lee, 1956)

Chirality in nature



D



L

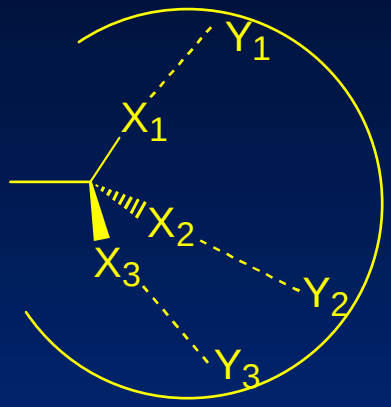
L

D

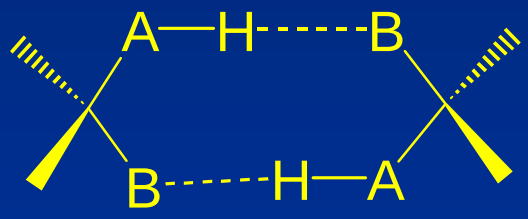
What is the origin of homochirality in nature?
Science, 86, **309** (2005) (1st July)

Chiral recognition

Three points



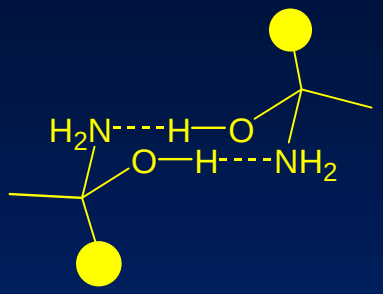
Two points



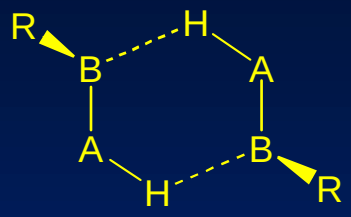
vs.

Homochiral: R:R or S:S
Heterochiral: R:S or S:R

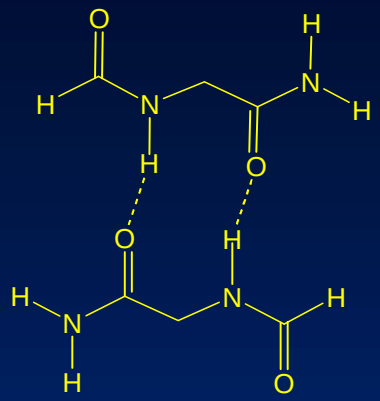
Systems studied



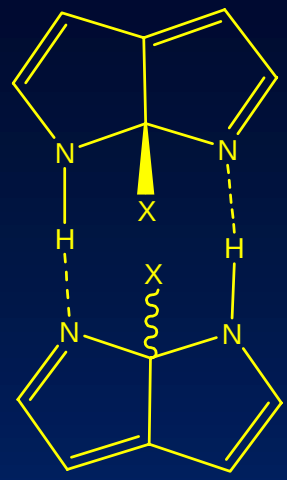
J. Am. Chem. Soc.
124,1488 (2002)



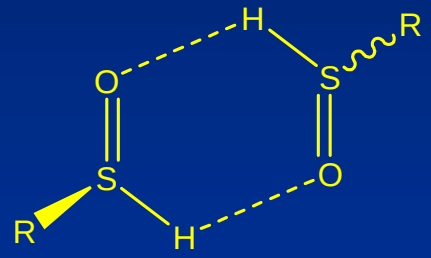
J. Chem. Phys.
117, 6463 (2002)



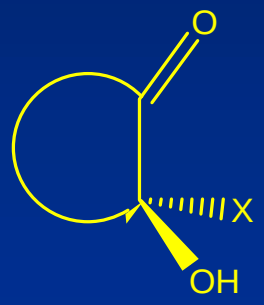
Theochem
680, 191 (2004)



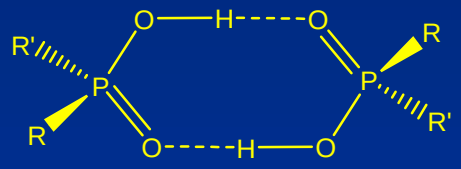
J. Org. Chem.
68, 7485 (2003)



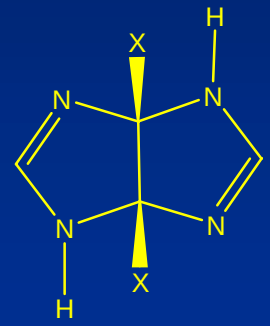
Tet. Asym.
15, 1391 (2004)



J. Phys. Chem. A,
109, 3262 (2005)

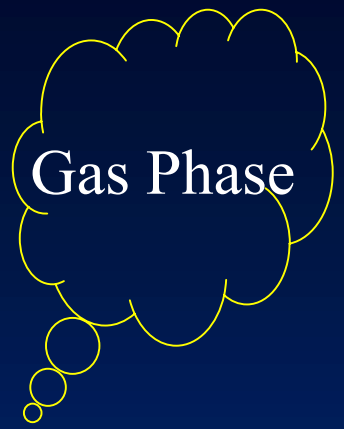


J. Phys. Org. Chem.
18, 491 (2005)



Submitted

http://www.iqm.csic.es/are/chiral.htm



Calculation Methods

Geometry and Energy:
MP2, B3LYP
6-31+G**, 6-311 +G**

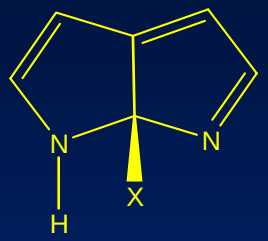
Electron Density Analysis
AIM

Orbitals Interactions
NBO

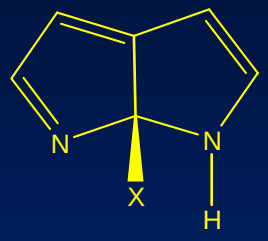
Chemical shifts
GIAO

Optical Rotatory power

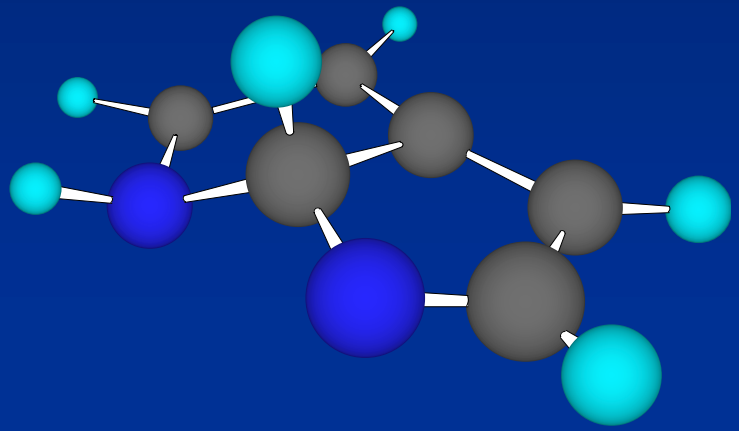
Pyrrolo[2,3-*b*]pyrrole



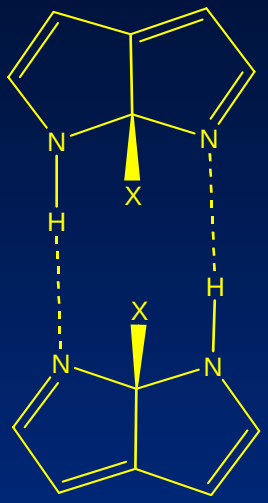
R



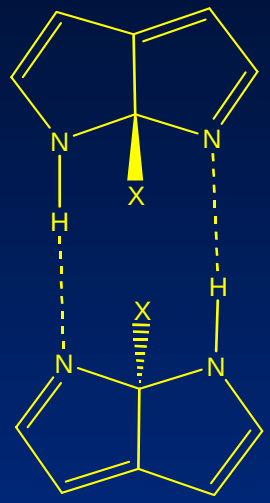
S



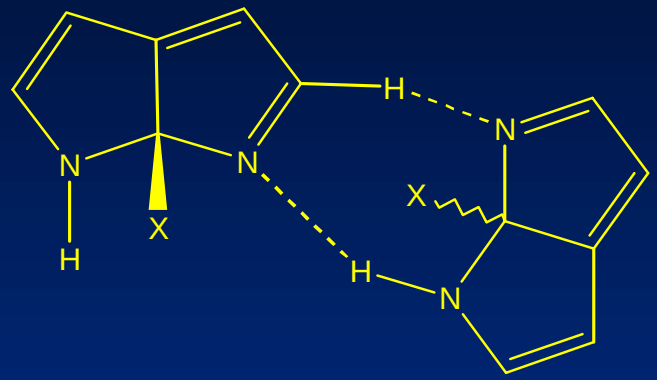
Minima



RR
(C_2)

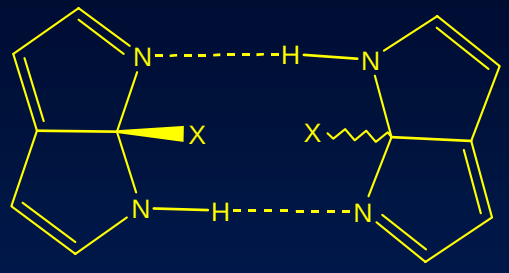


RS
(C_i)



C_1

Minima (energy, kJ/mol)

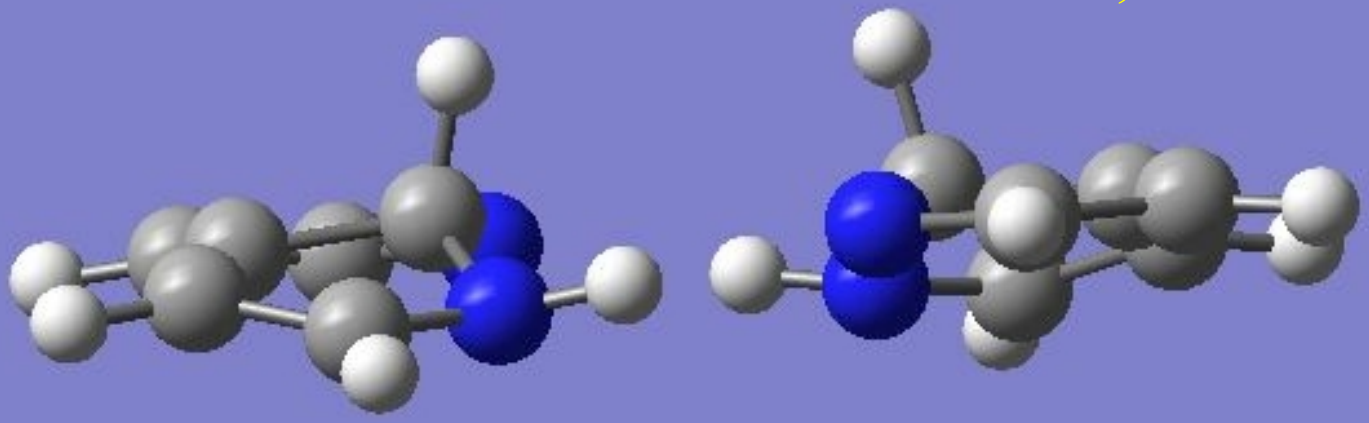


Erel (*R/R*) = 0.0

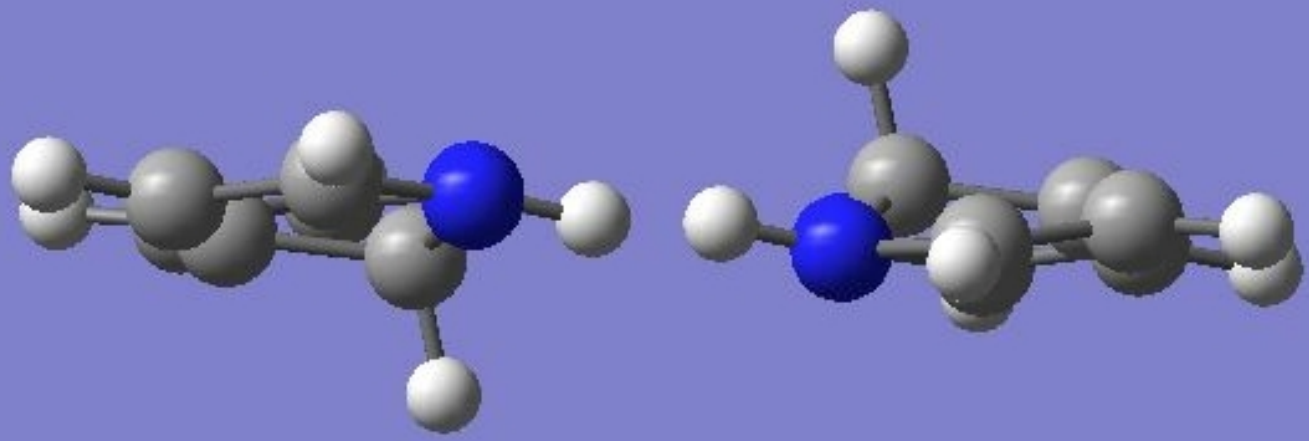
X	Chirality	Erel	$E_{I(CORR)}$
H	*R/S*	-1.8 (-1.5)	-54.5 (-56.7)
F	*R/S*	-2.6 (2.6)	-39.8 (-41.9)
Cl	*R/S*	-5.3 (-5.3)	-44.8 (-50.4)
CH_3	*R/S*	-6.6 (-8.3)	-52.0 (-62.4)
CN	*R/S*	-9.6 (-7.7)	-48.4 (-54.8)
CCH	*R/S*	-4.1	-41.7
CF_3	*R/S*	-8.8	-41.8
CCl_3	*R/S*	-13.7	-27.5
$C(CH_3)_3$	*R/S*	-7.9	-38.4
$Si(CH_3)_3$	*R/S*	-11.8	-49.3
SiF_3	*R/S*	-11.1	-51.3
$SiCl_3$	*R/S*	-16.9	-43.8

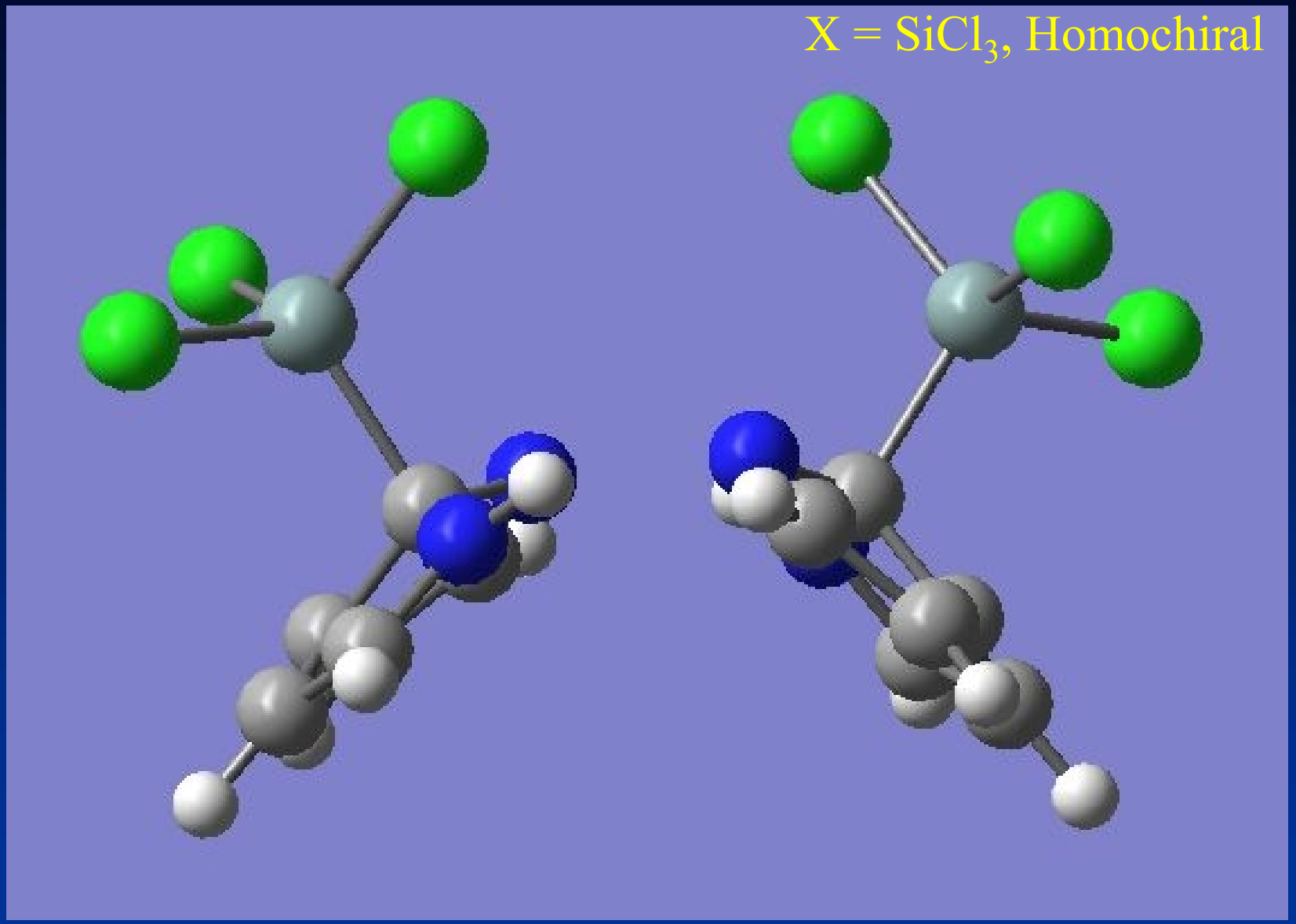
(MP2/6-311+G**)

X = H, Homochiral

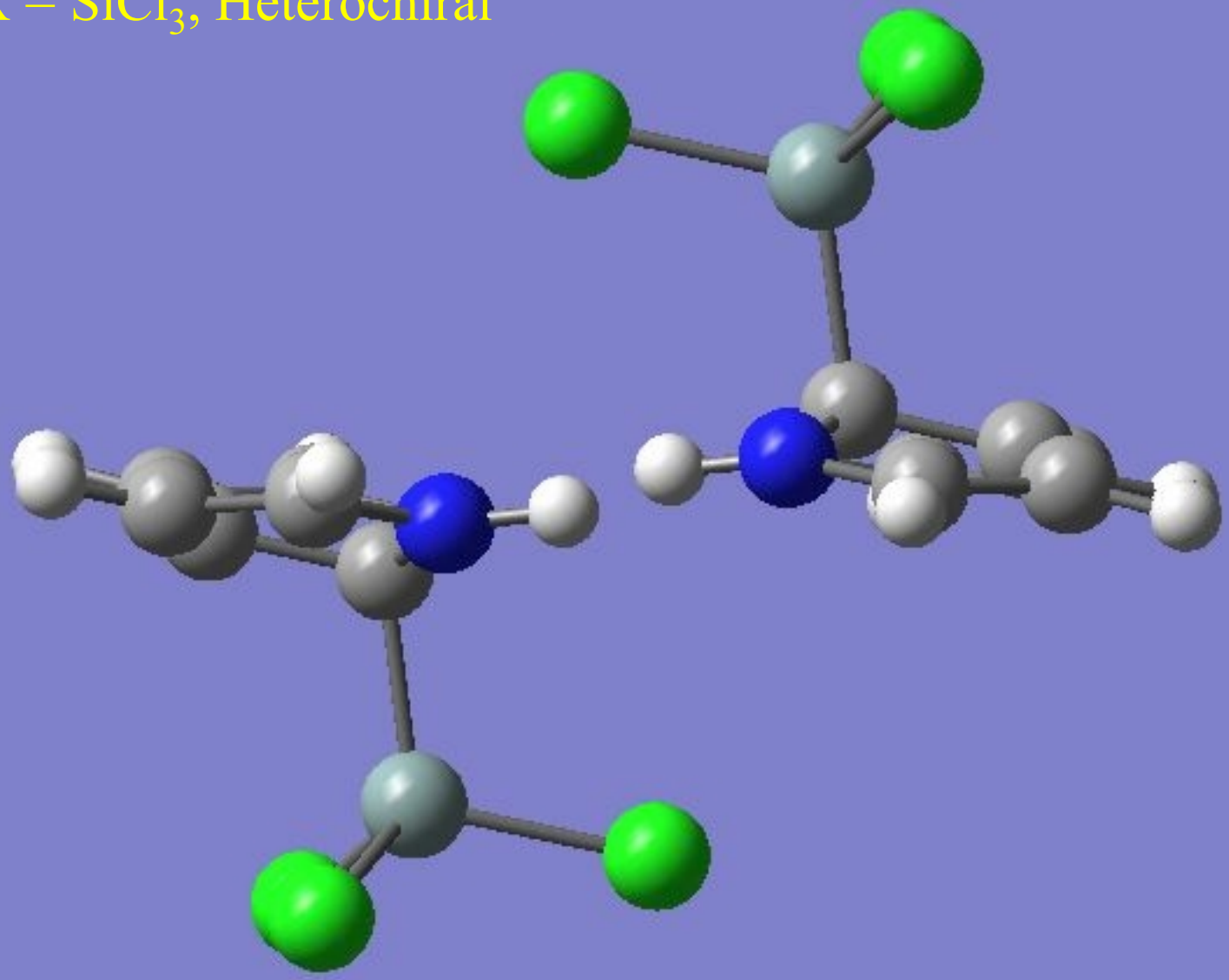


X = H, Heterochiral

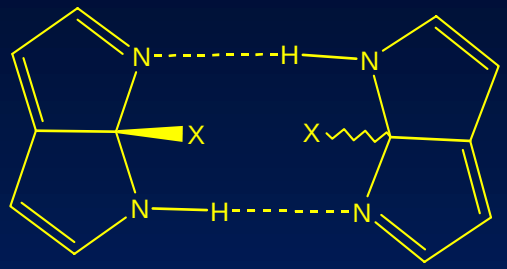



X = SiCl3, Homochiral

X = $SiCl_3$, Heterochiral



Minima (energy, kJ/mol)



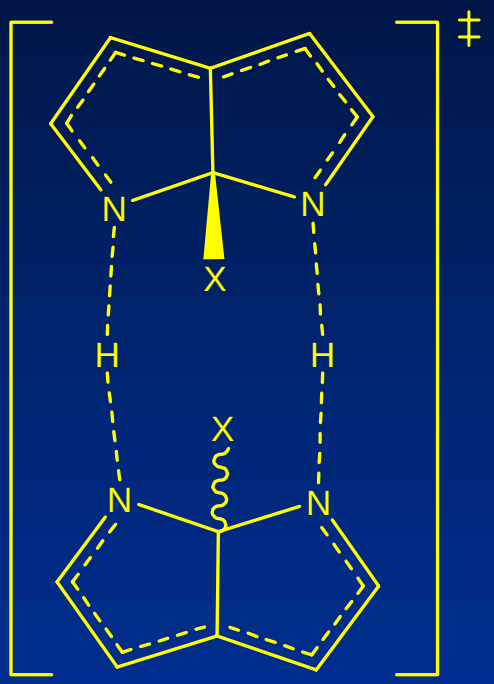
Erel (*R/R*) = 0.0

X	Chirality	Erel	$E_{I(CORR)}$
OH	*R/R*	0.00 (0.00)	-26.2 (-44.8)
OH	*R/S*	9.5 (5.2)	-20.7 (-42.2)
NH_2	*R/R*	0.00 (0.00)	-38.6 (-61.8)
NH_2	*R/S*	11.1 (11.5)	-30.6 (-53.6)

(MP2/6-311+G**)

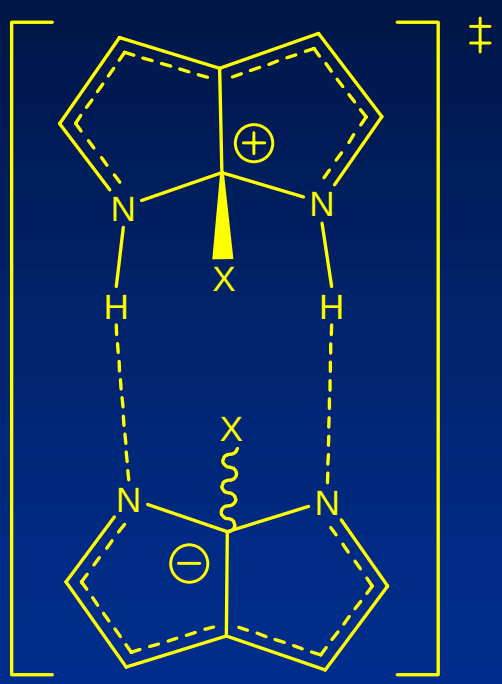
Transition States (TS)

Concerted TS



RR or SS (C_{2V})
RS or SR (C_{2H})

Non-Concerted TS



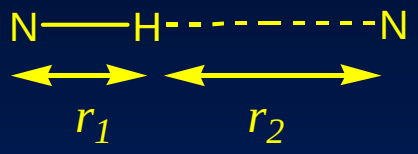
(C_s)

T.S. vs minima (energy, kJ/mol)

		Min.	ET n.c.	ET c.
X	*Quiral*	E_{rel}	E_{rel}	E_{rel}
H	*R/S*	-1.8 (-1.5)	-4.2 (-4.6)	-3.8 (-4.0)
F	*R/S*	-2.6 (-2.6)	-6.0 (-5.4)	-5.6 (-5.3)
Cl	*R/S*	-5.3 (-5.3)	-8.7 (-6.9)	-8.5 (-7.4)
CH_3	*R/S*	-6.6 (-8.3)	-8.2 (-12.4)	-8.7 (-12.3)
CN	*R/S*	-9.6 (-7.7)	-13.4 (-13.1)	-13.6 (-13.9)
			0.35Å	*0.4Å*

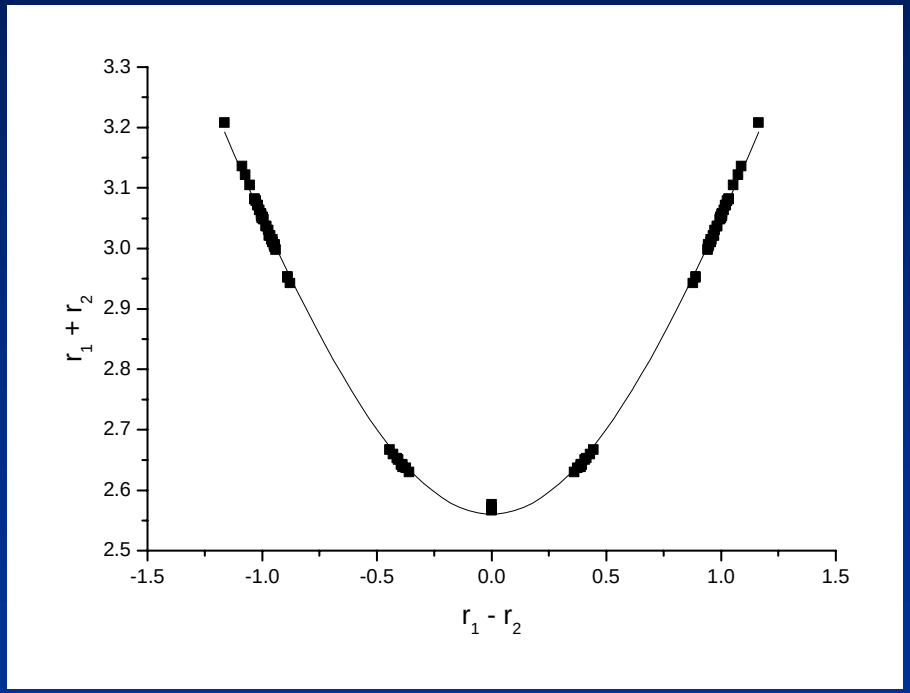
(MP2/6-311+G)**

Geometry (Steiner-Limbach plot)



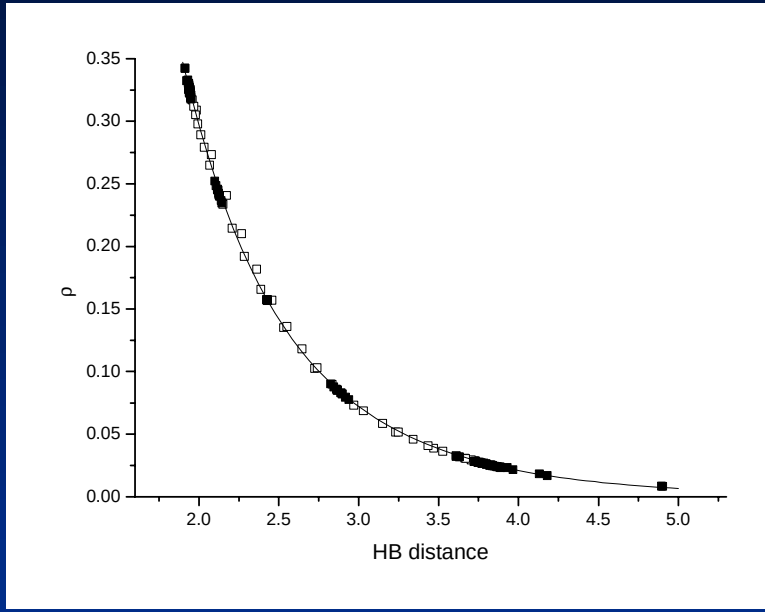
$$e^{(r_0-r_1)/b} + e^{(r_0-r_2)/b} = 1$$

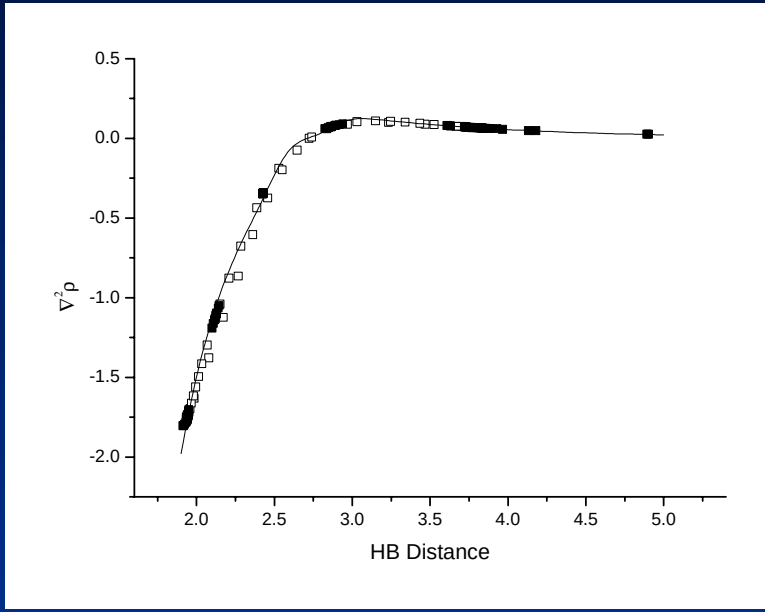
$$(r_1 + r_2) = 2r_0 + (r_1 - r_2) + 2b\ln(1 + e^{-(r_1-r_2)/b})$$



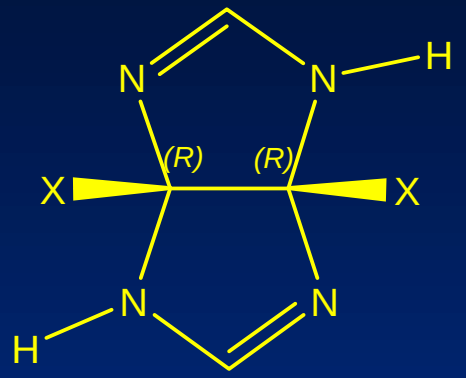
$r_0 = 0.9885 \pm 9.E\text{-}4$, $b = 0.421 \pm 0.002$, $r^2 = 0.999$, $n = 96$

Electron density

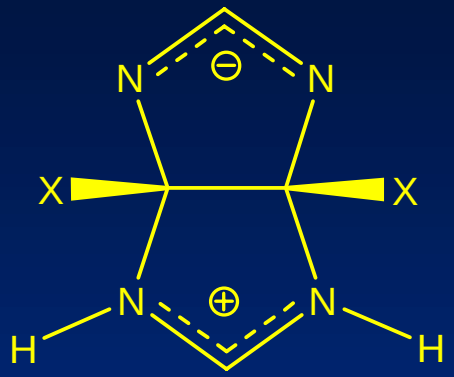




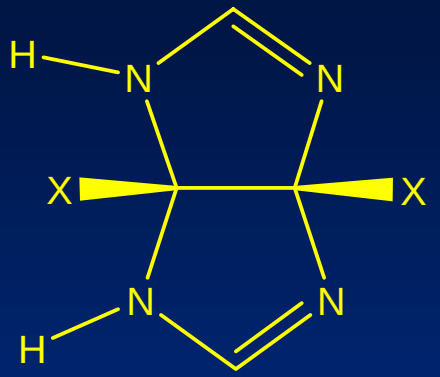
(3aR,6aR)-1,3a,4,6a-tetrahydroimidazo[4,5-*d*]imidazoles



A



B

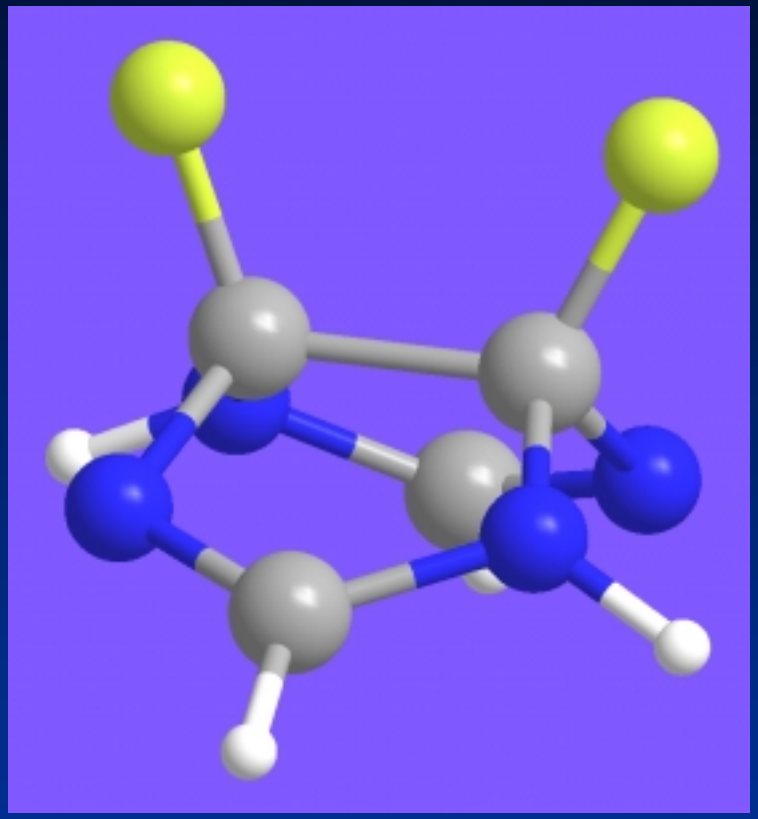


C

Tautomer (X = H)	B3LYP/ 6-31+G**	B3LYP/ 6-311+G**	MP2/ 6-311+G**
A	0.00	0.00	0.00
B	110.70	111.15	123.17
C	19.79	19.26	20.07

(kJ/mol)

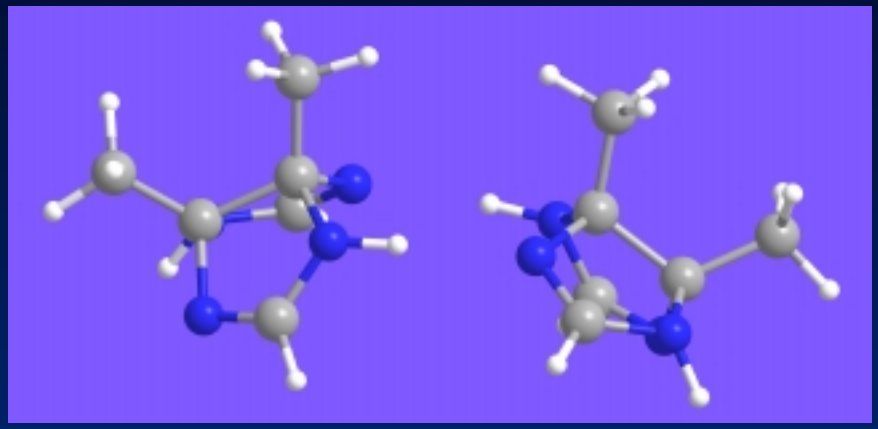
Monomers



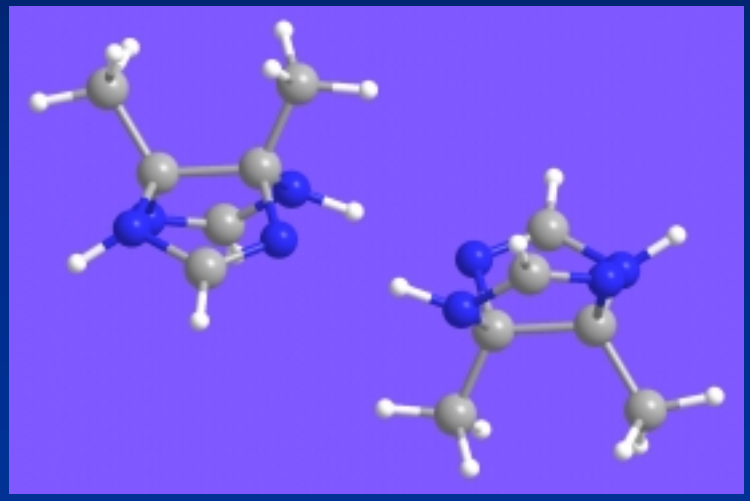
C_2 symmetry

Dimers (energy, kJ/mol)

X	Chirality	Chiral discrim.	E_I
H	*RR*:*SS*	-3.58	-49.89
CH_3	*RR*:*SS*	-4.32	-47.21
F	*RR*:*SS*	-9.25	-56.13
Cl	*RR*:*SS*	-11.52	-55.89
CN	*RR*:*SS*	-17.49	-54.90
CCH	*RR*:*SS*	-8.28	-51.84
CF_3	*RR*:*SS*	-17.74	-50.68



($X = CH_3$, homochiral)



($X = CH_3$, heterochiral)

Analysis of dimers

- Shorter distances in the HB hetero than homochiral.

- NBO N(lp)->NHσ* larger for the hetero.

- AIM analysis of the atomic energies.

average variation:
N1: -10.5 kJ/mol
N3: -11.5 kJ/mol
average H atoms: 5 kJ/mol
(negative favors heterochiral, positive homochiral)

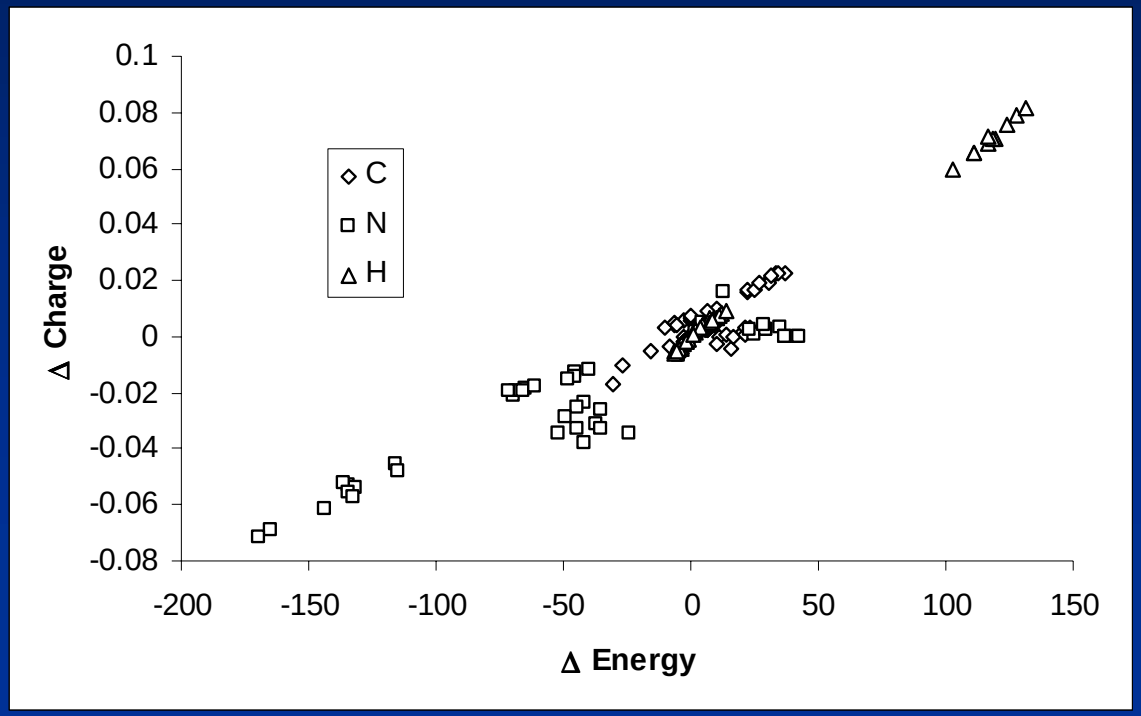
AIM

atomic energy variation in the complexation

- Largest variation in the NH donor (overall stabilization)

- N acceptor is stabilized (40 kJ/mol in aver.)

NH···



NH···

Polymers (energy, kJ/mol)

Number of monomers	chirality	E_I	Echiral
3	*RR:RR:RR*	-103.42	0.00
3	*RR:SS:RR*	-110.68	-7.27
3	*RR:RR:SS*	-107.14	-3.72
4	*RR:SS:RR:SS*	-168.80	-11.17
4	*RR:SS:SS:RR*	-164.89	-7.26
4	*RR:RR:SS:SS*	-161.48	-3.86
4	*RR:RR:RR:RR*	-157.62	0.00
5	*RR:RR:RR:RR:RR*	-212.19	0.00
5	*RR:SS:RR:SS:RR*	-227.05	-14.86
5	*RR:RR:SS:RR:RR*	-219.71	-7.52
5	*SS:RR:RR:RR:SS*	-219.90	-7.71
6	*RR:RR:RR:RR:RR:RR*	-266.09	0.00
6	*RR:SS:RR:SS:RR:SS*	-285.08	-18.99
6	*RR:RR:RR:SS:SS:SS*	-270.40	-4.30
6	*RR:SS:RR:RR:SS:RR*	-281.52	-15.42
6	*RR:SS:SS:SS:SS:RR*	-273.77	-7.68
6	*RR:RR:SS:SS:RR:RR*	-274.14	-8.04
7	*RR:RR:RR:RR:RR:RR:RR*	-320.58	0.00
7	*RR:SS:RR:SS:RR:SS:RR*	-342.94	-22.36

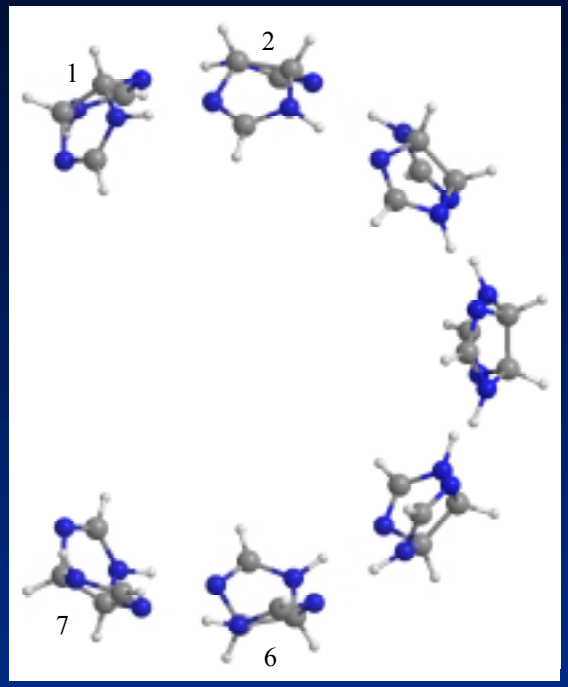
Polymers (energy, kJ/mol)

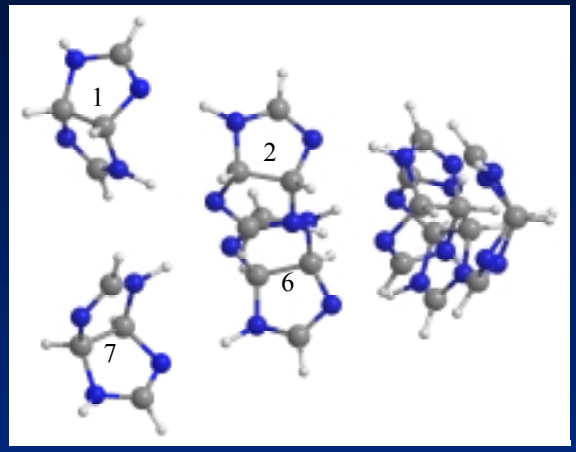
Number of monomers	chirality	E_I	Echiral
3	*RR:RR:RR*	-103.42	0.00
3	*RR:RR:SS*	-107.14	-3.72
3	*RR:SS:RR*	-110.68	-7.27
4	*RR:RR:RR:RR*	-157.62	0.00
4	*RR:SS:SS:RR*	-164.89	-7.26
4	*RR:RR:SS:SS*	-161.48	-3.86
4	*RR:SS:RR:SS*	-168.80	-11.17

$E_I = 5.11 - 27.15^*$ (No. HB) - 3.73 (No. heterochiral interactions)

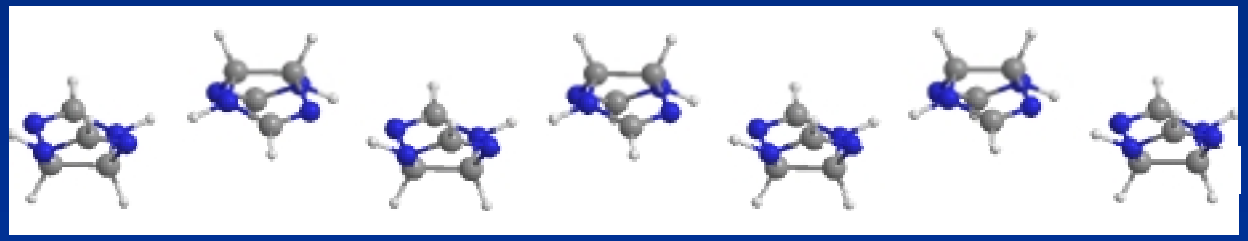
$n = 21$, $r^2 = 1.0000$, SD = 0.22

Polymers (geometry)





X = H (*RR:RR:RR:RR:RR:RR:RR*)



X= H (*RR:SS:RR:SS:RR:SS:RR*)

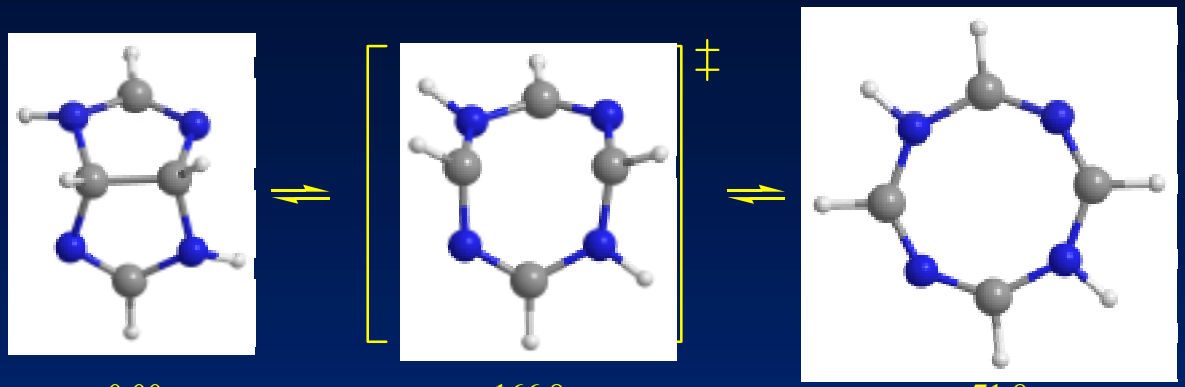
Polymers (optical rotatory power)

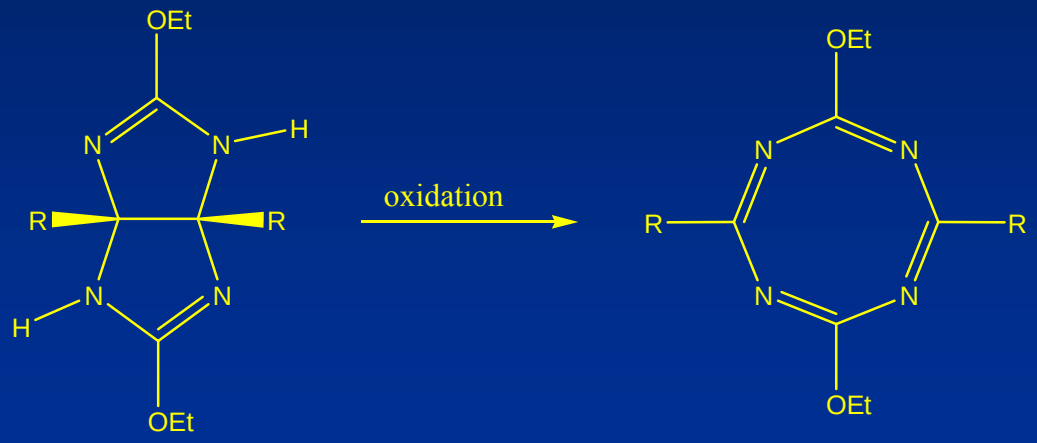
Number of monomers	Chirality	Optical rotatory power	N. of *SS*:*SS*–*RR*:*RR* interactions	N. of *SS* – *RR* monomers
1	*SS*	20.99	0	1
2	*SS*:*SS*	-116.91	1	2
2	*RR*:*SS*	0.00*	0	0
3	*SS*:*SS*:*SS*	-210.36	2	3
3	*SS*:*SS*:*RR*	-115.32	1	1
3	*SS*:*RR*:*SS*	9.20	0	1
4	*RR*:*SS*:*SS*:*RR*	-125.46	1	0
4	*SS*:*SS*:*SS*:*SS*	-333.55	3	4
4	*RR*:*SS*:*RR*:*SS*	0.00*	0	0
4	*RR*:*RR*:*SS*:*SS*	0.00*	0	0

ORP = –(126.2±3.3) * (No. homochiral inter.) + (11.4±2.3) (No. mon. *SS* – *RR*)

n = 17, $r^2 = 0.998$

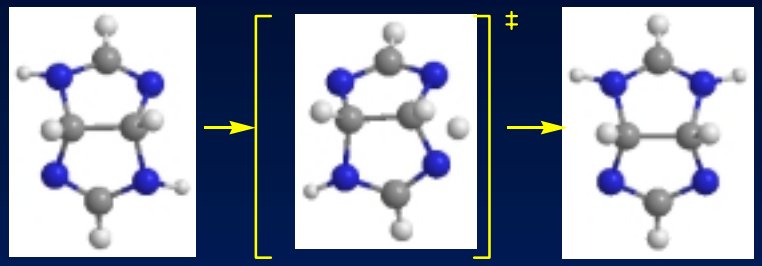
Racemization: carbon inversion





Gompper, Angew Chem Int Edit **1987,** *26*, 1039; **1983,** *22*, 543

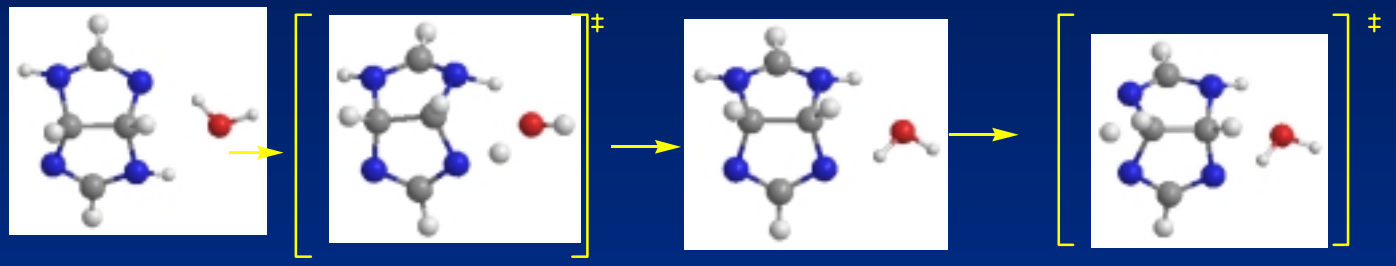
Racemization: Proton Tranfer



0.00
M1

218.62
TS1

110.70
M2

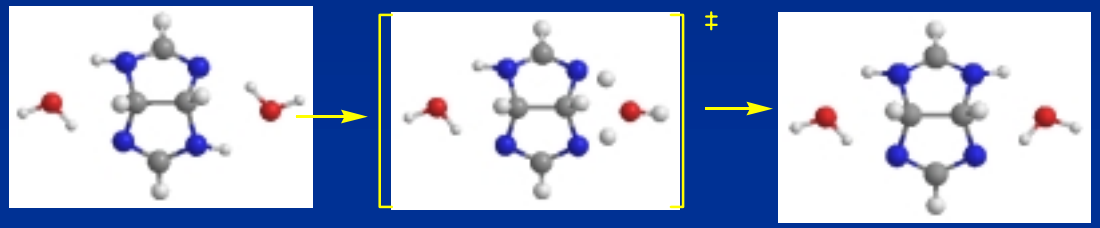


0.00
W-M1

108.71
W-TS1

83.81
W-M2

204.49
W-TS2

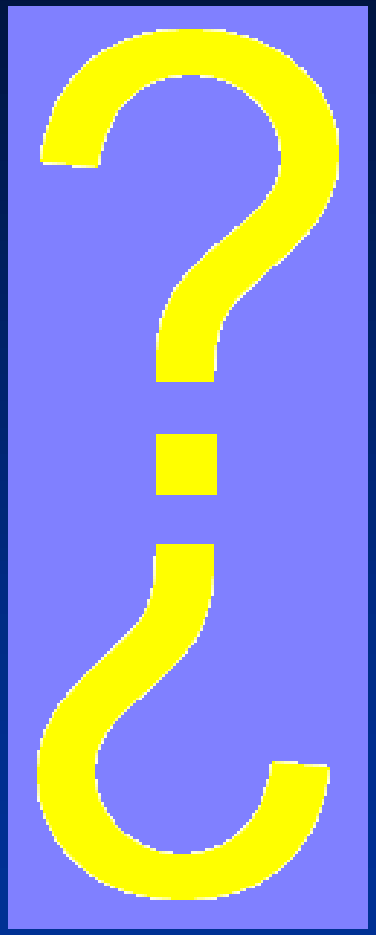


0.00
2W-M1

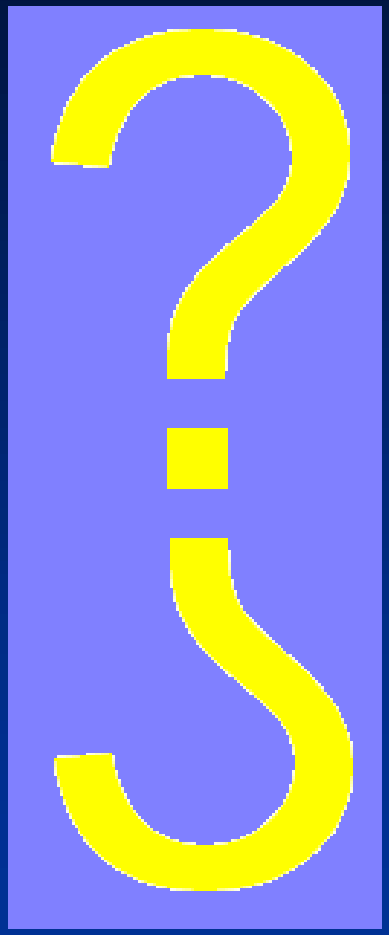
97.34
2W-TS1

64.04
2W-M2

Conclusion



vs.



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Hydrogen bonded clusters

Oscar Picazo

Chiral metal clusters

Prof. Markku Sundberg

Prof. Isabel Rozas

Optical rotatory power

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