Chiral Recognition in van der Waals complexes : (1R,2S)-*cis*-1-Amino-2-indanol/methyl lactate
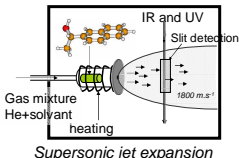
Spectroscopic methods:

- Supersonic jet-cooling
- Laser induced fluorescence (LIF)
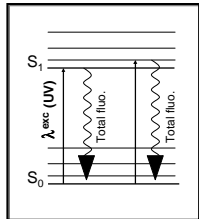- IR-UV double resonance spectroscopy

- Molecular source:

IR and UV
Slit detection

Gas mixture
He+solvent

heating

1800 m.s⁻¹

Supersonic jet expansion

- Laser induced fluorescence

S_1
λ^{exc} (UV)
Total fluo.
Total fluo.
S_0

- IR-UV double resonance spectroscopy

S_1
Pump
Probe
Total fluo.
S_0
(a)   (b)
S_0 vibrations: IR before UV

infrared laser= pump
excitation of vibrations in S_0
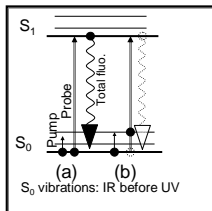ultraviolet laser=probe
probe of the population of the S_0 state.

Advantages:
-cold species
-isolated species
-complexes formation

UV laser in resonance with electronic transition induces fluorescence (measurement of the ground state population)

Advantages: selectivity of the method

Calulation strategy:

1- Geometry optimisation of the isolated molecules
at MP2/6-31G** level and charge distribution calculation. It is reduced to a set of Multipole (monopole, dipole and quadrupole) on each atom and one per chemical bond
(Vigne-Maeder procedure).

2- Interaction energy calculation (complexes geometries)
Claverie method further developed by V. Brenner (CEA Saclay)

Second order perturbation theory
Formal decomposition of the interaction energy

$$E = E_{elec} + E_{rep} + E_{pol} + E_{disp}$$

E_{elec} multipole-multipole, E_{pol} using experimental polarizability, E_{rep} atom-atom contribution as well as for E_{disp} which includes terms up to C_{10}/R^{10}

3- Exploration of the potential energy surface
simulated annealing (global) followed by a local optimisation

4- Ab Initio Calculations
B3LYP / 6-31G** complete optimization
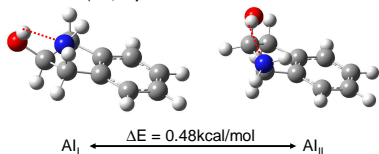BSSE and harmonic frequencies calculation (*0.96)
Optimisation of the "most significant" complexes at MP2/ 6-31G(d,p)

"most significant" = the most stable complexes calculated at B3LYP level + the structures which can undergo an important increase of the dissociation energy due to dispersion interactions
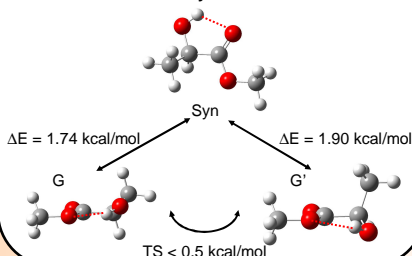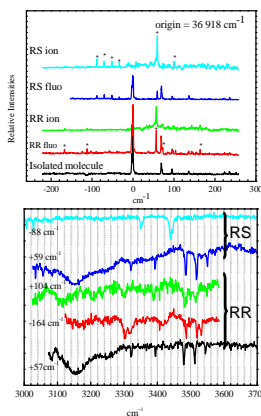
Results

Isolated molecules

(1R,2S)-*cis*-1-amino-2-indanol

AI_I $\Delta E = 0.48 kcal/mol$ AI_{II}

Methyl lactate

Syn

$\Delta E = 1.74$ kcal/mol $\Delta E = 1.90$ kcal/mol

G   G'

TS < 0.5 kcal/mol

Experimental results

origin = 36 918 cm⁻¹

RS ion
RS fluo
RR ion
RR fluo
Isolated molecule

-88 cm⁻¹
+59 cm⁻¹
+104 cm⁻¹
-164 cm⁻¹
RS
RR
+57cm⁻¹

- Two complexes very similar for both diastereoisomers
- One vibrational structure for the heterochiral complex
- Rare features for homochiral complex

Theoretical results

RS	BE	E_{def} AI	E_{def} ML	ν(OH)	ν(OH)	ν(NH)
head to head bifurcated/AI_{II}-G'	-12.59	1.39	1.99	3153	3537	
head to head/AI_{II}-Syn	-11.93	1.68	2.83	3139	3521	
insertion/AI_{II}-Syn	-11.39	1.34	2.42	3068	3506	
insertion/AI_{II}-G	-11.38	1.81	1.30	3181	3522	
addition/AI_{II}-G	-11.14	0.34	1.21	3364	3449	
insertion bifurcated/AI_I-G	-11.13	2.48	2.12	3110	3525	
insertion/AI_{II}-Gbis	-10.87	1.57	1.05	3166	3488	
head to head/AI_I-Syn	-10.80	3.19	2.70	3139	3534	
cycle bifurcated/AI_{II}-G'	-10.63	0.49	1.63	3442	3449	3554
insertion /AI_I-Syn	-10.42	2.43	2.60	3044	3509	
head to head/AI_{II}-G	-10.23	1.31	1.81	3229	3563	
cycle/AI_I-G	-10.12	0.28	0.77	3476	3511	
cycle /AI_I-G'	-9.83	0.24	0.37	3491	3510	
cycle/AI_{II}-Syn	-9.46	0.43	0.63	3453	3459	3487

E_{def} considered as high;
E_{def} considered as intermediate;
E_{def} considered as low

BE= Binding Energy MP2/6-31G(d,p) + 50%BSSE
E_{def} = E_{comp}-$E_{opt/closest}$

Complexes families

O—H···O
O—H···N
Head-to-head

O···H—O
H···O
Insertion

H—O···H—O
N—O
Addition

O···H
N···H
Cycle

Assignment

(1R,2S)-AminoIndanol + S methyllactate

RS -88 cm⁻¹
addition/AI_{II}-G
RS +59 cm⁻¹
insertion/AI_{II}-G
insertion/AI_{II}-G

CH…π interaction *vs* CH₃…π

(1R,2S)-AminoIndanol + R methyllactate

RR +104 cm⁻¹
cycle/AI_{II}-G
RR +57 cm⁻¹
insertion/AI_{II}-G'
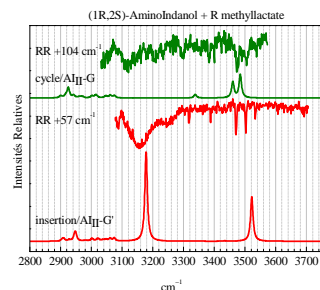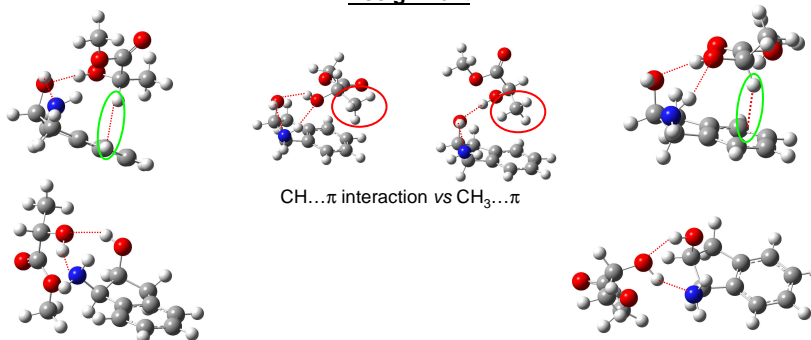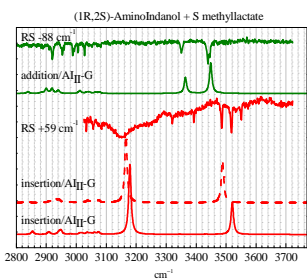
Conclusion

- Two isomers clearly identified for both diastereoisomers
  One of them is similar for RS and RR diastereoisomers :
  UV shift ~ 60 cm⁻¹ / IR : 3160 & 3500 cm⁻¹
  assigned to **Insertion AI_{II}-G**
  One RS diastereoisomer :
  UV : vibrational progression in low energy region
  IR : 3351 & 3440 cm⁻¹
  assigned to **Addition AI_{II}-G**
  One RR diastereoisomer :
  UV : single blue shifted band; IR : 3472 & 3505 cm⁻¹
  assigned to **Cycle AI_{II}-G**

- Clear discrimination between the two last complexes which evidence the major role of the **CH…π interaction**

- Very heavy calculations, especially if we want to increase the size of the system : We need for more accurate calculation methods : DFT-D, DFT-SAPT or "Return" to force fields (Anisotropic Polarizable Molecular Mechanics)